Cabin Design for Minimum Boarding Time

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Abstract

Single aisle aircraft with capacities ranging from 140 to 240 seats dominate the current short range air transport. These efficient aircraft are prone to lengthy boarding times, increasing turn-around times. Repeatedly the question is raised whether a small twin aisle might be a viable future replacement for parts of the current single aisle fleet, especially as average seat number is expected to increase further. As first part of a research into this topic this paper discusses the passenger boarding and de-boarding times of different cabin layouts. The objective is to establish a threshold for number of seats at which a twin aisle is in advantage. Current and alternative single aisles are compared to 6-, 7- and 8-abreast twin aisles. Twin aisles are found to be generally beneficial for all seat counts. The effect of a wider aisle is limited, but changed cabin layout can achieve a meaningful reduction in boarding time for single aisles.

1 Introduction

This chapter outlines the motivation for this work. In order to describe the context, a brief description of the turn-around process is provided. The chapter closes with a overview of the paper.

1.1 Motivation

Demand for aircraft in the B737 and A320 category continues on a high level. Manufacturers expect this demand to increase even further. Both aircraft families are very similar in capacity and range, and both are 6-abreast single aisle aircraft.
The launch of the new engine option on the A320 family (commonly called A320NEO) has started a debate on a possible replacement for the B737 Next Generation.

A replacement aircraft needs to excel in economic efficiency mostly by lower fuel consumption and lower maintenance cost. This can possibly be achieved by more advanced engines and materials and other evolutionary changes to the aircraft. However, the operator's true benefit is also determined by other performance indicators.
Many A320 and B737 family aircraft are used on short sectors, often below 500nm. On these sectors the actual utilization may suffer from lengthy turn-around times between flights and the cruise efficiency becomes less important for the actual cost of operation. However, the turn-around performance of single aisle aircraft of higher capacity suffers from lengthy boarding and de-boarding times. Lower utilization increases cost of ownership for each flight.

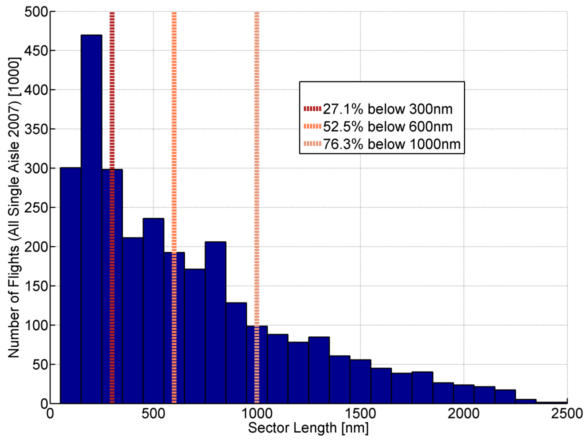

Figure 1: Sector Length of Single Aisle Aircraft (OAG 2007)

The current trend is clearly towards larger capacity aircraft in this category with average seat count of actually delivered aircraft topping 160 seats, up from slightly over 130 seats in late 1980ies.

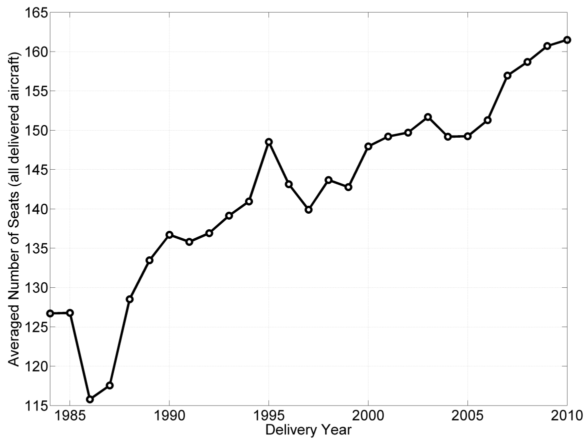

Figure 2: Average Seats of Delivered A320 and B737 Family Aircraft (Descend Database)

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The quest for potentially higher seat count, dominance of short sector length and importance of a quick turn around has raised the question if a twin aisle aircraft could be a more suitable replacement for current single aisle aircraft.
Addition of a second aisle in a 6 or 7 abreast layout is supposed to reduce the boarding and de-boarding time enough to allow for more utilization in a short range dominated flight plan. This would reduce the cost for the operator, especially the cost of ownership.
The obvious disadvantage is that the aircraft becomes heavier and thus consumes more fuel, increased maintenance cost and has to pay higher charges. Several comments and publications have voiced the opinion that a small twin aisle is feasible and beneficial, but so far no quantitative assessment was presented.

While the relative effect of a larger fuselage can be assessed using preliminary design methods, the true benefits of a second aisle for boarding times was not yet assessed. This is however of huge importance in order to pick the most promising cabin design for the intended capacity, as if the benefit was too small the concept can be abandoned altogether.

This paper determines the absolute and relative advantage of twin aisle cabin versus single aisle cabin for a variety of cross sections, passenger capacities and operational scenarios. This can then be used for an overall aircraft design process. The results are obtained with a self-developed calibrated boarding simulation.

1.2 The Turn-Around Process

"Turn-around" is the summary of all processes conducted between two flights. It involves the unloading of cargo and disembarkation of passenger. Replenishable items such as fuel, water and catering items are re-filled. The aircraft cabin is cleaned. The flight crew also has to prepare for the next flight. Cargo and passengers for the next flight are loaded.

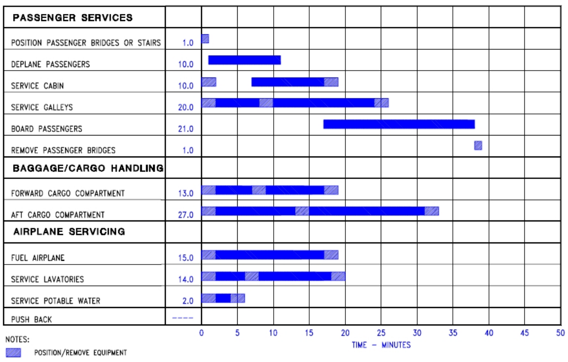


Figure 3: Turn Around Process Chart (B757-200) from [4]

Many of these processes are conducted in parallel, some are in sequence, an exemplary chart is shown in figure 3. The shortest possible route is called the critical path. This critical path is not fixed but depends on the duration of the individual processes. In the cabin the cleaning usually cannot start until the passengers have disembarked. The boarding of passengers cannot start until both the cleaning and the refueling[1] has ended. The latter is a matter of fact because passengers are not allowed on the aircraft while refueling is in progress. Short range flights do not require large amounts of fuel, so that the cabin cleaning process usually is situated on the critical path.
Cargo loading can be situated on the critical path. If only passenger baggage is loaded, and the operator uses containerized cargo, the cargo loading takes less time than the cabin processes. However, if boarding times are reduced below a certain time, other turn-around processes become critical and further reduction in boarding times will not yield a faster turn-around.
Consequently - within boundaries - the turn around time for short range operations depends directly on the boarding and deboarding time.

1.3 Paper Overview

This paper describes the investigation the boarding time of a variety of possible cabin layouts. Twin aisles with 6-, 7- and 8-abreast seating are compared to a current single aisle layout and a new single aisle layout.

Key element of this paper is a boarding simulation which uses microscopic modeling of passenger behavior. The boarding simulation is calibrated using available data and quoted boarding times.
The simulations are performed for 8 different passenger capacities for each of the 6 different cross section seating arrangements. Each cross section offers different stowage volume for carry-on baggage.

The simulations are further performed for different settings for amount of carry-on luggage and load factor.

The chapter "State of the Art" describes a selection of publications from this area. The section "Methods" details the boarding simulation and the used cross sections and cabin layouts. The section "Results" summarizes the simulation results for the different scenarios. In the section "Discussion" these are condensed into general findings.

2 State of the Art

This chapter provides a survey over the most relevant publications in the area of boarding and turn-around research.

The first notable publication and still of relevance is a Boeing study from the late 1990ies [8] although it was not published as scientific contribution. It offers valuable findings as it is the only study that directly relates

[1] Refueling and boarding can be done in parallel if additional safety measures are applied

to test data. Unique to all known publications, Boeing conducted actual tests under controlled conditions. The study concentrated on different boarding strategies and named one particularly successful strategy for reducing boarding times. The findings of the Boeing study were not reproduced in later publications, however, the high fidelity of the Boeing boarding simulation beats methods used by other authors. The Boeing study was aimed at specifically showing that the very long B757-300 can be boarded within the same time as the smaller B757-200 using a particular boarding strategy. It is interesting to note that the B757's ACAP posts the least optimistic figures for boarding and de-boarding times, and it also is the only aircraft for which a manufacturer ever conducted an actual boarding test (see 1). It is unknown if these facts are connected.

Philipp Krammer of the University of Applied Sciences Hamburg conducted a research into reduced turn-around time and published major findings in 2010 [7]. Though the majority of researched measures looks on the cargo loading process, boarding and de-boarding were also considered. The study does not simulate boarding but offers a statistical analysis of 168 turn-around processes of single aisle aircraft. One of the most notable findings that there is no correlation between aisle width and passenger boarding- and de-boarding time. The boarding time showed a large variation with only few factors having a significant statistical correlation. It should be noted that the authors did not have information about carry-on luggage, but only the number of passengers and some general characteristics of the cabin layout.

Albert Steiner and Michel Philipp of the ETH Zurich published another simulation study in 2009 in which they analyzed a number of boarding operations of Swiss Airlines flights [2]. The authors adapted a boarding simulation to the observed passenger behavior, which is based on 8 observed boarding processes of Airbus single aisle aircraft. The authors noted that the carry-on luggage is reason for many delays during the boarding process. The focus of the authors however was the pre-boarding setup and options of speeding up the boarding process there. However, their simulation showed the highest potential saving when carry-on luggage was reduced.

In a recent publication Holger Appel of RWTH Aachen analyzes de-boarding processes and the effectiveness of de-boarding strategies [6]. The effect of these strategies is found to be of no significance. However, although he uses a well-established simulation model for people interaction (TOMICS), no further remark concerning validation or calibration is given.

A number of additional studies exist that usually use a simulation model without further mentioning of validation method or any form of calibration. All cited and known publication address the boarding of single aisle aircraft. No publication is known that compares different aircraft layouts against each other. The general finding from most studies is that only very complicated boarding strategies yield noticeable advantage. The effect of carry-on luggage is stressed in several studies where this effect was modeled and/or observed.

Further sources of information concerning boarding times are the published Aircraft Characteristics for Airport Planning documents (ACAP). These include a section on aircraft ground handling and an exemplary chart showing the process, an example is given in figure 3. For this study data from [1], [5] and [4] are used, which represent the bulk of current single aisle fleets. The data given is however inconsistent and all manufacturers stress that individual airline procedures may result in different times. In table 1 an overview for a number of aircraft types is given, including 3 twin aisles. The table gives the number of passengers per minute leaving or entering the aircraft. Note the large variation between the single aisle, ranging from 9 per minute to 20 per minute. Numbers for deboarding range from 18 to 24.

Aircraft	PAX	Total Turn Time [min]	Boarding Pax Flow [1/min]	DeBoarding Pax Flow [1/min]	Remarks
A300-600	285	30	16	18	2 Doors
B767-200	216	35	20	25	Door 1L
B767-300	261	40	20	25	Door 1L
A319	134	30	16	22	Door 1L
A320	164	30	14	22	Door 1L
A321	185	35	20	24	Door 1L
B737-700	140	33	12	18	Door 1L
B737-800	160	38	12	18	Door 1L
B737-900	177	40	12	18	Door 1L
B757-200	186	37	9	18	Door 1L
B757-300	243	54	9	18	Door 1L

Table 1: Quoted Turn-Around Times from ACAPs

3 Methods

This section describes the boarding simulation used for the result section. It further outlines the different cross sections and cabin layouts used for the simulation.

3.1 Boarding Simulation

The boarding simulation was developed specifically to allow a boarding time estimation of different aircraft cabin layouts. Mature programs like TOMICS feature advanced solutions for the routing problem. But route finding is no issue in aircraft boarding. Main objective of the simulation was to generate a transparent program with as little assumptions as possible. All boarding programs are finally governed by the assumptions made on time required for different passenger actions (see below).

The simulation uses an agent-based approach, very similar to the program described in [9]. A separate and new program was deemed necessary to optimize the interface between cabin layout generator and boarding simulation. The coding required for a basic boarding simulation is rather simple and straightforward, so that usage of existing software is not necessarily beneficial.

A visual output is featured as optional post-processing, while the actual simulation runs independent of the visual interface. In the simulation many parameters are based on probability distributions, so that the final result differs between each simulation. Therefore a number of similar runs has to be conducted, usually at least 10 for each combination of boundary conditions. A single run takes about 1 minute on a standard desktop computer. Figure 4 shows a plain 2D view of the boarding of a 200 seat twin aisle layout. The circles represent the passengers. Their color indicates their current state (black: seated, red: blocked, blue: sitting down). Figure 5 shows a 3D view with similar color code. The view is from front to aft of the same 200-seat twin aisle.

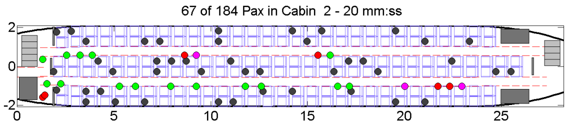


Figure 4: 2D Screenshot of Boarding Simulation (6-abreast twin aisle)

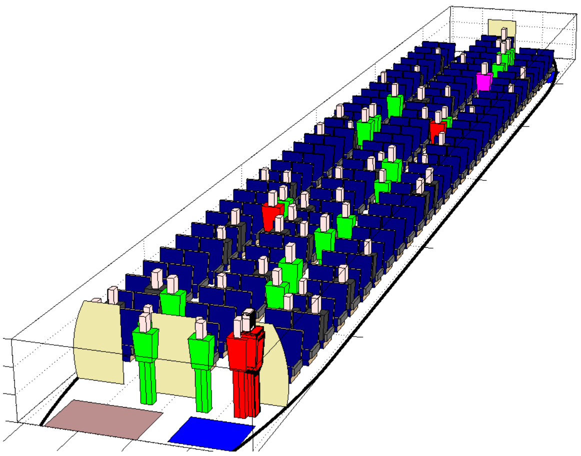


Figure 5: 3D Screenshot of Boarding Simulation (6-abreast twin aisle)

3.1.1 Basic Principle

The simulation uses microscopic modeling of the passenger behavior. That is, each passenger is described as individual set of physical size, walking speed, target seat and carry-on luggage. The distribution of characteristics is based on distributions given for average people within Europe. The simulation is a multi-agent system. The individual passenger agents can interact with each other. The basic principle is that a passenger occupies a physical spot inside the cabin and no other passenger can walk into this field as long as it is blocked. The aircraft cabin is represented by a matrix of blocks which are either walkable or blocked by cabin items. Many cited simulations use a different approach, namely discrete time event simulation. The path of the passenger is found via a path-finding algorithm (A-Star) using a cost minimization approach (see [9] for further explanation). However, the path finding does not represent a major problem as the aisles are straight and passengers are assumed to correctly identify the right aisle. Passengers can perform two different actions apart from walking and waiting: storing luggage and waiting for other passengers to leave their seat. These represent the major hold ups during boarding.

3.1.2 Luggage Storing and Seat Interference

Two issues have been identified by other studies as key reason for delays in aircraft boarding:

- aisle blocking due to loading of luggage
- passengers waiting for other passengers to get up in order to reach their seat

Both phenomena are difficult to describe in an analytical fashion. The general conclusion is that these processes are reflected by a time delay the passenger waits at his position while he blocks the aisle. The exact time of the particular process depends on many small factors and is subject of large variance between different passengers. For this study fixed times are assumed for occurance of seat interference that depend on the number of passengers that have to get up.

Carry-on luggage loading is given more attention as its effect was described in several studies as the decisive factor. The cross sections are modeled in detail and the cross sectional area of the overhead bins is known. Combined with the layout of the cabin, discrete local overhead bin capacity is calculated. As carry-on volume is also defined for each passenger, the time required to store carry-on luggage depends on the actual size and the remaining volume inside the overhead bin at the particular seat location of the passenger agent, with times increasing when the occupancy increases. If all overhead bins close the passenger's seat are occupied, an additional time penalty is applied. The stowage times are estimated and verified by observations. However, own observations confirm a very large variation between individual passengers. This is often due to random events, but it is observed that frequent travelers are usually quicker than infrequent leisure travelers.

The individual carry-on luggage is defined as heavy, medium and light. The number of pieces is not specified. The carry-on weight is oriented on a current weight survey financed by EASA [3]. "Heavy" represents items such as trolleys, which are very common for today's travelers. "Medium" represents smaller bags that are carried by passengers and can in theory also be stored below the front seat, although in the simulation the passenger always tries to use the overhead bin. "Small" represents items that are not stored in the overhead bin.

3.1.3 Aisle Interference

Aisle interference occurs when a passenger blocks the aisle and subsequent passengers have to wait. The decision for a multi-agent simulation was partly motivated by the ability to model the aisle behavior. In many discrete event simulations aisle passing is not possible. In order to capture the

effect of a wider aisle this feature was added.
Observation proved that actual passing is limited at normal aisle width, and normally the blocked passenger has no hurry to reach his seat. Besides the width of the aisle most people would consider it impolite and inconvenient to squeeze past the blocking passenger. Passing probability is calculated using the actual local aisle width, the size of the individual passenger and the occupancy of the aisle seat. Passing is further prevented when either passenger has bulky carry-on luggage. Again, frequent travelers behave differently and let people pass more frequently, for example by moving into the seat row when storing luggage. This is also considered in the simulation.

Aircraft		Attributes		Time [min]			Mean Rate	Remark
Layout	PAX	"Smartness"	Hvy CarryOn	Mean	Max	Min	PAX/min	
Single Aisle	200	50	35	17.5	19.5	15.8	11.5	Default
Single Aisle	200	50	60	22.0	25.4	20.0	9.1	Max Luggage
Single Aisle	200	50	10	16.7	19.3	14.3	12.0	Min Luggage
Single Aisle	200	100	35	14.6	17.3	12.4	13.8	Max Smartness
Single Aisle	200	0	35	21.4	24.7	18.4	9.4	Min Smartness
Single Aisle	200	100	10	13.6	15.7	11.6	14.8	Best Case
Single Aisle	200	0	60	25.8	28.0	22.4	7.8	Worst case
A321	194			22			8.8	Observed S&P
A321	193			21			9.2	Observed S&P
A321	192			25			7.7	Observed S&P
A321	198			28			7.1	Observed S&P
A321	197			26			7.6	Observed S&P
B757-200	201			22			9.1	Boeing PEDS

Table 2: Calibration of Boarding Simulation

3.1.4 Calibration

A full validation of a boarding simulation either requires an actual test under controlled conditions or the observation of many boarding processes. For this study observed values from various studies are used. Most insightful are those from Boeing [8] and ETH [2], also to some extent HAW [7]. The latter two have shown that a large variation exists. Reason is different passenger behavior. A simulation consequently remains a rough estimation including the most important effects. For this study individual action time assumptions are adapted to match the results of Boeing and ETH. The feeding rate (passengers arriving at the front door) is set to 25PAX/minute. The exact boundary conditions for the cited studies are unknown, especially the luggage distribution is not specified. Thus, an exact match cannot be expected.
The basic influential parameters are the percentage of passengers with heavy luggage and the general "smartness". "Smartness" describes the speed of the passenger to store luggage, clear his seat, walking the aisle and finally his willingness to let other passengers pass. As stated before, frequent flyers generally demonstrate better behavior inside the cabin, easing the boarding process.
Table 2 shows different simulation results (averaged values of 20 runs). The Default-scenario is slightly of the reference observed values from Steiner&Philipp. One possible explanation is that the passenger feeding rate (25 PAX/min in the simulations) was lower in reality. The simulation assumes that all passengers are pooled before boarding starts and there is no shortage of new passengers at the front door of the aircraft. In reality, also depending on the airline's business model, this can be different. However, the results show both a reasonable match to observed results and a reasonable spread with changed boundary conditions. In tendency the results are too optimistic so that all presented times possible represent the lower end actual times.

3.1.5 De-Boarding

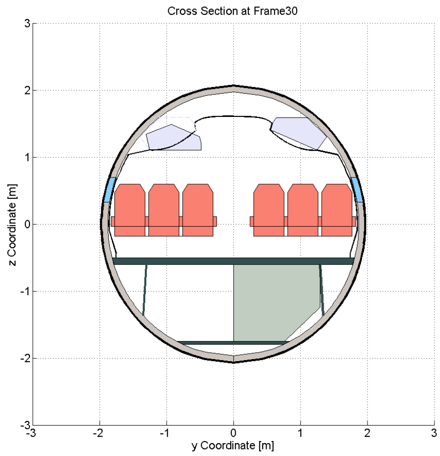
De-boarding differs substantially from boarding. Time consuming disturbances like seat interference and luggage stowing do not occur. The speed of de-boarding from actual data shows much lower variance. The Boeing study [8] gives 10 minutes for de-planing of 200 passengers, or 20PAX/minute. HAW's study [7] analyzed many de-boarding events and arrive at a slightly higher rate of roughly 22 PAX/minute. This fits well with the numbers given in the ACAP papers of the manufacturers, which have shown to be way off reality when it comes to boarding. The exit door is one of the potential bottlenecks.

3.2 Passenger Cabin

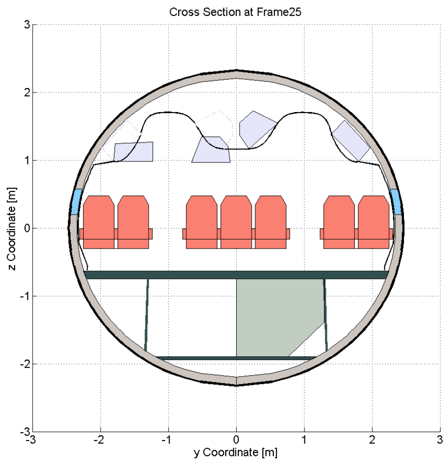
3.2.1 Cross Sections

The cross section determines the number of seats abreast, the number of aisles and the overhead bin capacity. 4 different cross sections are used. The basic cross section resembles the current A320 (see 6(a)). The wider 7-abreast twin aisle cross section represents a slightly smaller version of the B767 cross section (see 6(b)). The largest cross section (see 6(c)) is a resemblance of the Airbus widebody cross section (A300/330/340). All cross sections are designed for 18inch wide seats.

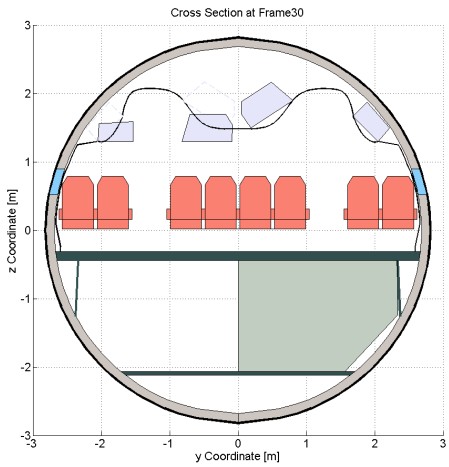
Another cross section is investigated: a slightly enlarged single aisle cross section that allows a substantially wider aisle at 18inch seat width and also larger overhead stowage bins. The same cross section is also used for a twin aisle 6-abreast layout. This layout uses smaller seats (17inch) and smaller aisle as well as a different overhead bin layout.



(a) 6-Abreast Cross Section



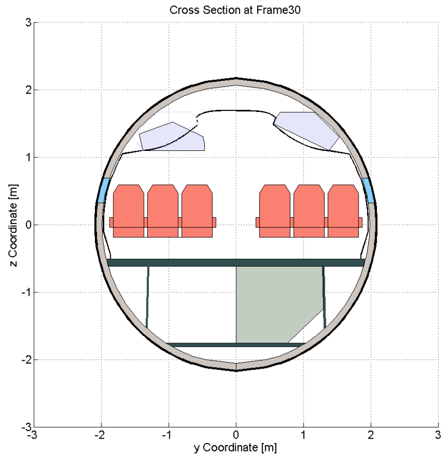
(b) 7-Abreast Cross Section



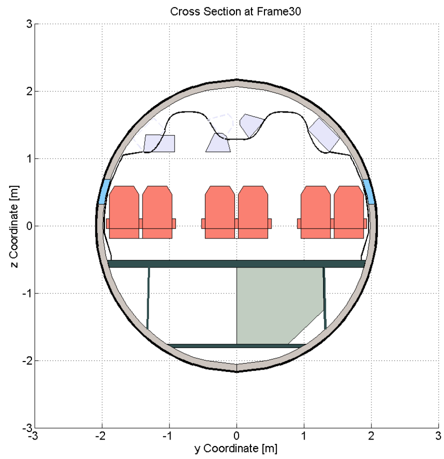
(c) 8-Abreast Cross Section

Figure 6: Cross Sections

The overhead bins are created using a generic layout that conserves enough space for passenger service units and structural attachment. Their design is not optimized for a particular type of luggage, so that incompabilities resulting from bulky luggage (like IATA Standard trolleys) is not regarded. Luggage is instead regarded as an amount of volume. However, luggage volume is always multiplied with a "volume efficiency factor" as the entire physical overhead bin volume can never be used.



(a) Advanced Single Aisle



(b) 6-Abreast Twin Aisle

Figure 7: Advanced Single Aisle cross section

3.2.2 Cabin Layout

Cabin layouts are generated using an in-house tool for a variety of applications. Key element of the tool is the quick generation of cabin layouts from a limited amount of input data. For each cross section layouts were established for 130, 150, 180, 200, 220, 240, 260 and 280 seats in an all-economy layout with 30inch seat pitch. This pitch are oriented on the new "Lufthansa Europa Kabine". The exit capacity limit is adapted to the number of passengers by addition of doors and overwing exits.

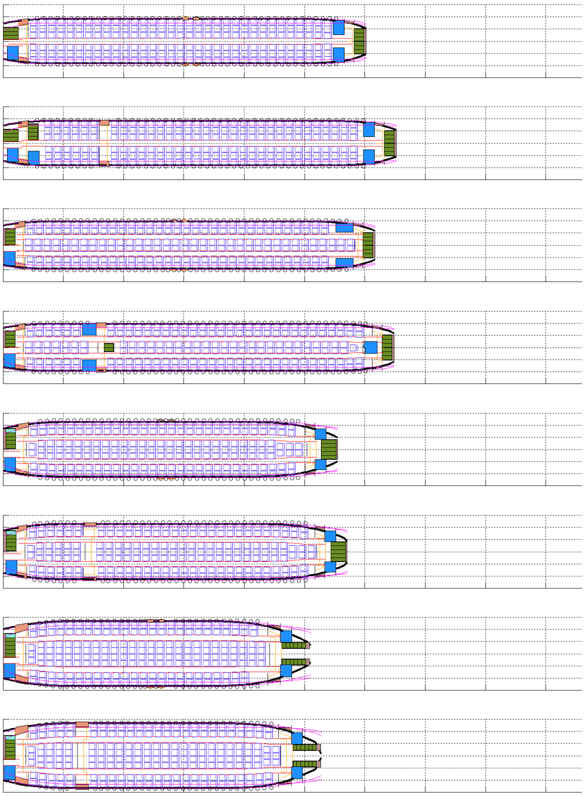


Figure 8: Different Layouts for 200 PAX

The number of monuments is matched to the number of seats, while depending on the layout some differences exist in galley and lavatory ratios. Generally, the galley ratio is set to one tray per passenger (resulting in 28 passengers per trolley) and a maximum number of 65 passengers per lavatory. For each cross section a specific rear galley layout was developed that matches the requirements of short range service.
As noted in the Boeing study the usage of a boarding door closer to the wing reduces boarding time. This is also reflected by the fact that many airlines board via the second door if possible. This second door is referred to as "Quarter Door" as it is located roughly at one quarter of the fuselage length. The door needs to have sufficient distance to the wing and the underwing engines in order to prevent any interference between passenger loading bridge and the airframe or engine. That makes the quarter door unsuitable for all layouts below 180 seats.

Figure 8 shows 8 layouts using 4 different cross sections. From top to bottom the standard single aisle, twin-aisle 6-abreast, 7-abreast twin aisle and 8-abreast twin aisle. Each cabin is realized as conventional layout and with Quarter Door.

4 Simulation Results

This section presents a selection of simulation results. A discussion follows in the next section.

4.1 Fixed Scenario Simulations

"Fixed scenario simulations" denote a set of simulations with fixed input settings. That is, load factor and carry-on distribution are kept constant. Variations in the result occur due to different seat assignment and randomized events like passing probability. The deviation usually is within 10-15% of the mean result (see table 2). For each cabin layout 15 simulations were run. The graphs show the calculated boarding time as function of the number of seats.

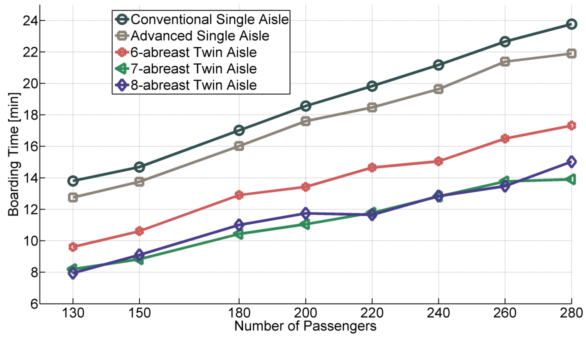


Figure 9: Boarding Times (Conventional Door)

Figure 9 displays the results. The standard single aisle shows the longest boarding times, closely trailed by the advanced single aisle with wider aisle. The 6-abreast twin aisle has substantially lower boarding time. The 7-abreast and 8-abreast twin aisles have shortest boarding times. All shown layouts are boarded via the forward left door.

Usage of a Quarter Door - a door that is located in front of the wing at approximately one quarter of the fuselage length - further reduces the boarding times as can be seen in figure 10. The conventional single aisle without quarter door is displayed as reference. As previously stated, the short fuselage of the 130- and 150-seater prevents usage of a Quarter Door. Even for the 180- and 200-seater a detailed analysis whether a door can be placed at the particular position is required.

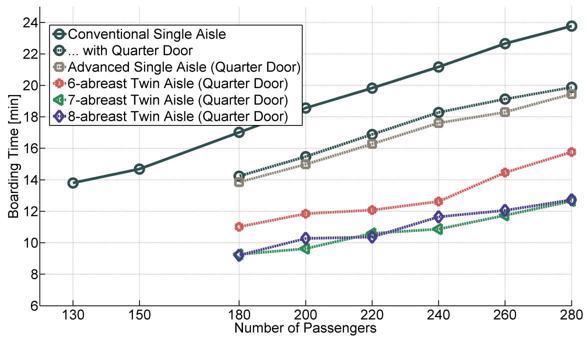


Figure 10: Boarding Times (Quarter Door)

In figure 11 the relative improvement in comparison to the conventional single aisle is displayed.

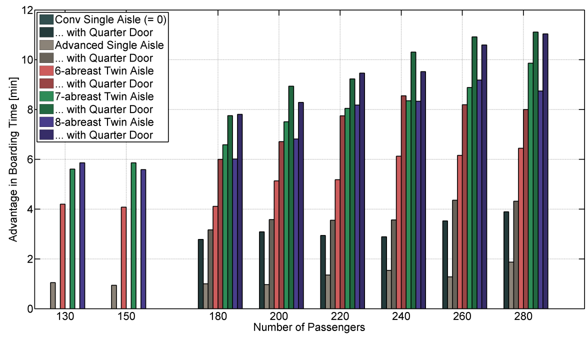


Figure 11: Relative Improvement in Boarding Times

4.2 Monte Carlo Simulations

"Monte Carlo simulations" denote simulations in which input parameters are varied randomly following a distribution function. The objective is to derive the average difference in boarding time. The previous scenario used a standardized scenario (100% Load Factor, substantial amount of heavy luggage), which represents a rather tough boarding scenario. In the following simulations load factor, carry-on distribution and passenger "smartness" are randomized for each run. The load factor is normally distributed around 80%, with 55% minimum and 100% maximum. The carry-on volume is normally distributed around 40%, with 60% maximum and 10% minimum. The "smartness" - indicator of how well the passengers behave inside the cabin - is uniformly distributed between maximum and minimum. As the "smartness" is a self-defined indicator of several time allowances, the values 0% and 100% denote the best or worst time allowances possible within the simulation.
The results show a large spread of results, similar to that seen in reality of airline business. In figure 12 the variation in boarding times is shown as histogram for the 200-seat conventional single aisle, which was used for calibrating the tool. Note the mean value of the default scenario (black dashed line) is substantially above the mean value for the 200 boarding events with randomized conditions.

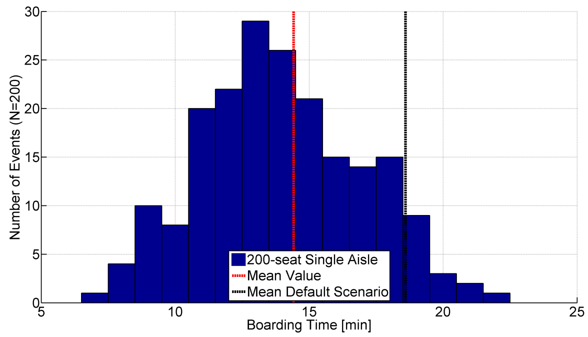


Figure 12: Spread of Boarding Times (200 PAX, Single Aisle)

These simulations are relevant as the reference scenario favors a design optimized for boarding of a fully loaded aircraft, and cited studies have always looked at fully loaded aircraft. Reality shows that average load factors especially for the mainline carriers in domestic service are in the region of 70%, with slightly increasing tendency though. The simulations are supposed to show the average difference between the different layouts. For that purpose each layout is subjected to 200 boarding events.

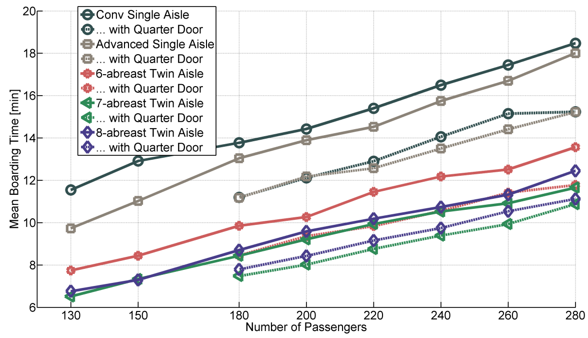


Figure 13: Mean Boarding Times (compare with figure 9 and 10)

Figure 13 shows that the previously seen advantage of the twin aisle remains, but is reduced as many boarding scenarios produce acceptable times with a single aisle. The figure combines conventional layout and quarter door layout. Compare with figures 9 and 10 from previous section.

The net advantage is displayed in figure 14. The 7-abreast twin aisle remains the design with the most significant improvement. However, the reduction is only between 5 and 8 minutes. The 200 Passenger aircraft for example needs an average of 14 minutes for boarding as standard single aisle (see figure 13), the 7-abreast twin aisle reduces this on average to 9 minutes. This represents a saving of 43%. The default scenario with the maximum load factor has the 200 passenger single aisle at 19 minutes boarding time, and the 7-abreast twin aisle at 11 minutes. The relative reduction boarding time is basically the same with 42%. However, for the turn-around only absolute advantages are relevant.

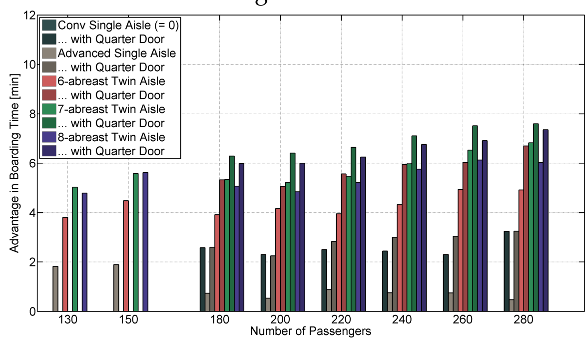


Figure 14: Relative Improvement in Boarding Times (compare with figure 11)

4.3 Combined Boarding and De-Boarding Times

As stated before de-boarding times are less susceptible to changes in parameters. The key influential parameter is the number of passenger using a single aisle. The 6-abreast twin fares best in this category. The deboarding rate is finally limited by the rate of passengers that can pass the door (set to 35 PAX/minute). Usage of a Quarter Door has no significant effect.

The boarding results are combined with the de-boarding results. Together with the cabin cleaning the resulting time would yield the minimum turn-around time if cargo loading operations can be accomplished within this time. The results are presented in figure 15 for the default scenario (fixed baggage distribution, 100% load factor). The reference time (200 PAX single aisle) is roughly 30 minutes.

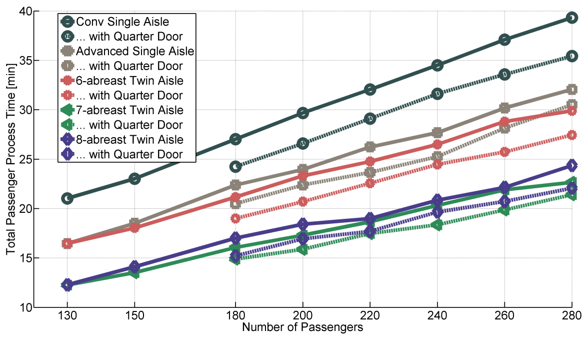


Figure 15: Combined Boarding and De-Boarding Times (Default Scenario)

The next two figures present the relative advantage compared to a conventional single aisle. The first figure (16) shows the net advantage for the default scenario. The next figure (16) displays the advantage of new cabin layouts using the Monte Carlo simulations. This simulation method represents the typical airline operational environment better and hence allows a more realistic idea about the expected time savings. For the 200-seat aircraft the 7-abreast twin aisle achieves a time saving of about 8 minutes.

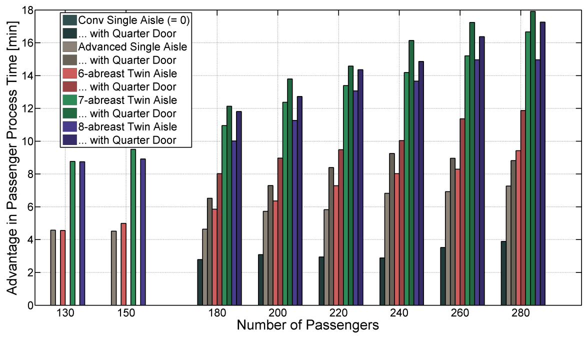


Figure 16: Time Advantage - Combined Boarding and De-Boarding Times (Default Scenario)

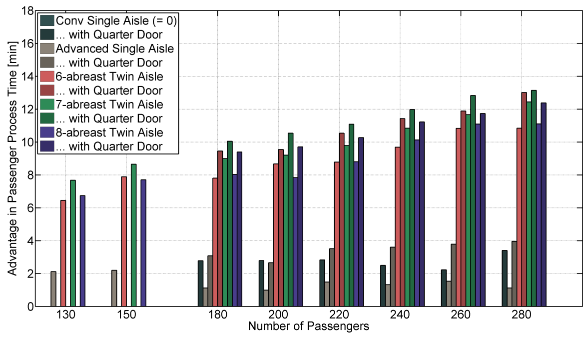


Figure 17: Time Advantage - Combined Boarding and De-Boarding Times (Monte Carlo)

5 Discussion of Results

The results show clearly the advantage of the twin aisles configurations for all simulated scenarios. Also the advanced single aisle (with wider aisle) provides noticeable benefits. The Quarter Door (a door at approximately one fourth of the fuselage length) reduces boarding times for each layout.

For the final assessment, figure 17 offers the best basis as it includes de-boarding and uses randomized input settings. It best reflects the average possible savings per turn-around compared to a conventional single aisle. In the most relevant region between 150 and 220 seats (current A320 family), savings of up to 2 minutes are possible with a wider aisle. Addition of a quarter door reduces passenger time by about 5 minutes. A twin aisle layout reduces passenger times by 8 minutes. The Quarter Door has a much more significant impact on the single aisle than on the twin aisle.

Most surprising is that the 6-abreast twin aisle does not achieve better results. By theory it offers minimum seat interference and maximum aisle space per seat. A closer look at the simulation unveils that the reduced overhead bin capacity increases the boarding times. It shall be noted that the used cross section is based on the single aisle, so the layout is rather confined. A dedicated cross section for a 6-abreast twin aisle would compensate for this but also have penalties in weight per seat.

The 7- and 8-abreast twin aisles achieve nearly similar boarding times. The increased seat interference of the 8-abreast layout is compensated by its higher availability of overhead stowage. In terms of overall aircraft design, the 8-abreast is less desirable for capacities below 300 seats.

The aircraft size influences the time benefit. The 7-abreast twin aisle saves 7 minutes for the 130-seater, 8 minutes for the 200-seater and 10 minutes for the 280-seater. However, the influence of seat count is weaker than could be expected.

In terms of overall time the 7-abreast twin aisle with quarter door offers best results. The advanced single aisle with 25in aisle and quarter door also offers significant advantages. Neither the 8-abreast twin aisle nor the 6-abreast twin aisle offer enough advantage to justify their rather unsuited layout. The 6-abreast twin aisle wastes too much floor space, the 8-abreast twin aisle has a undesirable relationship between fuselage diameter and length for most capacities.

It needs to be reminded that the results base on a number of assumptions. The results presented above are drawn from the randomized simulation (Monte Carlo simulation). Important variables are average load factor (80% mean) and average carry-on (40% mean), the "Smartness" was identified to be of low importance. The actual distribution is dependent on the airline's busines model. Some line carriers have average load factor below 70% on domestic routes, some "Low Cost" carriers have load factors above 80%. The carry-on volume depends on the type of passenger, but also on airline's policy. Many airlines charge substantial fees for additional checked luggage, and passengers compensate by increasing their carry-on luggage. Generally, an increase in carry-on luggage is observable and many passengers consider it added value when they can store larger amounts of carry-on luggage without the fear of being forced to check their luggage.

5.1 Future Research

The results have shown an advantage of twin aisle cabin layouts in passenger movement times (combined boarding and de-boarding). These advantages may allow a quicker turn-around if other parallel processes - dominantly the cargo loading - do not prevent an earlier push-back. The shorter turn-around may translate into additional flights per day or a more robust schedule, increasing the revenue per aircraft. On the opposite are added weight and drag of the wider fuselage, including snow-ball effects for a fixed design mission. Finally the viability of a twin aisle concept depends on the passenger count. Smaller aircraft will achieve a smaller time benefit.
In the end a cost advantage of disadvantage will result, depending on the many parameters stated (airline business model, number of seats, average stage length, etc). If cost difference is small - no noticeable difference - other factors like different comfort perception might favor the one over the other design.

6 Conclusion

The paper has presented a method for boarding time assessment and the results for a variety of aircraft layouts. The paper is especially aimed at ideas towards a twin aisle configurations as replacement for current single aisle aircraft. The results show that twin aisle configurations are beneficial, but that single aisle aircraft have the potential of reducing their boarding times. The results are sensitive to parameters like load factor and carry-on luggage. If a twin aisle design is sought, a 7-abreast layout appears most promising. Single aisles can reduce their boarding time primarily by addition of a boarding door just ahead of the wing (Quarter Door). The effect of a wider aisle was found to be limited. The final advantage of a design needs to be weighted against loss in transport efficiency (weight and drag), and changed revenue due to better utilization. This will be done in future studies.

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