BOARDING PROCESS ASSESSMENT OF THE AVACON RESEARCH BASELINE AIRCRAFT

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Abstract

In the LuFo research project "AdVanced Aircraft CONcepts" (AVACON), one of the areas of interest is the aircraft's cabin layout as well as its implication on the passenger flow during the boarding procedure. Starting with the research baseline aircraft and continuing with each of the research project's consecutive aircraft derivations, a dedicated work package comprising of Airbus and Bauhaus Luftfahrt e.V. (BHL) assesses those questions. The specific task of BHL in this package is to assess the boarding process of the different aircraft iterations using the PAXelerate boarding simulation tool.

PAXelerate[2] is an open source, 2D agent-based passenger flow simulation developed by BHL as a fast way to assess novel cabin layouts in terms of their boarding performance. The foundation of the simulation framework is a cheapest path A-Star algorithm operating in a grid based cabin representation. Support for the CPACS file format is implemented into PAXelerate for the AVACON project in order to achieve a seamless import and integration of the different aircraft iterations. The tool itself consists of two parts with one being the cabin configurator module, which renders the CPACS data and enables the verification of implementations and a modification of the cabin layout. The simulation itself is executed in the second, console based module, enabling a rapid batch simulation and trade study assessment.

In the scope of this publication, the passenger flow is simulated for the AVACON research baseline aircraft containing 252 passengers in a two-class layout. The assessment focuses on a variation of the applied boarding procedure (including a random, window-to-aisle sequence) as well as the respective door configuration. PAXelerate performs these different boarding scenarios and is capable of highlighting potential sensitivities. The results of the simulations not only deliver an average boarding time for a given scenario but also hint at other aspects such as the number of interruptions of passengers walking through the cabin. From this data, possible paths for a suitable boarding procedure as well as the impact of a different boarding door can be derived and highlight the path for the projects future cabin design.

Keywords

PAXelerate, Boarding Simulation, Agent based, Aircraft, Passenger, AVACON

Abbreviations

LuFo	Luftfahrtforschungsprogramm
BHL	Bauhaus Luftfahrt E.V.
ARB	AVACON Research Baseline
AVACON	Advanced Aircraft Concepts
n	Number Of Simulation Loops
PAX	Passengers
CPACS	Common Parametric Aircraft Configuration Schema
RTF	Rear to Front Boarding Procedure
FTR	Front to Rear Boarding Procedure
WTA	Window to Aisle Boarding Procedure
Ø	Average
Δ_{REF}	Delta; Difference to Reference Simulation
σ	Sigma; Standard Deviation

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1. INTRODUCTION

The aircraft cabin and its boarding performance are an important aspect of today's and future aircraft as they can enable an increased passenger comfort and an improved turnaround performance. As the boarding sequence during the turnaround lies on the so-called critical path [1], every saved second can lead to a faster process. This in the end enables a benefit for airlines as they can utilize the aircraft better and for passengers as the often exhausting boarding process can be made more fluid and relaxing.

The LuFo research project "AdVanced Aircraft CONcepts" (AVACON) aims to develop a new mid-range aircraft concept for the year 2028 and to strengthen interdisciplinary connections in the German aerospace research industry. One of the areas of interest within the project is the aircraft's cabin layout as well as its implication on the passenger flow during the boarding procedure.

Starting with the research baseline aircraft and continuing with each of the research project's consecutive aircraft derivations, a dedicated work package comprising of Airbus and Bauhaus Luftfahrt e.V. (BHL) assesses those questions. The specific task of BHL in this package is to assess the boarding process of the different aircraft iterations using the PAXelerate boarding simulation tool. In order to assess the boarding process on a wide scale, a variety of different boarding strategies (such as window to aisle, rear to front) as well as multiple boarding doors is taken into consideration.

2. THE PAXELERATE BOARDING SIMULATION

PAXelerate is an open source [2], 2D agent-based passenger flow simulation developed by BHL as a fast way to assess novel cabin layouts in terms of their boarding performance. The foundation of the simulation framework is a cheapest path A-Star algorithm operating in a grid based cabin representation. [3] [4]

Support for the CPACS file format was implemented into PAXelerate for the AVACON project in order to achieve a fast import and integration of the different aircraft iterations. [5] CPACS is a common language for aircraft design that can "hold data from a variety of disciplines considered in an aircraft design process" [6] and enables a seamless exchange of data between different tools and disciplines. This includes detailed cabin geometry data such as position and size of every object and the shape of the cabin, which is imported into PAXelerate via an interface.

PAXelerate itself consists of two modules that can be seen in Figure 1. The first module is the cabin configurator, which renders the CPACS data and enables the verification of implementations and modifications to the cabin layout. In addition, design rules such as CS25 certification for the positioning and the amount of doors are integrated.

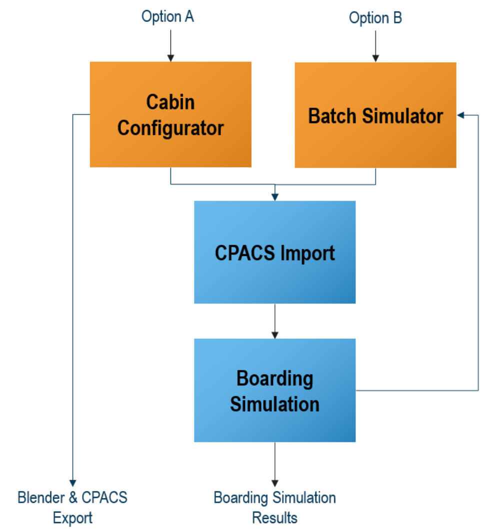

Figure 1: The different modules of PAXelerate and their interaction

The boarding simulation is executed in the second module providing a rapid batch simulation and trade study assessment. This structure enables a split in functionality and thus an increased performance by providing batch simulation capabilities without the burden of a user interface and its implications on the computing performance.

3. THE AVACON RESEARCH BASELINE AIRCRAFT

The AVACON Research Baseline (ARB) has been derived from the Boeing 767 top-level aircraft requirements and has been enhanced with technologies suited for an entry into service in the year 2028 [7]. The most important characteristics of the aircraft can be seen in Table 1.

Parameter	Value	Unit
Design Range	4600	nm
Passengers	252	-
Cabin Classes	2	-
Cabin Length	41.98	m
Maximum Cabin Width	4.9	m
Maximum Take-Off Weight	140.3	t
Wing Span	52	m
Cruise Mach Number	0.83	-

Table 1: Main characteristics of the AVACON research baseline aircraft [7]

The cabin layout of the twin-aisle ARB with 252 passengers in a 2-class configuration can be seen in the following Figure 2. Additionally, the door configuration with the nomenclature of the different doors and their respective type is highlighted.

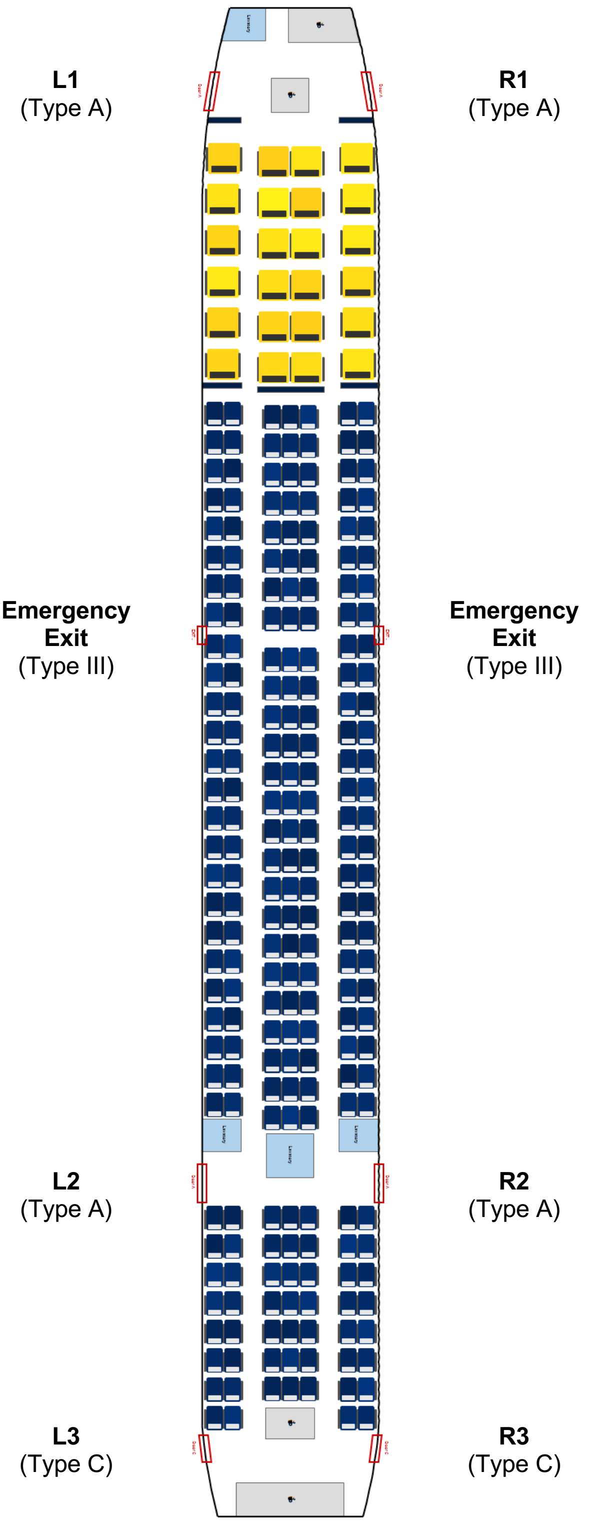

Figure 2: Cabin layout and door nomenclature of the AVACON research baseline aircraft

Additionally, the cross section of the ARB can be seen next in Figure 3. A seven-abreast layout with a maximum amount of three seats per group and two seats at the window is assumed to be an adequate comfort level for the year 2028. This means that no matter the position in the aircraft, a passenger never needs to pass more than one person when either trying to get to the assigned seat during the boarding process or leaving the seat during flight.

Figure 3: Schematic cross section layout of the ARB with seats (illustration only)

4. BOARDING SIMULATION APPLICATION

The boarding assessment of the ARB in PAXelerate focuses on a variation of boarding door quantity as well as on a variation of the applied boarding procedure. The following Table 2 gives a brief overview of the studies performed.

Assessing the different existing boarding strategies is done because the effort implementing the procedures at the gate is minor compared to the consequences it has when the turnaround process can be significantly swifter. For completeness, many different existing and suggested strategies are contained in the assessment of this paper. This includes the window-to-aisle (WTA) strategy, currently being investigated by Lufthansa under the term “WILMA” [8] as well as a random boarding sequence neglecting the typical “premium classes first” approach.

Concerning the multi door boarding scenarios, all possible combinations are assessed, regardless of their practicability in a real world scenario. This is based on the assumption that although operational hurdles may prevent certain door combinations, general insights concerning the positioning of doors may still be derived from their boarding simulation results.

Study	Amount of Active Doors	Boarding Procedure
Reference Case	1	CLASS
Single Door Scenarios	1	*various*
Dual Door Scenarios	2	CLASS + RANDOM
Triple Door Scenario	3	CLASS + RANDOM

Table 2: Collection of the different boarding simulation test cases

The CLASS boarding procedure using the L1 door is the default procedure used at airports around the world and will be considered as the reference case for the studies performed in this paper. The RANDOM boarding procedure delivers a boarding process with a random boarding sequence of all passengers, neglecting the type of class the passenger has booked. Other procedures investigated for the single door scenarios include a class wise boarding (CLASS), a window to aisle boarding (WTA), a rear-to-front (RTF) and front-to-rear (RTF) boarding as well as a combination of the both. Lastly, a boarding procedure introduced by Steffen [9] is applied, distributing passengers in a specific way, which aims to reduce interferences during the boarding process.

All boarding scenarios are simulated using a 100% load factor of passengers. The preset values for PAXelerate such as passenger anthropometrics and various settings remain unchanged, as they have already been validated in earlier publications. The distribution of anthropometrical data as well as carry-on luggage is based on a Monte-Carlo approach. Due to this, every single simulation is a unique combination of passengers and properties. This results in the fact that every simulation case mentioned above needs to be simulated many times in order to generate a more general statement. For this paper, every simulation is performed 100 times. Calculating an average boarding time and a standard deviation from the collection of results leads to the final boarding times being presented in the subsequent sections of this paper.

4.1. Single Door Scenarios

For the single door boarding scenarios, boarding procedures and door assignments in Table 3 are considered. Note that the STEFFEN boarding procedure is only simulated for the L1 configuration, as this procedure has specifically been crafted for a single aisle L1 boarding configuration and is not suited for a boarding scenario using the rear exits of an aircraft or multiple exits at once.

Procedure	L1	L2	L3
RANDOM	●	●	●
CLASS	●	●	●
RTF	●	●	●
FTR	●	●	●
WTA	●	●	●
WTA & RTF	●	●	●
WTA & FTR	●	●	●
STEFFEN	●	-	-

Table 3: Collection of the different boarding simulation test cases

4.2. Multi Door Scenarios

Concerning the multi door boarding strategies, all possible dual door configurations as well as a configuration with three doors (L1, L2 and L3) are assessed. Due to the symmetry of the cabin layout, not all door combinations have to be calculated explicitly but are a result of another combination as well (□ symbol in table below). Passengers boarding the aircraft will always choose the door closest to their respective seat.

		L2	L3	R1	R2	R3
Dual	L1	●	●	●	□	□
	L2		●	□	●	□
	L3			□	□	●
	R1				□	□
	R2					□
Triple	L1	●				

Table 4: Collection of the different boarding simulation test cases (□ = implicit result due to symmetry)

5. RESULTS

As seen in the following Figure 4, the Monte Carlo approach for the assignment of various simulation parameters results in a distribution of boarding times according to a normal distribution. Thus, for the boarding time results of the different assessments the average value of all the 100 simulation loops is calculated.

Exemplary, the average boarding time for the reference boarding simulation with a class wise boarding sequence is 16:27 minutes (vertical line in figure). The standard deviation sigma (σ) of this result is 34 seconds. In comparison, Boeing specified the boarding time of a B767 with 216 passengers at 13 minutes using the door L1 only [10], whereas Airbus specifies a roughly 25% longer duration than PAXelerate for a A330-200 with 293 passengers using two boarding doors [11]. Considering the ARB's 252 passengers, PAXelerate delivers plausible results for the default simulation case compared with data provided by OEMs.

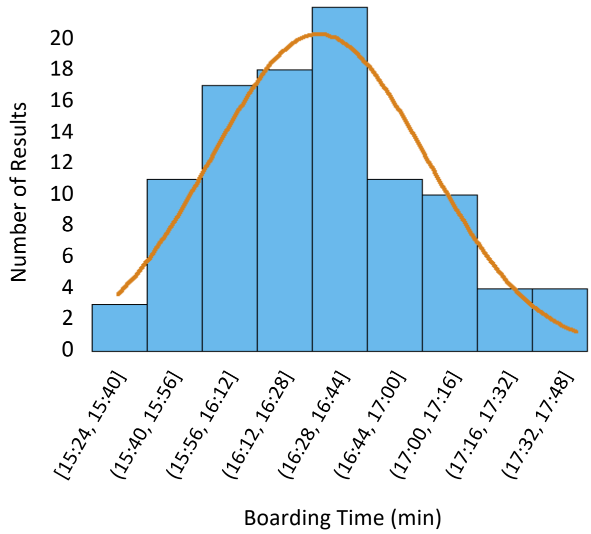

Figure 4: Distribution of simulation results for the reference simulation

Following in Table 5 is an overview of the resulting boarding times for each of the different scenarios. Next to the average boarding times (Ø), the values for the standard deviation (σ) as well as the relative difference to the reference scenario (Δ_{REF}) are given.

Scenario	Door	Ø	σ	Δ_{REF}
CLASS	L1	**16:27**	00:34	-
RANDOM		**16:20**	00:35	-0.7%
RTF		**31:15**	01:09	+90.0%
FTR		**44:40**	00:58	+171.5%
WTA		**15:51**	00:31	-3.6%
WTA RTF		**28:14**	00:45	+71.6%
WTA FTR		**41:48**	00:49	+154.1%
STEFFEN		**15:28**	00:44	-6.0%
CLASS	L2	**16:18**	00:52	-0.9%
RANDOM		**16:53**	01:23	+2.6%
RTF		**43:21**	01:22	+163.5%
FTR		**35:24**	02:06	+115.2%
WTA		**15:59**	01:05	-2.9%
WTA RTF		**38:55**	00:54	+136.5%
WTA FTR		**32:42**	01:11	+98.8%
CLASS	L3	**16:56**	00:55	+2.9%
RANDOM		**16:24**	00:31	-0.3%
RTF		**50:12**	02:01	+205.1%
FTR		**32:47**	01:29	+99.3%
WTA		**16:44**	01:18	+1.7%
WTA RTF		**43:31**	02:13	+164.5%
WTA FTR		**33:45**	01:54	+105.1%
CLASS	L1 L2	**11:56**	00:53	-27.4%
RANDOM		**12:17**	00:54	-25.4%
CLASS	L1 L3	**10:59**	00:57	-33.2%
RANDOM		**11:29**	01:15	-30.2%
CLASS	L1 R1	**15:34**	00:58	-5.3%
RANDOM		**15:59**	02:44	-2.9%
CLASS	L2 L3	**15:22**	00:53	-6.6%
RANDOM		**15:41**	01:41	-4.6%
CLASS	L2 R2	**12:38**	01:32	-23.2%
RANDOM		**13:06**	01:58	-20.4%
CLASS	L3 R3	**12:20**	00:44	-25.0%
RANDOM		**12:43**	01:08	-22.7%
CLASS	L1 L2 L3	**09:57**	00:31	-39.5%
RANDOM		**09:53**	00:33	-39.9%

Table 5: List of boarding times for the different boarding process scenarios.

The smaller the standard deviation, the more certain PAXelerate is performing a specific scenario, as the outcome of the 100 simulations is more precisely determinable.

5.1. Single Door Boarding Strategies

The boarding results for the different single door boarding strategies are shown graphically in Figure 5. It can be seen that all boarding procedures forcing the passengers to board the aircraft in a row-wise sequence (RTF & FTR) have a vast negative impact on the boarding times. This is caused by the luggage storing (aisle interference) and the way making actions (seat interference), if a passenger is already seated in between a passenger and her/his seat. Those actions cannot be performed simultaneously, but one row after another, as the gaps between two sequential rows do not provide enough space. This effect can be eased when the passengers are additionally sorted in a combined WTA sequence, which eliminates the seat interferences. Queueing due to aisle interferences caused by luggage storing can however not be mitigated by this approach.

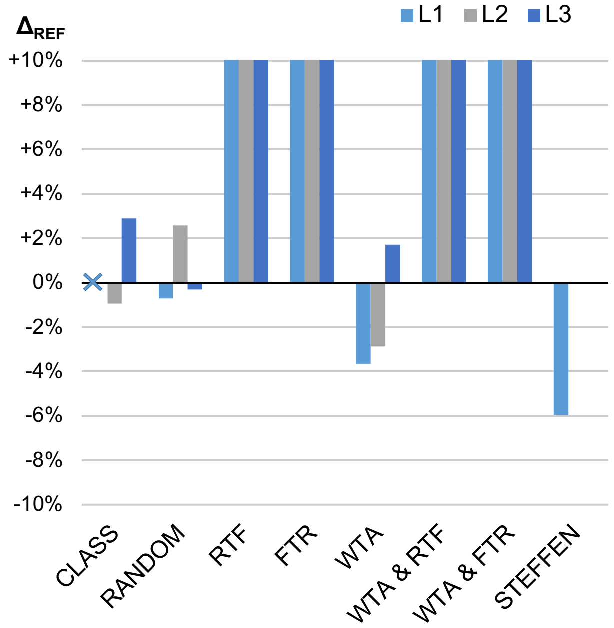

Figure 5: Boarding time difference for the different strategies compared to the reference simulation (excerpt).

In contrast to this, the boarding processes distributing sequential passengers throughout the cabin (CLASS, RANDOM, WTA, and STEFFEN) reduce the amount of both aisle as well as seat interferences (see Figure 6) and thereby enable a quicker boarding process.

Considering L1, the default boarding door, the random boarding sequence is slightly better than the class wise boarding process, followed by the window to aisle boarding process removing all seat interferences and only being topped by the STEFFEN boarding process, which is specifically designed to reduce all types of interference.

These facts can be supported by Figure 6 highlighting the average number of interruptions per passenger during the boarding process. These interruptions contain waiting due to queueing and waiting for other passengers to clear a row. These figures can be translated into the smoothness of the boarding procedure and the passengers' perception on it. Passengers having to stop and wait more often might have a more negative impression of the overall process compared to passengers not being interrupted.

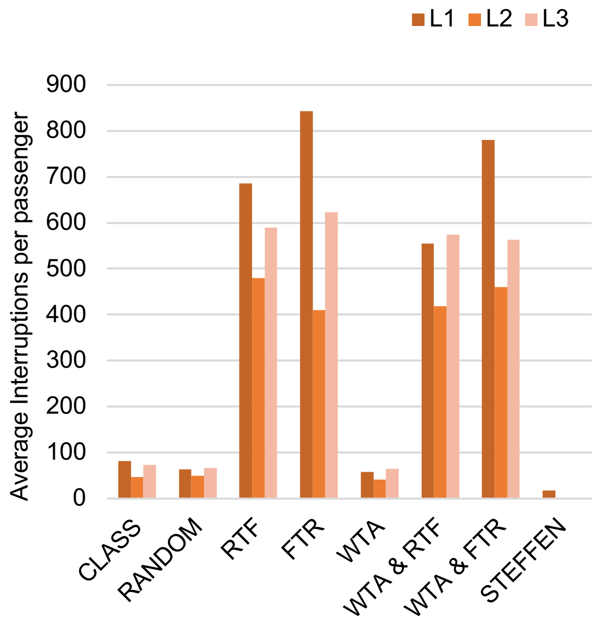

Figure 6: Average PAX interruptions for the different boarding procedures

Neglecting the RTF and FTR scenarios, which are clearly not recommended for boarding an aircraft in a reasonable timeframe, the STEFFEN sequence is the best performing procedure in this aspect as well. It is followed by the WTA, RANDOM and CLASS sequences.

5.2. Multi Door Boarding

The boarding results for the multi door boarding scenarios can be seen in the following Figure 7. As expected, boarding through multiple doors is, depending on the chosen doors, significantly faster than a single door boarding procedure. This is caused by the initial passenger throughput being multiplied by the number of doors.

The L1 R1 configuration only has a relatively low impact on boarding performance. The initial benefit of the doubled throughput is hindered by the fact that the cabin then behaves similar to two single aisle cabins with their respective aisle and seat interferences. This can be confirmed by Figure 8, which clearly shows a peak amount of interruptions in the boarding process for the L1 R1 configuration. Using a combination of L2 and L3 only has a minor impact as well. This can be explained by the small amount of passengers being served by the L3 door. As each passenger selects the door closest to her/his respective seat, the L3 door only serves for the last few rows and thus only has a minor impact.

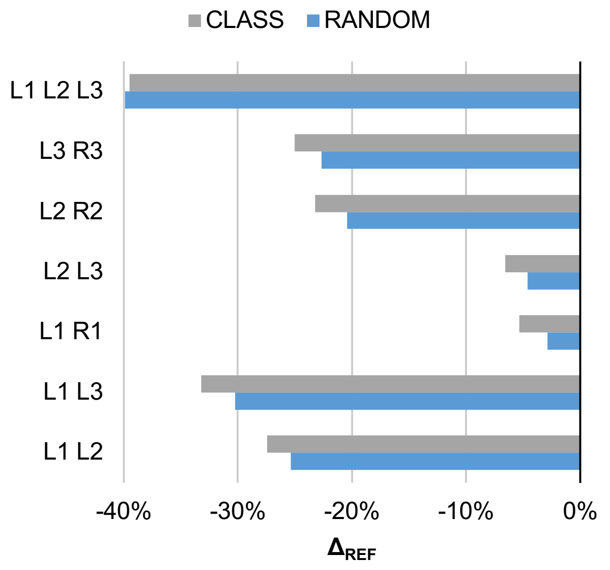

Figure 7: Boarding time difference for the different door combinations compared to the reference simulation.

Comparing the L2 R2 and L3 R3 configurations, the different scenarios behave relatively similar in terms of boarding performance as their relative position within the cabin is quite close. However, the L2 R2 configuration performs better when looking at the average interruptions per passenger.

Concerning the triple door L1 L2 L3 configuration, the result is added for completeness but does not have purpose for meaningful improvements of the boarding process as it either implies a stairway ("bus transfer") boarding process where passengers can access all doors on one side or implies a gate construction with three bridges delivering passengers behind the wings. Both of these options do however not seem feasible for a mid-range turnaround process on a current airport.

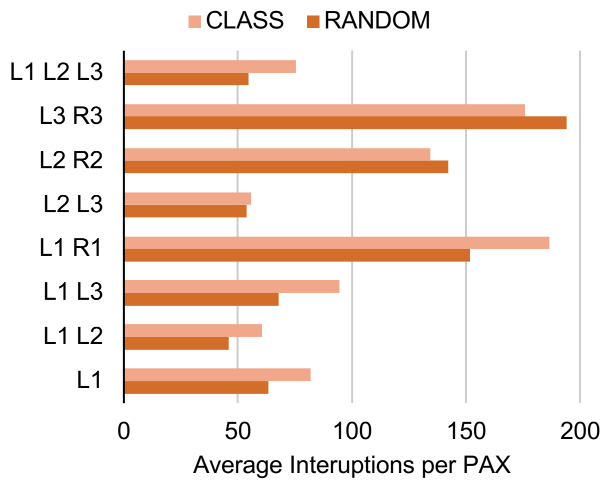

Figure 8: Average PAX interruptions for the different door combinations

Lastly, a reasonable combination of doors being fairly far apart (L1 L2 and L1 L3) seems to have the biggest benefit for both the boarding times and the number of interruptions. This can be explained by the fact that there is both a split of passenger streams at the doors as well as a split at the aisles, reducing the possibility for interferences immensely.

6. CONCLUSIONS

The results of the boarding process assessment for the AVACON research baseline aircraft highlight that even with relatively minor effort, it is possible to significantly reduce the boarding times and by that improve the turnaround process performance as a whole.

6.1. Results interpretation

Using the default L1 boarding door, a reduction of up to 6% can be achieved using the STEFFEN boarding process, which additionally provides the smoothest boarding due to its few interruptions. However, as this procedure is not easy to implement at current boarding gates, other options include boarding with a WTA sequence prioritizing passengers seated at the windows (e.g. as used by Lufthansa) as well as a RANDOM boarding sequence, which each slightly reduce the number of interruptions per passenger. Using the L2 or L3 door with different boarding scenarios shows that the effort of changing the default boarding door is in no case (except L2 CLASS) justified, as the L1 configuration will always perform better.

Considering the multi door boarding scenarios, as expected, a significant reduction in boarding times can be achieved. Due to operational implications and obstructions by the positioning of the ARB's wing, only a L1 R1 boarding process is considered feasible. The same benefit of a boarding time reduction can however be achieved with one of the L1 boarding processes above.

In future research, an application of various boarding scenarios onto different door combinations may highlight additional potential, which has not been considered within the scope of this paper. Additionally, a block wise boarding, like it is performed by Air France [12] as well as novel boarding strategies such as the Milne-Kelly procedure [13] could be assessed. Some of those strategies are however currently only designed for a single aisle aircraft and would need to be adapted for a use in multi aisle aircraft.

6.2. General remarks

Considering that the ARB is a mid-range aircraft with two aisles, the boarding process as well as the turnaround process does not take a comparably critical roll to that of a single aisle short-range aircraft, as the flight frequency is significantly lower.

Furthermore, different boarding strategies have a smaller impact on boarding times compared to the application in a single aisle aircraft with the same amount of passengers. One of the reasons for this effect is the existence of two aisles, which immediately enables a split of the passenger flow at the door area into two (Figure 9). The amount of interference is significantly reduced by this, as less people have to access an aisle per row compared to a single aisle configuration.

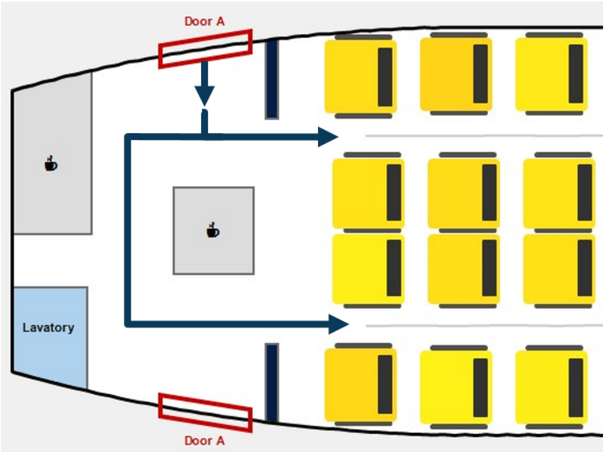

Figure 9: Flow of passengers during a boarding scenario with division of flow to different aisles.

Similar to the impact of the number of available aisles, the position of the boarding door has a huge impact on the boarding performance as well. As it can be seen in Figure 10, depending on the position of the door, the passenger flow is split into four separate streams delivering passengers to the seats in front of the door as well as behind the door. The more centered the door is within the cabin, the better the split of the passenger streams performs for boarding. This can also be seen in [3], where a quarter positioned door has been assessed by PAXelerate.

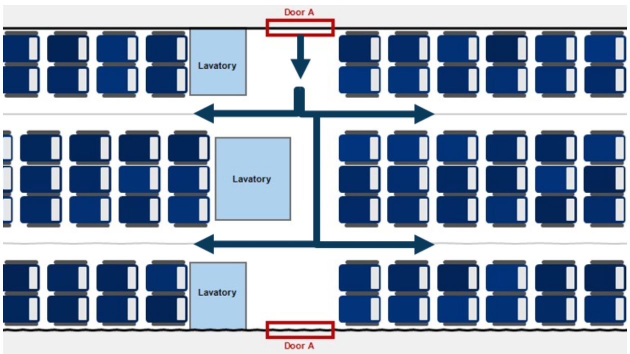

Figure 10: Flow of passengers with division of flow at the door.

7. NEXT STEPS

As a next step in the AVACON research project, a new passenger movement model will be introduced for the PAXelerate boarding simulation. This novel approach features an algorithm taking into account the surrounding cabin geometry during each of the passengers' steps and thus can derive a more accurate real time walking speed depending on the current geometry of the cabin around the passenger (see Figure 11). Other passengers as well as their respective hand luggage within the cabin are affecting the walking speed as well. Different layers enable the model to separately calculate the effects on the knee, hip, shoulder and head area, then combining it to a final braking factor for a specific point in time at a location within the cabin environment.

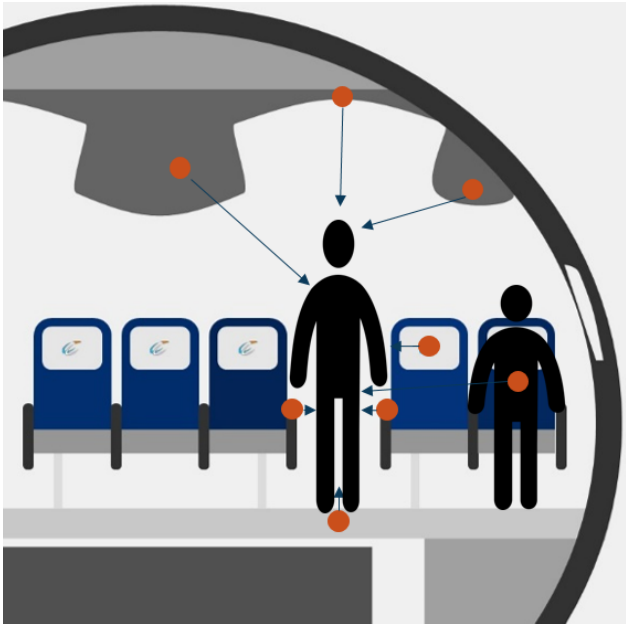

Figure 11: Schematic representation of the planned enhancements to PAXelerate.

This will enable the PAXelerate boarding tool to perform a more detailed analysis of passenger movement within the cabin during a boarding process and can thus highlight potential bottlenecks of minor cabin changes such as a change in aisle width or a change in the overhead bin design. The impact of these minor alternations of the cabin layout are not measurable in the current implementation state.

Furthermore, a more detailed carry-on luggage-handling model will be introduced in the future. This will empower PAXelerate to assess novel luggage storing options within the cabin as well as alternatives to the overhead bins currently being used in aircraft and might show paths for an improved boarding process.

Concerning the AVACON project and the cabin design in particular, a new position for the L/R2 door will be investigated due to repositioning of the engines to behind the wing of the aircraft. The new door will be located in front of the wing between the two travel classes and might enable an improved boarding performance, as the passenger flow can be split more even (see Figure 10).

8. ACKNOWLEDGEMENTS

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