Twin Aisle Aircraft for Short Range Operations - An Economically Attractive Alternative?

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Short range air traffic is dominated by single aisle aircraft. The average seat count of delivered single aisles has grown considerably. Single aisles are handicapped by lengthy boarding and deboarding times. Aircraft with twin aisle cabin layout may alleviate the boarding problem. But those aircraft may suffer from increased cost of operation. This paper studies how much better twin aisles fare in turnaround operations and how much more they cost to operate. These figures are analyzed for a selection of capacities and mission ranges in order to analyze where twin aisles offer benefits. The general finding is that twin aisles are more suitable above 240 seats capacity, but may offer superior economics even for lower capacities at short distances.

I. Introduction

This section provides the motivation and short introduction into aircraft turnaround. Further publications with comparable topics are introduced.

A. Motivation

The short and medium range traffic is dominated by single aisle aircraft. The dominating models are the Airbus 320 family and the Boeing 737 series. Despite being designed for ranges up to 3000nm, the majority of these aircraft are operated on shorter distances. Figure 1 uses the 2007 OAG schedule and shows that 37% of the flights are below 400nm, 65% are below 800nm.[1]

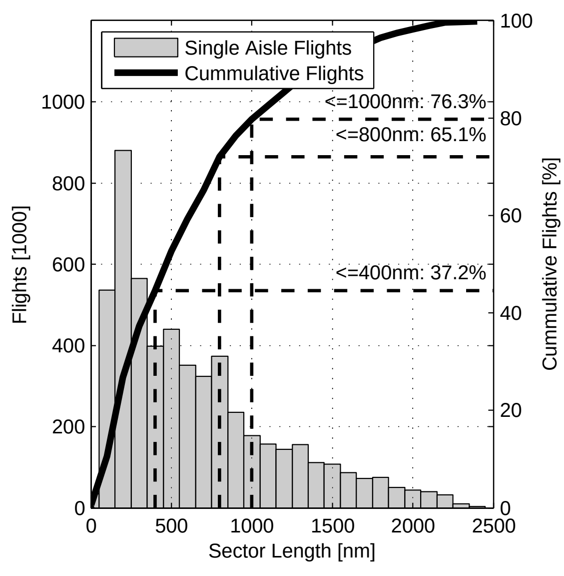

Figure 1. Flown single aisle distances. Data derived from OAG schedule of 2007.[1]

Besides the large number of short distance flights, other changes have taken place inside the aircraft cabin . The average seat count per delivered single aisle has increased despite the end of production of the B757. In figure 2(a) the development since the 1960ies is shown, data derived from Ascend database.[2] Average seat count is nearing 170 seats. Load factors are increasing industry-wide, too, as airlines try to increase their revenue per flight. In North America the average load factor is approaching 85%, and no real difference between low cost carriers and network carriers is visible any more (see figure 2(b)). In addition to this is a general increase in carry-on luggage. Samples have shown that people take more luggage into the cabin than they did before.[3] One contributing factor is the increasing tendency to

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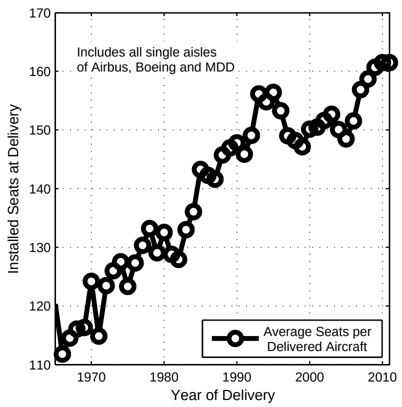
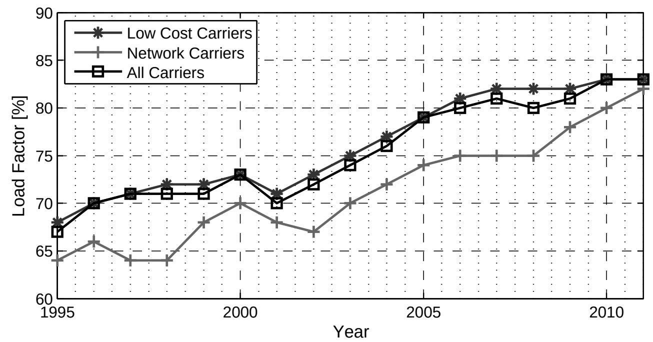
charge for checked luggage, motivating passengers to carry all luggage as carry-on.

Despite the recent decision by both manufacturers to re-engine their models, replacement models are still considered, utilizing newest technologies for improved efficiency. These models will probably grow in capacity over current single aisles, reflecting the growth in capacity over the last decades. Single aisles are known for lengthy boarding and deboarding times. These increase the time spent on the ground and reduce the revenue potential. An aircraft with faster turnaround time may offer better economics on short distance missions. One option of reducing the ground time is a different cabin layout with a second aisle allowing quicker boarding and deboarding. However, such layout would waste precious floor space and result in a heavier fuselage and more aerodynamic drag, causing a higher fuel burn.



(a) Seat Count



(b) Load Factor

Figure 2. Development in the short range sector: seats count per aircraft is increasing and load factors are approaching 85%, up from 65% in 15 years.

B. Turnaround and Boarding

Ground operations make up a major proportion of the daily operating time in short range air traffic. Shortening the ground time allows higher utilization. The ground time consists of the taxi time and the gate time. The gate time is the time the aircraft spends parked at the gate. During this time the aircraft is prepared for the next flight. Fuel is added, cargo is loaded and unloaded. The passengers disembark as soon as the passenger bridge is in position. When cabin cleaning is finished, the passengers for the next flight can enter the aircraft. Some of these processes have to be conducted in sequence, and some depend on the cessation of the other. In figure 3 a generic turnaround chart is provided. Typically, the processes in the cabin (deboarding - cleaning - boarding) represent the critical path, that is these processes set the length of the entire turnaround process. Cargo loading can usually be accomplished within this time, especially if containerized luggage is used. Refueling is accomplished quickly when ranges are short.

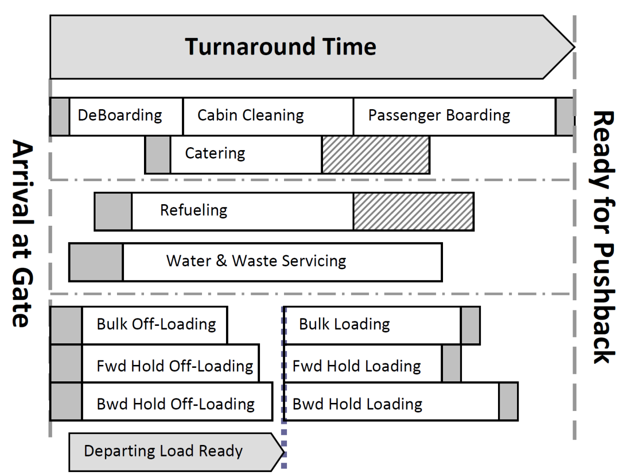


Figure 3. Generic turnaround process chart.

A reduction in ground time is desirable for better economics. Aircraft design cannot influence taxi times, so a reduction in gate time is the remaining option. Any reduction in gate time can only be achieved with shorter boarding and deboarding times. Consequently, any reduction in boarding or deboarding time directly reduces the gate time, and hence increases the utilization.

C. Related Publications and Research

Boarding time reduction has attracted several publications since the late 1990ies. These focused on the reduction of boarding time by using so called boarding strategies. A boarding strategy is a special sequence in which passengers enter the cabin. Depending on the strategy the passenger located in the rear part may enter first, or all passengers sitting in window seats. This is opposed to the usual random boarding where passengers enter in random order but with assigned seats. This is not to be mixed with random seating, a strategy pursued by some low cost carriers. Random seating means that no passenger has an assigned seat and can take any seat he finds unoccupied. This strategy motivates passengers to enter the cabin quickly in order to get an attractive seat. This strategy is successful but unsuitable for any carrier with comfort standards.
Several studies have looked at boarding strategies (Marelli,[4] van Landeghem,[5] van den Briel,[6] Nagel,[7] Steiner,[8] Bazargan,[9] Steffen[10]). An overview was generated by Nyquist.[11] One of the first publications was by Marelli (Boeing). Most studies concluded that only rather complicated strategies beat the random boarding. These strategies again require the passenger to adhere strictly to the order of entering the cabin, reducing his comfort and requiring some sort of enforcement. A recent publication by Steffen[12] has found the ideal order for quickest boarding. However, such strategies are usually unsuitable for daily airline operations in which even simple strategies like "'back-to-front"' are difficult to implement and enforce. Even a small number of passenger not adhering to the enter sequence increases boarding time by 20%.[10]
Krammer and Scholz[13] focused on low cost ground handling. Their concept allows quicker loading of cargo and better accessibility by ground handling vehicles. However, the cost savings in the turnaround process could not compensate the additional cost of operation. The additional cost originates from a double-digit increase in empty weight, which is result of the high-wing configuration with fuselage mounted engines. It demonstrates fairly well that advantages in ground handling and turnaround cannot compensate large deviations from the configuration for optimum flight performance.

II. Methods and Tools

In this section the used tools and methods are explained. The problem is researched using an advanced fuselage design tool, a boarding simulation and an aircraft design tool. The boarding simulation is also described in more detail in a different publication.[14]

A. Boarding Simulation

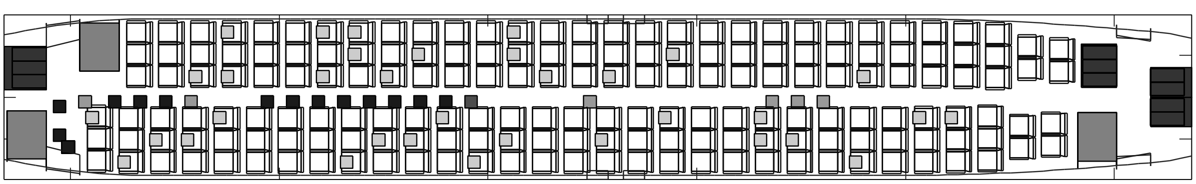


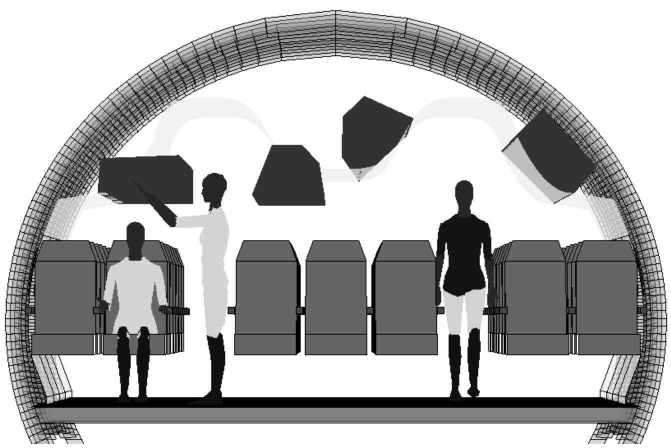
Figure 4. Screenshot from boarding simulation. Passengers in lighter colors are already seated or have not entered the simulation yet. Dark passengers are active but not moving as they are either accomplishing tasks or are blocked.

The analysis of boarding times can be achieved by two different methods: first statistics can be used to estimate the boarding time using a collection of actual results. This method is attractive if a database exists. It fails to yield any results if a new aircraft with a new cabin is introduced. Krammer[13] attempted this approach but was unable to derive reliable data from a set of recorded boardings. The more difficult but also more common approach is a simulation (see studies cited above). A boarding simulation is commonly implemented as so-called discrete time or discrete event simulations. These simulation types have their origin in queuing simulations. The Boeing study[4] actually used a program framework that is commonly used for factory planning.

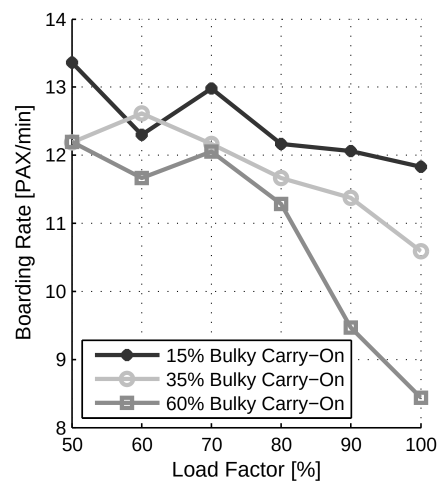
For this study an advanced type of simulation was developed. A discrete-time approach is used that simulates the boarding process in time steps. The cabin is separated into discrete nodes that can be occupied by the passengers. Passengers are modeled as individual agents with individual characteristics. In the simulation an agent walks to his seat using a path finding algorithm[a]. During the simulation the agents accomplish tasks like luggage storing or getting seated.

The basic functionality allows to simulate agents entering and leaving the cabin. Modeling of interruptions is of major importance. These interruptions are luggage loading or people standing up in order to allow other people to get to their assigned seat. These interruptions are modeled as time delays in which the aisle is blocked. A passenger carrying a piece of carry-on will remain in the aisle for a defined time period in order to store his luggage. The same happens when the passenger has to reach for example a window seat and the middle seat is already occupied. A few key features are introduced here for a better understanding of the later results.

1. *Special Features*



(a) Overhead Bin Modeling



(b) Boarding Rate

Figure 5. Overhead bin modeling and influence of carry-on in the simulation. Left the overhead bin size is derived from the fuselage cross section characteristics, as example a 7-abreast twin aisle. On the right side the decrease in boarding rate is visible as function of load factor for three different carry-on distributions.

In this study the basic functionality of the boarding simulation was extended. The type of carry-on is set individually for each passenger. Usually 45% of the passengers are supposed to carry bulky carry-on items such as roller trolleys. Passengers are further modeled in body dimensions according to normal distributions of body sizes. The cabin is modeled in greater detail. Figure 5(a) shows a screenshot of the actual model including the overhead bins. The size of the overhead bins are modeled in dependence of actual location. During the simulation run, the fill status of the individual overhead bins are changed with the loaded carry-on. When the bins are filling up the time required for carry-on storage increases. In figure 5(b) the influence in the simulation is shown. When carry-on and load factor increases, the boarding rate decreases. This sets a strong non-linear influence in the simulation. The model further includes aisle passing. When a passenger is blocking the aisle the following passenger has the chance to pass if the aisle width and body dimensions allow a passing without contact. Passing is less likely when passengers carry bulky carry-on luggage. Some

[a]A path finding algorithm is not strictly necessary but simplifies the simulation.

passengers are faster than others, and boarding processes may be very quick despite the aircraft being fully booked. Frequent flyers usually exhibit a faster boarding rate, whereas tourists or families take longer. This fact is considered in the simulation as "Smartness". If increased, luggage storing becomes faster and aisle passing more frequent.

2. Calibration

Behavior of passengers during a boarding process is subject of wide variation. Considerable effort was spent in analyzing recorded boarding events and observations. The time allowances for the individual tasks were set according to observations. Still adjustment is necessary to align the simulation with actual boarding results. Publications from Boeing,[4] ETH Zrich[8] and TU Dresden[15] have been used in the process. The simulation achieves similar times than the one described by Boeing with a slightly more optimistic tendency (see table 1). It is further shown that results for very pessimistic and very optimistic input settings achieved the range of boarding times observed in practice. The minimum time simulated for a 200 seat single aisle is just under 12 minutes, the maximum time is 28 minutes. Note that the spread with similar settings is 5 minutes, solely caused by the different enter sequence of the passengers.

Aircraft		Attributes		Time [min]			Mean Rate	Remark
Layout	PAX	Smartness	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
B757-200	201			22			9.1	Boeing PEDS

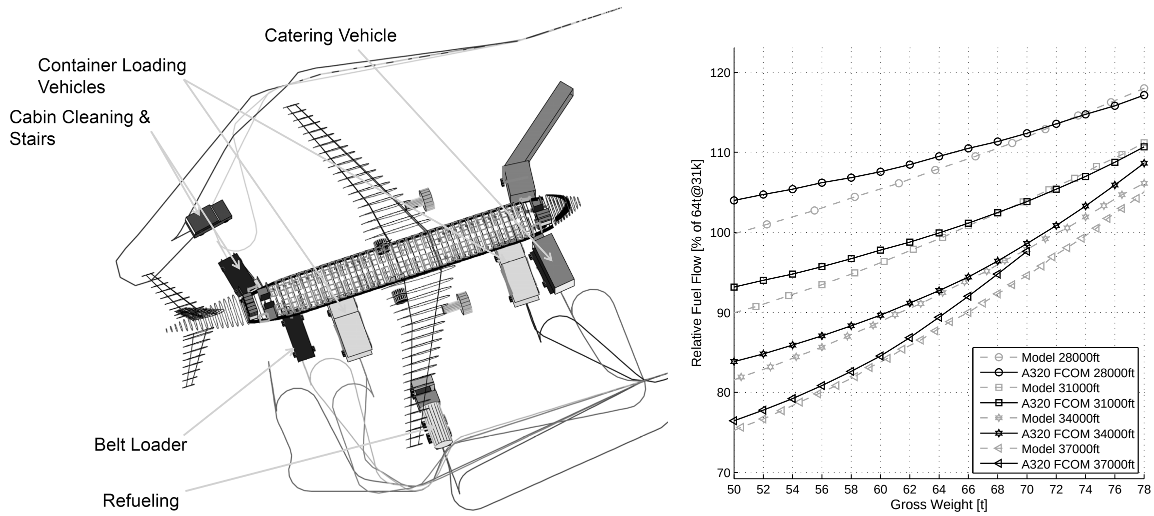
Table 1. Calibration of boarding simulation: Values from the Boeing study[4] and from ETH[8] are taken for calibration. Note the considerable influence of the parameter "Smartness".

3. Turnaround Simulation

In order to make sure that the boarding and deboarding process always constitute the critical path, the boarding simulation was integrated into a full turnaround simulation. The turnaround simulation primarily calculates the time required for cargo loading, catering and vehicle positioning. In accordance with expert statements it was found that cargo loading rarely determines the critical path, and no case it is relevant for the findings of this paper. In figure 6(a) a typical set-up for a turnaround is shown. Vehicle path are simulated, as are container movements. Availability of ground service vehicles and readiness of the departing load are assumed.

B. Aircraft Design

An aircraft design environment is required to study the effect of different fuselage layouts. An advanced fuselage layout tool is used to generate detailed cabin layouts. Fuselage structural weight is calculated using a semi-analytical approach by Ardema.[16] It was enhanced using current aircraft weights for a new calibration. Overall the structural weight of current generation aircraft is met with an average offset of less than 6%. Other important mass contributors such as furnishings, systems and operating equipment are estimated using statistical relationships or actual component weights (in case of the operator's items). Twin and single aisles differ in the weight of their cabin lining, so a more detailed analysis was necessary to capture this effect.



(a) Turnaround Modeling

(b) Fuel Flow Comparison

Figure 6. Left: ground service modeling for turnaround time estimation. Right: comparison of estimated fuel flow from aircraft design tool with data from actual flight manual.

The aircraft design loop sizes wing, tails and the engine in accordance with the top level aircraft requirements. Component weights are determined using a number of recent formulas for component weight estimation that offer a higher level of accuracy compared to other methods of similar complexity.[17] Aerodynamics are estimated using preliminary design formulas as found in Roskam[18] and Torenbeek.[19] All designs use a geometrically similar wing with same aspect ratio and sweep. The wing loading is fixed at just over 600 kg/sqm oriented on current single aisle aircraft. An engine deck representing a geared turbofan is used for engine performance estimation, a conventional turbofan was used for validation. The aircraft design loop is validated against state-of-the-art aircraft and achieves good resemblance in component weights and fuel burn. For validation purposes flight manual data of the A320 and A330-300 have been used. Figure 6(b) shows the estimated fuel flow versus the true fuel flow taken from the Flight Crew Operating Manual.[20] The fuselage length and the wing area was defined, all remaining parameters were determined by the aircraft design tool.

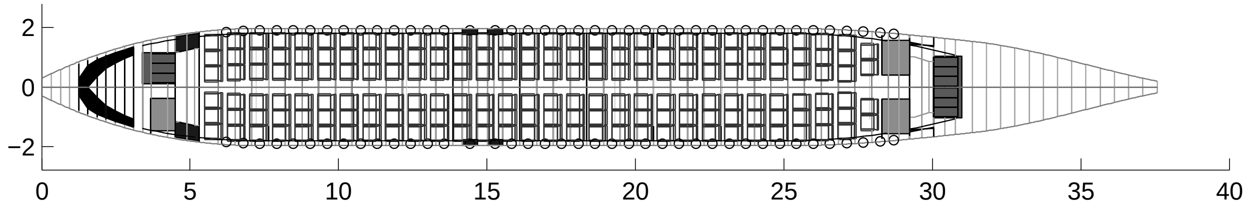
III. Basic Results

This section introduces the studied layouts and presents basic results. These are important for a better understanding of the analysis that follows up.

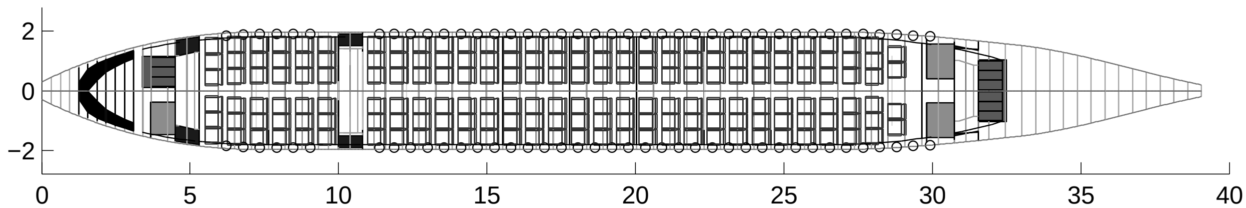
A. Cross Sections and Fuselage Design

Current 6-abreast single aisles cover a seat range from 130 to 280 seats in a single class layout. This capacity region is used for this study. As shown in figure 7, five cross sections are chosen for the study of which two are oriented on existing aircraft. The smallest resembles the A320 cross section. The common comfort standards of the A320 were used on all other cross sections, too. The next larger cross section is an enlarged single aisle with wider fuselage, which allows a wider aisle (25 instead of 19inch) and more overhead bin volume. The first twin aisle is a 6-abreast twin aisle, slightly smaller than the proposed B7J7 cross section.[21] The 7-abreast twin aisle is slightly smaller than the B767. The 8-abreast cross section is similar to that of the A300/330, and as such only slightly smaller than that of the B787.

For all layouts from 180 seats onwards alternative versions were studied. These include a second door in front of the wing, roughly at one fourth of the fuselage length. This so-called quarter door enables quicker boarding by splitting the passenger flow. The effect was already acknowledged by Marelli et al.[4] In figure 8 the effect on the fuselage layout is shown for a 180 seat single aisle. One can see the increase in length. However, at larger capacities an emergency-type door is required anyways, and the upsizing into a full scale boarding door is only connected to a small weight penalty.



(a) Conventional Design



(b) Quarter Door Design

Figure 8. Cabin of 180-Pax Single Aisle with and without quarter door.

Figure 9 shows the results of the fuselage design process. The left plot shows the fuselage weight, normalized with the number of seats. The weight is the complete operating empty weight, including systems, structures, seats and furnishing. It can be seen that the standard single aisle remains the lightest fuselage for the entire capacity band. However, the gap to the twin aisles becomes smaller. Note that the standard single aisle is the only one that is becoming heavier after having achieved a local minimum, indicating that the long fuselage and undesirable slenderness increases the seat-specific weight at some point. The 7-abreast twin aisle shows the best figures of the twin aisles. On the right plot the fuselage fitness ratio is shown. The fitness ratio is the relationship between length and diameter and an important indicator for aerodynamic and structural efficiency. The hatched region represents the fuselage fitness ratios between 10 and 11, which is considered the multidisciplinary optimum.[22]

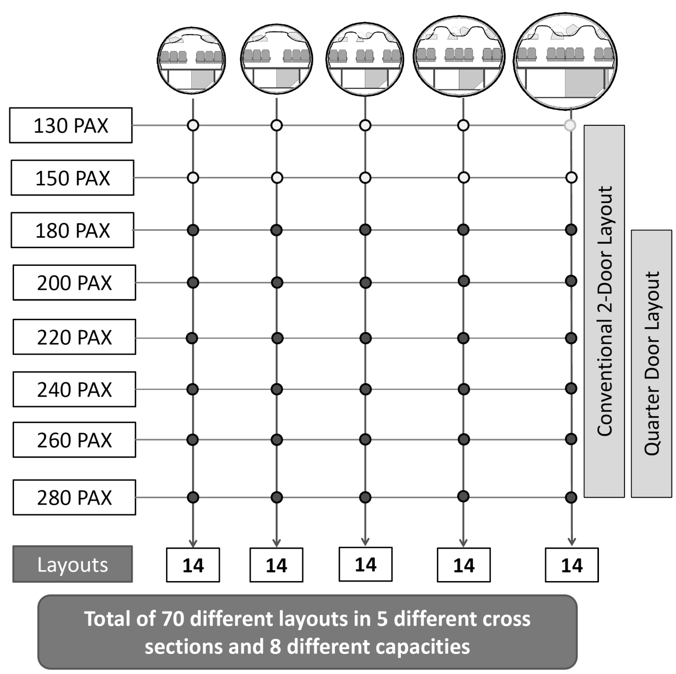
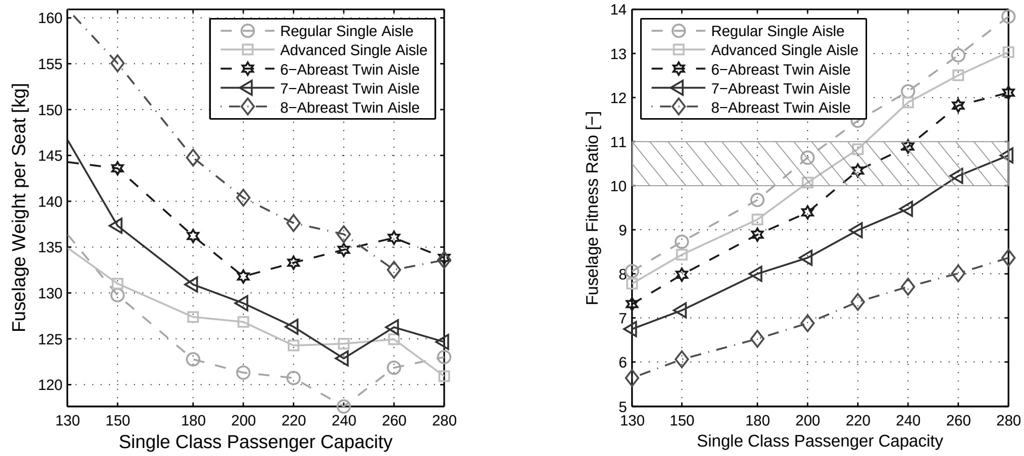


Figure 7. Studied cross sections and capacities.

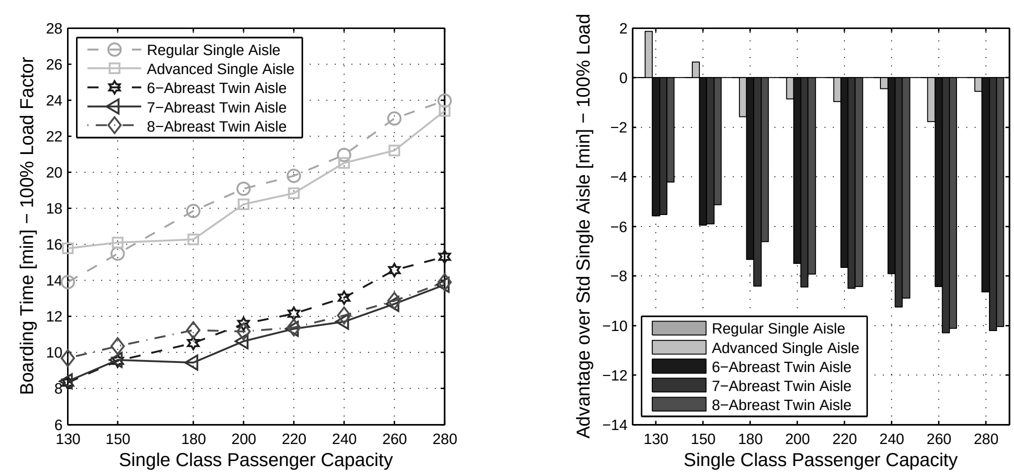


(a) Fuselage Weight (b) Fitness Ratio

Figure 9. Fuselage performance indicators: left the operating empty weight per seat. On the right side the fuselage fitness ratio. The hatched region represents the optimum region for fitness ratio.

B. Boarding and Turnaround Simulation

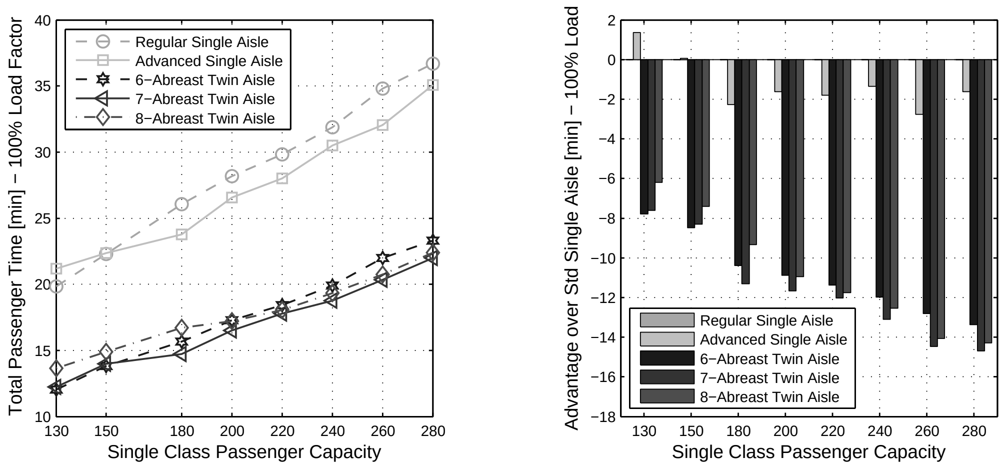
The turnaround simulation results were obtained with standard input set of 100% load factor and 45% bulky luggage (i. e. trolley-like pieces of carry-on). An alternative input setting with 85% load factor was also simulated. Boarding and de-boarding is conducted through the forward left door as normal when parked at gate positions with passenger bridge. Each simulation has random seat distribution and passenger characteristics. Consequently, a number of simulations need to be performed to arrive at a stable mean value. The results are shown in figure 10. The twin aisles demonstrate a shorter boarding time, cutting the required time by 50% at some capacities. Despite the inclusion of an aisle passing model, no real advantage of the wider aisle could be identified. This is probably a failure of the simulation technique. The advantage of the twin aisle over the standard single aisle (shown right) increases with capacity, but not in a linear fashion.



(a) Boarding Time (b) Difference to Single Aisle

Figure 10. Basic boarding time for 100% load factor. The right side shows the difference to the standard single aisle.

The twin aisles also demonstrate better de-boarding times. In figure 11 the total passenger time is shown. That is the sum of boarding and de-boarding time. As cabin cleaning is assumed equally fast for all designs, the advantage gained in total passenger time directly translates into an advantage in turnaround time. The simulated advantage reaches 12 minutes at 220 seats. The 7-abreast twin aisle achieves the best results, beating the other twin aisle designs by a small margin. Although the 6-abreast has less seat interference, it offers less overhead bin volume and in consequence has longer luggage stowing times.



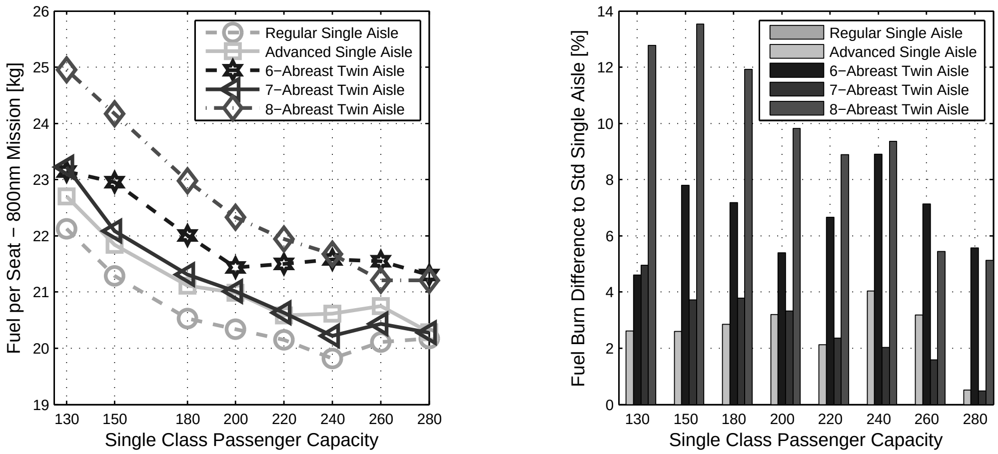
(a) Passenger Time (b) Difference to Single Aisle

Figure 11. Passenger time (boarding and de-boarding for 100% load factor. The right side shows the difference to the standard single aisle. These difference directly translate into a turnaround time advantage.

C. Aircraft Design and Cost Estimation

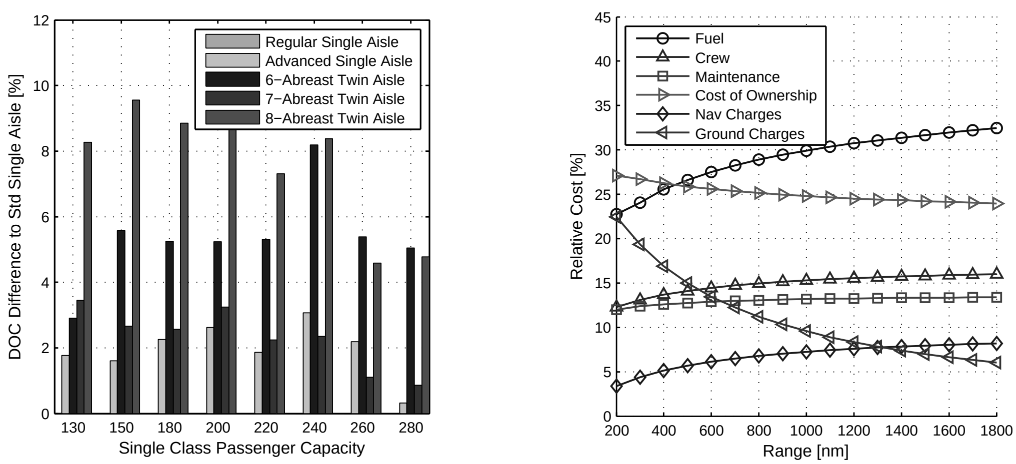
The aircraft design results are proportional to the weight differences observed for the equipped fuselage. The increased fuselage weight is the main driver for the differences in fuel burn and weight. The additional wetted area of the fuselage contributes less. The operating empty weight develops proportional to the fuselage weights. The fuel burn for a mission of 800nm shows considerable differences, again very similar to those observed for the fuselage weights. Although the differences appear substantial, it needs to be remarked that the overall absolute difference is limited: compared to the single aisle, the 180 seat 7-abreast twin aisle requires 1kg of additional fuel per trip and seat for the 800nm mission, which is about 5% more.

The model used for direct operating cost (DOC) estimation is oriented on a NASA report from the mid 1990ies.[23] It uses regressional formulas for most cost items, especially maintenance and crew cost. The cost have been updated to 2011 standards by applying a cost escalation factor. Comparison with Form 41 data of the Bureau of Transport Statistics (BTS) has demonstrated that crew cost exceeded those found even at the traditional network carriers. On the other hand, the maintenance cost were far lower. Although Form 41 report standards are difficult to validate against, the maintenance cost were increased whereas crew cost were reduced by 15%. The model was further enhanced by adding a ground handling cost module. Ground handling cost constitute a major cost item in short range operations and may exceed the fuel cost.
In figure 13(a) the resulting DOC differences are shown for a 500nm reference mission. The standard single aisle remains the most cost efficient over the entire capacity range. The shown data assumes a fixed utilization for all designs, hence the effect of boarding and turnaround is not reflected in that figure. In figure 13(b) the development of DOC over range for a 180 seat single aisle is shown. Notice the large impact of ground handling cost for short mission ranges.



(a) Fuel Burn per Seat (b) Fuel Burn Difference

Figure 12. Fuel burn per seat for a 800nm mission. Note that the fuel burn correlates strongly with the empty weight respectively fuselage weight. Further note that the absolute difference is in the range of 1kg, corresponding to roughly 1 USD per seat and trip.



(a) DOC Difference (500nm Mission) (b) DOC Distribution

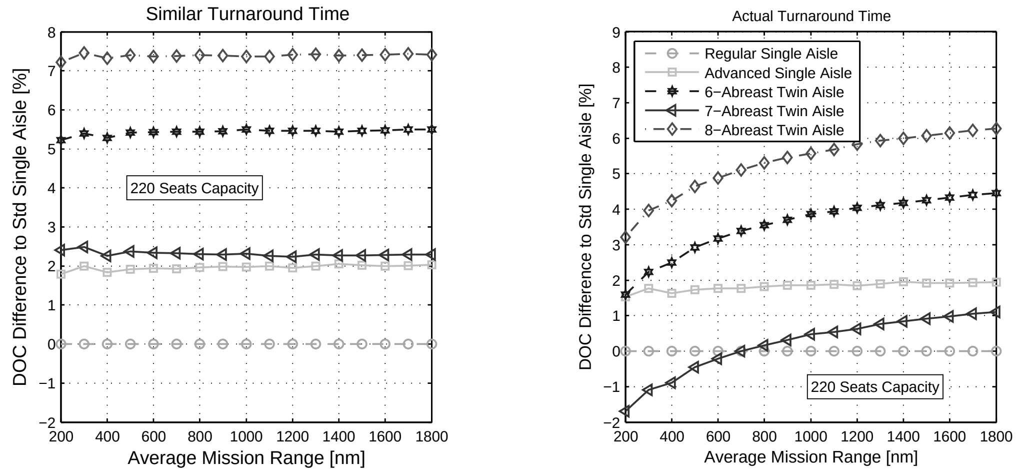
Figure 13. Direct operating cost. Shown left are the differences between the cross sections over the capacities, 500nm mission and similar utilization for all models. Right is a the calculated share of DOC items over mission range for a 180 seat single aisle. Notice the large contribution of ground handling cost at lower ranges.

IV. Analysis

This section uses the previously generated results and creates framework for analysis.

A. Analysis Method

With 5 different cross sections, 8 different capacities and a range spectrum from 200 to 1800nm a lot of results can be produced. The influence of the turnaround time becomes apparent when aircraft are compared with the reference over mission range. In figure 14 the DOC relative to the standard single aisle are shown, for a single capacity of 220 seats. On the left a standard turnaround time independent of the actual fuselage layout is assumed. The DOC difference over range is nearly constant and similar to the ones shown in figure 13(a). On the right side the turnaround times as estimated by the simulation are applied. On shorter mission ranges the DOC of the twin aisle decrease relative to the single aisle, reflecting the increased number



(a) Similar Turnaround Times

(b) Actual Turnaround Times

Figure 14. Influence of the turnaround times on DOC. The numbers are the difference to the standard single aisle. Especially lower ranges demonstrate the influence of the turnaround times. Right plot legend also valid for left plot.

of flights per year. In the particular example the 7-abreast twin aisle beats the single aisle at distances below 700nm.

B. Scenarios

The 7-abreast twin aisle has advantages over the 6-abreast and the 8-abreast both in DOC and in boarding times, hence only this concept is further analyzed. The advanced single aisles is not further investigated, either, as the simulation failed to identify any meaningful advantage of the wider aisle.

When plots like shown in figure 14(b) are created for each capacity, a DOC difference can be established as function of range and seat capacity. That allows to identify the capacity-range regions in which either design has an advantage. In figure 15 such map is shown. The hatched areas show where the twin aisle is in advantage or disadvantage by DOC. The "draw region" is the region where less than 0.75% DOC difference exists. In that region both aircraft are equally suitable for operation. The twin aisle is clearly in advantage for capacities of 240 seats and more. Below the twin aisle only has advantages at distances below 400nm. For capacities of less than 180 seats no advantage is identifiable. The DOC are estimated using 1 USD/kg kerosene as fuel price, an 8% interest rate and a 12 year lease period. The vertical dashed lines show the approximate maximum capacity of the current A320/B737-800 and A321/B737-900. It becomes apparent that in the capacity region of current single aisles no meaningful advantage exists despite the huge savings in turnaround time.

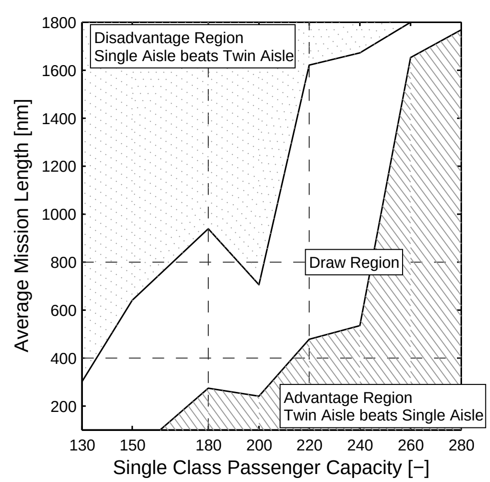
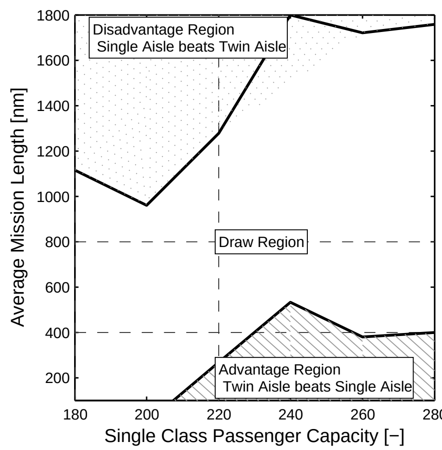
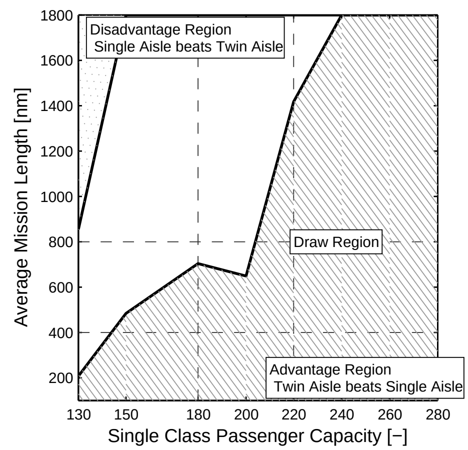


Figure 15. Range-capacity map with regions of advantage and disadvantage of the 7-abreast twin aisle, compared with the 6-abreast single aisle.

The situation becomes even less desirable when the 7-abreast twin aisle is compared to the quarter door variants of the single aisle. Capacities below 180 seats are omitted as these do not allow the installation of a useful door in front of the wing. The 7-abreast twin aisle is not equipped with a quarter door. In figure 16(a) the results are presented. The single aisle wins terrain in the higher capacity regions. Although ranges below 400nm (at which - according to figure 1 - 30% of all flights take place) are still occupied by the twin aisle, a large draw region exists where no design can achieve an advantage. The quarter door appears to allow the single aisle to be operated into higher capacity regions without a disadvantage. Not shown here are scenarios that assume higher fuel cost in reflection of future operational environments. Fuel cost have only a limited effect, as the twin aisle is shown to have nearly the same fuel consumption at capacities above 220 seats. More important is the load factor. All results are done with 100% load factor. Such load factors are rarely achieved. However, in order to plan the aircraft schedule a full load needs to be assumed. Additionally, the quicker boarding allows an aircraft to absorb delays. In short range operation delays are difficult to make up during flight.



(a) Quarter Door



(b) Different Design Range

Figure 16. Left: single aisle equipped with quarter door reduces the advantage of the twin aisle substantially. Right: if the twin aisle is optimized for shorter ranges than the single aisle a solid advantage region exists.

The final scenario presented here includes different range optimization. Current single aisle easily achieve ranges in excess of 2000nm, despite the fact that few flights actually use this range. Of course, additional range yields flexibility, but better economics could be achieved if the design range is shortened. In the scenario shown in figure 16(b) a twin aisle design for 1800nm range with full passenger load is compared to a single aisle with 2400nm range[b]. Single and twin aisle have similar wing loading and similar engine technology. The longer range required for the single aisle cancels out any weight advantage from the smaller fuselage. In fact, both designs have nearly the same wing area. The fuel is further assumed to be more expensive in this scenario, a price of 1.5 USD/kg kerosene reflects a crude oil price of roughly 175 USD/barrel[c]. The twin aisle now achieves an advantage over a wide region of capacities, even at 130 seats. Above 180 seats an advantage exists up to a comfortable range of 700nm.

V. Summary and Conclusion

This paper has compared twin aisle design with single aisle design for short range missions. For that purpose a boarding simulation, a detailed fuselage design tool and an aircraft design tool have been developed, validated and used. Capacities ranging from 130 to 280 seats have been analyzed. The analysis of the turnaround processes identified clear advantages for the twin aisles. However, the higher fuel burn and weight especially at capacities below 220 seats reduces their attractiveness. Of the 3 analyzed twin aisles,

[b]Note that the A321-NEO and B737-9 MAX are supposed to have ranges of more than 3000nm
[c]Kerosene is on average 10% more expensive than the official crude oil price.

the 7-abreast performs best in turnaround and flight performance.
The analysis shows that under current operational conditions only seat capacities of 240 seats and more can competitively be operated by a dedicated twin aisle. If the single aisle is equipped with a quarter door, the advantage of the twin aisle shrinks considerably. However, if the twin aisle was optimized for shorter design ranges, it could compete against the single aisle.

Current single aisles are positioned between 150 and 220 seats. In this region only the very top end could be covered by a twin aisle. A twin aisle is consequently not suited as a general one-on-one replacement for current single aisles families. For some special routes it could compete down to seat capacities of 180.

This paper only considered direct operating cost. No consideration is given to comfort. A twin aisle will probably win more passenger acceptance than the current single aisles, and the reduced boarding and de-boarding times are probably well received by passengers. However, translating such advantage into a proportional cost advantage is impossible.

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