IMPROVEMENTS TO GROUND HANDLING OPERATIONS AND THEIR BENEFITS TO DIRECT OPERATING COSTS

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Abstract

This paper systematically identifies and investigates ideas to improve ground handling operations and determines their influence on Direct Operating Costs (DOC). First, the importance of ground handling costs is highlighted and the ground handling operations carried out by low cost airlines are described. Then, the main possible features and airplane modifications that can lead to cost benefits are identified and analysed. A methodology has been established to systematically evaluate the contribution of those features to DOC is developed and justified. All the described modifications in ground handling operation are then quantitatively assed with this method. As a last step, recommendations towards ground handling cost reductions are given: several new systems can be adapted to the current aircrafts to improve the ground handling operations. Results show that a 3.5 % DOC reduction could be achieved.

1. INTRODUCTION

Ground handling compromises the many services to an aircraft between the time it arrives at a terminal gate and the time it departs from the gate for its next flight. Speed, efficiency and accuracy are important in ground handling operations in order to minimize turnaround time and ground handling costs. Airlines are interested to look at a reduction of Direct Operating Costs (DOC), because DOC include not only ground handling costs, but also depreciation, interest, insurance, fuel costs, maintenance costs, crew costs, landing fees and navigation fees. Improvements to ground handling operation always aim at reducing turnaround time and ground handling costs, however it needs a close look to find out, if improvements to ground handling operations also reduce Direct Operating Costs. This has to be done because in some cases a reduction in ground handling increases the aircraft weight and delivery price, which lead to snowball effects, indirectly increasing other DOC cost items. [1]

With the reduction of ground handling costs, low cost airlines (LCA) have been particularly successful. Well-known examples of LCA are Ryanair, EasyJet, GermanWings and Air Berlin. Ryanair was the first European LCA and was created in 1985. LCA fly short and medium range aircraft, in particular the Boeing B737 and the A320. [2] [3] Hence, the A320 will be the reference aircraft for this paper [4]. The B737 was developed in the 1960's, the A320 in the 1980's. [5] This explains why requirements of low cost airlines regarding ground handling operations were not considered in the design of the B737 and A320. The manufacturers have already announced successors of the B737/A320 [6] [7]. For the first time in history, the requirements of the LCA can be taken into account when designing new aircraft.

The aim of this paper is to systematically identify and investigate ideas to improve ground handling operations and determine influence on Direct Operating Costs.

2. LCA GROUND HANDLING OPERATION

Ground handling costs have a huge influence on the LCA because their low ground handling costs are one of their main advantages compared to the flag carriers. Because of this, low cost airlines have developed new procedures in ground handling operations in such a way that low ground handling costs are considered as one of the key factors of their business model.

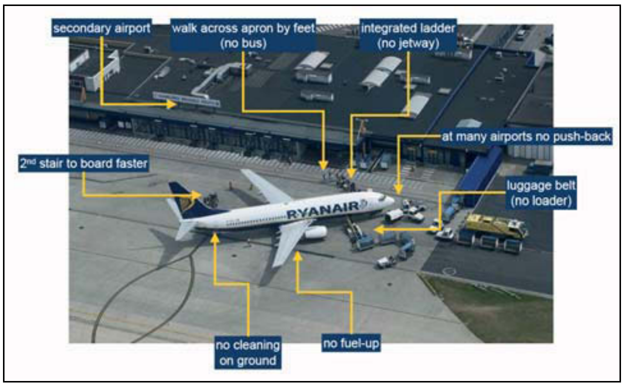

FIG 1. LCA Turnaround Characteristics [8]

The main characteristics of the low cost airline's procedure are:

– Parking on apron in front of terminal and parallel to the terminal building, if possible. This enables "taxi in and taxi out" without ground support equipment like pushback tractors. Thus, there is a cost reduction in terms of equipment and manpower. In addition, any possible delay caused by the pushback operation is avoided. [9] [10] .
– Passengers are always boarded by means of stairs, so the airline can avoid the airport charges related to airbridges. In addition, a second stair for the rear door of the airplane is used in order to speed up the boarding and deboarding process. These stairs are integrated on-board in some cases in order to avoid

mobile stair fees and delays. This can be seen in FIG 1. [8]
- The aircraft is in its parking position at a walking distance to the terminal gate in order to avoid the transport by bus of passengers between the terminal gate and the aircraft. Thus, similar to the pushback, there is a cost reduction in terms of equipment and manpower. In addition, any possible delay caused by the availability of the buses is avoided. [3]
- The avoidance of on-board passenger services results in reduced turnaround times. Cleaning vehicles are not always required due to the lower in-flight food consumption. Waste water removal services are also not required after every flight. Therefore, the elimination of catering services makes it possible to skip the required time for loading trolleys and shortens the cleaning time. [2]
- Because of the low revenue rate of cargo transportation, cargo is rarely transported by low cost airlines. Therefore, only luggage is loaded into the bulk cargo hold, and belt loaders are the only required ground support equipment for the loading operation. [11]
- Because of the short stage lengths, it is not necessary to refuel at every flight and the so-called "tankering" technique can be carried out. This means ferrying enough fuel for more than one flight segment, in order to avoid the higher fuel cost and additional time on ground at destination airports. [2]
- Low cost airlines achieve utilizations of 4000 ... 4200 flight hours per year in contrast to conventional airlines focusing on business travellers, which usually only reach 2500 ... 2700 flight hours [11]. This can only be achieved with short turnaround times [2] [3] [8] [11].

3. MEASURES AND IDEAS TO IMPROVE GROUND HANDLING OPERATIONS

3.1. A more Autonomous Aircraft

From the previous chapter, it can be concluded that self-sufficiency is the most important characteristic in order to obtain ground handling cost reductions and faster turnaround times. This autonomy can be achieved by means of specialized systems that are incorporated onboard the aircraft. In addition, the ground characteristics of the aircraft equipped with these systems must be compatible with the operation on main airports.

Nowadays, the main specialized systems leading to autonomous capabilities that can be found on current aircraft are:

- Auxiliary Power Unit (APU)
- Large fuel and water capacity[1]
- Ground level baggage handling
- On-board stairs

An aircraft equipped with the abovementioned systems can perform remote operations where there is limited ground support equipment available or its use shall be avoided. In order to enhance the current autonomous capabilities of future aircraft, new system must be developed. Such is the case of the APS (Automatic Pushback System), which allows autonomous pushback and taxiing.

3.1.1. Autonomous pushback

Current pushback and taxiing procedures are very fuel-inefficient and noisy mission phases because of the high fuel consumption of the engines compared to the work required. [9] Furthermore, the action of a pushback tractor and the additional communication with the driver of the pushback tractor leads to undesirable time consumption. Autonomous pushback could make it possible to avoid the necessity of a tractor for the pushback operation. Therefore, the ground handling costs could be reduced on every flight because ground handling fees for the pushback tractor would be avoided. Additionally fuel and time could be saved.

There are already special APS systems, such as the "Wheeltug" [9], or the solution by Airbus and DLR [12] that are currently under development. The "WheelTug" is a fully integrated ground propulsion system for aircraft. Built into the hubs of the nose wheels, it gives aircraft of all sizes full ground mobility (forward and reverse with steering) without engine thrust or external tugs. It does not require airframe modifications and it can be powered by the APU. Schematics of the APS are shown in FIG 2.

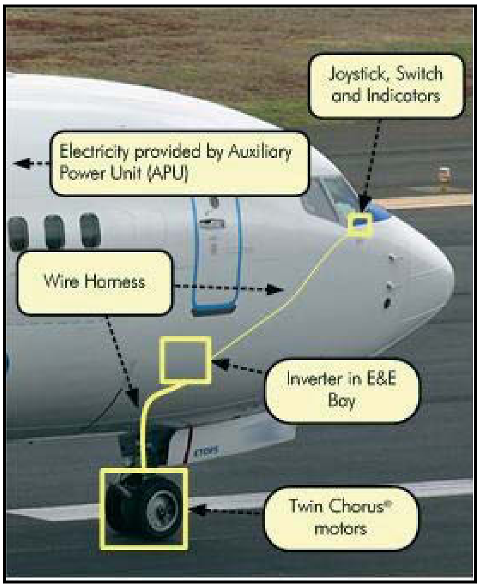

FIG 2. Automatic Pushback System [9]

Despite its benefits, the installation of an APS increases the aircraft weight and so the burnt fuel during flight. Therefore, a trade-off analysis of the cost reduction possibilities is required. For this purpose, studies about the economic benefit of the Automatic Pushback System have been carried out [9] [10]. The results are shown in the last chapter.

3.1.2. Airstairs

So-called 'airstairs' are a passenger stairway that is carried inside the aircraft. These airstairs can be extended or retracted while the aircraft is on blocks, allowing

[1] Carrying large amounts of fuel and water could also lead to higher Direct Operating Costs because of the higher burnt fuel.

passengers and ground handling staff to board and deboard the aircraft without the need for a mobile staircase or an airbridge.

Typical airstairs integration can be seen in FIG 3. In this case, the airstairs is fully retractable and can be allocated in the lower fuselage just below the door. This enables the possibility to use airbridges if it is required.

First versions of the B737 included on-board stairs, but they were removed in order to avoid delays, maintenance problems and to save fuel for every sector by removing the weight [13]. However, nowadays, airstairs have become more popular on small regional planes and airplanes that operate into secondary airports with minimum ground support. Therefore, the airstairs are very popular among the low cost airlines fleet and the new B737 version is able to carry airstairs again [13].

According to the manufacturer Monogram Systems [14] the benefits of the use of airstairs are:

– Airstairs provide aircraft with a degree of independence from ground services that can be useful in special circumstances.
– Airstairs decrease ground turnaround times allowing operators greater flexibility for increasing revenue flights.
– Airstairs allow operators to land at remote airports where mobile stairs or airbridges are not available.
– Airstairs have low ownership cost.
– With airstairs no ground services are necessary.

In addition to this, the use of airstairs leads to less damage of aircraft from mobile stairs or airbridges. This saves repair costs and avoids aircraft being put out of service. [15]

The mass of the stairs increases with the sill height of the door airplane. Therefore, airstairs are rarely incorporated into long-range aircraft designs. An alternative possibility to at least ease the integration is to incorporate the stairs into the cargo compartment and link somehow the cargo compartment with the main deck of the aircraft.

Regarding the turnaround time, the extension or retraction cycle lasts around 30 seconds, which is considerably faster than the operation with airbridges or mobile stairs, which typically takes about 2 minutes. [14] [16]

If both front and rear airstairs are installed on an aircraft, passengers can deboard the aircraft while cleaners can service the aft lavatories and move forward, enabling quicker aircraft turnarounds [2]. This benefit is also possible using a combination of airstairs with mobile stairs or airbridges, but the ground handling charges would be comparatively higher due to the higher number of required ground support equipment.

FIG 3. Airstairs [14]

3.2. Boarding and De-Boarding Improvements

One of the main possible improvements on boarding/deboarding is the use of a **third door**. This third door may be placed on the centre of the fuselage. In case of an aircraft with conventional layout, the third door should be installed near the wing root. On the other hand, the door could be installed over the wing in case of low-wing aircraft configurations. Rear-mounted engines lead to additional room for a door along the fuselage without disturbance of the wings. TAB 1 shows the estimated boarding and deboarding rates due to the use of a third door.

TAB 1. Estimated boarding and deboarding rates depending on available doors ([16] and own estimations).

Boarding Speed	1 door Datum	2 doors Datum	3 doors Estimation
Boarding [pax/min]	12	18	24
Deboarding [pax/mix]	20	30	40

This time-saving has a great importance in the low cost airlines' turnaround process; where boarding and deboarding take part on the critical path. In those cases, the turnaround time t_a directly depends on the number of passengers and it can be described with an equation such as:

(1) $t_a = k_1 + k_2 \cdot n_{pax} + k_3 \cdot R$

where the variables are based on [17]:

t_a [min]	turnaround time
k_1 [min]	not related to passenger and range time constant,
k_2 [min/pax]	passenger time constant (see TAB 2.),
n_{pax} [pax]	airplane seats count,
k_3 [min/km]	range related time constant,
R [km]	stage length.

TAB 2. Estimated passenger depending constants as a function of available doors (own estimations).

Time constant	1 door	2 doors	3 doors
k_2 [min/pax]	0.133	0.089	0.067

Calculations based on Equation 1 show that for a typical 180-passenger layout, the use of a third door leads to a time-saving of about 4 minutes in the turnaround process comparing to the two door case and a time saving of 12 minutes in the case of one door. The time saving of two doors versus one door is almost 8 minutes.

Another possibility of boarding improvements is the use of **wider doors**. This is especially important when passengers travel with hand luggage, because carrying luggage decrease the passenger mobility through doors. However, an increase of the size of the door leads to a rise of the fuselage structural mass and the corresponding improvement can scarcely be evaluated.

In the same direction, **wider aisles** contribute to a faster boarding and deboarding process. This can be achieved by decreasing the airplane's seat width or introducing foldable seats (FIG 4.). However, the structural layout of many seats does not allow foldable seats. Furthermore, foldable seats will have a weight penalty.

Foldable passenger seats provide additional space to the aisle by automatically folding the aisle seat. According to the design company AIDA [18] [19] the foldable passenger seats affect important components of turnaround times. The new boarding situation means that travellers can move directly into the seat row to stow their hand luggage without blocking the aisle, so passengers behind them can pass without delay. This leads to improved boarding and disembarking times.

FIG 4. Foldable Passenger Seats [18]

Another possibility is the use of **bigger overhead bins** for faster and easier loading. But the available volume of the cabin limits the possible size of the overhead bins. However, this is no longer an important issue because of the current restriction on dimension on hand luggage imposed by many airlines.

Regarding seating policy, there are multiples studies about it [20] [21]. Boarding methods have a great influence on the turnaround time and the Direct Operation Cost of an airplane. The reason for this: boarding and de-boarding processes take part on the critical path of the turnaround process and, therefore, a reduction in boarding time has a direct impact on the turnaround time. As a result, several airlines currently apply boarding policies to optimise turnaround processes. However, there is not a clear identification of the best method. As an example, EasyJet uses free seating policy, British Airlines uses Back-to-From method and the Window-Middle-Aisle (WMA) method is used by United Airlines. There also exist combinations of different boarding policies, such as the Block Boarding, developed by Delta Airlines. Most used for low cost airlines is the policy of free seating [20] [21]. This means, that the first passengers boarding the airplane can freely choose their seats. The free seating policy leads to the shortest boarding times and hence should be the preferred choice.

3.3. Baggage and Cargo Loading Improvements

There are new products that speed up the process of baggage and cargo loading, making it more economic and/or safer. Examples of these products are the power stow, the sliding carpet or the ramp snake, which speed up the loading and unloading of the aircraft and make the process in the baggage compartment more ergonomic. This can be seen in FIG 5, FIG 6 and FIG 7. The functional principle of all these devices is a roller or conveyor belt respectively that moves the baggage in and out of the baggage compartment.

The ramp snake (FIG 5.) is a vehicle that makes use of powered belts that can be extended inside the aircraft cargo compartment at a proper angle. The advantages of such a system are [22]:

– Avoidance of injuries from manual handling.
– Reduction of required handling staff.
– Faster loading/unloading operations.
– Less damage to aircraft doorsills.

FIG 5. Ramp Snake [22]

The Power Stow (FIG 6.) is a roller track conveyor equipped with a belt loader extension that is built into a mobile belt conveyor in order to facilitate the loading and unloading of passenger baggage into and out of the aircraft cargo hold. It shares the same advantages as the ramp snake. [23]

FIG 6. Power Stow [23]

The sliding carpet system (FIG 7.) consists of a thin moveable belt at the bottom of the cargo compartment and a driver unit situated at the far end of the compartment. Previous mechanical systems consist of moveable sets of metal trays, which themselves take up typically 20% of the available space. Therefore, the sliding carpet enables space for bulk cargo and weight saving. Another advantage is that only one member of staff is required to be inside the cargo compartment. [24]

FIG 7. Sliding Carpet [24]

The use of normalized containers for bulk cargo is another improvement possibility. Loading the containers is usually carried out in a make-up room before the turnaround and will safe time during turnaround. However, loading containers is slower than loading bulk cargo, if the abovementioned systems are used. Therefore, the advantage is only with respect to costs. If labour costs are high, the containerised aircraft could be an advantage. [15]

Simultaneously loading and unloading would lead to an important reduction in turnaround time. This could be done if the AFT and FWD cargo holds are connected, so both doors could be used at the same time. The connection of the two cargo holds could be achieved by eliminating the main landing gear, e.g. by making use of:

– a tandem landing gear as on the Boeing B52 [25] or the Baade 152 [26] (FIG 8.)

– a ground-based landing gear system (as it is investigated in the project GroLaS within the Hamburger Spitzencluster) [28].

FIG 8. Baade 152 [26]

– a landing gear integrated into the engines nacelles, as on the Fokker 50 [27] (FIG 9.)

FIG 9. Fokker 50 [26]

3.4. Less Fuel Burn

In case of conventional configuration aircraft, it is possible to reduce the fuel burn on route by placing the center of gravity of the aircraft (CG) further aft. [15] [29] This displacement of the CG could be achieved within the turnaround process by placing passengers in the back rows by means of:

1) Indications of the cabin crew while boarding takes place.
2) Blockage of the front rows in the time between boarding and deboarding.

TAB 3. Fuel burn increase with a more forward CG [29]

Aircraft types	Fuel increment [kg/1000nm/10%CG]
A300-600	240
A310	100
A320	Negligible
A330-300	90
A340-600	130

The Airbus document "Getting to grips with fuel economy" [29] shows variations of fuel burn with CG shift (see TAB 3.) It can also be seen that in case of the A320 family fuel burn is almost independent of the CG position. For this reason placing passengers in back rows does not lead to a reduced fuel burn on A320 family aircraft. On the B737 however fuel burn can be reduced with a more aft CG. This can be experienced when boarding that plane, and finding out that the front rows have been blocked already by the cabin crew.

3.5. Environment for Ground Handling Crew

Fast ground handling processes can lead to a high exposure of long term back injury problems for the ground handling staff in charge of the loading and unloading processes. Studies [30] show that the average total cost for an airline related to a single back injury corresponds to about 10000 USD [30]. Limitation on check luggage mass and warnings about heavy weight luggage for the operator are measures that have already been carried out in order to prevent these injuries [30]. In addition, all the systems described in the previous sections also avoid injuries caused by manual handling of cargo.

Another factor that has an influence on the baggage handling environment is the sill height of the cargo doors or the ground support equipment that transport the luggage from the dollies to the cargo hold door. The luggage should be delivered at waist height inside the cargo compartment in order to achieve ergonomic working conditions [30]. This is also confirmed and quantified with an effort factor in FIG 10. from [31], where it can be seen that the effort factor is minimum for a working environment situated at waist height.

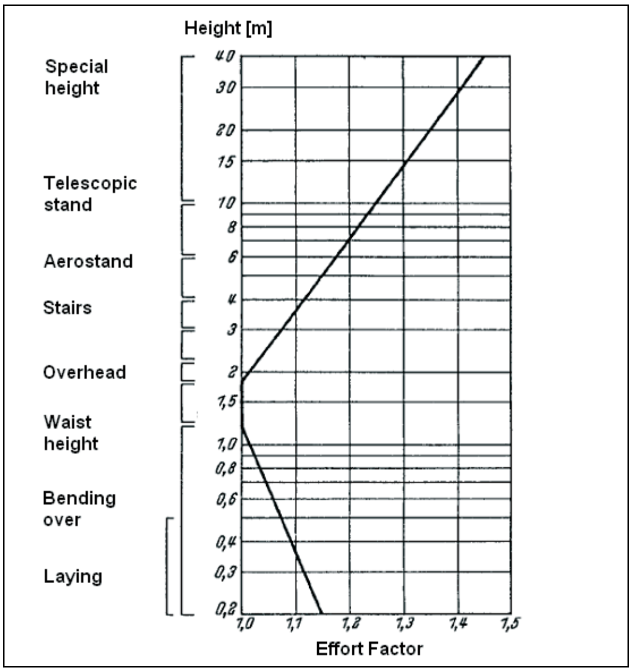

FIG 10. Effort factor versus height of working environment [31]

4. IMPACT ON DIRECT OPERATING COSTS

4.1. Selection of DOC Method

There are several models for cost analysis, but the DOC method is most often used from the perspective of the operator because it describes the aircraft-related costs.

As a general rule, DOC methods calculate the Direct Operating Costs of an aircraft from the costs *C* incurred due to different cost items over a year [34].

(2) $$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE}$$

Depreciation cost C_{DEP} represents the distribution of the reduction in value of the aircraft over its useful life. The interest cost C_{INT} represents the financial costs corresponding to the acquisition of the aircraft by means of an external financial source. The insurance cost C_{INS} cover the expenses caused by insuring the aircraft against hull damage or even against hull loss. Fuel cost C_F is incurred for the fuel consumed during aircraft operations. Maintenance cost C_M corresponds to the expenses caused by the actions required for restoring or maintaining the aircraft in serviceable condition. The maintenance cost C_M consists of the sum of airframe maintenance $C_{M,AF}$ and the power plant maintenance $C_{M,PP}$.

(3) $$C_M = C_{M,AF} + C_{M,PP}$$

The crew cost C_C include the costs of the cabin crew $C_{C,CA}$ in addition to the costs of the cockpit crew $C_{C,CO}$.

(4) $$C_C = C_{C,CO} + C_{C,CA}$$

The fees C_{FEE} consists of the sum of landing fees $C_{FEE,LD}$, navigation charges $C_{FEE,NAV}$ and ground handling charges $C_{FEE,GND}$:

(5) $$C_{FEE} = C_{FEE,LD} + C_{FEE,NAV} + C_{FEE,GND}$$

Finally, the overall Direct Operating Costs are calculated by means of the sum of all the cost items as shown in Equation 1.

The DOC can also be related to the distance flown and the number of seats or the maximum number of passengers on the flight n_{pax}. This then gives the seat-mile costs per flight (depending on the unit used). [34]

(6) $$C_{s,m} = \frac{C_{DOC}}{n_{f,a} n_{pax} \, R}$$

There exist DOC methods with different approaches and scopes. For the purposes of this research, the DOC Method of the Association of the European Airlines (AEA) [32] has been selected. The AEA method present the following advantages:

– It is complete, because it calculates all the cost items described in Equation 2
– It is publicly available

In addition, [33] suggests AEA as the most accurate method for ground handling calculation in medium stage lengths.

4.2. Methodology

A methodology is selected in order to assess the DOC variations caused by the ground handling features mentioned in Chapter 3.

This methodology consists of:

– Performing DOC calculations using the AEA method with the reference aircraft and mission as input data.
– Performing DOC calculations using the AEA method with the modified aircraft and mission as input data.

– Carrying out comparisons between the DOC results.

One important topic is the delivery price of the aircraft. This price needs to be input in the DOC method but it is not public data because it comes from private negotiations between the airline and aircraft manufacturer. Therefore the delivery price needs to be estimated. There are three methods for delivery price estimation. The delivery price can be assumed to be

– proportional to the Maximum Take-off Weight,
– proportional to the Operating Empty Weight,
– proportional to the Number of seats.

The delivery price related to weight is more accurate because it is based on aircraft statistics and the estimation based on maximum take-off weight has been selected. Since, as it will be shown, there will be no changes on maximum take-off weight, the causes of an increase on delivery price will be the acquisition of additional new aircraft systems.

Then, in order to assess the influence of the potential improvements to ground handling operation, the changes caused by these improvements on the aircraft mass and delivery price are studied. The reason for that is that the aircraft weight and delivery price have a big influence on the DOC. In general, an increment of weight leads to:

– Higher fuel costs – due to higher induced drag [35] [36]
– Higher landing and navigation fees – in cases of an increase of maximum take-off weight (MTOW), because those fees depend on the maximum take-off weight and range [34]

And an increment of delivery price leads to:

– Higher depreciation costs
– Higher interest costs
– Higher insurance costs [32]

More detailed cost prediction can be carried out if there is enough available information of each particular feature. For instance, maintenance costs of pushback systems and airstairs can be calculated independently and added to their corresponding cost item.

In other cases, the improvement of the costs is produced by a feature that does not affects the airplane, such as the use of different ground support equipment for ground handling operations. In this case, only the ground handling cost contribution is computed.

As a last step, a reference aircraft is chosen. The A320 has been selected because of its popularity among the LCA [3] [4].

4.2.1. Utilization

The Direct Operating Costs depend on the number of flights in a year. If a large number of flights is carried out each year with an aircraft, then the fixed costs of aircraft ownership are spread much more widely, with a correspondingly beneficial effect on costs per flight.

The number of flight hours carried out in a defined period is called utilization. There is a fixed correlation, between flight time, the number of flights per year and the aircraft utilization [34]:

(7) $$U_{a,f} = t_f \frac{k_{U1}}{t_f + k_{U2}}$$

Where t_f is the flight time, k_{U1} the airplane annual availability A_a, which depends on time constraints during the year, such as maintenance schedules. k_{U2} corresponds to the turnaround time t_a plus taxi time t_t.

The AEA method indicates that the utilization $U_{a,f}$ can be written as [32] [34]:

(8) $$U_{a,f} = t_f \frac{A_a}{t_f + t_a + t_t}$$

Where the AEA DOC method recommends 3750 h as value for the annual availability A_a.

A direct relationship between turnaround time and the utilization of the aircraft is established by means of equation (8). FIG 11. shows the variation of the relative utilization for the reference aircraft against the turnaround time for different stage lengths.

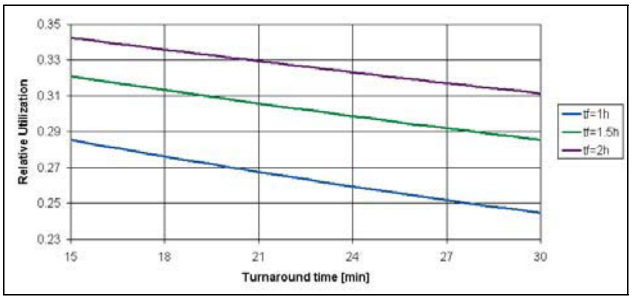

FIG 11. Relative utilization against turnaround time for different flight times t_f

It can be seen that for short flight times the utilization decreases. This can also be seen in FIG 12: the relative utilization is calculated using data from different DOC methods [34]. The conclusion is that more flight hours can be flown with fewer but longer flights.

It is remarkable that for short stage lengths, the utilization is more sensible to changes in turnaround times. For this reason, shorter turnaround times are especially important to LCA. The derivative of the utilization with respect to the turnaround time shows this effect (Equation 9) and it can be graphically observed in FIG 13.

(9) $$\frac{\partial U_{a,f}}{\partial t_a} = -t_f \frac{A_a}{\left(t_f + t_a + t_t\right)^2}$$

As it has been mentioned and shown in Equation 6, the changes on utilization (number of flights) have a direct impact on the overall Direct Operating Costs. For this reason, it is fundamental to calculate the changes on utilization produced by the modifications to ground handling operations already described. In addition, Equation 8 can be combined with Equation 6 to highlight the importance of the turnaround time on the seat mile costs.

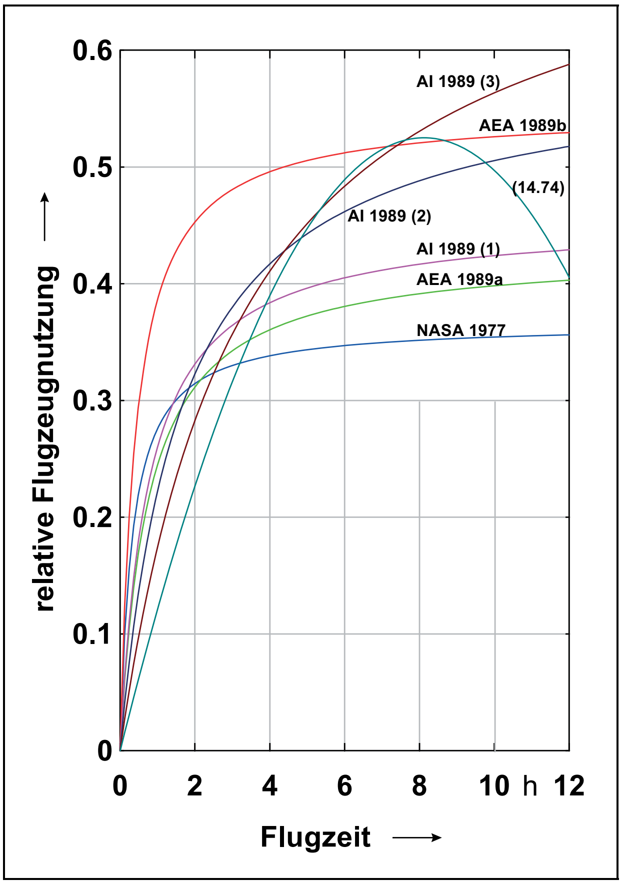

FIG 12. Relative aircraft utilization calculated according to different DOC methods (t_a=0.5 h) [34]

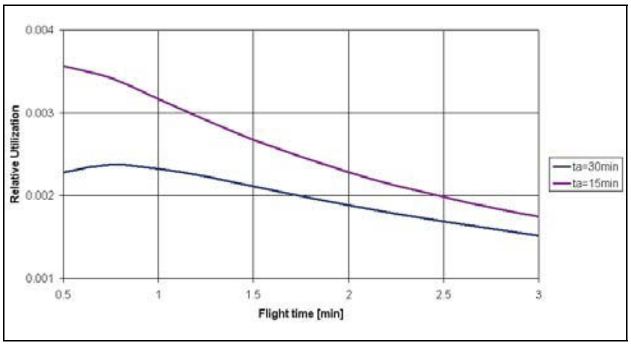

FIG 13. Increase on relative utilization for 1 minute turnaround decrease for different flight times (A_a = 3750 h, t_t=0.25 h)

FIG.13 shows that shorter turnarounds are more important for shorter flights.

(10) $$C_{s,m} = \frac{C_{DOC}}{n_s\ A_a\ V}(1 + \frac{t_a + t_t}{t_f})$$

Where V correspond to the cruise speed. In the last term of this Equation 10, it can clearly be seen the importance of the ratio between the turnaround plus taxiing time and the flight time on the seat mile costs.

4.2.2. Increment of Weight and Delivery Price

It is common practice to relate the determined DOC to the transported payload, therefore a payload has to be selected as an input into the DOC method in order to obtain results. The AEA DOC method [15] makes the following recommendations: "Payload should be the Volume Limited Payload or the Maximum Zero Fuel Weight limited payload, which ever is the lesser. The Volume limited payload is the sum of the cargo capacity and the passenger weight derived from the nominal capacity." "The initial maximum zero fuel limited payload shall not be less than 90% of the volume limited payload…"

This recommendation means that for the reference aircraft transporting 180 passenger and 4300 kg cargo, this leads to a payload of 21400 kg. In the case of low cost airlines, there is no transported cargo [11], so the payload corresponds only to passenger weights, which is 17100 kg.

Even assuming that the reference aircraft is completely filled on every reference fight, the recommended take-off weight for DOC calculation is smaller than the MTOW. This means that, in general, increments of weight due to aircraft modifications do not raise the maximum take-off weight of the aircraft. This is especially important, since the MTOW is the main cost parameter for navigation and landing fees. Therefore, increments of weight only lead to higher fuel costs.

4.3. Input Data for the DOC Method

The A320 and its standard ground handling procedures are considered as the data input for the calculations [6]. The selected stage length input for the DOC method is 500 nm, because it is the average stage length for LCA [37] [38].

The data for the separated estimation of the ground handling costs have been obtained from the airport operator AENA (Spanish Airport and Air Navigation) [39]. The use of ground support equipment and manpower are both taken into account.

For the evaluation of each feature, it is supposed that the ground handling services, on which the feature has influence, are included in the turnaround critical path. For example, it is supposed that boarding and deboarding process take part on the critical path in order to evaluate the benefits of the introduction of the airstairs. In addition, the utilization is also modified in this way.

For mass Δm_{OEW} and price delivery ΔP_{dev} estimations, the specification sheets of each system [9] [14] [22] [23] [24] and specific technical data [16] are consulted.

5. RESULTS AND DISCUSSION

This paper focuses on improvements to today's aircraft. Some of these improvements can be assessed with respect to their financial impact (measured in USD). Other ideas can in this context only be judged qualitatively. Improvements that require a new aircraft or aircraft configuration are not (or only limited) part of this paper. The systematic of these thoughts is presented in TAB 4.

TAB 4. Systematic of possible ground handling improvements

type of improvement	today's aircraft (e.g. A320 or B737)	new aircraft / aircraft configuration adapted to GH needs
improvements that can be assessed only qualitatively	not a primary topic of this paper	not a primary topic of this paper
improvements that can be assessed with respect to their financial impact	**considered in TAB 5.**	not a primary topic of this paper

TAB 5. shows primarily only those studied features that can be applied to today's aircraft and can be assessed by the calculation of Direct Operating Costs. The increments in weight Δm_{OEW} and delivery price ΔP_{dev} are listed in the first two columns. The estimations of the turnaround time Δt_a decreases are included in the next column. Ground handling cost reductions $\Delta C_{FEE,GND}$, due to the avoidance of use of ground support equipment or a decrease in the required manpower, are also incorporated in the table. Then, the change in seat mile cost per flight $\Delta C_{s,m}$ are listed. The reason for choosing this parameter as cost indicator is to include the effect of the utilization. If the turnaround time decreases, then the number of flights will increase, so it is obvious that the total costs will increase with the number of flights. Therefore, the seat mile cost per flight is a better indicator of cost reduction. The change in annual utilization $\Delta U_{a,f}$ has also been listed in the table in order to emphasize this effect.

The automatic pushback system avoids the use of pushback so it reduces the ground handling costs. However its installation into the aircraft implies an increase of the weight and the delivery price. Details about cost calculations can be found on [9] and [10].

The airstairs have the same effect as the automatic pushback regarding ground support equipment. Therefore, the ground handling costs are decreased. And, as every system mounted into the airplane, it implies an increment of weight and delivery price. The decreases of turnaround time are calculated with Equation 8.

It is difficult to estimate the increase of weight and delivery price caused by the installation of a main third door for passengers in the airplane because the aircraft layout will suffer big modifications and it may not be possible due to emergency door regulations. [40] [41] Since this third emergency door may be derived from other smaller emergency doors, it is supposed that there are no significant weight and price increments. The decreases of turnaround times have been calculated again with Equation 8.

At the moment of this publication, there was no available data about delivery price of the sliding carpet systems. However, it is claimed that the break-even is achieved within one year [24]. In addition, the loading/unloading times are reduced by 50% according to the manufacturer [24]. This is also the case of the power stow and ramp snake. The turnaround time reduction has been calculated with that information.

The turnaround times are dramatically decreased with a simultaneous loading and unloading operation. However, the ground handling costs are higher because more equipment and ground handling staff is required.

TAB 5. Influence of ground handling improvements on Direct Operating Costs. Results based on the AEA DOC method. [32]

Ground Handling Improvement	Δm_{OEW} *(kg)*	ΔP_{dev} *(USD)*	Δt_a *(min)*	$\Delta C_{FEE,GND}$ *(USD)*	$\Delta C_{s,m}$ *(%)*	$\Delta U_{a,f}$ *(%)*
Automatic Pushback System	200	100.000	-	-190	-0.96	-
One Airstairs plus a mobile stair	177	120.000	7	-	-0.75	5.67
Two Airstairs	350	240.000	7	-61.8	-1.12	5.67
Third door	-	-	12	-	-1.29	10.1
Sliding Carpet	-	No Data	10.5 *	-48	-1.37	8.7
Power Stow / Ramp Snake	-	-	10.5 *	-	-1.13	8.7
Simultaneous loading / unloading (containers)	-	-	21 *	+279	-0.51	19

* Assuming that the loading process is on the critical path

6. CONCLUSIONS

It has been shown that all the modifications to ground handling costs described in this paper may have a positive influence on the Direct Operating Costs of the aircraft. In the best-case scenario, the benefit in Direct Operating Cost per flight could rise to 3.45 % if all the compatible modifications to ground handling operation are taken into account simultaneously. This means, that an A320 mounting two airstairs, an automatic pushback system and a sliding carpet will have a cost per flight and seat 3.45% lower compared to a standard A320. Therefore, it can be concluded that these systems must be incorporated into the next generation of LCA aircraft.

In addition, it has to be mentioned that some of these features may improve the ground handling staff working environment avoiding injuries and therefore, reducing costs indirectly.

Finally, the trend in ground handling improvements is not only focused on aircraft modifications or new ground support equipments. For example, there are new innovative management systems to plan ground handling operations in advance. Such is the case of the Southwest's Load Planning System (LPS) [42]. This LPS system considers all the accepted baggage and freight, number of passengers and the amount of fuel to be loaded on the aircraft. From that information, the LPS calculates the best way to efficiently load the aircraft. The Ramp Agent then ensures that the ground handling operation is carried out according to plan.

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