

Study of a Lower-Deck Galley for Airliners

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Abstract. *The present work is concerned with the preliminary design of galleys for long-haul airliners. As usual approach galleys are located in the main deck of airliners or even in some few cases in the lower-deck cargo compartment. The present concept considers placing trolleys, items that occupy a significant room in galley installations, in the lower-deck and transport them to the main deck by a dedicated lift system. The main intention behind this proposal is to provide more room in the passenger cabin for accommodating additional passengers. By careful analysis that considers the necessary structural modifications the payoff of the present proposal is investigated. This was carried out by using the PADLAB[®] 2.4 routine written for MATLAB[®] and an in-house routine to evaluate performance and calculation of Direct Operating Costs (DOC) per seat mile. PADLAB[®] is tailored to the design of the cabin and the device and systems aimed to operate the trolleys by the passenger cabin crew; the in-house routine was validated against data obtained for the category of airliners under consideration.*

Keywords: *aircraft design, aircraft performance, cabin design*

1. INTRODUCTION

Airliners have areas in the main deck that are dedicated to food and beverage storage and other items associated to passenger comfort. The activities carried out in those areas can be basically divided into two categories: preparation for the next flight; the remained activity is characterized by flight attendants duties when the airplane is flying. The areas under consideration are known in the aerospace community as galley installations.

The proper galley operation galleys are important during the preparation of flight, before passenger boarding is cleared. This is directly linked to the perception of passengers concerning the level of service provided by the flight attendants. The galley of the airplane has a crucial impact on turnaround time (TAT) at the airport. In this context, it is of primary concern how long it takes from the moment passengers leave the cabin up right to the time the passenger cabin crew is ready to service the next turn of customers. The ground service team at the airport shall clean the cabin and cater the aircraft in the minimum time possible under strong safety rules. The area of galleys is also used by flight attendants to prepare meals before servicing passengers and general care of the airplane once it is airborne. In this area there is provision for trash disposal and communication equipment. There is usually an extra seat, in the shape of a revolving chair, for the comfort of the cabin crew during flight. Figure 1 reveals how inappropriate the galley environment in airliners in operation can be.

Many airliners are fitted with more than just a single galley installation. The number of galleys is strongly dependent on passenger seating capacity. Typical figures for sizing are employed according to the numbers of passengers that a single galley can service. For smaller single-aisle airplanes ranging from regional jets to Boeing 737 and Airbus A320, the main galley is usually located on the rear part of the fuselage, with an auxiliary smaller galley on the forward part, close to the cockpit. For two-aisle airplanes, the position may vary much. However, the composition of the galley regarding its mechanical components and specially its geometrical size is not heavily modified. That is because in double-aisled cabins the galley cannot occupy the whole diameter of the fuselage, being restricted to the area within the two aisles.

Galleys usually accommodate from 6 up to 8 trolleys, which are stowed and loaded when necessary. In addition, galleys have just small area for preparation of food or other items, and equipment for in flight service other than additional stowage room on the upper portion. Equipment usually consists of ovens, trash compactors, and kettle for hot

water. More than one of those facilities is necessary to hold the catering cargo required to serve all passengers. Galley location in the passenger cabin is defined by their total loading capacity. Considering 6-8 trolleys, which can hold up to 28 trays, each galley can accommodate catering for around 120 passengers. This means that the number of seat rows between the galley stations is targeted to service the number of passengers close to that factor.



Figure 1. This picture of an Airbus A-340 galley compartment reveals how inappropriate the galley design of current airliners can be (Source: Wikipedia)

Airliners such as Airbus A340 are already configured to accommodate some facilities in their lower deck. Some Airbus A340-600 operated by Lufthansa accommodate in their lower deck lavatory, galleys, and crew rest areas. Access to those facilities is provided by stairs and lift connects trolleys from going from the main to the lower deck and vice versa. Figure 2 shows an Airbus A340 cross-section encompassing the crew rest area that is located in the lower deck compartment.

Trolleys occupy a large amount of area in galley installations. For this reason, the concept for a new galley arrangement considers that they shall be accommodated in the lower deck and transported to the main one by a special purpose lift system (Figure 3).



Figure 2. Lufthansa Airbus A340-600. Pictures show the entrance for lavatories located in the lower deck

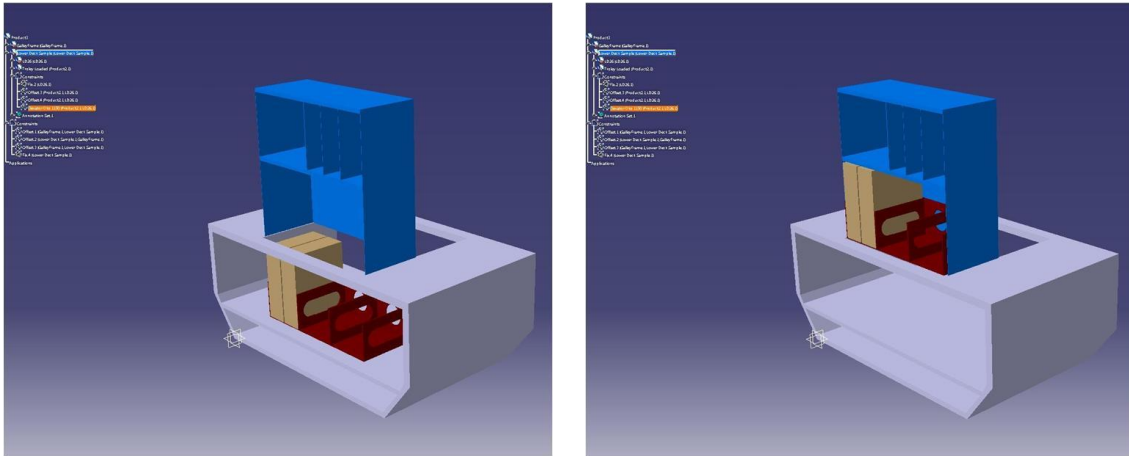


Figure 3. CAD model of the lower-deck galley lift system

2. METHODOLOGY

The methodology that was employed for the design of the new galley system is described in this section. In order to evaluate the impact on airplane performance and its general characteristics, a computer code was developed and validated. Its methodology and validation is also shown here.

2.1 Galley design

2.1.1 Airliners that could take benefit from the new concept

Galley areas of main passenger decks were compared with different types of airliners and cabin layouts. The higher area rates are for wide-bodied airliners (figure 4). This concerns high-capacity airplanes that have two aisles in the passenger cabin and that are tailored for long-haul flights. This seems to be normal because the length of the flight imposes that 2 or more meals must be served to a higher number of passengers. This typically results into a greater area of main decks for food and beverage stowage, up to 25% for the typical economy class of a B777-300 airliner.

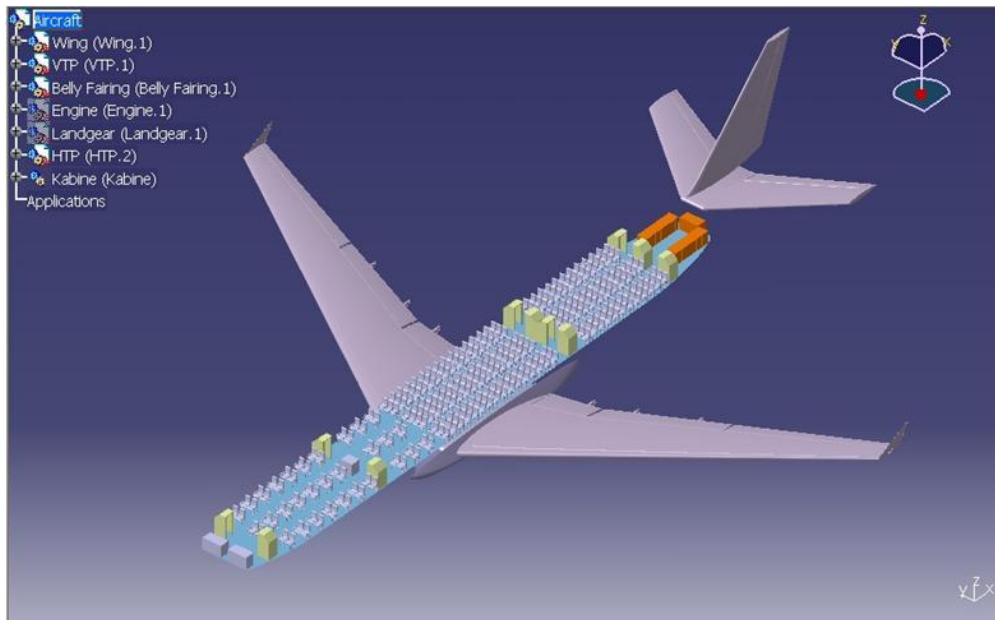


Figure 4. Gallies demand a considerable area in passenger cabins. Above Boeing 777-200 two-class typical cabin layout

Galleys for the business and first class present a greater volume per seat dedicated for stowage. In this case, items served to passengers are unique and require more time for preparation. First and business classes would benefit from beverage storage on the lower deck rather than food by itself. It is important to point out that the presence of first and business classes in the cabin makes the allocation of the galley on the lower deck less effective. The smaller density in occupation of the passenger deck implies a smaller total volume of passenger luggage, releasing room in the cargo compartment for the automated galleys.

Smaller aircraft that operate on low cost airlines may also benefit from the lower deck galley. Even though current galleys occupy a smaller portion of the area, the higher density of seats to be installed in that area could justify the necessary investment. These airlines also tend to have a higher occupation on their flights and very restrictive luggage allowances, allowing the cargo compartment to be used for the automated galley. This would also be very simple due to the highly limited service provided by this kind of airline to passengers during flight. Therefore, just long-haul airliners could benefit from this new galley concept. Smaller planes like the Embraer 190/195 do not have cargo compartments big enough to house the trolleys and the necessary elevator system.

2.1.2 Dimensional design constraints

The main dimensional constraint that can be defined in the conceptual design is that the automated galley should be compatible with the size of the current cargo load containers. By imposing this constraint, it would be simpler to adapt the current airplanes to the new model of galleys, as well as to simplify the design of new models. The previous calculations reveal that all necessary food, beverage and other items allocated on the galley can be stored within these dimensions, as the overall occupation tends to be considerably low.

2.1.3 Logistical design constraints

Galley installations impact ground operations as well as in-flight services. Thus, any modification has to improve such operations. The utilization of current trolleys will simplify ground operation during the preparation of catering cargo, avoiding an increase in turnaround time due to specific airplane requirements. Also, this would not require the adaption of cabin crew to new work material. The current equipment used in galleys must also be compatible with the automated galley, in order to reduce installation costs and avoid new certification issues.

Considering that airliners have a long useful life and tend to change their operation characteristics during that time, it is demanded that the new model of galleys can be easily installed and removed from the airplane, and therefore increase the aircraft's residual value.

From this it is possible to establish another driving project factor that is related to a dock-oriented design. The whole system must be easily removed and installed in the widest possible range of aircrafts, such as current lower deck cabin crew compartments and other current applications for lower deck non cargo room.

2.1.4 In-flight service operation

The logistics of in flight service are crucial for the development of galley installations. The configuration must increase the level of service, decrease the work load of flight attendants, and, if not, it must deliver the same levels of service as current equipment. It is essential to understand the logistics of the service for each meal on the aircraft.

The total number of trolleys can be calculated simply by defining how many meals, each meal serving one passenger, meals each trolley can take, and calculating the number of necessary meals for each flight, based on how many courses will be served. A safety margin must also be allowed for this number.

Another way to define the total number of trolleys necessary on each aircraft is to define, based on statistical data, a certain volume of catering per seat for each cabin configuration, and then use the total number of seats to define the total necessary volume. It would be simple to consider the differences between economy class and business class catering cargo. If based on extensive statistical data, the parametric value will be very accurate and will be simpler to apply to various projects within preliminary design.

Yet, even with this simpler, parametric method of defining the total necessary volume of catering cargo, it is still mandatory to have some knowledge of how the galleys are operated during flight service, in order to identify parameters that might influence the position of the galleys inside the passenger cabin and other factors that might interfere with turnaround time or flight service level.

is the number of necessary trolleys due to provide excellent service for all the passengers is a major parameter. Naturally, this figure is strongly dependent of passenger number. Based on that, we can define how many trolleys must be presented for service on the main deck at each round of service. By round of service this thesis refers to the serving of quick snacks, lunch & dinner, drink and refreshments, and, as has lately become usual, duty free sales. This is a crucial factor, since most of the trolleys will not be available in the passenger cabin, not only the number must be defined, but also in what order they must be produced on the upper deck, in order to define the operation and positioning of the lower deck mechanisms that will take the trolleys to the upper deck.

2.1.5 Snacks

Usually not more than a sandwich or a small pack of snacks are served for each passenger. Given the low storage space that is necessary to accommodate these items, and the fast distribution procedure, usually one flight attendant can cover one aisle with one trolley. Some airlines chose to deliver snacks together with drinks or refreshments, and if that is so, one trolley will be used per alley, noting that two flight attendants are necessary.

2.1.6 Lunch & Dinner

This round of service is responsible for most of the catering required onboard. Each passenger will be provided with one tray holding various cold items that may vary, usually consisting of salad, small juice, and dessert, as well as disposable utensils. These items were prepared during ground service and boarded the plane within the trolleys. They require no attention from the flight crew.

Other than that, one main hot meal will be added to the tray. Usually the airline will offer two options on each flight, which will be described to passengers in general terms such as “Pasta or Beef”, “Chicken or Fish”. That main meal must be heated, and this is achieved by heating many meals in the same oven and then placing them on the top part of the trolleys holding the trays and then proceeding to distribution.

Each of the current ovens can heat two loads of up to 25 economy class meals or 16 upper class meals. Those hot meals are stored on containers that can go into the ovens, and flight attendants must only place them in the oven for heating and initiate the process. Ideally, there shall be a spare oven for items such as bread that are also commonly served.

Once all the items are ready, service begins. For wide-bodied aircraft, usually two trolleys with two flight attendants each will cover each aisle. They will cover a section of up to 120 passengers, as defined by the positioning of the galleys, beginning each from an opposite end of the aisles until they meet in the middle. If a passenger asks for a second hot meal, usually the flight crew will politely decline at least until all the passengers are served, and then, if asked again, will serve a second hot meal if there are any available.

After each main meal service, usually there is a round of drink service or, after a short time, the collection of disposals. This is a simple process, basically collecting the trays and stowing them in the original trolleys, separating glass items on top of the trolley. Further disposables are collected later on with disposable bags and no trolleys, one flight attendant covering each aisle.

2.1.7 Drinks and refreshments

For the service of drinks and refreshments two trolleys shall be used in each aisle, with two flight attendants working from each trolley. Cold drinks are loaded onto the airplane and kept cold with the use of cold ice. Modern airliners are equipped with chillers, while most of the older aircrafts use chillers for items such as dairy products and fruit slices for garnish, that will not hold quality if heated.

Many options are usually available for different drinks, and then few or not any options within each type of drink. For instance, passengers can choose from a range of up to 4 sodas, 3 juices, 1 red wine, 1 white wine, 2 kinds of beer, milk, water. Each passenger will be served around 200 ml unless he requires another drink. If a passenger asks for multiple options in one service alone, for instance: red wine, one soda and a cup of water, he will be served.

On most flights drink service is offered before snacks or hot meals. Sometimes it is offered together with snacks, and it is mostly served right after hot meals. On average, there will be 2 drink services for each hot meal or snack service and most of the time a third one by itself.

2.1.8 Galley layout

Based on the preceding sections, the galley design will be outlined well as its equipment and operation.

It is mandatory that all the necessary catering for each service is available on the main deck, but not necessarily at all times. Dinner or lunch catering can be stored on the lower deck while snacks are served, saving room and allocating more passengers on the same fuselage.

Using basic cargo containers with definite geometry and small adjustments to fit machinery used for allocation of the trolleys on the lower deck, a sample, preliminary design has been developed on CATIA, to simulate the allocation of the design on CATIA models of full aircrafts provided by TU-Berlin tool to assist in aircraft preliminary design.

The main geometric constraints of the equipment are: The width of the portion within the passenger deck within each aisle, since that is a direct restriction to the galley width, and therefore to the total number of trolleys that can be stored side by side on the passenger deck, and the size of the containers within the cargo compartment, that define the storage capacity within the lower deck. These may vary for each different project, and so are made as input variables to the preliminary design software. The width of the central portion, within the aisles, is basically defined by how many seats are allocated in that area, and what the width of each seat is.

PADLAB[®] is a software package targeted for cabin design. It was available at ILR (Institut für Luft- und Raumfahrt der Technischen Universität Berlin). PADLAB[®] is able to deal with major geometric constraints of any configuration, allowing the user easily customizing it according to his needs. Thus, a module to consider the trolley storage in cargo compartments was easily incorporated into the package.

2.2 Lower Deck Geometry: LD-26 Container

The lower deck geometry and sizing is based on the dimensions of the cargo compartment, which usually accommodate standard cargo containers. There are many types of cargo containers, and this design has been based on the LD-26 (Figure 5). This container presents a suitable capacity and would be the safest option for housing the necessary machinery that will operate on the lower deck.



Figure 5. Sample LD-26 container (Source: Driessen Cargo Equipment)

Table I. LD-26 container specifications

| | |
|------------------------|--|
| Design | According to NAS 3610-2A2C; TSO-C90 |
| MGW | 13,300 lb (6033 kg) TARE WEIGHT: 250 kg |
| Max. Dimensions | 159/125x88x64 in. |
| Internal Volume | 459 ft ³ (13.0 m ³) |

The container shall be adapted to accommodate the trolleys in organized stocking positions. In addition, there must be an opening on its upper side to allow communication with the main passenger deck. Most of all, there must be structural changes in order to support the operation of the trolley elevator. There must also be a system to lock the trolleys into their positions when they are stored on the lower deck. Yet, there must be the necessary mobility to allow trolleys to reach the lift in the appropriate order. Based on that, it is convenient to allocate the trolleys on special stowage hubs, so that they can be easily handled by the lower deck machinery system (Figure 6). As can be seen, there is an extra platform rising from the bottom part of the container, which serves as the main structure for the trolleys. The areas below that surface will be used for the allocation of the necessary equipment to move the trolleys from their stowing positions to the elevator, and vice versa, once they have been used.

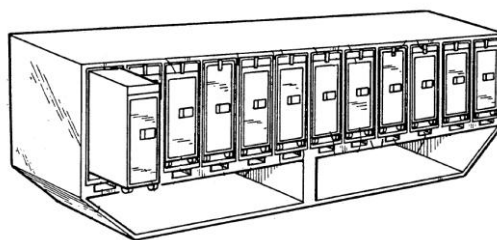


Figure 6. Lower Deck LD-26 trolley organizer

Figure 7 shows the junction between lower and main passenger decks. Trolleys are represented on the lower deck. This sketch displays the non optimal configuration, using the lift to bring one trolley at a time to the main deck.

In Figure 7-A it is possible to note the way trolleys are allocated in the galley on the main deck. The lift area is displayed and it can be seen that with a single lift it would be necessary to control the position of the trolleys on the lower deck using a bi-axial system, which would compromise the level of service and increase the work demand from the air crew.

The optimal configuration consists of the same basic layout, though using a multi trolley lift to cover the full length of the lower deck area, so that trolleys must be handled in a single direction on the lower deck.

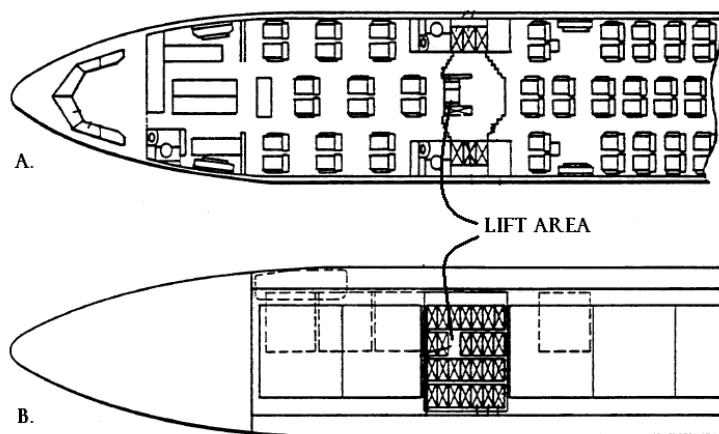


Figure 7. Main passenger deck and lower deck area of a modified airplane that incorporated the new galley concept

2.3 Structural concerns of the new system

The galley frame due to the main passenger deck should not differ much from current approaches. The frame is built using aeronautical aluminum and low density polymers in order to reduce structural weight.

The structural design is usually modular, based on the dimension of the equipment that the galley should enclose. According to the quantity of galley's specific equipment and taking into account geometric constraints imposed by the cabin sizing and geometry, it is possible to define the galley structure.

Based on that information, a sample Galley Frame Design Tool has been developed. The user should enter the basic dimensions and the calculations provide specific coordinates for assembly using a CAD tool. The frame designed is very simple, composed basically by the bottom area for trolley storage and the main working surface for the in-flight service. As the project develops, items are to be added to the frame.

Preliminary design of aircraft interiors could greatly benefit from such a tool. Based on that demand, a MATLAB Graphic User Interface was developed and could represent a good further development for TU-Berlin's PADLAB tool.

Basic galley equipment design was based upon Driessen Aircraft System galley equipment. The company has agreed to provide basic information regarding its models geometry and technical specifications. That information has been used as a background for the CATIA models, so that the design can be consistent in terms of dimensions.

2.4 Lift for trolleys

The necessary technology for the trolley lifts has been in use since the Boeing 747, which uses the main deck to storage of trolleys targeted for servicing the upper deck on the forward part of the airplane during ground service. During flight, however, most trolleys are already on the same deck where they will be utilized, and so operation is simpler once there is no great demand of time. Similar trolleys are used on the Airbus A380 design. The basic application remains the same, lifting up to 2 trolleys at each time. Yet, on the A380 the ground service team can reach the upper and lower deck through service doors on the fuselage, making the re-stocking process simpler to use. Yet, there remains the high occupation of both decks by the galley kitchen, since all trolleys are still on the deck even when they are not being used.

For the current design, trolleys will be lifted from one deck to the other during flight, prior to and then after each round of service, and so that task must be accomplished in a reasonable time. However, the existence of trolleys that operate similar tasks is an important work relief, since there should be considerably less effort made to develop and certificate the new equipment.

Based on the technical data available for the current dual trolley lifts, it is possible to estimate the weight and capacity of the new equipment. The estimation can be achieved in a parametric way, evaluating the impact of the number of trolleys on the engineering features in order to result in the same operational conditions. Table II displays the results of this estimation.

Table II. Weight estimation for the lift system

| | <i>2 Trolley Lift Data</i> | <i>5 Trolley Lift Estimation</i> |
|-----------------------|----------------------------|----------------------------------|
| <i>Weight (lift)</i> | < 320 kg | < 800 kg |
| <i>Weight (trunk)</i> | < 60 kg | < 150 kg |
| <i>Speed</i> | 0.2 to 0.4 m/s | 0.2 to 0.4 m/s |
| <i>Payload</i> | 240 kg during flight | 600 kg during flight |
| | 480 kg on ground | 1200 kg on ground |

The critical factor is the payload on the flight, since all trolleys will be filled to their maximum capacity on their first trip to the main deck, and waste trolleys will be full on the trip back to the lower deck area. The trolley's tare weight is around 25 kg, resulting on a total 125 kg for 5 trolleys. Hence, total payload for the lift considering trolley cargo only is reduced to 475 kg.

2.5 Machinery placed in the lower deck

The machinery system for the lower deck is the only item which is not currently under aeronautical operation in commercial aircrafts that will be necessary for completion of this design. However, there are similar applications under operation for freighter jets.

Once it has been defined that the lower deck machinery system should allow movement in a single direction, the axis of the airplane, the ideal solution is one that can move the group of trolleys as a whole. A simple solution is a revolving chain to be attached to the trolley groups in order to hold their position and allow their movement on the container platform.

This system will operate in a horizontal direction, and due to that reason it can be assumed that it will have a smaller impact on weight than the trolley lift system. Engines and necessary structures will be considerably lighter since they are stable on top of a surface and must not hold the total weight of the trolleys.

It is hard to pin point the weight of such a system. This would require the full development of the material, and such labor is way beyond the purpose of a preliminary design of the lower deck galley. However, estimations are to be considered, as well as a sensitivity analysis regarding the estimation parameters.

A good estimation can be achieved by determining the weight of the total lower deck equipment as the sum of the tare weight of the container and the machinery items. The machinery items can be estimated in co-relation to the lift, representing a fraction of its weight, since the operation is restricted to horizontal movement, as described before. The tare weight of the container, however, is a known factor.

By varying the fraction of weight of the lift that is assumed to represent the horizontal positioning control system, it is possible to determine the total increase of weight produced by each occurrence of the lower deck machinery system.

Table III. Machinery weight estimation

| <i>Units in kg</i> | <i>% of Lift Weight</i> | | | |
|----------------------------|-------------------------|------------|------------|------------|
| | 80% | 60% | 40% | 20% |
| <i>Machinery weight</i> | 640 | 480 | 320 | 160 |
| <i>Machinery+Container</i> | 890 | 730 | 570 | 410 |

Based on the estimations above, it is possible to determine that the total weight of the lower deck system may vary between 400 kg and 900 kg (Table III).

2.6 System Operation

Operation of the present concept can be adapted in many ways, as there are many options regarding how automated the galley is. This design is not meant to be a final conclusion to this subject, and so it is necessary to identify as many different operations as possible, in order to open many possibilities to further research. Initially, the idea was to introduce a fully automated galley, one that would present trolleys to the passenger deck completely ready to serve passengers. That would mean the automated use of ovens for heating the meals, moving items on the lower deck, for instance cold drinks from the refrigerator to the trolleys, and several other tasks.

This option would benefit airlines, since it would probably allow the use of fewer flight attendant for each flight, as their work load would be seriously reduced.

This would require some knowledge of many areas such as robot mechanics and control, and then the use of these technologies for the requirements of the aeronautical industry, such as low weight and extreme high reliability. For that reason, this option has been abandoned for a simpler one, which reaches the same basic goal of allowing extra room for passenger allocation on the main deck.

This second option consists of basic storage on the lower deck, maintaining the main tools such as ovens, water heaters and others on the main deck. Doing this, items that are not required for each round of service could be kept on the lower deck, and, at the time that they become necessary, they could be presented to the flight crew, who prepare them for service. For instance, hot meals would have to be manually placed in the ovens for heating and garnishing would be done by the flight crew as well as cold drink distribution from the trolleys.

With that option, lower deck equipment can be reduced to a minimum. Basically a lift, to move trolleys from the lower deck to the main deck, and a horizontal controller, or maybe a matrix oriented controller, to move the trolleys on the lower deck. Also, there would be more considerations regarding special stowage needs for the lower deck, with would also have to be fully automated and highly reliable to comply with safety requirements.

For this option, the main factor to determine the operation of the galley is the lift that will move the trolleys between the lower deck and the main cabin. Current lifts that operate on Boeing 747, between the main deck and the upper cabin in the forward part of the airplane, and also the ones that operate on A340 with lower deck galleys with access to flight attendants operate lifting 2 trolleys at a time. This number is not the optimum possible, as most of the trolleys will have to be lifted, moving 2 at a time would take a long time, both during flight service and during ground preparation, impacting turnaround time. Lower deck positioning of the trolleys would also have to be much more complex, since there would be only one place where all the trolleys could go, in order to be taken to the upper deck.

One possibility would be to have a number of those lifts, 2 or 3, operating in each galley. This would decrease the time it takes to bring all the necessary trolleys up or down, and simplify the moving criteria on the lower deck, due to the multiple positions of lifts. Yet, it would cause a significant increase in weight to the project, and, more importantly, in machinery. This would lead to a less efficient occupation of the galley area on the lower deck and also in the container below.

An optimal configuration can be achieved by developing a new lift, capable of moving up to 6 trolleys to the main deck at each time. Doing this, the time required to move all necessary trolleys is reduced as well as the complexity of the moving mechanism on the lower deck, since all 6 trolleys could be moved as a group, removing the necessity for a matrix oriented allocation system, replaced by a single direction operator. The drawback lies in the necessity of the development of a new tool, yet, due to its simplicity, it would probably not represent a high demand on research.

Using this configuration, each galley service capacity could be raised up to 150 passengers, and doing so, operation would be simple. Slots of up to 6 trolleys could be prepared by the ground operation team to accommodate each round or service. At each round, the galley would send to the main deck only the trolleys required, keeping the others on the lower deck, meanwhile moving them to accommodate the upcoming disposals when the current service is completed.

The initial concept also included a lower deck door out to the airport service team, so that ground service could replace all the trolleys without entering the airplane. It is feasible, yet it will not be considered for further developments, as it would require heavy structural calculations.

2.7 Weight estimation for airliners

Besides the equipment related to the new galley concept, structural reinforcements must be taken into account that are necessary to accommodate the increased payload resulting from the more available room for additional passengers in economy class. We are talking about 3 tons of extra payload weight for long-haul airliners. However, this may not be the case, if airlines opt to increase passenger comfort in the business or first class.

It is clear that the MTOW will change if payload is increased and/or structural weight is added to the configuration. The lift coefficient will be also change in so the overall drag. All this will lead to additional fuel for fulfill the mission. Thus, everything changes and the new airplane parameters must be computed. For this purpose, a computer code was developed in MATLAB[®] language. The code was christianized WEST.

WEST calculates iteratively the MTOW and other important weight figures. Airplane component weights are calculated according to Roskam's Class II methodology. Calculation of aerodynamic coefficients also fits into a Class II approach. Figure 8 presents the workflow utilized for WEST. In the present work, engine was modeled into a simpler way, with the specific fuel consumption being provided for some flight phases. No more sophisticated engine deck was elaborated.

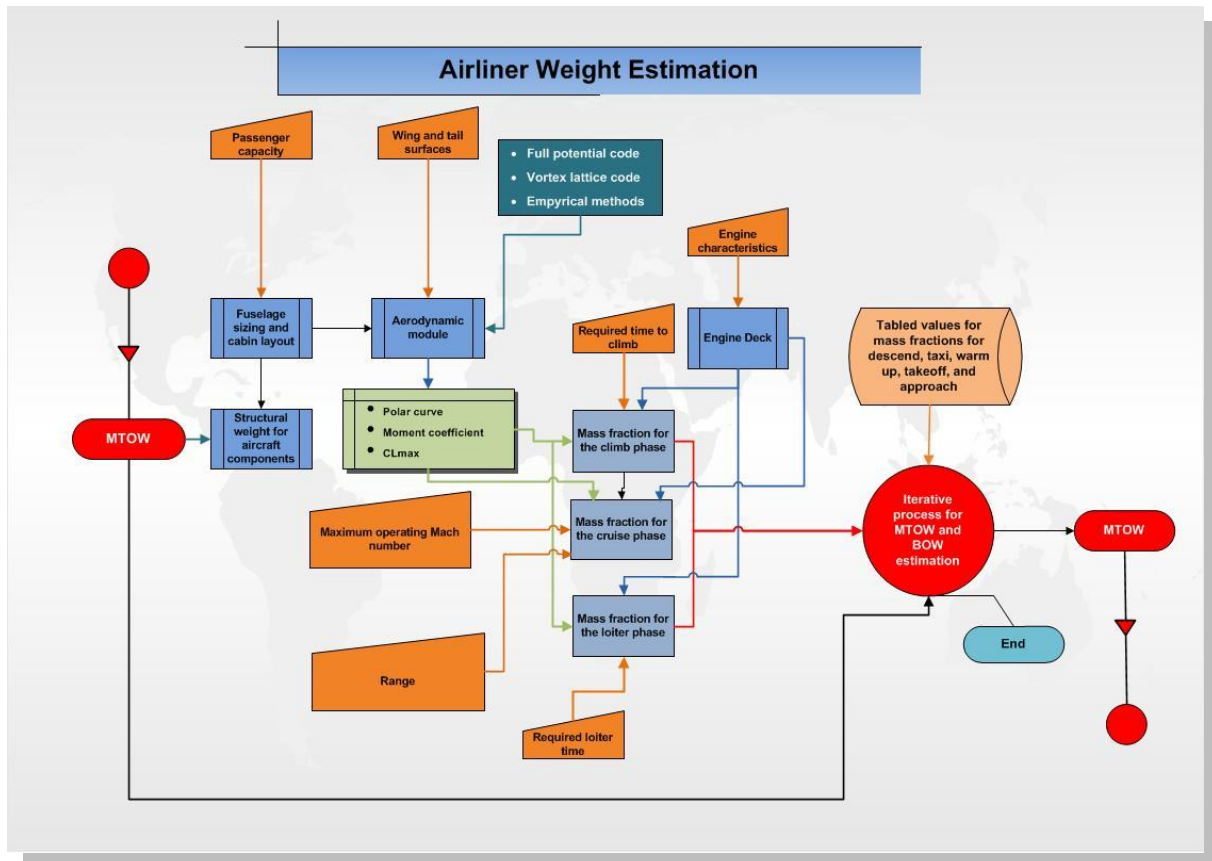


Figure 8. WEST code structure for weight estimation

WEST was employed for weight estimation of the following airliners:

- Airbus A340-300;
- Boeing 777-200;
- Boeing 767-200.

A module was added to WEST in order to incorporate the impact on component weights caused by the incorporation of the new galley concept. An extra 2.5 tones accounted for the systems and structural modifications. This represents an overestimation of the galley components total weight, and also encompasses two lower deck galley installations in the same aircraft, if necessary.

Passenger capacity was increased as result of the new galley concept. A sensitivity analysis was carried out to evaluate its impact on aircraft weight. Passenger increase of 5, 10, 15, and 25% relative to standard configuration was carried out for the airliners analyzed in the present work.

2.7.1 Airbus A340-300

The Airbus A340-300 is a long-range four-engined wide-body commercial passenger airliner designed and manufactured by Airbus, a subsidiary of EADS (Figure 9). It seats up to 335 passengers in a two-class layout (the stretched 600 series carries 440), and has a range between 12400 and 16600 km. It is very similar in configuration and systems to the twin-engined A330 with which it was concurrently designed. Initial A340 versions share the fuselage and wing of the A330 while later models are longer and have larger wings. Over 370 A340s are in operation worldwide as of September 2010.

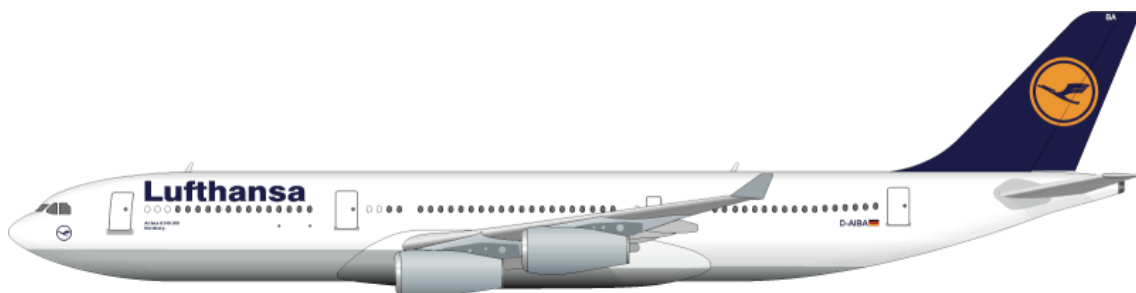


Figure 9. Airbus A340-200 profile

Table IV displays the estimation carried out for weight estimation for the A340-300 with the WEST code. Table V contains the results of a sensitivity study of passenger capacity for the A340-300 series. The extra weight due to the lower deck galley concept was considered in the model.

The increase in the required fuel to fulfill the mission lies close to the error margin as seen in Table IV. The increase observed for MTOW and OEW values takes into account the structural modifications to accommodate the increased payload.

Table IV. A340-300 weight estimation (all figures in tones)

| | <i>Airbus Data</i> | <i>WEST Results</i> | <i>Error</i> |
|---------------------|--------------------|---------------------|--------------|
| <i>Empty Weight</i> | 126 | 123.8 | -1.8% |
| <i>MTOW</i> | 251.7 | 246.1 | -2.2% |
| <i>Mission Fuel</i> | 72.5 | 70.0 | -3.4% |

Table V. Sensitivity analysis for increasing passenger capacity of Airbus A340-300

| | 5% | | 10% | | 15% | | 20% | |
|---------------------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|
| | <i>Total</i> | <i>Increase</i> | <i>Total</i> | <i>Increase</i> | <i>Total</i> | <i>Increase</i> | <i>Total</i> | <i>Increase</i> |
| Passenger capacity | 305 | 15 | 319 | 29 | 334 | 44 | 348 | 58 |
| <i>Empty Weight</i> | 128.1 | 3.5% | 128.4 | 3.8% | 128.5 | 3.9% | 128.7 | 4.0% |
| <i>MTOW</i> | 252.8 | 2.7% | 255.2 | 3.7% | 256.7 | 4.3% | 258.6 | 5.1% |
| <i>Mission Fuel</i> | 72.4 | 3.5% | 73.4 | 4.9% | 73.9 | 5.5% | 74.6 | 6.5% |

2.7.2 Boeing 767-200

Launched in July 1978, the Boeing 767 (Figure 10) was developed in tandem with the narrow body 757 with which it shares a common two crew EFIS flight deck (with six color CRT displays) and many systems. The 767 also features a unique width fuselage typically seating seven abreast in economy, and a new wing design with greater sweepback than that of the 757 wing. The 767 first flew on September 26 1981, and entered service with United on September 26 1982. Certification with P&W engines was awarded on July 30, 1982.



Figure 10. Boeing 767-200 side view

Table VI display the validation of the present methodology for the weight estimation of the Boeing 767-200 airliner. WEST error estimation for the Boeing 767-200 can be considered good for a Class II approach. The estimated empty weight is now slightly higher than provided by Boeing.

Table VI. Boeing 767-200 weight estimation (all figures in tones)

| | <i>Boeing Data</i> | <i>WEST Results</i> | <i>Error</i> |
|---------------------|--------------------|---------------------|--------------|
| <i>Empty Weight</i> | 80.1 | 81.5 | 1.8% |
| <i>MTOW</i> | 142.9 | 138.9 | -2.8% |
| <i>Mission Fuel</i> | 29.9 | 28.8 | -3.9% |

Table VII. Sensitivity analysis for increasing passenger capacity of Boeing 767-200

| | 5% | | 10% | | 15% | | 20% | |
|-------------------------|-------|----------|-------|----------|-------|----------|-------|----------|
| | Total | Increase | Total | Increase | Total | Increase | Total | Increase |
| Passenger number | 210 | 10 | 220 | 20 | 230 | 30 | 240 | 40 |
| Empty Weight | 85.3 | 4.6% | 85.6 | 4.9% | 86.1 | 5.5% | 86.1 | 5.5% |
| MTOW | 142.9 | 2.9% | 144.4 | 4.0% | 146.8 | 5.7% | 147.3 | 6.1% |
| Mission Fuel | 29.4 | 2.4% | 29.8 | 3.7% | 30.5 | 6.1% | 31.3 | 9.0% |

Table VII displays the results of the sensitivity study carried out for Boeing 767-200. The increase in the required fuel is now higher than that calculated for the A340-300, especially for the 20% passenger increase. If both airliners are able to transport 20% more passenger thanks to the new galley concept, the Boeing 767-200 will required 6.5% more fuel while the Airbus aircraft will consume 9% more kerosene. However, considering that the Boeing aircraft carry typically 200 passengers and the Airbus 300, the impact on DOC could be present a different trend. The results are consistent and display potential DOC reduction, as the increase in the number of passengers is always higher than the increase in the mass of the components. The results of the DOC analysis will be presented in Section 3.

2.7.3 Boeing 777-200

The Boeing 777 (Figure 11) is the world's largest twinjet. The airplane has seating for over 300 passengers and has a range from 5,235 to 9,380 nautical miles (9,695 to 17,370 km) depending on model. It is able to accommodate 550 passengers in a single-class cabin layout. Its distinguishing features include the largest diameter turbofan engines of any aircraft, six wheels on each main landing gear, a circular fuselage cross-section, and blade-shaped tail cone. Developed in consultation with eight major airlines, the 777 was designed to replace older wide-body airliners and bridge the capacity gap between the 767 and 747. The 777 was Boeing's first fly-by-wire airliner.

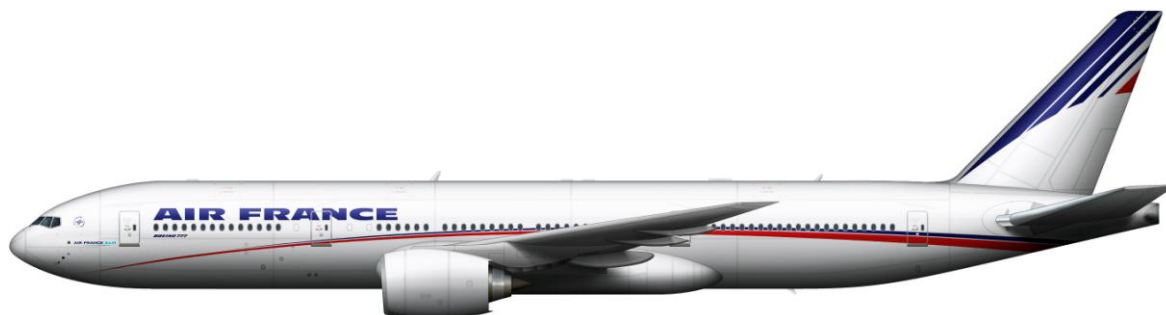


Figure 11. Boeing 777-200ER in Air France livery

WEST slightly underestimates MTOW, OEW, and the required fuel mass (Table VIII). However, the accuracy is very good considering the simplicity of the model; all the results fall below 3%. After was validated, the lower deck galley was incorporated into de modeling and tests were then carried out for passenger capacity increase. The table IX illustrates the results obtained. The fuel increase is very significant for the Boeing 777. Maybe due to its huge powerplant, the airliner has to operate at higher load factors.

It is necessary to evaluate the total impact on DOC per seat mile, a task which will be addressed in following sections.

Table VIII. Boeing 777-200 modeling accuracy analysis

| | Boeing Data | WEST Results | Error |
|---------------------|-------------|--------------|-------|
| Empty Weight | 139.2 | 136.0 | -2.3% |
| MTOW | 247.2 | 240.0 | -2.9% |
| Mission Fuel | 71.2 | 69.7 | -2.0% |

Table IX. Results from the B777-200 weight impact analysis

| | 5% | | 10% | | 15% | | 20% | |
|-------------------------|-------|----------|-------|----------|-------|----------|-------|----------|
| | Total | Increase | Total | Increase | Total | Increase | Total | Increase |
| Passenger number | 383 | 18 | 402 | 37 | 420 | 55 | 438 | 73 |
| Empty Weight | 141.2 | 3.8% | 142.6 | 4.9% | 143.2 | 5.3% | 144.0 | 5.9% |
| MTOW | 248.4 | 3.5% | 255.0 | 6.2% | 255.5 | 6.5% | 262.6 | 9.4% |
| Mission fuel | 72.6 | 4.1% | 75.5 | 8.3% | 76.8 | 10.1% | 78.6 | 12.8% |

3. FEASIBILITY ANALYSIS

The Figure 12 presents a cutaway of a passenger cabin related to an aircraft designed by the PADLAB[®] tool. Part of the surface was set to be transparent in order to enable a view of airplane interior. This is an example of the PADLAB[®] output file for CATIA. The program generates a complete aircraft layout for the entire cabin. The specifications such as economy class seats, seating pitch, and the number of seats abreast can be defined by the user with a simple interface. The code generates an output file which is read by a CATIA macro code, producing the full aircraft as seen in Figure 12.



Figure 12. Computer model of the Airbus A340-300 airliner

Figure 13 now displays a sample of the lower deck galley overview, including the galley frame, the trolleys on the lower deck and the LD-26 container adapted for the task.

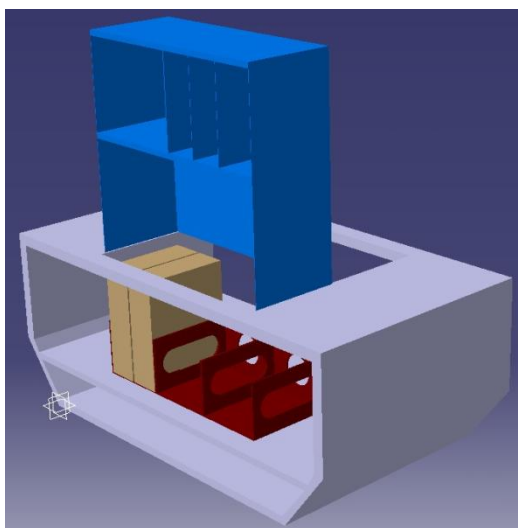


Fig. 13. Lower-deck galley system overview

Based on the two models it is possible to develop the cabin interior with some samples of the lower deck galley concept, and evaluate the possible impact in terms of passenger capacity. It very is important to verify if the lower deck galley can be installed into any aircraft using the TU-Berlin preliminary design tool. Based on this, the capacity of the lower deck galley is set to be equal to its correspondent actual model for each aircraft.

Figures 14 to 16 show the original cabin layout compared to its reconfiguration after the new galley concept is adopted for the airliners studied in the present work. Table X shows how many additional passengers can be transported in the main cabin of the three airliners studied in the present work after changing the galley configuration. The galley concept described in the present work proved to be advantageous for the three airliners that were studied here (please, refer to Table XI).

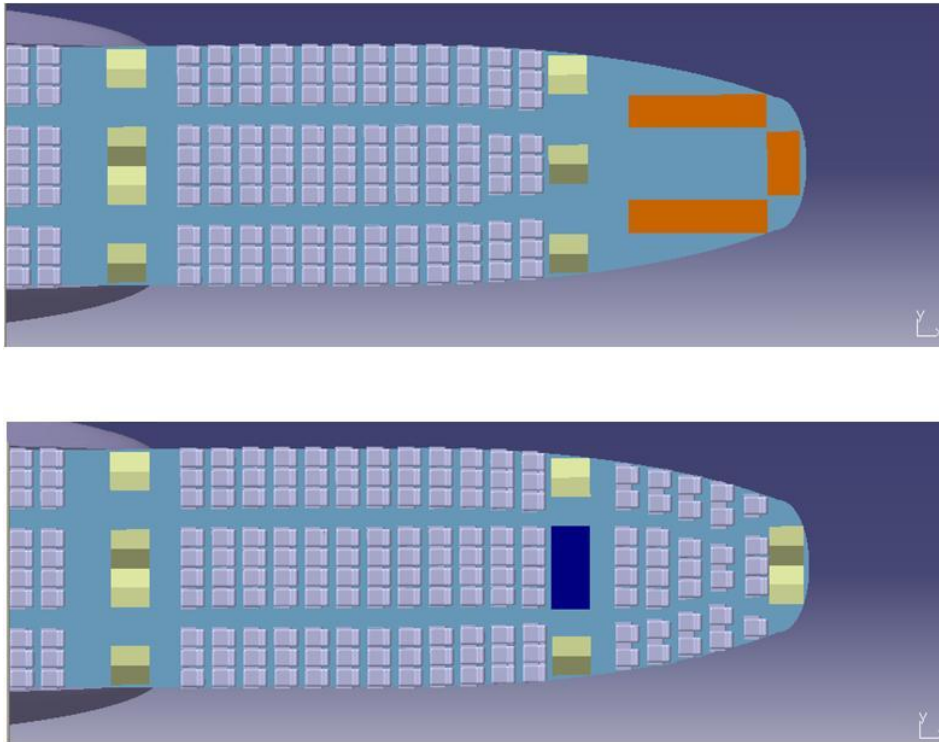


Figure 14. Original cabin layout of the Boeing 777 airliner (top) and the additional seats that were added after the incorporation of the new galley concept (bottom)

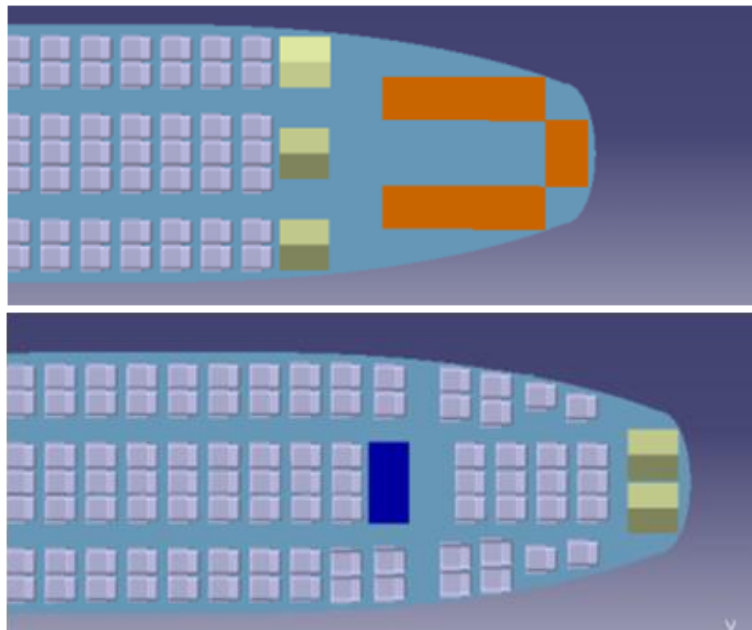


Figure 15. Original cabin layout of the Airbus A340-300 airliner (top) and the additional seats that were added after the incorporation of the new galley concept (bottom)

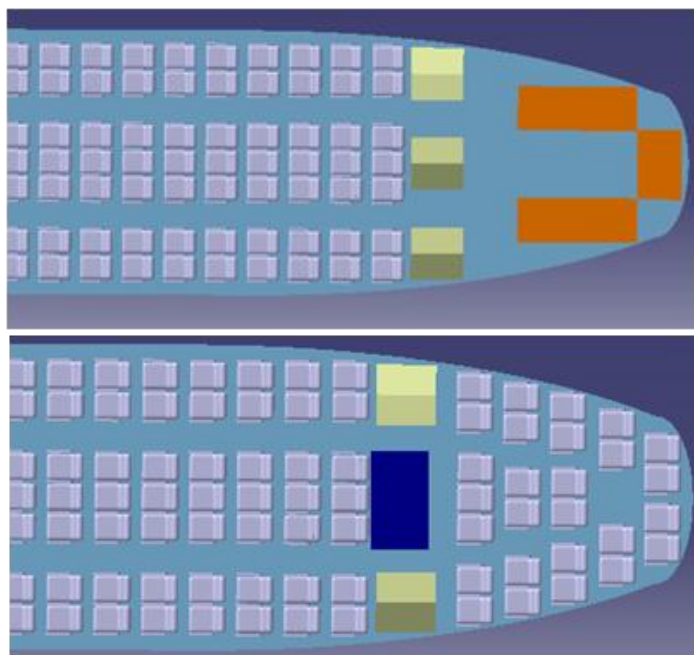


Figure 16. Original cabin layout of the Airbus Boeing 767-200 airliner (top) and the additional seats that were added after the incorporation of the new galley concept (bottom)

Table X. The present concept enables increasing the number of passengers that can be transported in the main cabin of three major airliners

| | A340-300 | Boeing 767-200 | Boeing 777-200 |
|----------------------------------|----------|----------------|----------------|
| Economy class typical | 238 | 175 | 280 |
| Extra seats in the economy class | 28 | 27 | 34 |
| Capacity variation | +11.8 % | +15.4 % | +12.1 % |

Table XI. The galley concept described in the present work proved to be advantageous for the three airliners that were studied here

| | A340-300 | Boeing 767-200 | Boeing 777-200 |
|-----------------------------|----------|----------------|----------------|
| DOC per seat mile variation | -4.17 % | -5.42 % | -3.25 % |
| Capacity variation | +11.8 % | +15.4 % | +12.1 % |

4. CONCLUDING REMARKS

The main goal of the present concept was the reduction of DOC by increasing the passenger capacity of the airliners studied here. In addition, there will be a healthier and more efficient work environment in galley installations thanks to the new concept. There is an aircraft ownership cost increase in the manufacture of the new system. However, the ultimate figure is the DOC per seat mile. The DOC considered the increase in passenger capacity, thanks to the extra room that would be available in the economy class. DOC per seat mile improvement ranges from 11.8% to 15.4%, very significant values for the three airliners analyzed here.

A feature that could be improved through further developments of the lower deck galley is the utilization of modern galley products focusing on new aircraft. Airbus SPICE concept elements can be utilized in the design of the lower deck galley reducing its total weight, and therefore allowing a better result in terms of DOC. The design as described in this research, as was stated in the initial concept, utilizes equipment available in current galleys, in order to achieve better acceptance on the market. However, as standards may change, it is important to readapt the design to the new technologies there would be available.

A further development for this design would consist of a detailed design of the lower deck machinery system, in order to define with higher precision what the weight impact is of that element of the concept, on the overall aircraft. This is also a critical area of development for the design, as it is the only major part of the lower deck galley that does not exist under the same operational requirements. This means that this technology would have to undergo the necessary homologation according to international agencies. It is likely that this would be the critical stage of the design and creation of a prototype, once all the other necessary equipment is available on the market.

Another area that could be very sensitive for the success of the concept presented on this report is related to safety regulations, especially the evacuation requirements. FAR 25 requires that all passengers must be able to evacuate the cabin within 90 seconds. Santos (2004) utilizes software simulation to evaluate the possibility of evacuation from wide bodied aircraft equipped with a lower deck passenger seating area. It is possible that the same routine can be adapted for the calculation of the evacuation time for the models described, providing important data to support further research on this subject, or indicating problems that must be solved.

It would be interesting to communicate with members of the developing teams of companies such as Boeing and Airbus to verify the most important points regarding the lower deck galley, and to evaluate the possibility of development based on this preliminary review. Focusing on a more technical approach, it would be fascinating to eventually create a prototype to evaluate the real impact of this concept.

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