Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Master Thesis

Department of Automotive and Aeronautical Engineering

Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations

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Abstract

This master thesis deals with the analysis of ground handling processes, the description and application of software programs that are able to simulate aircraft ground handling processes and possible innovative aircraft configurations, in the form of sketches, that could improve the turnaround process in terms of time and cost. The analysis of ground handling processes has been conducted from real-time ground handling videos recorded at Berlin-Schönefeld Airport. The data obtained has been used to develop statistical models in order to obtain mathematical equations. The equations have been constructed with rates which represent typical ground handling procedures. Based on the equations, typical input parameters for SIMBA (Simulation Tool for Aircraft Servicing) have been found. The simulation conducted shows a representative turnaround layout of the Airbus A320-200. The results of the simulation have been the turnaround costs, the turnaround bar chart and the compatibility of the ground vehicles movements. Knowledge has been gained through an expert interview. The information that has been found out with the interview is the critical paths in a normal turnaround with the relation of these critical paths with aircraft configurations. Sketches of innovative aircraft configurations are defined with a study of the main conventional attributes in ground handling. Innovative configurations are proposed and described with the assistance of three-view drawings. An analysis of these configurations has been carried out with the theoretical ground handling advantages and disadvantages in comparison of a conventional aircraft. Based on the different analyses conducted, all the information presented might be useful when developing an aircraft optimized for ground handling.

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DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations

Project work towards a thesis at ETSIA UPM

Background

Ground handling costs are an important part of the overall direct operating costs of an aircraft. Moreover, in the airline business, where all competitors operate similar aircraft for comparable route length, a cost-efficient ground handling is one of the main competitive advantages. Hence, low cost ground handling is a key factor of the low cost airlines (LCA) business strategy. However, the potential competitive advantage of cost-efficient ground handling procedures is limited by the current aircraft configurations. Requirements for low cost ground handling could not have been taken into account for the existing aircraft, because LCA simply did not exist back then. For a new design, ground handling aspects must be taken into account, not only to successfully operate within the existing airport facilities but also for airline economics. This project is part of the aircraft design research project "ALOHA".

Task

The tasks of the project are as follows:

- Investigation on the single-aisle aircraft ground handling characteristics.
- Investigation of ground handling characteristics with the help of expert interviews.
- Analysis of the ARC (Airport Research Center) ground handling videos.
- Creation of analytical or statistical models for each ground handling service.
- Ground handling simulation of aircraft configurations with SIMBA (Simulation Tool for Aircraft Servicing).
- Ground handling simulation of aircraft configurations with CAST (Comprehensive Airport Simulation Tool)
- Creation, analysis and selection of the possible new innovative aircraft configurations.

The report has to be written in English based on German or international standards on report writing.

Declaration

This Master Thesis is entirely my own work. Where use has been made of the work of others, it has been totally acknowledged and referenced.

Date	Signature
September 28, 2009	RICO SÁNCHEZ, Diana

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List of Symbols

B_s	Breguet factor
d	Distance
D	Drag
FR	Flow rate
k	Constant
L	Lift
m	Mass
n	Number of
pax	Passenger
RF	Refuelling
SFC_T	Specific Fuel Consumption for jets
t	Time
v	Velocity
V	Volume

Greek Symbols

α	Alpha factor

Subscripts

Subscripts for flight phases

$( )_{CR}$	Cruise phase
$( )_{i}$	Flight phase
$( )_{i+1}$	Next flight phase
$( )_{LOI}$	Initial Loiter phase
$( )_{TO}$	Takeoff

Subscripts for ground handling processes

$( )_{,boa}$	Boarding process

$()_{cargo}$ Cargo
$()_{CAT}$ Catering
$()_{,deb}$ Deboarding process
$()_{f}$ Fuel
$()_{LD}$ Loading process
$()_{LDc}$ Loading process with containers
$()_{PB}$ Pushback process
$()_{PBc}$ Pushback process with conventional tractor
$()_{PBt}$ Pushback process with towbarless tractor
$()_{PW}$ Potable Water Service
$()_{ULD}$ Unloading process
$()_{WWS}$ Waste Water Service

Subscripts for ground handling vehicles, equipments and objects

$()_{AB}$ Airbridge
$()_{AS}$ Airstairs
$()_{bag}$ Baggage quantity
$()_{BL}$ Belt Loader
$()_{CL}$ Container Loader
$()_{container}$ Container quantity
$()_{CV}$ Catering Vehicle
$()_{GPU}$ Ground Power Unit
$()_{,hb}$ Hand baggage quantity
$()_{trolleys}$ Trolleys quantity

Subscripts for movements

$()_{inR}$ Rate of passengers getting in the aircraft
$()_{outR}$ Rate of passengers getting out the aircraft
$()_{,bs}$ Boarding process stopped
$()_{,con}$ Connecting
$()_{,dis}$ Disconnecting
$()_{,ds}$ Deboarding process stopped
$()_{,in}$ Passenger getting in the aircraft
$()_{,out}$ Passenger getting out the aircraft
$()_{,pos}$ Positioning
$()_{,pre}$ Preparing
$()_{,rem}$ Removing

Other subscripts

$(\ )_{pax}$	Passengers
$(\ )_{speed}$	Speed
$(\ )_{speed,0}$	Initial Speed

List of Abbreviations

Aero	Aircraft Design and Systems Group
AFT	After
ALOHA	Aircraft Design for Low Cost Ground Handling
ARC	Airport Research Company GmbH
ATC	Air Traffic Control
AVC	Aviospecialties
CAD	Computer Aided Design
CAST	Comprehensive Airport Simulation Tool
DOC	Direct Operating Costs
FWD	Forward
GH	Ground Handling
GPU	Ground Power Unit
HAW	Hoschschule für Angewandte Wissenschaften (University of Applied Sciences)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ISO	International Organization for Standardization
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LCA	Low Cost Airlines
OPS	Operations
OTW	Over The Wing
MATLAB	MATrix LABoratory
NACA	National Advisory Committee for Aeronautics
SIMBA	Simulation Tool for Aircraft Servicing
SUMO	SUrface MOdeling tool for aircraft configurations
SXF	Berlin-Schönefeld Airport
SZG	W. A. Mozart, Salzburg Airport
ULD	Unit Load Device
URL	Universal Resource Locator
WWW	World Wide Web

1 Introduction

1.1 Motivation

This Master Thesis is part of the aircraft design research project Aircraft Design for LOw cost ground HAndling (ALOHA).

ALOHA is a research project focus on decrease the Direct Operating Costs (DOC) related with time and costs of the ground operations at the airports. Under this project, new aircraft designs are investigated. (**Scholz 2007**)

For Low Cost Airlines (LCA) the costs regarding ground handling operations have a high share among the total operation costs, nevertheless the reduction of these costs can lead to an increase in other DOC types, as maintenance or fuel costs. Therefore, it is necessary to maintain a holistic view on aircraft design. (**Gomez 2009a**)

Nowadays, the most popular commercial transport jets utilized by LCA are the Airbus A320 and the Boeing 737. In the design of both aircraft were not included the requirements of LCA. Aircraft manufactures have announced successors for the both models. ALOHA can help to include LCA requirements into the development of the successors of current single aisle aircraft, taking into account these requirements for the first time in history. (**Gomez 2009a**)

This Thesis, *Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations*, as a part of ALOHA project, is a research of turnaround features which leads to a first overview of possible innovative conventional aircraft configurations in order to reduce the turnaround time.

1.2 Definitions

<u>Turnaround</u>

The concept of turnaround is defined in **Airbus GH 1995** as follows:

> *"Turnaround is the period of time that the aircraft is on the airport ramp, from blocks on at the aircraft arrival to blocks off at the aircraft departure. This includes the positioning of the pushback tractor and tow bar in preparation for the pushback process."*

Ground handling

The Ground Handling (GH) is all kind of processes, including operative procedures, services, equipment and personnel, necessary to prepare the aircraft for the next flight, including the passengers and cargo movements, during a turnaround.

Conventional aircraft configuration

An aircraft has a conventional configuration if it has been designed with all of these three main attributes: one fuselage, one wing and the empennage at its rear end. The most aircraft which have been built today have a conventional configuration. One reason is that the experience base dealing with conventional configurations is very large. (based on **Roskam II 1997, Scholz 2009**)

Innovative conventional aircraft configuration

An innovative conventional configuration is a conventional configuration which has some changes to the common transport aircraft, for instance an inverted V empennage at the rear end instead of a conventional tail. The three main attributes mentioned above remain while some characteristics of the structure may vary.

Low cost airlines

Low Cost Airlines (LCA) are airlines type which offer low cost fares in its flights. LCA are providers of a basic flight where seating comfort is reduced and the traditional flight services are reduced or eliminated, such as the onboard catering, rebooking options, etc. (adapted from **Gross 2007**)

1.3 Objectives

The objective of this master thesis is the creation of possible innovative aircraft configurations, in form of sketches, which could improve the turnaround procedure in terms of time and cost.

The creation phases have to start with a deep study of the GH characteristics. Therefore, one task is to investigate in detail all the processes and equipment involved in an entire turnaround. This knowledge has to be gained with all the information available, such as literature, internet, expert interviews and real data.

This research is focused in LCA ground handling requirements. Therefore, another task is the study of the commercial transport jets mostly used by LCA.

As part of ALOHA project, the final goal of this thesis is to assist ALOHA in reduce the ground handling costs and turnaround times with a first view of aircraft configurations optimization.

1.4 Literature

Books

The references used for this thesis include a large number of specialized books, written either by professors, engineers or specialists in the aircraft design field and/or in the ground handling field. The most referenced books are described bellow.

For the study of conventional configurations and innovative conventional configurations of aircraft, **Roskam II 1997** and **Scholz 2009** have been used**. Roskam II 1997: "***Airplane Design. Preliminary Configuration Design and Integration of the Propulsion System"* gives a detail description of all main structures of the aircraft, including a big amount of data of existing aircraft, as well as the first steps in aircraft design and preliminary sizing. **Scholz 2009 "***Short Course on Aircraft Design"* presents the entire design process of an aircraft, therefore, it describes the requirements to initial sizing, configuration layout, analysis, sizing, etc. The book is a very good tool for study the current conventional configurations, and it has been used to complete the information of **Roskam II 1997.**

For the study of turnaround and ground handling processes the main book that has been used is **IATA 2009 "***Airport Handling Manual".* The book gives a complete description of all ground handling processes and equipments, as well as the main directives and functional specifications which must be followed during a turnaround (based in IACO and JAR-OPS 1 directives). Furthermore, the book provides a description of the ground handling features of the most common commercial airplanes.

For specific directives and specifications of ground handling procedures have been utilized **JAR-OPS 2007** *"JAR-OPS 1. Commercial Air Transportation (Aeroplanes)",* which explains all directives which must be followed for commercial air transportation.

The data of the general features of the Airbus A320, Airbus A319, Boeing 737-700 and Boeing 737-800, has been taken from **Jane's 2008** *"All the Worlds Aircraft 2008-2009"*. The book gives a general description and data of every airplane and helicopter which have been produced.

The ground handling characteristics of the aircraft mentioned above have been taken from **Airbus 1995b** *"A320 Airplane Characteristics For Airport Planning"*, **Airbus 1995a** *"A319 Airplane Characteristics For Airport Planning"*, and **Boeing 2005** *"B737 Airplane Characteristics for Airport Planning"*. These books are the technical description of the aircraft for airport planning, which contain the airplane description, airplane performance, ground maneuvering, terminal servicing, operating conditions, pavement data and derivative airplanes.

The information of low cost airlines has been based on **Gross 2007** *"Handbook of Low Cost Airlines"*, which gives a detail description of the low cost airlines, their procedures and their impact in the air transport market and so on.

For the description of ALOHA project **Scholz 2007** ***"****Flugzeugentwurf für kostenoptimierte Bodenabfertigung"* has been used. It describes the ALOHA project and its main objectives.

Thesis and papers

An important reference is the database of ALOHA project: papers and thesis written to work, to contribute or to assist ALOHA project. The most referenced thesis and papers are described bellow.
(URL: http://ALOHA.ProfScholz.de ; URL: http://bibliothek.ProfScholz.de)

The investigation of innovative configurations optimized for ground handling has been based on **Gomez 2009b "***Optimized Ground Handling Aircraft"*. This reference is a report created for ALOHA project which proposes innovative aircraft configurations, in form of sketches, to improve the turnaround procedure, and it gives the hypothetic advantages and disadvantages of each configuration.

For a research of turnaround and ground handling processes **Gomez 2009a** *"Improvements to ground handling operations and their benefits to direct operating costs"* has been utilized. This report is an investigation of the possible improvements of turnaround procedures and it gives a description of the possible benefits in direct operating costs. The thesis **Raes 2008** *"Efficient autonomous pushback and taxiing – a step forward to reduce costs and pollution"* have been used for the same purpose.

For specific studies of ground handling processes in concrete, **Hortsmeier 2001** and **Bouchareb 2007** have been consulted. **Hortsmeier 2001** *"Influence of ground handling on turn round time of new large aircraft*" gives a general description of turnaround and ground handling processes. It is focus on the cleaning procedure. **Bouchareb 2007** *"Low Fare Airline Optimized Aircraft"* is an innovative aircraft design which has into account the improvement of ground handling procedures; in concrete it has a deep investigation of the passengers deboarding/boarding.

Internet

Internet is a very big database to find information for this thesis. The most web pages used are described bellow.

For a study of the software program Comprehensive Airport Simulation Tool (CAST) the information of **ARC** *"Airport Research Center*: *Main web page"* have been used, as well as several web pages, inside the main of **ARC,** which describe CAST program.

For a research of turnaround and ground handling processes has been consulted **AEROWAY 2009**, **Airfleets 2009**, **Dewbridge 2009**, **Planespotters 2009** which are the official web pages of the corresponding ground handling equipments manufacturers.

For the input data of turnaround cost **SZG 2007** *"Handling charges"* have been used. It summarizes the handling charges and prices of the W. A. Mozart Salzburg Airport.

1.5 Structure of Work

This thesis is structured in eight Chapters and four appendixes, as follows:

Chapter 2 describes the GH processes and equipments existing nowadays, as well as a normal turnaround sequences, analyzing the critical paths of it.

Chapter 3 investigates and compares the GH features of the Airbus A320, A319 and the Boeing B737-700, B737-800.

Chapter 4 analyses the data collected from videos recorded in Berlin - Schönefeld Airport.

Chapter 5 creates equations based on statistical models of the GH processes using the data and information analyzed in the previous Chapters.

Chapter 6 describes the computer program SIMBA. With this program is simulated a turnaround of an aircraft based on the Airbus A320. The results of the simulation are analyzed.

Chapter 7 describes the computer program CAST.

Chapter 8 explains the reason for conducting expert interviews, describing which information should be obtained. Besides, the Chapter shows the final results of Prof. Dr.-Ing. G. Konieczny interview.

Chapter 9 investigates the aircraft configurations regarding GH characteristics, and it studies the possible modifications in the configurations to optimize the GH processes. In this Chapter innovative configurations within the point of view of GH are created, analyzed and the most promising are selected.

Appendix A summarizes the data collected from the videos engraved in Berlin - Schönefeld Airport. The data is arranged according of each GH process.

Appendix B shows graphic results of the statistical models created in Chapter 5.

Appendix C presents the transcription of the Prof. Dr.-Ing. G. Konieczny interview.

Appendix D describes the general features and GH characteristics of the Airbus A320, A319 and the Boeing B737-700, B737-800.

2 Ground handling

2.1 Turnaround

When airlines plan their route structure, schedules and fleet utilisation they need to define the procedures during a turnaround. The duration can vary extensively depending on the type of the turnaround scenario and on the extent of the work processes to be performed.

Many factors have to be taken into account by the airlines when planning turnaround procedures for their various destinations, such as:

- Aircraft types: Narrow Body or Wide Body Aircraft
- Different types of flights: scheduled or charter flights
- Airports: international or secondary airports
- Company ideology: Low Cost airlines, Charter airlines, Classic full service airlines or Premium class airlines
- Next stage length: short or long flights
- Destination: transit, final destination or home base airport
- Parking position at the airport: at terminal or remote
- Season
- Available slots at the airport

2.2 Ground handling general description

Strict safety regulations have to be obeyed by ground personnel while performing ground handling during a turnaround.

All the activities can be separated in concrete tasks. Some of them can be carried out simultaneously because they are independent from each other, but most of them must follow a specific order. For instance, the cabin cleaning process cannot take place if passengers are still on board the aircraft. (**Stavenhagen 2002)**

An obvious characteristic of GH is the limited space around the aircraft. Figure D.3 in Appendix D shows a static snapshot of the ramp layout during turnaround, but whether work processes can actually be performed simultaneously depends very often on the fact, if ground vehicles can operate around the aircraft while other ground vehicles are already in their positions.

2.3 Ground handling processes

The main GH procedures for a complete turnaround layout are:

- Passengers: deboarding/boarding.
- Cargo: unloading/loading.
- Catering.
- Cleaning.
- Refuelling.
- Lavatory service
- Potable water service
- Push back.
- Ground power.
- Ground air preconditioning.
- Pre-flight inspections.
- De-/anti-icing.

GH activities are carried out in the following way:

After landing and the subsequent taxiing to the parking position, the personnel sets the parking brakes of the aircraft on.

Since the aircraft is on blocks, the operators connect the Ground Power Unit (GPU) to supply power while the aircraft is on ground and the engines are shut off. All aircraft require 28V of direct current and 200V 400 Hz of alternating current. The Ground Air Preconditioning Unit is connected if necessary.

In case the apron is close to the passenger terminal a passenger bridge links the aircraft cabin with the terminal and it is placed in the correct position. When the aircraft is parked further away from the terminal, in a remote apron, the boarding stairs, also called air stairs, need to be situated. Once the air stairs/bridge is positioned the passengers deboarding starts. In case of remote apron, the passengers are taken by busses or directly walk from the aircraft to the terminal.

At the same time, a belt or ground loader is driven up to the compartment in the bottom of the aircraft, to help in unloading/loading process. If the baggage is stored into containers the ground loader is used, a special loader described in the Chapter 2.4. Otherwise, if the luggage is stored without containers - known as bulk - a belt loader is used. Baggage carts, moved by a tractor, are used to transport the luggage from the aircraft to the terminal. The unloading/loading process is independent to the rest of processes, whenever the equipment does not disturb the other tasks. Stowage of baggage and cargo is regulated by JAR-OPS 1.270: "*Stowage of baggage and cargo*", within the JAA region. (**JAR-OPS 2007)**

Once the passengers are deboarded, cleaning and catering activities begins, as they are usually performed simultaneously in the aircraft cabin.

The catering takes place by substituting the trolleys.

The cleaning service performs the emptying, brushing and vacuum cleaning of the interiors of the aircraft. This type of cleaning is characterised by a high concentration of physical activities in time and space in a confined workspace (due to maximisation of carrying capacities and comfort of passengers). (**Stavenhagen 2002)**

LCA performs a simple cleaning, which consist in a quickly check of the seats and toilets carried out by the cabin crew.

For an intensive cleaning, the conventional airlines prefer to contract expertise companies in cabin cleaning. Each team member of the service is assigned to each section of the plane and with a specific duty, such us vacuuming, exchanging pillows, removing trash, cleaning lavatories or galleys, etc. (**Stavenhagen 2002)**

Although cleaning and catering crews very often have the possibility to enter the aircraft through the after (AFT) service door, working while deboarding is still going on in forward (FWD) service door, it is considered by most airlines as unacceptable due to customer service reasons, as the GH activities inside the aircraft might disturb the passengers. Due to the same reasons cleaning and catering processes obviously need to be finished before passenger boarding can start.

At similar time, when the passengers deboarding is finished, the water tanks are loaded or vacuumed, case of potable water or waste water respectively. The valves of both tanks are very close situated at the tail cone of the aircraft. Because of this, the potable water and lavatory vehicle cannot operate at the same time.

The potable water vehicle is the first renewing the tank, following by the lavatory vehicle. For hygienic reasons, the order must be this and not the opposite. (**IATA 2009**)

Lavatory service vehicles empty and refill lavatories onboard aircraft. Waste is stored in tanks on the aircraft until these vehicles can empty them and get rid of the waste. Instead of a self-powered vehicle, some airports have lavatory carts, which are smaller and must be pulled by tractor. Remove and refill potable water is performed within the same procedure.

Aircraft refuel servicing is the transfer of a flammable or combustible liquid fuel between a bulk storage system and the fuel tanks of the aircraft. The transfer is usually accomplished by using a tank truck or a hydrant vehicle, latter hooks into a central pipeline network and provides fuel to the aircraft.

Where large volumes of fuel are being regularly transferred into aircraft the fixed hydrant system should be strongly considered. A fixed hydrant system provides a safer refuelling of the aircraft and the large refuelling trucks could cause interference of the air traffic side. Fixed hydrant systems are typically found at larger international airports.

Under certain conditions and additional safety regulations, refuelling can be performed while passengers are on board of, deboarding or boarding the aircraft. Within the JAA region is regulated by JAR-OPS 1.305: "*Refuelling/defuelling with passengers embarking, on board or disembarking*" (**JAR-OPS 2007**), which can locally be supplemented by national regulations in JAA member countries. These regulations require airlines to apply additional safety measures, which increases the workload of the cabin crew and complicates simultaneous performance of other ground handling processes. Due to these reasons, airlines typically prefer not to refuel during the passenger boarding or deboarding process.

After the cleaning, the new passengers are boarded into the aircraft. At the same time, the ground staff performs the rest of activities: pre-flight inspection, push-back preparation, disconnecting and reallocating equipment and trucks.

Finally the passenger bridge/stairs can be removal. Also the ground power can be disconnected at this time point, if the crew uses the APU. In case a de-/anti-icing process needs to be performed at the gate, it is the last GH activity to take place before the removal of the blocks and the end of the turnaround.

The aircraft is removed from blocks with the pushback operation. The pushback is carried out by special, low-profile vehicles called pushback tugs. Within the JAA region is regulated by JAR-OPS 1.308: "*Push back and Towing*". (**JAR-OPS 2007)**

More details and information about the GH processes are described in Chapter 5.

The following figure is an illustrative example of a typical ramp layout.

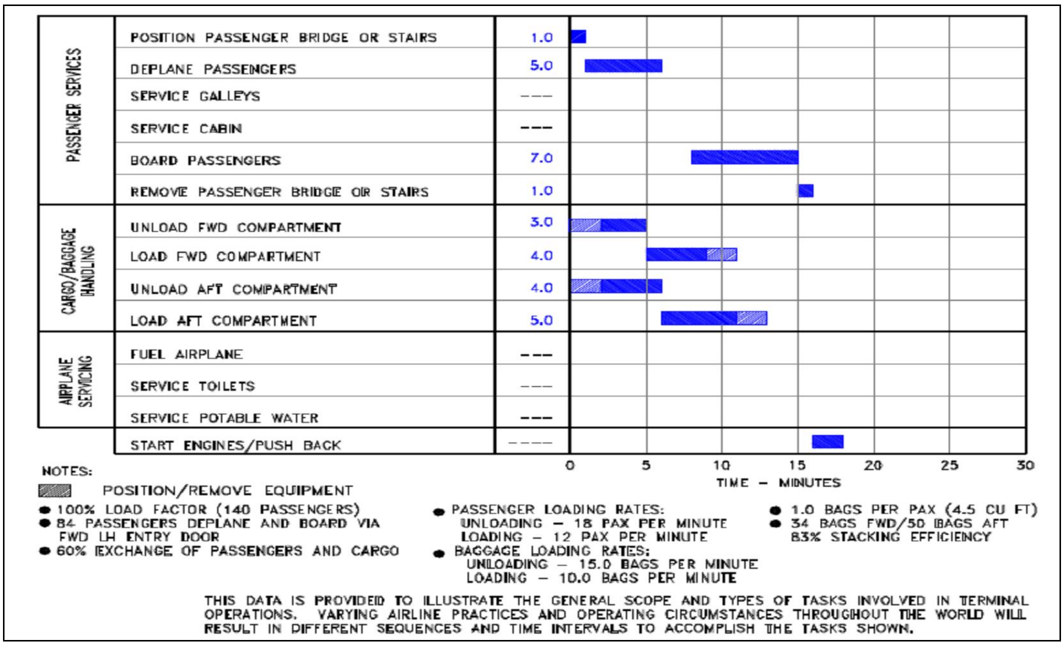

Figure 2.1 Turnaround chart of the B737 – 700 **(Boeing 2005)**

2.4 Ground handling equipment

The GH equipment is used to support the operations of aircraft on the ground. The equipment is totally specific and it is designed for each activity or task, in order to make the processes simpler and cheaper.

Below is described the common GH equipment used for each activity. (Based in **AVS 2009, AEROWAY 2009**)

- <u>Passenger boarding bridge</u>

  The passenger boarding bridges linking airport terminals with passenger airplanes are important facilities that freely adjust to the location shift of the aircraft and assure boarding safety and comfort.

  The bridges are available for all sizes depending on the aircraft type. Their configurations vary, depending on building design, sill heights, refuelling positions, and operational requirements, and they can be fixed or movable, swinging circularly or extending in length with telescopic finger and mechanism servers. The design can be standard steel walls or glass-walled.

  Special bridges can reach the AFT doors of the airplanes, as for example the bridges Over The Wing (OTW) (**Dewbridge 2009**)

Figure 2.2 Passenger boarding bridges (left and centre) and bridge OTW (right) (**Dewbridge 2009**)

- <u>Mobile stairs</u>

There are two mobile kinds: manually positioned stairs, or a stair truck. The configurations vary depending on the aircraft type. The stairs can be fixed or telescopic and covered or not. Some aircraft have integrated stairs.

Figure 2.3 Manually stair (left), stair truck (centre) and integrated stair (right)

- <u>Catering vehicle</u>

It is a new kind of catering vehicle, driven by hydraulic pressure with scissors lifting and a working platform, able to move in four directions. It is a kind of special equipment to load and unload foods for aircraft, stored in galleys.

Figure 2.4 Catering vehicles

- <u>Belt loader</u>

The belt loader is used in the airport for loading the luggage to and from the aircraft. It is a self propelled vehicle which allows, owing to its elevating boom, the access to the load bays of all kind of aircraft for the transfer of baggage.

Figure 2.5 Belt loaders

- <u>Baggage cart</u>

Baggage carts, also called dollies, are vehicles dragged by tractors used to move the luggage and a between the aircraft and the airport terminal. There are many different sizes and kinds, and for safety reasons the operator generally fits it with a brake.

Figure 2.6 Baggage cart

- <u>Container/Pallet dolly</u>

It is a cargo conveyor which is specially designed to transport and transfer palletized and containerized cargo to other load handling vehicles such as aircraft cargo loaders.

They are designed with a horizontal rotating platform to execute the transfer between the vehicle and the ground loader easily. It can be dragged by tractors or self-propelled.

Figure 2.7 Container and pallet dollies

- <u>Container loader</u>

Container loader is a dual platform cargo loader with which it is possible to elevate two containers to the aircraft cargo hold at a time. While storing the containers with one platform the other one is used to provide a continuous container flow by taking up the next container from the ground. The two loading platforms have multi-directional rollers, a swing-out power module, and solid tyres.

Figure 2.8 Container loader

- <u>Tractors</u>

Tractors are designed to tow luggage carts from the airport terminal building to the aircraft and vice-versa and different equipment like ground power units or air stairs.

Figure 2.9 Tractors

- <u>Potable water vehicle</u>

The potable water can be delivered to the aircraft holding tank via a hosepipe from an airport watering point or via a water truck. The potable water vehicle consists of a suitable chassis, the engine locates on the rear, stainless steel tank and drinking water supply system.

Figure 2.10 Potable water vehicle

- <u>Lavatory service vehicle</u>

Lavatory vehicle is designed to remove the waste water from the aircraft lavatory and to provide clean water for flushing and refilling. The lavatory vehicle consists of a suitable chassis, stainless steel tanks, a clean water supply and a waste water system.

Figure 2.11 Waste water vehicle

- <u>Refuelling vehicle</u>

The refuelling tank vehicles are based on trailers or self propelled rigid vehicles with built in dispensing systems. All these trucks have a raised platform to connect the hose to the inlet valve located on the wing, or a small step for the same purpose in case the wing is low.

Figure 2.12 Refuelling vehicles

- <u>Dispenser vehicle</u>

Based on a diesel or electrically powered vehicle, hydrant dispensers connect the airports underground hydrant system to deliver fuel safely into the airplane. Metering, filtering and managing fuel pressure are the 3 major functions of a hydrant dispenser and successfully managing these 3 operations determines the flow rate, and therefore the time it takes to load the plane.

Figure 2.13 Dispenser vehicle

- <u>Groung power unit</u>

Ground power unit (GPU) is a vehicle capable of providing electrical power to parked aircraft on the ground while the engines are stopped. GPU can also be built into the passenger bridge, making it even easier to supply electrical power to the aircraft.

Figure 2.14 Ground power unit

- Air conditioning unit

The Air Conditioning Unit (ACU) is a vehicle capable of supplying air conditioning to aircraft parked on the ground while the engines are stopped. Like GPU it can also be built into the passenger bridge.

Figure 2.15 ACU (left) and ACU built in the passenger bridge (yellow hose in the right picture)

- Pushback tug

Pushback tugs are mostly used to push an aircraft away from the gate when it is ready to leave. Pushback tractors use a low profile design to fit under the aircraft nose. To have enough traction, the tractor needs to be heavy, and most models can have extra ballast added. Often, the driver's cabin can be raised to increase visibility when reversing, and lowered to fit beneath the aircraft.

There are two types of pushback tractors: conventional and towbarless. Conventional use a tow-bar to connect to the nose wheel of the aircraft, while towbarless tugs lift the nose gear off the ground to make it easier to tow or push, this allows more secure control of the aircraft, allowing greater speeds, and lets aircraft be moved without anyone in the cockpit. However, a towbarless tractor may be usable for fewer aircraft types than a conventional tractor.

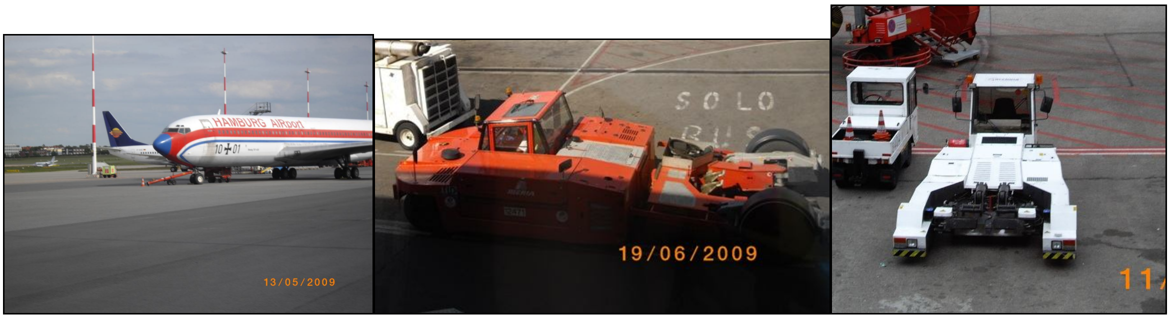

Figure 2.16 Tow bar (left) and pushback tugs (centre and right)

2.5 Critical path of a turnaround

Turnaround is an activity depending on many factors, hence a process that can be considered as critical path in one situation, cannot be in another. For instance those factors can be the next stage length, the number of passengers, the number of containers, etc.

Due to this, it is difficult to find out which process is most critical in a complete turnaround procedure.

A critical path is considered as the process that involves more time or it disturbs or prevents the carrying out of another process. As Figure 2.1 illustrates, three processes can be critical: refuelling, unloading/loading, passengers deboarding/boarding. It is necessary to study in particular every process to understand better the reasons of its complexity.

<u>Unloading/loading process</u>

The unloading/loading procedure can be a critical path because of the following reasons:

- It is a complex procedure which contains the use of 3 different kinds of equipment: belt or container loader, baggage carts or container dollies, and tractors.

- A minimum of three operators is necessary to carry it out, instead of other processes that only need one operator.

- It is independent from all others and it cannot be finished until the very last of the TR. The reason is that some bulks can appear in the last moment to be loaded, for instance child carts, which must be loaded in the cargo hold.

Refuelling

The refuelling procedure can be a critical path because of the following reasons:

- It is carried out by only one operator and it takes normally a long period of time.

- Due to the possibility of fire, as the fuelling liquid is inflammable, there are special regulations that need to be followed (**JAR-OPS 1**) Owing to that, the refuelling only can start after all passengers deboarded the aircraft as well as boarding cannot start until refuelling is finished.

Deboarding/boarding passengers

The deboarding/boarding procedure can be a critical path because of the following reasons:

- The passengers need a lot of time to board the aircraft as they want to feel comfortable during the flight, which means: time to put their hand baggage in the correct places, as well as to allocate accessible the personal belongings which they might need during the flight. For deboarding the aircraft the passengers do not need as much time as they want to leave the aircraft as soon as possible.

- Passengers on board of the aircraft influence other processes which cannot be carried out before the deboarding procedure is accomplished. So deboarding/boarding has a critical impact on the whole turnaround span of time.

- The presence of the human factor is an important criterion because of its difficult evaluation and hard anticipation.

3 Aircraft ground handling features for LCA

Aircraft families under consideration in this project are: Airbus A320, Airbus A319, and Boeing 737. The families of these aircraft are the most popular commercial jets transport, short to medium range airplane, 120 to 180 passengers, and the preferred for Low Cost Airlines (LCA). The fleets of the most important LCA are shown in Table 3.1 (based in data from **Airfleets 2009, Germanwings 2009, Ryanair 2009 and Planespotters 2009)**

Table 3.1 LCA fleets in Europe

Company	**Fleet active**								
	A319	A320	A321	A330	B737	B757	B767	Other	Total
Germanwings	26	0	0	0	0	0	0	0	26
easyJet	125	9	4	0	20	0	0	0	158
Ryanair	0	0	0	0	183	0	0	0	183
Air Berlin	18	32	6	13	51	2	1	2	120
Clickair	0	23	0	0	0	0	0	0	23
Jet2	0	0	0	0	21	9	0	0	30
Vueling	0	18	0	0	7	0	0	0	18

This section discusses and describes the Ground Handling Features of aircraft mentioned based on the Aircraft Manual of manufactured companies Airbus and Boeing, since varying handling companies' practices and operating circumstances may result in different sequences and time intervals to do the activities shown.

In Appendix D, charts and tables collect the data of the manuals.

3.1 General characteristics of aircraft

The Airbus A320 family and the Boeing B737 family compete in the same sector of the aviation market, this means similar range, pay load and general characteristics. Air companies study in detail all aircraft and select one based in its own politics and requirements. For instance, easyJet Company writes in its main web page (**easyJet 2009**):

> *"There are a number of noticeable differences between the Boeing 737 and the Airbus A319. The Airbus is bigger and heavier (by some 4 tonnes), and is also around 14" wider. These additional inches create a wider aisle to allow crew and passengers to move around the cabin more easily, also helping to keep turnaround times to a minimum. In addition, the A319 has 156 seats, compared to 149 on the 737s, which means that each flight will require four members of cabin crew"*

Obviously easyJet fleet is mainly composed of Airbus A319.

All aircraft have similar general dimensions, payload and range.

Dimensions: the length varies only by 6 m between the shortest and the longest, the height varies with less than 1 m, the fuselage diameter differs only within 40 cm, and the wingspan is 34 m in all cases. (**Jane's 2008**)

Basic operation data: each aircraft has two engines and an operating mach number of approximately 0.8. The range is around 5.000 km with some variations depending on the extra fuel deposits.

Payload: the single class layout for these aircraft ranges from 134 passengers in the smallest and 175 in the biggest aircraft.

For the exact values and more general data see Appendix D.

3.2 Comparison of aircraft ground handling features

This Chapter compares the time for each GH process that each aircraft takes. In Appendix D all the general characteristics regarding GH are summarized in tables.

See Appendix D for the exact data of each aircraft, as well as the general characteristics influencing GH processes.

Although all the airplanes studied in this Chapter are very similar, the differences cause different GH procedures which can be reflected in the times to carry them out. See Table 3.2

Table 3.2 Time of the GH processes of the most popular commercial jets transport (**Boeing 2005, Airbus 1995a, Airbus 1995b)**

Total time of the GH process min	**Airplane** A319	A320	B737-700	B737-800
Deboarding	9,1	9,4	8	10
Boarding	11,4	15	12	15
Cleaning	13,4	16,8	14	15
Refuelling	15,6	13 (60%)	13	13
Unloading and Loading	29,5	39	26	29
Potable Water Service	6,5	6,5	6	6
Waste Water Service	6,5	6,5	14	14
Turnaround time	30	40	32	38

Deboarding and boarding

The time to carry out the passengers deboarding/boarding is very similar in all the airplanes, approximately 9 minutes for deboarding and 13 for boarding.

The difference in processing time is due to different passenger capacities of aircraft as well as to different considerations of the deboarding/boarding passenger rate by the manufacturers.

Cleaning

Cleaning time is approximately 15 minutes for each aircraft. Hence, the manufactures consider very similar procedures for cleaning. The small time variations are due to the different amount of toilets and numbers of seats.

Refuelling

The fuel volume capacity of the Airbus airplanes is 23.800 l, and for Boeing Airplanes 26.000 l, but the time for refuelling the Boeing is less than for Airbus, that can be considered an incongruity.

The reason can be the maximum fuel rate capacity of the connections on the wing and the time to connect the pipe to the valve considered by the manufactures.

Unloading and loading

The unloading and loading times for each aircraft differs.

This difference is due to various cargo hold capacities and unequal considerations of the unloading/loading cargo rate by the manufacturers.

Potable and waste water service

In all cases the time need is almost the same, which is logical as the tank capacity is 200 l in all airplanes and the valves are very similar. In case of waste service in Boeing aircraft the required time of processing is twice the time than for potable water, it is probably because the manufacturer consider more time to vacuum than for pump.

Turnaround time

Although each aircraft has differences in the times of the individual GH processes, finally the TR times are very similar considering on one side the biggest capacity of the A320 and B737-800 (about 40 minutes), and on the other hand the A319 and B737-700 (about 30 minutes).

4 Turnaround video analysis

A proper study of GH procedures requires an analysis and research of the actual turnaround that takes place in airports, since varying handling companies' practices and operating circumstances may result in different sequences and turnaround times.

Airport Research Company GmbH (ARC), a partner of HAW University within the ALOHA project, installed cameras in many aprons of different airports in Germany to analyze in real-time the GH processes.

Most of aircraft that are studied belonged to LCA. Therefore, the most all the turnaround analyzed are perfect for the purpose of this project, few operators working fast with the least amount possible of equipment, and turnaround shorts.

4.1 Videos at Berlin-Schönefeld Airport

Berlin-Schönefeld Airport, SXF in international net code, is one of the airports studied and selected for the goal of this project.

On the 24th of October in 2008 the cameras took videos of all aircraft that stopped in the following aprons: position 50, 51, 61, 62, 63 and 55B.

This means tens of GH procedures for taking data in order to create statistical models.

Aircraft are: Airbus A319, some aircraft from the Boeing Family B737, and one Airbus A320. Most of them belong to LC Airlines: Germanwings, easyJet, Ryanair, Aer Lingus and Norwegian Air Shuttle.

In total 51 aircraft were engraved. Due to some poorly recorded videos, and ones that do not allow to use reliable data of times, the total number of analysed aircraft is 38.

The TR is an average of 40 minutes and the minimum of 23 minutes. Table A.3

These videos are studied to take times of all GH processes.

4.2 Examples of the information taken from videos

There is much information to take in the videos, for instance:

- Staff: operators, number of them working in each process, different ways to carry out the same process, human error and so on.

- Equipment: number of machines, instruments and/or trucks involved in each process, positions before, during and after the processes, number of operators necessaries to move and control them, specials requirements and so on.

- Aircraft: service points, differences between the models, pre-flight inspections and so on.

Processes: procedure and time to carry out each process, best ways to execute processes, ways to improve it changing aircraft configurations, common mistakes

All this information is taking in account in the project, and is described and analyzed in depth in the following Chapters.

Following, some examples are described with the assistance of screenshots taken from the videos.

Staff

One example can be the number of operators and their positions to carry out the exchange of the cargo. In case of bulk exchange, three operators are necessary, but their positions change between unloading to loading.

For unloading, one operator is working inside the cargo hold and two are working on the ground, moving the baggage between the belt loader to baggage dollies. Figure 4.1 is an example at the apron number 50 of SXF.

Figure 4.1 Unloading staff

On the other hand, for loading, two operators are working inside the cargo hold and one is working on the ground, moving the baggage between the belt loader to baggage dollies. Figure 4.2 is an example at the apron number 50 of SXF.

Figure 4.2 Loading staff

Equipment

One example can be the starting positions of the equipments at the arriving moment of the aircraft. Figure 4.3 is an example at the apron number 51 of SXF.

Figure 4.3 Vehicles: start positions

<u>Aircraft</u>

One example can be the different procedures between aircrafts. For the Boeing 737-500 the bulk is unloaded/loaded at the FWD cargo hold without the use of a belt loader, the bulk is directly moved from the FWD cargo hold to the baggage dolly. Figure 4.4 is an example at the apron number 51 of SXF.

Figure 4.4 Loading process without belt loader

5 Statistical models

This section summarizes the data that was obtained with SXF Airport videos. Statistical models and equations have been created which represent mathematically each GH procedure.

5.1 Passengers: deboarding/boarding

The deboarding/boarding operation depends on the number of doors used and on the involved GHE. The classification is as follows:

- One door with airstairs or mobile stairs (manually or by truck)
- Two doors with airstairs or mobile stairs (manually or by truck)
- One door with an airbridge
- Two doors with an airbridge
- Airbridge plus stairs

Most aircraft use two doors with airstairs or mobile stairs. Generally, the airstair is used at the FWD door and the mobile stair is used at the AFT door.

The deboarding/boarding procedure consists in the following movements and actions: when the aircraft is securely parked on blocks, the operators start to move the stairs to their positions. Once they are correctly positioned, the left doors are opened and the passengers deboarding starts. Both stairs are independent of each other.

The total process time is the sum of the times for positioning stairs, removing stairs, deboarding and boarding. For each procedure one equation is created, which simulates the real process.

In some videos, the process is carried out by one airbridge. Unfortunately, these airbridges were opaque, which made it impossible to make accurate time delays for passengers deboarding or boarding.

<u>Time for positioning (removing) stairs</u>

This time depends only on the vehicle speed, distance and time opening (closing) the door. Assuming a constant speed, the distance between the aircraft door and the initial position of the ladder is approximately equal in all cases. In addition, the time opening (closing) the door is similar as well. Therefore, the time is constant.

This constant time is calculated with the average of all times obtained in videos (Table A.4). The same applies to the time for removing stairs.

$$t_{AS,pos} = 52\,\text{sec} \tag{5.1}$$

$$t_{AS,rem} = 31\,\text{sec} \tag{5.2}$$

Where:

- $t_{AS,pos}$ Time for positioning airstairs
- $t_{AS,rem}$ Time for removing airstairs

In the case of the airbridge a similar conclusion can be drawn:

$$t_{AB,pos} = 54\,\text{sec} \tag{5.3}$$

$$t_{AB,rem} = 40\,\text{sec} \tag{5.4}$$

Where:

- $t_{AB,pos}$ Time for positioning airbridge
- $t_{AB,rem}$ Time for removing airbridge

Deboarding time

This time is related to the number of passengers and the amount of hand baggage carried by them. In many LCA, carrying normal baggage means a surcharge in the ticket price, while the hand luggage is free within certain limits of size and weight. Hence nowadays, most of the passengers carry only hand baggage, which increase the passenger time. The reason of this increase is that the passenger is stopped in the aisle, disturbing the free flow of the passengers, during the moment that the passenger needs for take the hand baggage from the overhead compartments. (**Bouchareb 2007**)

Therefore, the time depends linearly on the number of passengers and it is augmented by another term which represents the number of passengers carrying hand baggage.

$$t_{pax,deb} = k_{pax,deb} \cdot n_{paxs,out} + k_{pax,ds} \cdot n_{pax,hb} \tag{5.5}$$

Where:

- $t_{pax,deb}$ Deboarding time
- $k_{pax,out}$ Time for deboarding per one passenger. Constant
- $n_{pax,out}$ Number of passengers getting out the aircraft
- $k_{pax,ds}$ Time one passenger deboarding is stopped in the aisle. Constant

- $n_{pax,hb}$ Number of passengers with hand baggage

Unfortunately, the constants in the equation above are not possible to be calculated, due to the limited amount of available data that is the total time of deboarding and the number of passengers. This leads to a simple equation instead of the previous:

$$t_{pax,deb} = \frac{n_{pax,out}}{k_{pax,outR}} \tag{5.6}$$

Where:

- $t_{pax,deb}$ Deboarding time [min]
- $k_{pax,outR}$ Passengers getting out rate constant [pax/min]
- $n_{pax,out}$ Number of passengers getting out aircraft

From Table A.5, $k_{pax,outR}$ results an average of **34 pax/min**.

Also, $k_{pax,outR}$ could be calculated by a trend line. This line is drawn in Figure B.1

$$k_{pax,outR} = 0.0986 \cdot n_{pax,out} + 19.747 \tag{5.7}$$

Therefore, the deboarding time equation is:

$$t_{pax,deb} = \frac{n_{pax,out}}{0.0986 \cdot n_{pax,out} + 19.747} \tag{5.8}$$

Boarding time

There is more time needed for boarding than for the deboarding, mainly because while deboarding the passengers are in a hurry to finish their trip; instead of the passengers entering the aircraft who only want to feel comfortably in their seats. (**Bouchareb 2007**) However, the analysis and equations applied above to deboarding time can easily be used for boarding time by merely changing the characteristic constants:

$$t_{pax,boa} = k_{pax,in} \cdot n_{paxs,in} + k_{pax,bs} \cdot n_{pax,hb} \tag{5.9}$$

Where:

- $t_{pax,boa}$ Boarding time
- $k_{pax,in}$ Time for boarding per one passenger. Constant

- $n_{pax,in}$ Number of passengers getting in aircraft
- $k_{pax,bs}$ Time one passenger boarding is stopped in the aisle. Constant
- $n_{pax,hb}$ Number of passengers with hand baggage

In case of deboarding time, there is limited amount of available data. The only data known is the total time of boarding and the number of passengers. So finally this simple equation is used instead of the previous:

$$t_{pax,boa} = \frac{n_{pax,in}}{k_{pax,inR}} \tag{5.10}$$

Where:

- $t_{pax,boa}$ Boarding time [min]
- $k_{pax,inR}$ Passengers getting in rate constant [pax/min]
- $n_{pax,in}$ Number of passengers getting in aircraft

Frome Table A.6, $k_{pax,inR}$ results an average of **20 pax/min**. This is a lot less than in the case of deboarding as predicted above.

Also, $k_{pax,inR}$ could be calculated by a trend line. This line is drawn in Figure B.2

$$k_{pax,inR} = 0.0839 \cdot n_{pax,in} + 9.324 \tag{5.11}$$

Therefore, the deboarding time equation is:

$$t_{pax,boa} = \frac{n_{pax,in}}{0.0839 \cdot n_{pax,in} + 9.324} \tag{5.12}$$

5.2 Cargo: unloading/loading

The unloading/loading operation depends on the cargo type, the involved GHE and the cargo compartment used. The classification is as follows:

- Baggage and bulk load with a belt loader
- Baggage and bulk load manually
- Containers load with a container loader

- Unload/load only at the AFT cargo compartment
- Unload/load only at the FWD cargo compartment
- Unload/load both cargo compartments

Studied aircraft have low wing position, which separates the cargo hold in two: cargo hold after the wing (AFT) and forward the wing (FWD). Normally, the greatest burden is placed in one of the two cargo compartments, owing to the aircraft gravity centre must be positioned within a narrow margin because of static and dynamic stability reasons.

As the wing is not positioned in the exact half of the fuselage length, there is one compartment bigger from the other, which coincides with the compartment mentioned above.

The other compartment is used solely if there is not enough space in the first for place the entire load.

In case of the Airbus A320 family the main compartment utilized is the AFT cargo hold; in case of the Boeing 737 family it is the FWD cargo hold. See Figures D.2, D.9, D.15 and D.20

Usually, only one belt loader or container loader, where appropriate, is used in unloading/loading process. Therefore, if the both cargo compartments require being unloaded (loaded), the normal procedure is positioning the belt loader -or container loader- in the biggest cargo hold to unload (load) it, then the belt loader is moved to the other cargo hold and the process is repeated. It is not possible unload (load) both compartments at the same time with only one belt loader.

The unloading/loading procedure consists of the following movements and actions: when the aircraft is securely parked and on blocks, one operator opens the AFT and FWD cargo hold doors to check which cargo hold is required to unload. Afterwards, the belt loader is positioned at one of the cargo hold doors to assist in the unloading process; normally it is positioned first in the cargo compartment with more amount of baggage. Then, one tractor with baggage dollies is moved close to the belt loader and the unloading/loading process begins.

The general characteristics of the process for each aircraft studied are shown in Table A.7.

The total process time is the sum of the times for positioning belt/container loader, removing belt/container loader, unloading and loading. There is one equation created for each time which simulates the real process.

Time positioning (removing) belt/container loader

This time depends only on vehicle speed, distance and time opening (closing) the cargo hold door. Assuming a constant speed, the distance between the cargo compartment door and the initial position of the loader vehicle is approximately equal in all cases. In addition, the time opening (closing) the cargo hold door is similar as well. Therefore, the time is a constant.

This constant time is calculated with the average of all times obtained in videos (Table A.8). The same applies to the time for removing the loader vehicle.

$$t_{BL,pos} = 41\,\text{sec} \tag{5.13}$$

$$t_{BL,rem} = 33\,\text{sec} \tag{5.14}$$

$$t_{CL,pos} = 57\,\text{sec} \tag{5.15}$$

$$t_{CL,rem} = 37\,\text{sec} \tag{5.16}$$

Where:

- $t_{BL,pos}$ Time for positioning belt loader
- $t_{BL,rem}$ Time for removing belt loader
- $t_{CL,pos}$ Time for positioning container loader
- $t_{CL,rem}$ Time for removing container loader

Unloading bulk time

This time depends linearly on the quantity of cargo discharged:

$$t_{ULD} = \frac{m_{cargo}}{k_{ULD}} \tag{5.17}$$

Where:

- t_{ULD} Unloading time [min]
- k_{ULD} Rate unload [kg/min]
- m_{cargo} Cargo mass [kg]

Unfortunately, the amount of data was limited, as the weight and balance sheets of each considered aircraft were not available. Therefore, the cargo mass was unknown, and it is necessary to calculate the rate unload k_{ULD}.

The process to calculate the k_{ULD} parameter is as follows:

- First, the number of baggage unloaded was counted in each video when possible.

  In many videos it was not possible to count the baggage, so an equation had been set up that relates to the number of passengers and the number of luggage loaded in the lower deck compartments. Thus, it was possible to obtain the number of baggage unloaded or loaded in each aircraft. Table A.9.

  The equation is calculated by a trend line. This line is drawn in Figure B.3

$$n_{bag} = 0.4296 \cdot n_{pax} + 19.05 \tag{5.18}$$

Where:

- n_{bag} Number of baggage loaded in lower deck compartments
- n_{pax} Number of passengers [pax]

  With this equation 5.18 the number of baggage (n_{bag}) is calculated, as the number of passengers is known in each arrival flight analyzed.

- Afterwards, with n_{bag} obtained above and the average mass of baggage (m_{bag}), the m_{cargo} is calculated by the following formula:

$$m_{cargo} = n_{bag} \cdot m_{bag} \tag{5.19}$$

Where:

- m_{cargo} Cargo mass [kg]
- n_{bag} Number of baggage charge in lower deck compartments
- m_{bag} Average mass of baggage

Applying the following Table 5.1, m_{bag} is **13.6 kg**.

Table 5.1 Assumptions on mass of passengers and their baggage (**Roskam I 1997**)

Average mass of	Short and Medium Range kg	Long Range kg
Passenger	79.4	79.4
Baggage	13.6	18.1
Sum	93.0	97.5

- Finally, the equation 5.17, with m_{cargo} calculated and the time for unloading (t_{ULD}) known for each aircraft, leads to the k_{ULD} parameter.

The results of these operations are summarized in Table A.10.

The parameter k_{ULD} results an average of **218.84 kg/min**.

In Figure B.4 is checked the constant nature of k_{ULD} parameter.

Loading bulk time

Similarly to the case of unloading time, this time depends linearly on the quantity of cargo charged.

$$t_{LD} = \frac{m_{cargo}}{k_{LD}} \tag{5.20}$$

Where:

- t_{LD} Loading time [min]
- k_{LD} Rate load [kg/min]
- m_{cargo} Cargo mass [kg]

The process to calculate the k_{LD} parameter is the same as the process used above for k_{ULD}. The same equations are used changing the data of the arrival flights by the departure flights.

The results of these operations are summarized in Table A.11.

k_{LD} results an average of **132.4 kg/min**.

In Figure B.5 is checked the constant nature of k_{LD} parameter.

Unloading/loading containers

The unloading/loading process with containers includes movements and actions very similar to the case of baggage and bulk, but there are the following differences: once the container loader is situated in front of one of the cargo hold doors, one tractor with pallet dollies or a container tractor is situated close to the container loader. Then one operator elevates the platform of the container loader to the cargo compartment door, and a maximum of two containers are moved from the aircraft to the platform. Afterwards the platform is moved down and the containers are moved to the container tractor or the pallet dollies. Once all the containers are unloaded from that cargo hold, the same process is repeated in the other cargo hold.

The process with containers is faster than in the case of bulk and baggage, due to the fact that in the case of bulk, the operators have to move the baggage manually whit their hands one per one, instead of the containers (a maximum number of sever or eight depending on the aircraft) which are moved by special equipment, which consist in different rotating platforms with wheels and rollers, without any physical force. Another advantage is that the baggage is stored inside the containers in the airport terminal.

The time for unloading and for loading containers is similar, and it only depends on the number of containers, the influence of the operators is minimized; differing from the bulk process, where the staff works manually and the time varies greatly with the amount of baggage.

Unfortunately, the only data available belongs to three aircraft, thus it is not enough information to calculate exactly the rate of time for unloading/loading containers. Therefore, the following equation 5.21 must be revised with more data in the future to obtain more reliable results.

Unloading/loading containers time:

$$t_{LDc} = \frac{n_{container}}{k_{LDc}} \tag{5.21}$$

Where:

- t_{LDc} Unloading/Loading containers time [min]
- k_{LDc} Rate containers unload/load [containers/min]
- $n_{container}$ Number of containers

From Table A.12, k_{LDc} results an average of **0.45 containers/min**.

5.3 Refuelling

The refuelling operation depends on the involved GHE. The classification is as follows:

- Refuelling with a refuelling vehicle.
- Refuelling with a hydrant vehicle.

All aircraft have two connections to refuel the wing tanks available. The connections are situated on the bottom surface of the wing, one on the left and one on the right side. Usually, only one connection is used for refuelling the aircraft, corresponding with the opposite side that is used for the deboarding/boarding process.

See Figures D.4, D.11, D.17 and D.22 to locate the fuel connections of the Airbus A320, A319 and the Boeing B737-700, B737-800.

The refuelling procedure consists of the following movements and actions: when the aircraft is securely parked and on blocks, and all passengers deboarded the aircraft, the refuelling vehicle or dispenser vehicle is positioned below the wing or close to the wing if the height between the wing and the floor is not enough. Afterwards, a hosepipe is connected between the tank vehicle or the pipeline network and the wing valve. Usually, only one operator carries out the process.

The total process time is the sum of the times for positioning tank vehicle or hydrant car, removing tank vehicle, connecting hosepipe, disconnecting hosepipe and refuelling. There is an equation created for each time simulating the real process.

Unfortunately, in all GHP that have been analyzed the refuelling process was carried out by a refuelling truck. Therefore, all the equations are related only to this kind of GHE. It would be necessary to complete a study in largest airports with hydrant system to have results for refuelling process with hydrant cars.

Time positioning and removing fuel tank vehicle

This time depends only on the vehicle speed and on the distance to the aircraft. Both are different for each GH procedure. This positioning (removing) time is estimated out of data in Table A.13.

$$t_{f,pos} = 30\,\text{sec} \tag{5.22}$$

$$t_{f,rem} = 31\,\text{sec} \tag{5.23}$$

Where:

- $t_{f,pos}$ Time for positioning fuel tank vehicle
- $t_{f,rem}$ Time for removing fuel tank vehicle

Time connecting and disconnecting tank vehicle

This time depends on the GH equipment, on the aircraft, and on the experience and quick movements of the operator connecting the hosepipe with the valve. The period of time is greater in case of higher wings in some aircraft models, but it only varies in a few seconds so its consideration in the equations it is not necessary. This positioning (removing) time is estimated out of data in Table A.13.

$$t_{f,con} = 85\,\text{sec} \tag{5.24}$$

$$t_{f,dis} = 83\,\text{sec} \tag{5.25}$$

Where:

- $t_{f,con}$ Time for connecting hosepipe
- $t_{f,dis}$ Time for removing hosepipe

<u>Refuelling time</u> (based on **Hortsmeier 2001**)

The refuelling process is very different and decreases exponentially in time. The main reasons for that are:

- During refuelling, the static pressure is built due to the increasing fuel level.

- Within the wings and the centre section, the tanks are connected with valves, and are closed when a certain tank is completely filled, thus increasing drag.

This differs with different aircraft. In this project the data of the Airbus A320 is considered.

The following equations can only be applied to this aircraft. However, the equations can be used for all aircraft by recalculating the parameters.

The refuelling time results in the following equation, which describes the refuelling speed:

$$RF_{speed} = RF_{speed,0} \cdot \exp(t \cdot \alpha) \tag{5.26}$$

Where:

- RF_{speed} Refuelling speed [l/min]
- $RF_{speed,0}$ Initial refuelling speed [l/min]
- α Alpha factor [min^{-1}]
- t Time [min]

Whit the data of A320 family the fuel flow rate is 1475 l/min per connection (**Airbus 1995b**).

Normally only one valve is used, thus the initial refuelling speed, $RF_{speed,0}$ = **1475 l/min** is selected as parameter.

By integrating in time the equation 5.26 over the time, the volume of fuel loaded into the tanks can be calculated:

$$V_f = \int_{t_0=0}^{t^*} RF_{speed} \cdot dt = 1475 \cdot \frac{\exp(t^* \cdot \alpha) - 1}{\alpha} \tag{5.27}$$

The total volume of the A320 wing tank is 23860 l. The aircraft manual predicts 6 min to refuel 20% of the total tank volume, and 13 min to refuel the 60% of total tank volume.

With these data the alpha factor can be calculated iterating in the equation 5.27, resulting
α **= -0.036 min^{-1}**

Therefore, the time for refuelling is given by the following equation:

$$t_f = \frac{1}{\alpha} \cdot Ln\left(1 + \frac{V_f \cdot \alpha}{RF_{speed,0}}\right) = \frac{1}{-0.036} \cdot Ln\left(1 + \frac{V_f \cdot (-0.036)}{1475}\right) \tag{5.28}$$

Where:

- t_f Refuelling time [min]
- $RF_{speed,0}$ Initial refuelling speed [l/min]
- V_f Volume of fuel loaded [l]

Implementing the equations with MATLAB software program, the fuel volume and the refuelling speed over the refuelling time are plotted in Figure 5.1.

It can be seen, the refuelling speed drops to approximately 700 l/min in 22 minutes, and the aircraft is totally loaded at the same time.

However, to calculate the time for refuelling the aircraft for each GH the volume of fuel loaded V_f is necessary.

This quantity depends on the flight range, payload and on the amount of fuel remaining from the last flight. The pilots transmitted the information of these quantities to the airport. Unfortunately, this information is not known, as the weight and balance sheets of each considered aircraft are not available.

The limited amount of data available is the next stage length for the flight and the time refuelling the aircraft. See Table A.14.

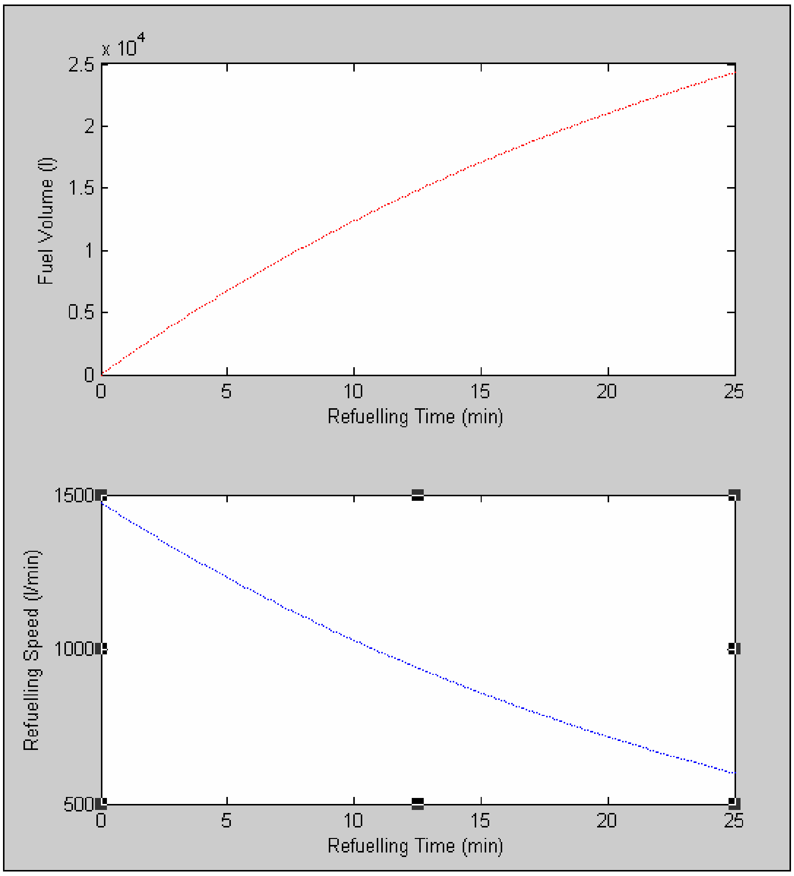

Figure 5.1 Refuelling time

With this time refuelling the aircraft can be calculated the fuel volume. However, it is not known the fuel remaining from the last flight, which is very important, as the time refuelling the aircraft varies on the quantity of fuel that the aircraft needs for the next stage length. There were flights with the same aircraft in similar ranges, but with very different refuelling times, these differences can be caused by the different payload that is carried, and by the fuel remaining on the last flight as well. Figure B.6 shows the difference of the flights in the refuelling times.

However, the amount of fuel can be calculated as follows:

- The fuel consumption is calculated using the following equations:

$$\frac{m_f}{m_{TO}} = 1 - M_{ff} \tag{5.29}$$

$$M_{ff} = \sum_i \frac{m_{i+1}}{m_i} \tag{5.30}$$

Where:

- M_{ff} Mission fuel fraction
- M_f Fuel mass

- m_{TO} Takeoff mass
- m_i Mass at the beginning of a flight phase
- m_{i+1} Mass at the beginning of the next flight phase
- i Flight phase (take off, landing, climb, cruise, loiter, …)

- The mass ratios for cruise and loiter are determined according to Breguet:

$$B_s = \frac{\frac{L}{D} \cdot v_{CR}}{SFC_T \cdot g} \tag{5.31}$$

Where:

- B_s Breguet factor
- L/D Aerodynamic efficiency
- v_{CR} Cruise velocity
- SFC_T Specific Fuel Consumption for jets
- g Gravity constant

- Then the mission segment mass fraction for the cruise phase is:

$$\frac{m_{LOI}}{m_{CR}} = e^{-\frac{d_{CR}}{B_S}} \tag{5.32}$$

Where:

- m_{LOI} Mass at the beginning of loiter phase
- m_{CR} Mass at the beginning of cruise phase
- d_{CR} Distance covered in the cruise phase

- For the remaining flight phases, it is scarcely possible to calculate the mass ratio without more details and parameters.

Hence, without more data, for instance the cruise velocity or the takeoff mass, the Breguet factor and the mission fuel fraction M_{ff} can not be calculated, therefore, the fuel load in aircraft is not known and because of that it is not possible to have a good estimation of the refuelling time.

5.4 Catering

The catering operation depends on the number of galleys, their positions in the aircraft, and on the involved GHE. The classifications are as follows:

- Reload one galley in the rear of the aircraft.
- Reload one galley in the front of the aircraft.
- Reload two galleys of the aircraft at the same time with two catering vehicles.
- Reload two galleys with only one catering vehicle.

The catering process starts when all the passengers deboarded the aircraft. The reason is that if the door for catering is open, it can create airflows and bad air condition inside the cabin when the passengers are still inside, disturbing their comfort. In addition to that, noises and bad smells are possible in the cabin because of the trolleys remove.

The catering procedure consists of the following movements and actions: first the catering vehicle is correctly positioned in front of the aircraft door, elevating the platform and placing a little footbridge between the platform and the door. Usually, only one operator carries out the process, waiting on the platform to open the aircraft door until the passengers deboarding is finished. Afterwards, the person starts to remove the trolleys, changing the trolleys used in the galley by the past flight for new trolleys, walking through the little footbridge between the aircraft and the catering vehicle platform.

The total process time is the sum of the times for positioning catering vehicle, removing catering vehicle and changing trolleys. There is one equation created for each time which simulates the real process.

See Figures D.1, D.8, D.14 and D.19 to locate the galleys of the Airbus A320, A319 and the Boeing B737-700 and B737-800.

Unfortunately, the only data available belongs to few aircraft, thus it is not enough information to calculate exactly the rate of time for catering process. Therefore, the following equations 5.33, 5.34 and 5.35 must be revised with more data in the future to obtain more reliable results.

<u>Time positioning (removing) catering vehicle</u>

This time depends only on the vehicle speed and on the distance to the aircraft. Both are different for each GH procedure. This positioning (removing) time is estimated out of data in Table A.13.

This time depends only on the vehicle speed, on the distance to the aircraft and on the time positioning the platform. Discounting the time the operator is waiting until the deboarding process is finished; the time is constant, the sum of the vehicle movement and the platform positioning.

This constant time is calculated with the average of all times obtained in videos (Table A.15). The same applies to the time for removing stairs.

$$t_{CV,pos} = 88\,\text{sec} \tag{5.33}$$

$$t_{CV,rem} = 101\,\text{sec} \tag{5.34}$$

Where:

- $t_{CV,pos}$ Time for positioning catering vehicle
- $t_{CV,rem}$ Time for removing catering vehicle

<u>Catering time</u>

This time depends on many factors:

- Number of galleys, their position in the aircraft and their accessibility
- Quantity of trolleys to be changed
- The size of the trolleys: half or full size
- Trolleys with two wheels, four or without wheels
- Number of operators involved in the process

Therefore, the catering time is hardly defined by one equation.

A simple estimation of time needed by the operator to remove one trolley and to install the new one in the galley is the only possibility. Considering all the factors mentioned above, this equation can not represent the reality.

$$t_{CAT} = \frac{n_{trolleys}}{k_{CAT}} \tag{5.35}$$

Where:

- t_{CAT} Catering time [min]
- k_{CAT} Rate catering [trolleys/min]
- $n_{trolleys}$ Number of trolleys

From Table A.16, k_{CAT} results an average of **0.86 trolleys/min**.

5.5 Ground power

The ground power process has the same duration of almost all TR time. The GPU is connected all the time that the aircraft remains in the apron, after the aircraft is securely parked and on blocks. Thus, it makes no sense to calculate the time that the GPU is connected.

The ground power procedure consists of the following movements and actions: once the aircraft is securely parked and on blocks, one operator moves the GPU close to the aircraft nose with the assistance of a tractor. Then the GPU is connected with a cable to the switch in the aircraft.

Sometimes, instead of a GPU, the airbridge has a cable to supply electricity to the aircraft performing the same function, saving the use of the GPU equipment and one tractor.

The total process time is the sum of the times for positioning catering vehicle, removing catering vehicle and changing trolleys. There is one equation created for each time which simulates the real process.

See Figures D.4, D.11, D.17 and D.22 to localize the switch of the Airbus 320, A319 and the Boeing 737-700, B737-800.

The only time that is relevant of the ground power process is the time that the staff spends connecting or disconnecting the GPU. Both times are equal.

These times are depending on the kind of aircraft and on the GPU equipment. Connecting and disconnecting GPU times are calculated with the average of all times obtained in videos (Table A.17).

$$t_{GPUcon} = 49.1\sec \approx 49\sec \tag{5.36}$$

$$t_{GPUdis} = 49.9\sec \approx 50\sec \tag{5.37}$$

Where:

- t_{GPUcon} Time for connecting GPU
- t_{GPUdis} Time for disconnecting GPU

5.6 Potable water service

The potable water service consists of the following movements and actions: when all passengers deboarded the aircraft, the potable water vehicle is positioned on the bottom of the aircraft, close to the tail cone. Then, a hose is connected between the vehicle and the aircraft valve for the holding water tanker and the water pumping begins. Usually, only one operator carries out the process.

The total process time is the sum of the times for positioning potable water vehicle, removing vehicle and pumping. There is one equation created for each time which simulates the real process.

See Figures D.4, D.11, D.17 and D.22 to localize the potable water valve of the Airbus 320, A319 and the Boeing 737-700, B737-800.

<u>Time positioning (removing) potable water vehicle</u>

This time depends only on the vehicle speed, on the distance to the aircraft and on the time positioning the hosepipe. Assuming a constant speed, the distance covered for the water vehicle is approximately equal in all cases. In addition, the time connecting the hose is as well equal. Therefore, the time is a constant.

This constant time is calculated with the average of all times obtained in videos (Table A.18). The same applies to time for removing the water vehicle.

$$t_{PW,pos} = 47\,\text{sec} \qquad (5.38)$$

$$t_{PW,rem} = 30\,\text{sec} \qquad (5.39)$$

Where:

- $t_{PW,pos}$ Time for positioning potable water vehicle
- $t_{PW,rem}$ Time for removing potable water vehicle

<u>Pumping time</u>

This process time depends only on the flow of pumping water. The holding tank of potable water has a capacity of 200 l in all aircraft studied, so it is not necessary to take the pressure gradient into account, which can change the flow rate as in the case of refuelling process. Hence, this flow can be considered as a constant.

$$t_{PW} = \frac{V_{PW}}{FR_{PW}} \tag{5.40}$$

Where:

- t_{PW} Potable water service time [min]
- V_{PW} Volume of the potable water tank [l]
- FR_{PW} Flow rate of the potable water service [l/min]

The main characteristics of that service for the Airbus A320 are (**Airbus 1995b**):

- Tank capacity: 200 l
- Maximum pressure: 3,45 bar
- Maximum Flow Rate: FR_{PW} = **67 l/min**

However, with the real data from Table A.19, FR_{PW} results an average of **63.14 l/min**. Nevertheless, data about the volume of potable water pumped is not available, and this can be the reason of the different results of FR_{PW}. Owing to that, the FR_{PW} calculated from the data can not be correct, so is more reliable to use the theoretical parameter gave by the manual.

5.7 Waste water service

The waste water service starts when all passengers deboarded the aircraft, because of possible smells inside the cabin that may interrupt the passengers' comfort. In addition to that, the waste water vehicle and the potable water vehicle cannot operate at the same time because the service points of these processes are not far from each other in the aircraft. For hygienic reasons, the potable water service must be realized before than the waste water service. (**IATA 2009**)

The waste water service consists of the following movements and actions: when all passengers deboarded the aircraft and the potable water service has finished, the waste water vehicle is positioned on the bottom of the aircraft, just below the tail cone. Then, a hosepipe is connected between the vehicle and the aircraft valve for the holding water tanker and the water pumping begins. Usually, only one operator carries out the process.

The total process time is the sum of the times for positioning waste water vehicle, removing vehicle and emptying. There is one equation created for each time which simulates the real process.

See Figures D.4, D.11, D.17 and D.22 to localize the vacuum lavatory valve of the Airbus 320, A319 and the Boeing 737-700, B737-800.

Time positioning (removing) lavatory service vehicle

This time depends only on the vehicle speed, on the distance to the aircraft and on the time positioning the hosepipe. Assuming a constant speed, the distance cover for the waste water vehicle is approximately equal in all cases. In addition to that, the time connecting the hosepipe is similar as well. Therefore, the time is a constant.

This constant time is calculated with the average of all times obtained in videos (Table A.20). The same applies to time for removing the water vehicle.

$$t_{WWS,pos} = 38\,\text{sec} \tag{5.41}$$

$$t_{WWS,rem} = 31\,\text{sec} \tag{5.42}$$

Where:

- $t_{WWS,pos}$ Time for positioning lavatory service vehicle
- $t_{WWS,rem}$ Time for removal lavatory service vehicle

Emptying time

This process time depends only on the flow of emptying water. The holding tank of waste water has a capacity of 200 l taking into account the pressure gradient, which can change the flow rate. Hence, this flow can be considered as a constant.

$$t_{WWS} = \frac{V_{WWS}}{FR_{WWS}} \tag{5.43}$$

Where:

- t_{WWS} Waste water service time [min]
- V_{WWS} Volume of the waste water tank [l]
- FR_{WWS} Flow rate of the waste water service [l/min]

The main characteristics of that service for the Airbus A320 are (**Airbus 1995b**):

- Total tanks capacity: 200 l
- Maximum pressure: 2,4 bar
- Single toilet capacity: 58,7 l

- Total toilets: 3
- Chemical fluid: 9,5 l
- Maximum Flow Rate: FR_{WWS} = **38 l/min**

Unfortunately, data about the volume of waste water is not available. Nevertheless, using the theoretical FR_{WWS} given by the manual, the volume of water removed can be obtained, as Table A.21 shows, and it is checked that all the values remain to the limit of 200 l of the tank capacity. Therefore, the theoretical FR_{WWS} must be correct.

5.8 Pushback

The operation depends on the involved GHE. The classification is as follows:

- Pushback with conventional tractor.
- Pushback with towbarless tractor.

The pushback process consists of the following movements and actions: close to the end of the entire GH procedure, the pushback tractor is positioned in front of the aircraft nose, in line with the centre line of the aircraft. Just before of the pushback operation, the pushback tractor is joined to the nose gear, directly in the case of the towbarless type, or with the tow-bar in the case of the conventional type. In the last case, the tow-bar must be connected in advance to the nose gear. When the aircraft is ready to leave, the pushback truck pushes the aircraft backwards away from the airport gate.

The number of operators depends on the pushback tractor type. With towbarless tractor only one operator is needed to carry out the process; with conventional tractor usually two operators are necessary, one for driving the tractor and the other is disconnecting the tow-bar.

The total process time is the sum of the times for positioning pushback tractor, removing tractor, preparation and pushback. There is one equation created for each time which simulates the real process.

Time positioning (removing) pushback tractor

This time depends on the vehicle speed and on the distance to the aircraft.

The time for positioning the pushback tractor is given within a span. Table A.22 contains the maximum and minimum value of all aircraft analyzed. The same is applied to removing time.

$$0{,}12 \text{ min} < t_{PBc,pos} < 1{,}52 \text{ min} \tag{5.44}$$

$$0{,}10 \text{ min} < t_{PBt,pos} < 0{,}70 \text{ min} \tag{5.45}$$

$$0{,}75 \text{ min} < t_{PBc,rem} < 1{,}95 \text{ min} \tag{5.46}$$

$$0{,}92 \text{ min} < t_{PBt,rem} < 2{,}83 \text{ min} \tag{5.47}$$

Where:

- $t_{PBc,pos}$ Time for positioning conventional pushback tractor
- $t_{PBt,pos}$ Time for positioning towbarless pushback tractor
- $t_{PBc,rem}$ Time for removing conventional pushback tractor
- $t_{PBt,rem}$ Time for removing towbarless pushback tractor [min]

There is more time needed to position the tractor in case of conventional tractors than for towbarless tractors. The removing time in both cases is similar.

Time preparing pushback

This time depends only on the involved GHE and on the experience of the staff connecting the tractor with the nose gear.

In the case of the conventional tractor, the preparing time is defined by the time that the operators are connecting the tow bar to the nose gear, and the tractor to the tow bar.

In case of the towbarless tractor, the preparing time is defined by the time that the tractor, controlled by the operators, is tugging lift the nose gear off the ground.

From Table A.22, this time is calculated as an average of **1.71 min** in case of conventional tractor, and **0.90 min** in case of towbarless tractor.

$$t_{PBc,pre} = 38 \text{ sec} \tag{5.48}$$

$$t_{PBt,pre} = 31 \text{ sec} \tag{5.49}$$

Where:

- $t_{PBc,pre}$ Time for preparing conventional pushback tractor
- $t_{PBt,pre}$ Time for preparing towbarless pushback tractor

For towbarless the preparing time is less.

Pushback time

This time depends only on the vehicle speed and on the distance covered by the tractor.

The speed is approximately constant in all cases, complying with the appropriate aviation standards and procedures (**JAR-OPS 2007**) and the safety rules recommends by IATA (**IATA 2009**). The towbarless tractor can be moved with higher velocity.

The distance between the aprons and the taxiways can vary from one to another, and in some aprons, the aircraft can be positioned in different taxiways.

Owing to the above, it is only possible to estimate the time with a relation between the tractor speed and the distance cover:

$$t_{PB} = \frac{d_{PB}}{v_{PB} \cdot 60} \tag{5.50}$$

Where:

- t_{PB} Pushback tractor time [min]
- v_{PB} Pushback tractor speed [m/s]
- d_{PB} Distance covered by pushback tractor [m]

Table A.23 shows the pushback time of all aircraft analyzed.

5.9 Cleaning

Unfortunately, there is no available data about cleaning process for any analyzed aircraft. Therefore it is not possible to present any statistical model.

6 Turnaround simulation with SIMBA

6.1 Description of SIMBA

Simulation Tool for Aircraft Servicing (SIMBA) is a Ground Handling simulator program developed by ARC at the beginning of nineties.

SIMBA simulates most of the processes that take place during a turnaround of one aircraft. The vehicles and equipments movements around aircraft are studied considering the type of aircraft, rules, restrictions and operational strategies.

With SIMBA it is possible to obtain the following results:

- Possible dispositions of the equipments and vehicles
- Conflicts in the movements of the vehicles
- Detection of collision between the vehicles
- Measure of distances in every moment of the simulation
- Compatibility of the processes
- Turnaround chart of the aircraft
- Calculation of ground handling costs
- View of the movement in real time in relation with the top, side and front view of the aircraft

These results are very interesting for all companies involved in GH: handling companies, airports, airlines and aircraft manufacturers. For instance, changing a simple parameter, as the number of vehicles, the new turnaround time and the new GH costs of the processes involved will be obtained. Therefore, it is important information that could help to improve the aircraft dimensions and service points, the equipment dimensions, the processes, and so on.

SIMBA is deterministic; it is not possible to have any stochastic variation. Hence, the simulation is far from the reality. However, it is possible to compare different scenarios of GH for the same aircraft and to obtain the results: which scenario is better in time, cost, less vehicles used and so on, although these scenarios are not simulating exactly the reality.

Once the program is running, SIMBA compares all dimensions, distance and position points with the official rules and requirements of SAE International and ISO Standards. This function of the program is very useful, because it reduces the possibility of errors in the representation of the reality. Figure 6.1 is one example.

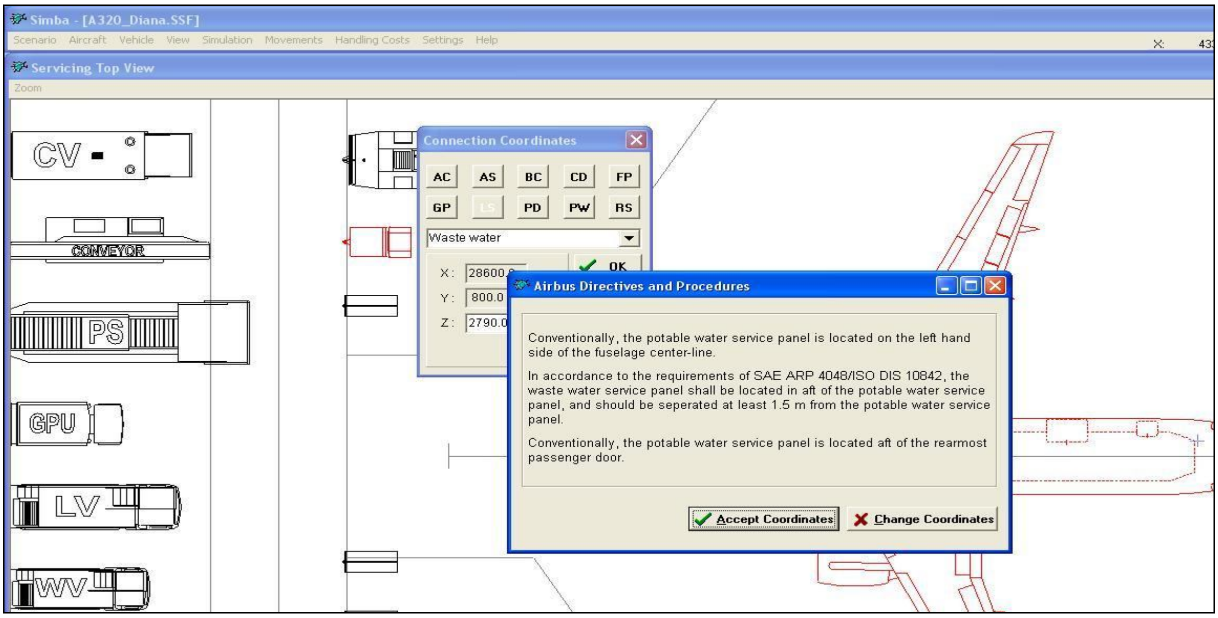

Figure 6.1 SIMBA Airbus directives and procedures

With SIMBA is possible to simulate the following GH processes:

- Air condition
- Ground power
- Boarding/Deboarding
- Loading/Unloading baggage and/or bulk cargo
- Loading/Unloading containers
- Catering
- Cleaning
- Lavatory service
- Potable water service
- Refuelling
- Transport of passengers
- User defined process: created by the user

Operating the program

SIMBA is a program which is not difficult to handle. The screen layout is similar to most of the programs prepared to run within Windows computer operating system: a main bar with all options available in a menu structure. In Figure 6.2, these menus are described.

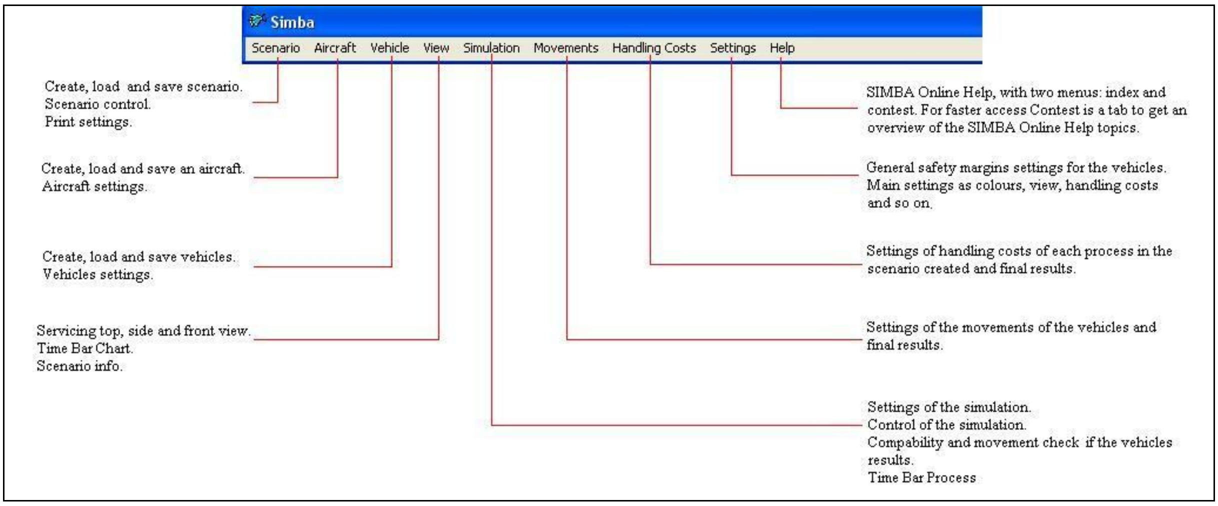

Figure 6.2 Main menu bar of SIMBA

To create a ground scenario with SIMBA the steps are the following:

- Load or create a scale aircraft drawing. Define the external configuration of the aircraft: length, height, wingspan, and main coordinates of the engines, wing, nose wear and elevator.

- Load the three views of the aircraft: top, side and front.

- Set the aircraft service point coordinates and system performance. SIMBA provides two possibilities to enter all aircraft coordinates into the system: using the keyboard or the mouse. The keyboard is used when the point has to be clarified with the exact coordinates. On the other hand, using the mouse the points of the surfaces are easily marked on the top and front views of the aircraft. Although the precision is not exact, the mouse is a quickly way for input data.
  Figures 6.3 and 6.4 are examples of the system described above.

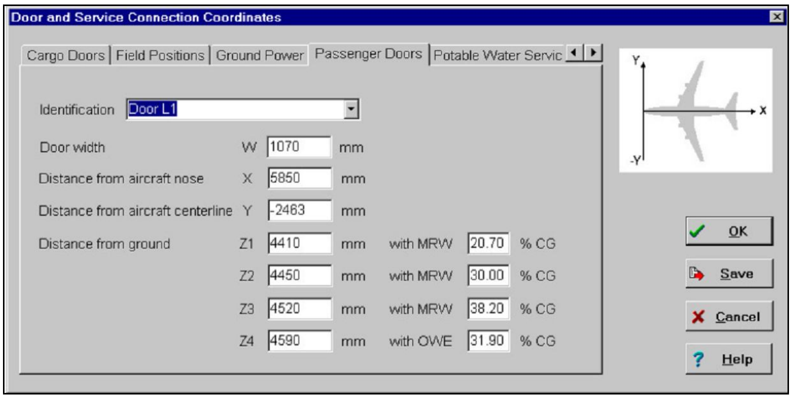

Figure 6.3 SIMBA coordinates specified with the keyboard

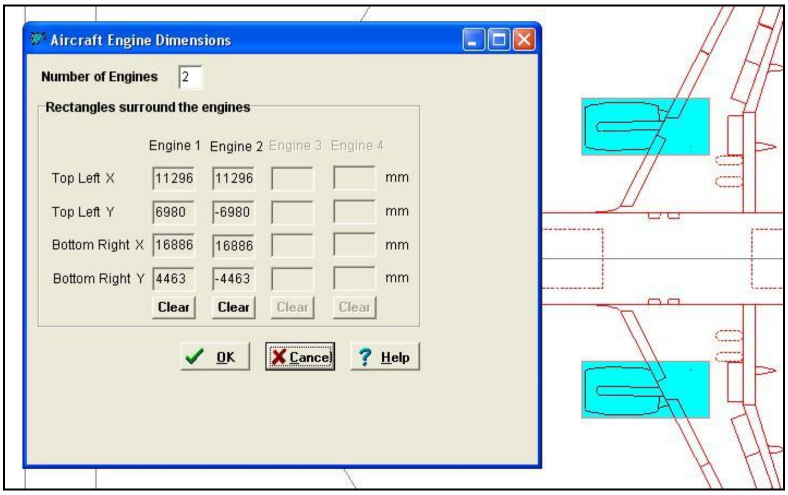

Figure 6.4 SIMBA coordinates specified with the mouse

- Set passenger cabin of the aircraft: seats, galleys and toilets.
- Set the parameters of the processes for simulation. As case of aircraft service points, this is easy as well. Once the menu to specify the parameters is selected in the main bar, a window interface appears. This window interface is divided in tabs; each tab corresponds to one process. Depending on the kind of process different parameters have to be written in the tabs.
- Define the external configuration of the vehicles and equipment and load the vehicles created. Also to load a default vehicle from the program is possible.
- Choose corresponding aircraft connection for each vehicle.
- Define the vehicles movements.
- Set the cost parameters of each ground handling process and equipment.
- Check the vehicles movement compatibility.
- Check the compatibility of the turnaround with the Airbus directives and procedures ABD0065. (**Airbus GH 1995**)
- Run the simulation.
- Results: time bar chart, compatibility of the processes, service arrangements and handling costs.

All steps are described in detail in the next Chapter 6.3 with the simulation created.

6.2 Application of SIMBA to a reference aircraft

The reference aircraft is based in the Airbus A320. All the aircraft data necessary to be input in the program has been taken from the technical manual of the Airbus A320-200. In the following paragraph the steps to create the simulation are described.

Steps to create the simulation (**Airbus 1995b**)

1. First, the following data has been used to define the reference aircraft:

- External geometry: length 37570 mm, wingspan 34100 mm and height 12140 mm.
- Three view drawings of the Airbus A320 from the SIMBA data base.
- Position of the following structures: engines, wing, nose gear and elevator. Figure 6.3 shows the engines setting.
- Passenger cabin data. Number of seats in single class: 164; number of full trolleys in the FWD galley: 4; number of full trolleys in the AFT galley: 7; number of toilets: 3.
- From the data of the technical manual of the Airbus A320-200, the service points of the reference aircraft are positioned. The following Table 6.1 summarizes the service points position with a coordinated system. The origin centre is located at the aircraft nose.

Table 6.1 SIMBA service points coordinates of the reference aircraft

Service Point	**X coordinate** mm	**Y coordinate** mm	**Z coordinate** mm
AFT bulk cargo door	26295.0	1062.0	2200.0
AFT cargo door	22690.0	754.0	3450.0
FWD cargo door	8160.0	759.0	1990.0
Ground Power	2550.0	0.0	2000.0
Lavatory	31714.1	0.0	2790.0
FWD Door Left	5020.0	-1950.0	3390.0
AFT Door Left	29640.0	-1757.0	3450.0
FWD Door Right	5020.0	1950.0	3390.0
AFT Door Right	29640.0	1757.0	3450.0
Potable Water	28700.0	-420.0	2590.0
Fuel (right)	17644.0	10113.5	3400.0

2. The next step is input the parameters of the service processes. All the rates and times necessary to be input in the program have been taken from the statistical data analyzed in Chapter 5. An example is Figure 6.5

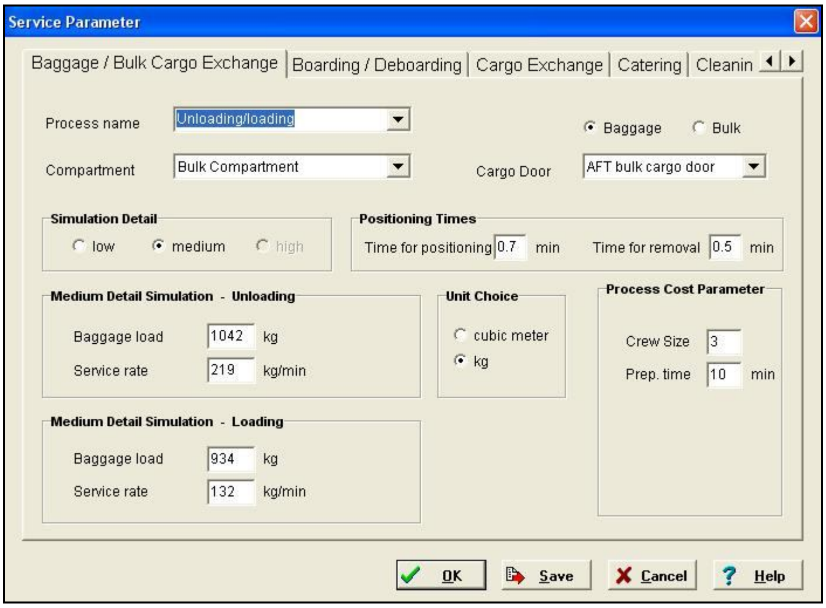

Figure 6.5 SIMBA service parameters of the reference aircraft

The ground handling processes considered in the simulation have been based in a typical turnaround carried out by LCA. Therefore, the processes are as follows:

- Bulk exchange
- Passenger deboarding/boarding through the two left doors of the aircraft. Two stairs are situated at the doors. Passenger transportation is not considered: hypothetically the passengers walk directly to the terminal, like it is possible in secondary airports.
- Catering of only 4 full trolleys in the AFT galley.
- Refuelling
- Ground power
- Pushback
- Potable and waste water services
- A basic cleaning is considered. Usually in LCA this process is carried out by the cabin crew, therefore, the cleaning vehicle is not necessary in the simulation.

3. Then, the processes interdependence is created. As in a normal turnaround, the processes cannot start until the aircraft is on blocks, so the beginning of the processes which are independent from others is defined as the period of time that had passed respect to the on blocks time. The beginning of the process which are dependent from others is defined as

the period of time that had passed respect to the final time of the process from it is dependent. One example is Figure 6.6

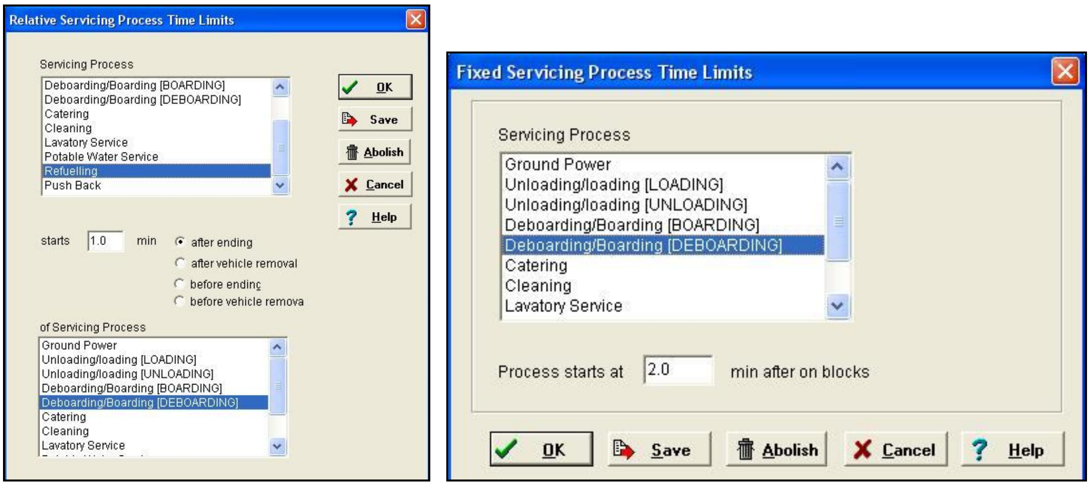

Figure 6.6 SIMBA relative servicing process (left) and fixed servicing process (right)

4. Afterwards, the vehicles and equipments necessaries are load from the data base of SIMBA. The refuelling vehicle has been created and exported to the data base. The vehicles have to be connected with their respective process and service connection point. See Figure 6.7

   The following vehicles/equipments have been loaded for the simulation: one GPU, two stairs, one refuelling truck, one pushback truck, one conveyor belt, one tractor, three baggage dollies, one catering vehicle, one waste water vehicle and one potable water vehicle. See Figure 6.9

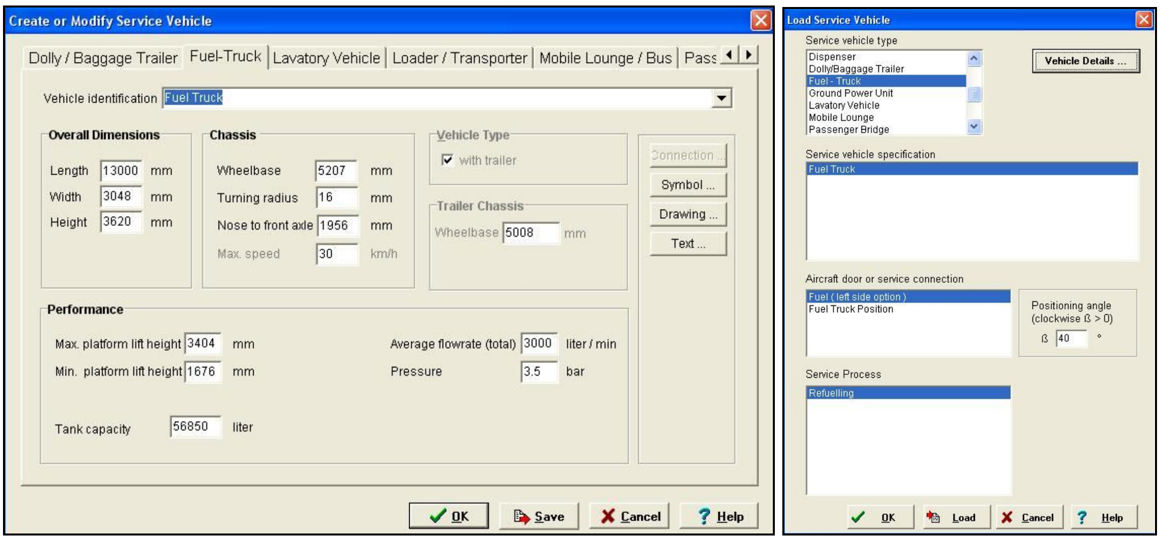

Figure 6.7 SIMBA creation of a vehicle (left) and loading a service vehicle (right)

5. Once the vehicles are loaded and connected whit their respective connections points, their positions around the aircraft are checked in the three views. Figure 6.8 shows the front view and Figure 6.9 shows the top view.

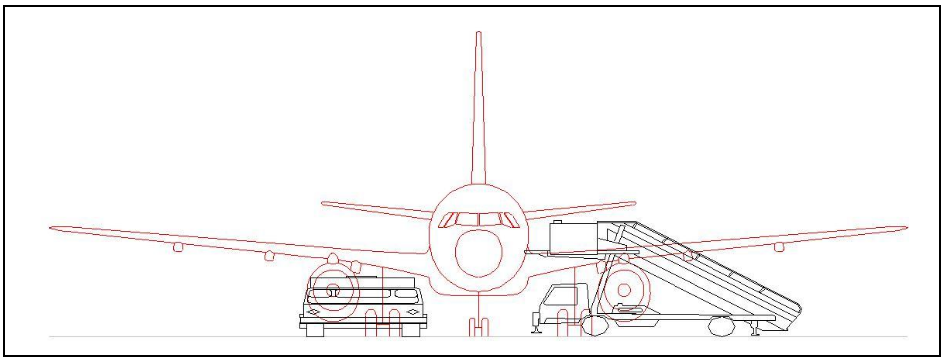

Figure 6.8 SIMBA servicing front view

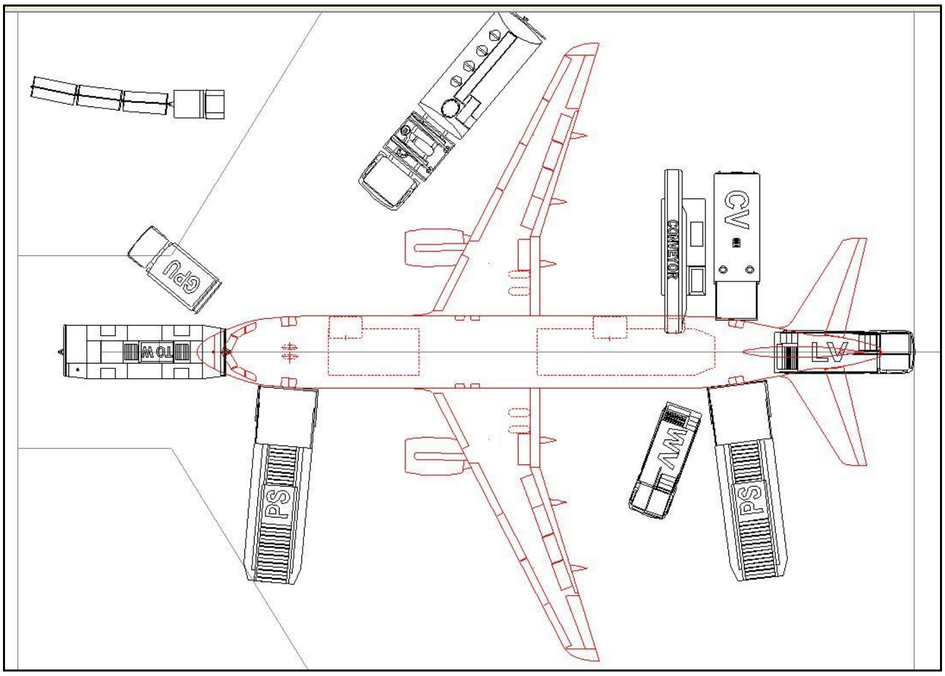

Figure 6.9 SIMBA servicing top front view

6. The vehicle movements are defined drawing in the top view the corresponding curve with all the points that the user considers necessaries. For each vehicle are defined two movements: the positioning and the removing. The positioning is described with a path which joins a start position defined by the user with a position corresponding with the vehicle process. The removing is described with a back path which joins a position corresponding with the vehicle process with a final position defined by the user. The positions corresponding with the vehicle process are fixed and they cannot be modified. The path can be simulated and tested to find collisions with other vehicles or with the

aircraft. The curve of the path can be drawn. Figures 6.10 and 6.11 are examples of the path creation.

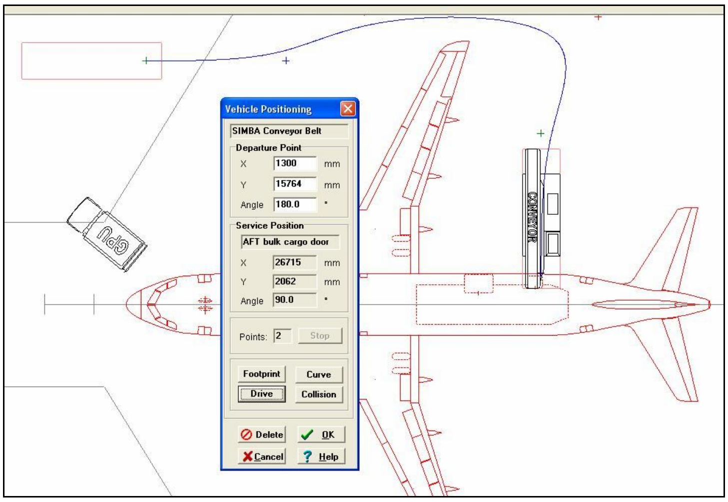

Figure 6.10 SIMBA path

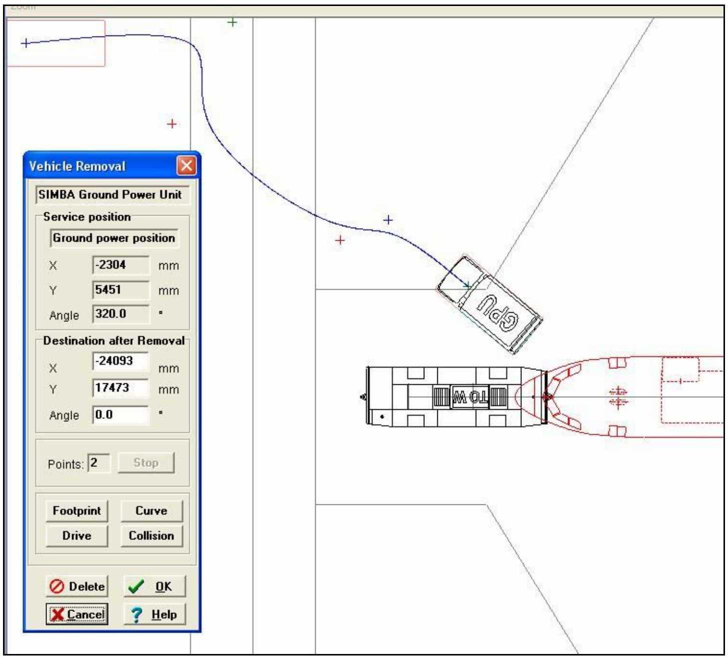

Figure 6.11 SIMBA back path

7. Before run the simulation, SIMBA has the possibility of: to check the results of the movement collisions, to check the compatibility of the vehicles at their start positions and to check the compatibility with the Airbus directives and procedures ABD0065 (**Airbus GH 1995)**. Figures 6.12 and 6.13 are two examples.

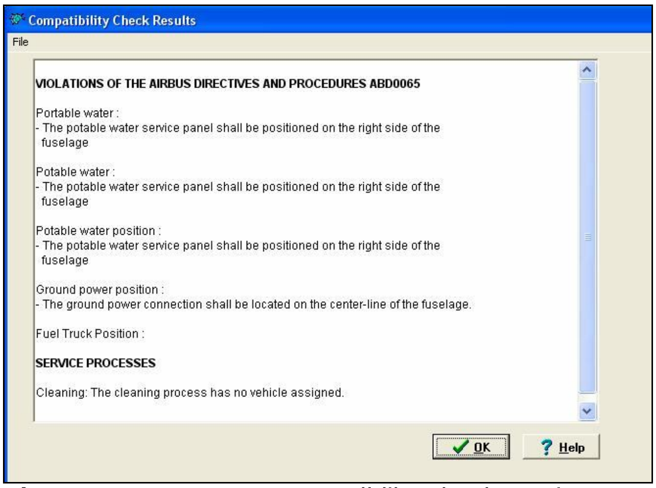

Figure 6.12 SIMBA compatibility check results

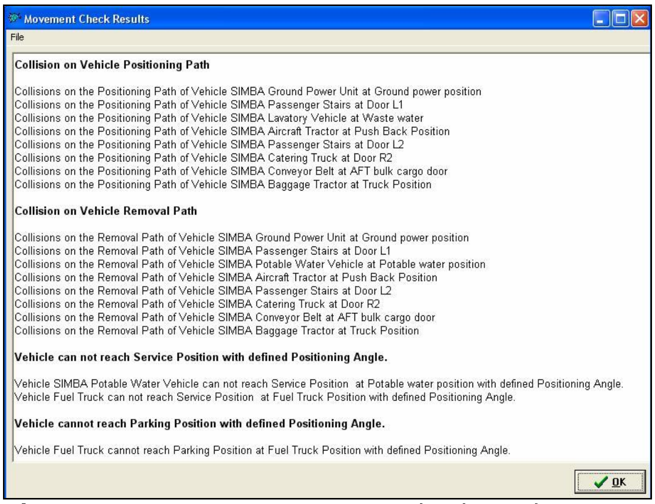

Figure 6.13 SIMBA movement check results

8. The last step before run the simulation is input the costs data. For that, the data from the secondary airport Salzburg Airport W. A. Mozart were used. It is necessary to set the cost of the manpower for each process, the cost per hour of utilization of each vehicle, additional costs and the terminal handling costs. (**SZG 2007**) See Figure 6.13

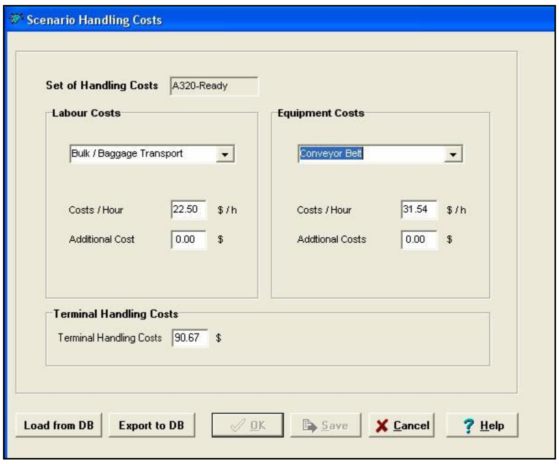

Figure 6.14 SIMBA scenario costs

Running the simulation

Once the turnaround scenario is created it is possible to run the simulation.

Before, it is necessary prepare the driving of the scenario. There are to ways to prepare the driving, normal and without check. Without the check of the possible collisions the preparation of the scenario is faster. The normal preparation can takes many minutes depending on the amount of movements necessary to be checked. See Figure 6.15

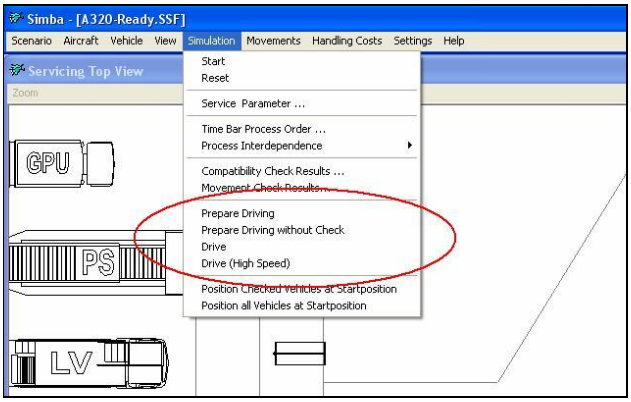

Figure 6.15 SIMBA prepare driving and drive

Then, the simulation is ready to be run. There are two ways to run the simulation, normal and high speed. In case of normal, the simulation runs in real-time. In case of high speed in few seconds all the simulation is run. See Figure 6.15

During the simulation it is possible to see the movement of the vehicles in the three views. One example of the simulation is shown in Figure 6.16

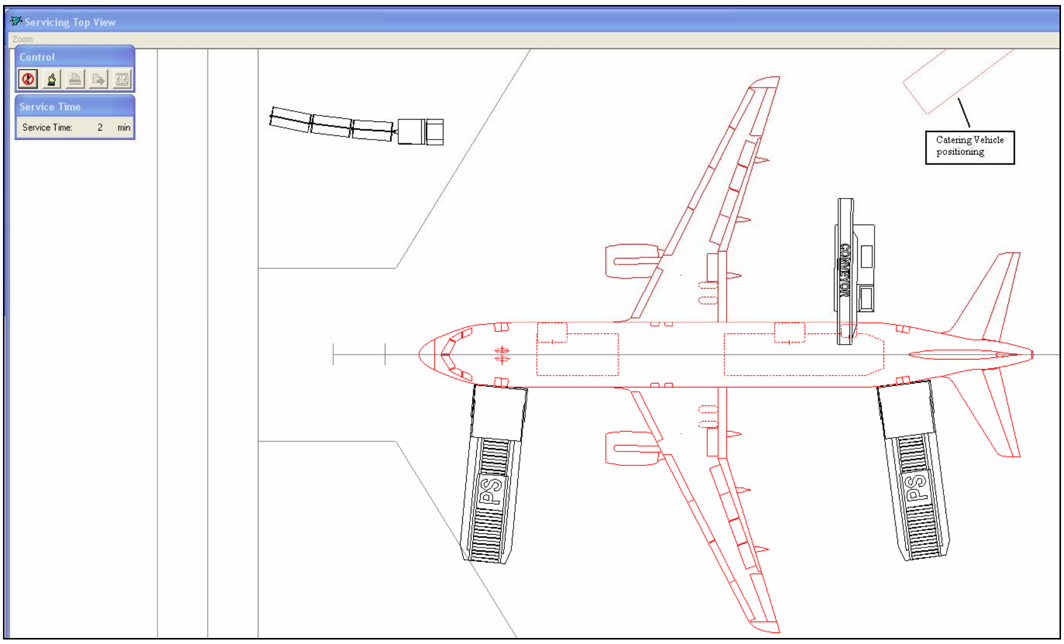

Figure 6.16 SIMBA simulation running

<u>Simulation results</u>

In Chapter 6.1 have been described all the possible results which SIMBA produces.

The results regarding with the positions and movements of the vehicles are already analyzed during the construction of the simulation, detecting their possible collisions and conflicts and creating the best path of them.

The main results of the simulation are as follows:

- Time bar chart of the turnaround.

  The total time of the turnaround is 38 minutes.

  In red colour the critical paths of the turnaround are showed. The critical paths have been: the refuelling and the passengers deboarding and boarding. It can be seen that these critical paths coincide with the hypothesis made in Chapter 2.5.

  Figure 6.17 shows the time bar chart.

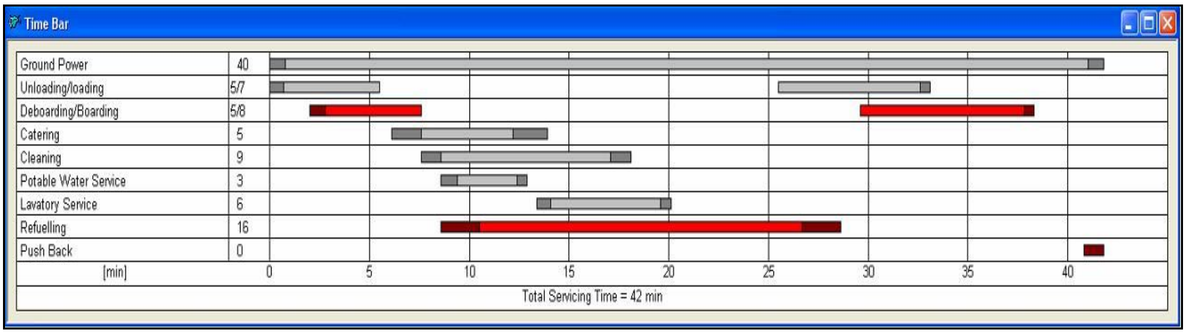

Figure 6.17 SIMBA time bar chart of the reference aircraft simulation

- Turnaround costs of the simulation.

  The costs are based in the handling prices of the secondary airport Salzburg Airport W. A. Mozart in 2007 (**SZG 2007**). These costs are probably higher nowadays, as usually the price of life grows every year.

  The total cost of the turnaround simulated is 560.14 $.

  The more expensive processes are: the cargo unloading/loading, because it is the process which uses more equipment and operators, and the passengers deboarding/boarding, as the price of the stairs utilization per hour is very expensive.

The following Figure 6.18 shows the cost results.

Handling Costs

Activity	Crew size	Time on aircraft [min]	Preparation Time [min]	Man minutes [min]	Labour cost/hour [$/h]	Labour cost [$]	Labour add. cost [$]	Equipment cost/hour [$/h]	Equipment cost [$]	Equipment add. costs [$]	Costs [$]
Ground Power	----------------	42	----------------	0	0.00	0.00	0.00	38.86	27.20	0.00	27.20
Unloading/loading	3	33	10	129	9.05	19.00	120.00	31.54	22.60	0.00	161.60
Deboarding/Boarding	----------------	36	----------------	0	0.00	0.00	0.00	145.00	87.00	42.22	129.22
Cleaning	3	10	10	60	11.80	12.00	0.00	0.00	0.00	0.00	12.00
Potable Water Service	1	4	10	14	11.80	3.00	0.00	43.66	10.19	0.00	13.19
Lavatory Service	1	7	10	17	11.80	3.00	0.00	45.73	12.96	0.00	15.96
Push Back	2	1	5	12	9.05	2.00	0.00	19.24	1.92	0.00	3.92
Luggage Transport	1	33	2	35	22.50	13.00	0.00	51.36	29.96	0.00	42.96
Total ramp handling costs										=	406.05
Terminal handling costs										+	90.67
Total ground handling costs										=	496.72
Catering items										+	12.42
Fuel amount										+	51.00
Total costs										=	560.14

Export OK Help

Figure 6.18 SIMBA turnaround costs of the simulation

7 CAST computer tool

7.1 Description of CAST

Comprehensive Airport Simulation Tool (CAST) is a simulation system for airport processes developed by ARC, with the cooperation and support of companies and organization as EUROCONTROL Experimental Centre, British Airport Authority, Fraport AG, etc. The project started in the beginning of this century and it is continuously developed, extended and adapted.

The program is a powerful simulation engine, with a high-performance 3D fast time simulation system for all airport processes (**CAST 2009**):

- Passenger Terminal Simulation
- Pedestrian Simulation
- Airport Simulation
- Vehicle Traffic and Ground Handling Simulation
- Aircraft Simulation
- Process Simulation and Visualisation

CAST provides a simulation with the highest level of detail and accuracy that is currently available. Therefore, it offers the possibility to simulate most logistic processes and traffic flows within an airport.

Even though CAST is a powerful simulation engine, it is optimised to run on personal computers and no expensive simulation equipment is needed.

To simulate different parts of an airport CAST is built in a modular simulation platform. The actual principal products constituting the CAST family are CAST Terminal, CAST Aircraft, CAST Vehicle and CAST Aproncontrol (Figure 7.1). In addition, in the near future CAST Ground Handling and CAST Pedestrian will be ready.

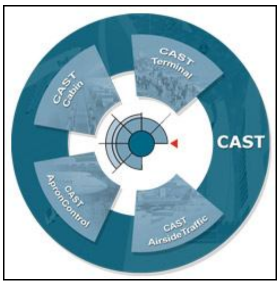

Figure 7.1 CAST product family (**CAST 2009**)

Although all these applications can be utilised as stand-alone, CAST has the advantage to combine two or more applications into one integrated simulation within one environment. Figure 7.2 is one example of CAST family.

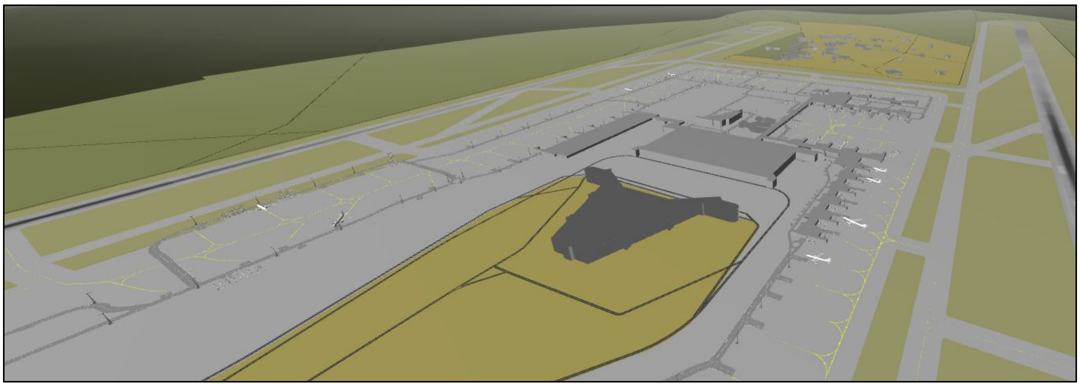

Figure 7.2 CAST Simulation of Palma de Mallorca Airport (**ARC** and **EUROCONTROL**)

The main features common to all of them are:

- CAD interface.
- The simulation and distributions are stochastic, not deterministic.
- Simultaneous simulation and animation in real time. The data and events are recorded during the simulations. Video sequences can be recorded for demonstration and presentation purposes.
- Multi agent 3D technology. Every agent (passenger, vehicle, machine, object or aircraft) represents an actor, reacting according its individual characteristics, making their way and performing the processes independently, and interacting with the other objects considering priority rules and restrictions to ensure the solution of collisions and conflicts in its way.
- Data visualization while the simulation is running. The analysis and results can be assessed during the simulation run with animations and analysis functionalities as graphs or colour-coding. The results are post-processed through the tool "Log-Analyser". Figure 7.3

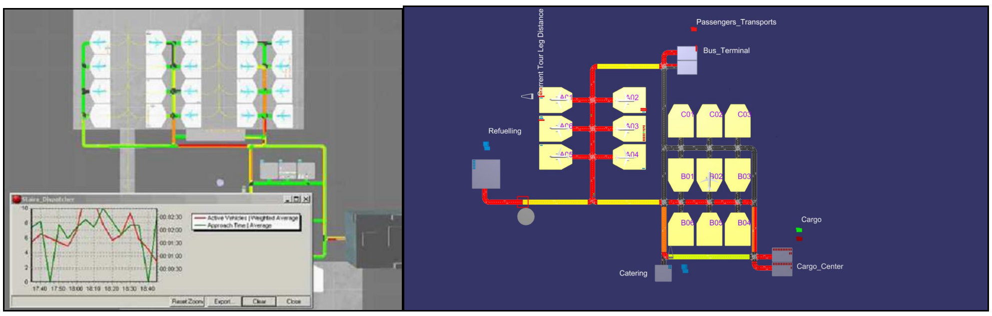

Figure 7.3 Analysis functionalities during CAST Vehicle simulation (**ARC** and **EUROCONTROL**)

- Simulation in 3D with a coordinate system defined by the user. The simulation model can be observed by the six views of 2D representation, isometric, orthogonal and perspective views and zoom options by multitude of perspective cameras default or created by the user. For instance, a camera can follow one agent in concrete. Two examples of the same moment of one simulation are shown in Figure 7.4

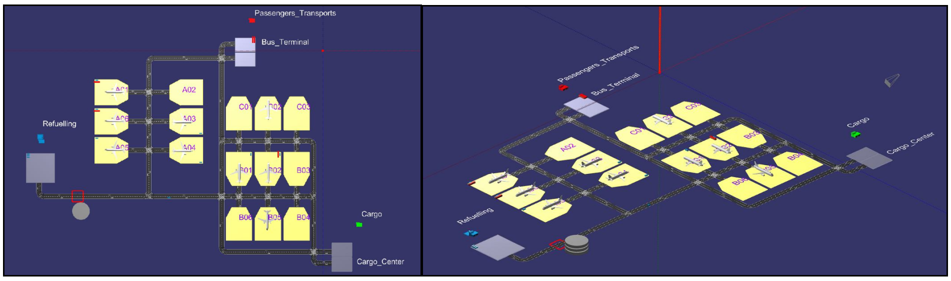

Figure 7.4 Top view and isometric view (**ARC** and **EUROCONTROL**)

- Screen layout similar to the most of the programs prepared to run within Windows computer operating system: a main bar with all the options available in a menu structure. Thus is an advantage, since most users are accustomed to working with similar windows environments. See Figure 7.5

- The main options, views, objects and processes can be selected with a simple click of the mouse in different toolbars continuously visible in the workspace. See Figure 7.5

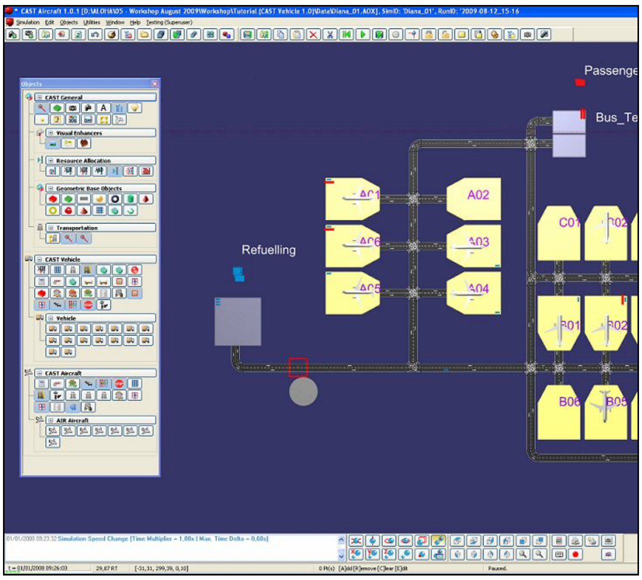

Figure 7.5 Screen layout and toolbars of CAST Vehicle (**ARC** and **EUROCONTROL**)

Below, the main modules currently available are described with a brief summary. Due to the interest of this project, CAST Ground Handling is described in the next Chapter.

<u>CAST Terminal - Passenger Terminal Simulation Tool</u> (adapted from **CAST T. 2009**)

CAST Terminal is a dynamic simulation tool to model the passenger flows within the passenger terminal with visual representations. See Figure 7.6

The program utilises quick and easy modelling of passenger layouts to generate relevant statistical data on:

- Traffic, queuing and waiting areas
- Workload of passenger handling facilities
- Time of stay of the passengers in terminal
- Waiting times for passengers
- Handling facilities for passengers

The simulated elements include:

- Traffic and circulation areas
- All types of check-in, for instance: flight, airline, bagdrops, etc
- All processes related with flight: security, passport, gate, immigration control, baggage claim, etc
- Service for innovative self-service solutions as body scanner or automated border control
- Lifts, escalators, moving walkways, etc

Consequently, a complete airport can be examined, or its individual parts can be considered in detail, to cost-effectively conduct analyses aimed at:

- Planning of optimal future airport infrastructure developments
- Identifying bottlenecks and solutions to complex operational problems and planning tasks
- Improving terminal capacity without reduction of operational quality
- Identifying the most efficient and cost-effective options
- Optimising retail facilities and ensuring highest passenger convenience
- Supporting tactical and strategic decision-making in airport operations and management

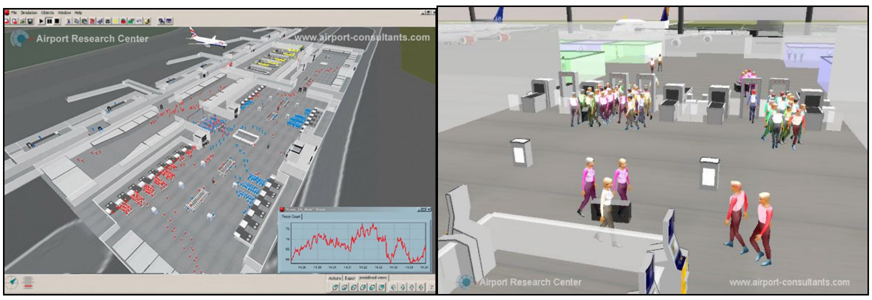

Figure 7.6 CAST Terminal screenshots (**CAST T. 2009**)

<u>CAST Aircraft - Simulation of Aircraft Traffic and Processes</u> (adapted from **CAST A. 2009**)

CAST Aircraft simulates the aircraft traffic on and around an airport considering infrastructure, rules, restrictions, and operational strategies. For instance, the runway sequencing is based in Air Traffic Control (ATC) rules, considering departure separation, the individual properties of each aircraft, runway occupancy times and so on. See Figure 7.7

The aircraft traffic simulation is created following the chronological course of a central flight schedule handling system.

The level of details is scalable, basing the delays and scheduled deviations on probabilities and creating detailed rules different from the default settings for the routing.

The simulated elements include:

- Setup of runway and taxiway network by predefined modules and imported from CAD
- Schedule based generation of flights
- Dynamic gate allocation and aircraft routing
- Accurate calculation of delays, taxi-times and other process parameters
- Use of stochastic distributions
- Conflict detection and recognition during taxi way

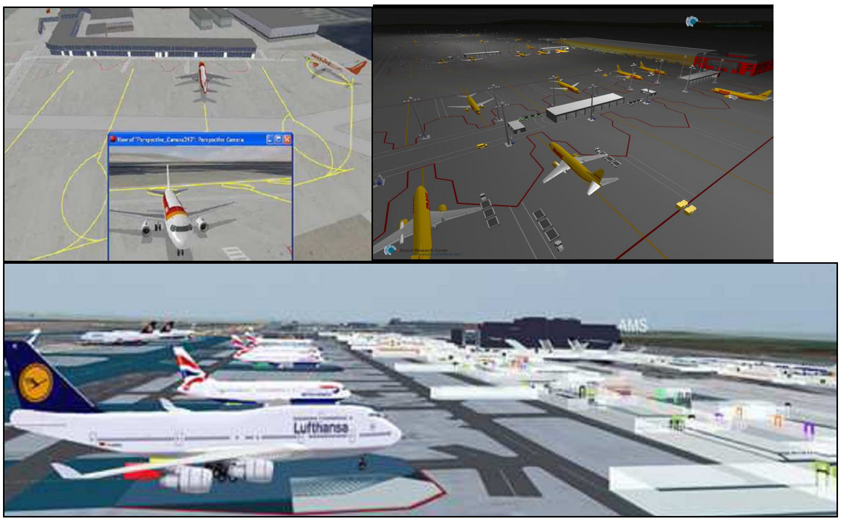

Figure 7.7 CAST Aircraft screenshots (**CAST A. 2009**)

CAST Aircraft, together with CAST Vehicle, constitute CAST Airside Traffic, a powerful tool in order to help airports, airlines and ground handling companies. This goal is explained in detail in the following paragraph CAST Vehicle.

CAST Vehicle - Airside and Apron Traffic Simulation (adapted from **CAST V. 2009**)

CAST Vehicle simulates the airside ground traffic considering infrastructure, rules, restrictions, and operational strategies. See Figure 7.8

In the case of CAST Aircraft, the ground traffic simulation is created following the chronological course of a central flight schedule handling system, but in this case, the traffic generation takes into account the flight load information, such as passengers, baggage, cargo, etc.

The level of details of the movements is very high. The vehicles can accelerate, turn, change lanes and overtake according to their cinematic and dynamic properties, obeying the special traffic rules in the airside.

The vehicles find their routes considering many factors, such as taxiing aircraft and the actual traffic situation on potential route segments.

The simulated elements include:

- Ground vehicles and aircraft
- Road elements and taxiways
- Controllers and dispatchers
- Stand positions, vehicle depots and storage areas
- Powerful import and editing functionalities for rapid scenario set-up
- Generation of traffic based on flight plan
- Dynamic dispatching according to individual strategies
- Accurate model of microscopic driving behaviour including lane changing, overtaking and conflict resolution at junctions
- Use of stochastic distributions

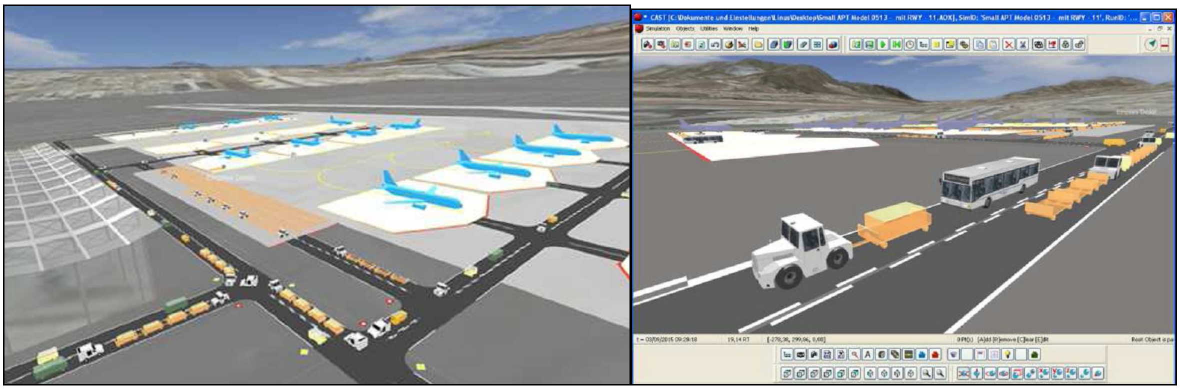

Figure 7.8 CAST Vehicle screenshots (**CAST V. 2009**)

CAST Vehicle supports airports, airlines, ground handling and air freighter companies to plan and develop the airport infrastructure, optimising the airside ground processes, and keeping the operations on the most efficient level.

For airports, CAST Vehicle together with CAST Aircraft, are very good tools to plan infrastructures and construction measures, compare different layouts, predict future bottlenecks, speed up and standardises planning processes, avoid planning mistakes and so on.

For airlines and ground handling companies, the tool can help, to plan operations and calculate their costs, create and check new procedures and configurations, determine the required equipment and predict future resource demand and so on.

CAST Aproncontrol - Planning and Simulation of ATC-Facilities (Adapted from **CAST Ap. 2009**)

CAST Aproncontrol is a tool created in order to plan, evaluate and optimise the airport layout considering Air Traffic Control (ATC) requirements. See Figure 7.9

With CAST Aproncontrol a quality visualisation of the 3D airport in study is created. This precise model is analysed to determinate the optimal position of ATC, taking into account the visualisation of shaded areas, sensitive fields of vision from the point of view from towers, safety regulations concerning ICAO, simulation and visualisation of aircraft movements and so on.

But not only the ATC is consider in CAST Aproncontrol, for instance the user can simulate the view conditions from every point of the airport, estimate the maximum heights of new buildings planned to be constructed and evaluate their effects.

It is obvious that the advantage of using this tool in airport director planning as the optimal position of the ATC is one of the most important issues.

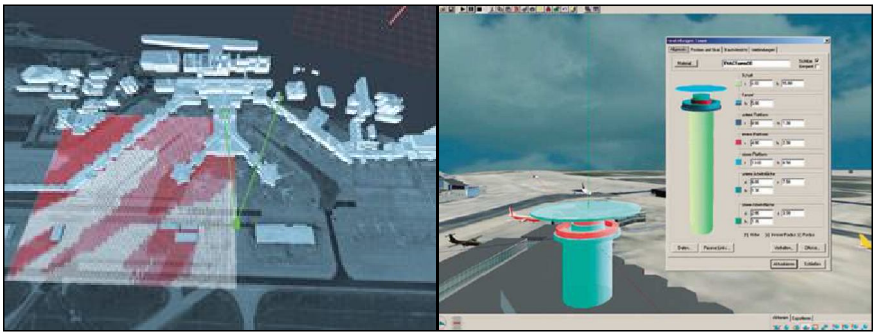

Figure 7.9 CAST Aproncontrol screenshots (**CAST Ap. 2009**)

7.2 Analysis of ground handling with CAST

ARC is currently developing CAST Ground Handling, which constitutes a new module of CAST family, although it could be integrated as a part of CAST vehicle. (**CAST GH 2009**)

The goal of CAST Ground Handling is the simulation of GH processes, thus the turnaround time is minimized with a more efficient use of resources, equipment and vehicles.

In a GH operation, not only the turnaround time is considered. Costs and other aspects as the amount of vehicles and equipment used the passengers comfort as well as the apron extensions can also be improved.

Therefore, CAST Ground Handling simulates a GH scenario with many different elements to improve all the aspects related to aircraft servicing. Figure 7.10

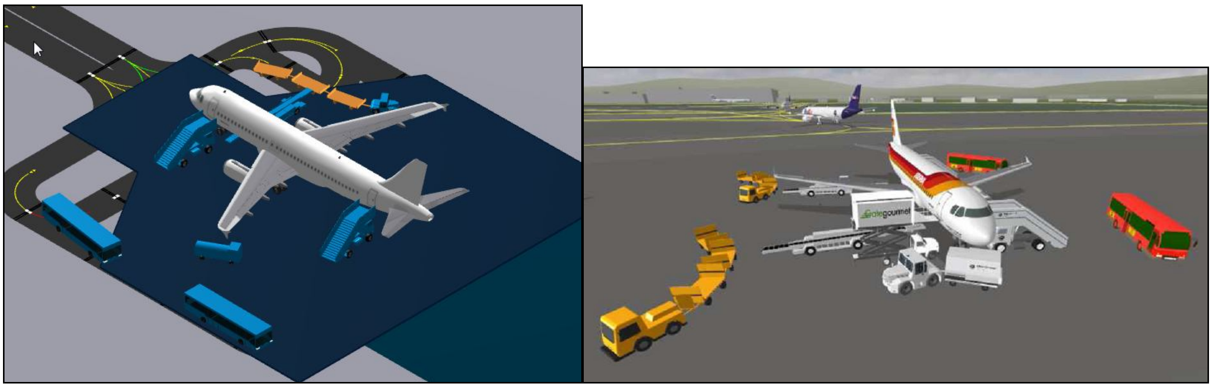

Figure 7.10 CAST Ground Handling screenshots (**CAST GH 2009**)

The simulated elements include:

- GH vehicles and equipment database, with measures and performance details. The vehicles are completely defined by the height, width, weight, etc, considering restrictions
- Different types of vehicles in accordance with type of process, type of aircraft, airline, time, origin and destination, etc
- Aircraft database with predefined service connections and systems
- The vehicles have a define route: length, allowed speed, movement restrictions, backwards positioning around the aircraft, blocking situations as push-back and so on
- Dynamic simulation of service vehicle movements, considering a possible collision
- Simulation of tow curves of the vehicles
- Service processes: fuelling, catering, GPU, waste water, etc, defined with performance parameters
- Interdependent processes

- Chronological process simulation. Rules and delays of processes are considered (for example refuelling must not start before passengers are deboarded)
- Load dependent with the central flight schedule handling system, the passenger and cargo amounts are considered
- Collision detection and additional geometry functionality
- Layout of apron positions
- Compatibility analysis of the equipment and vehicles movements around the aircraft.
- Detailed animation of apron movements. Figure 7.11

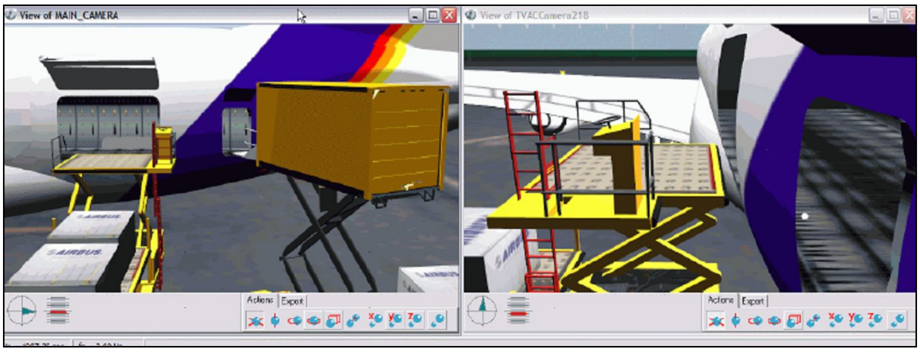

Figure 7.11 CAST Ground Handling details of vehicles approaching to the aircraft (**CAST GH 2009**)

CAST Ground Handling supports airports, airlines, ground handling and air freighter companies to plan and develop the GH processes, optimising the turnaround time, minimizing the costs and keeping the operations on the most efficient level.

Going into more detail, CAST Ground Handling provides the following results and analysis:

- Process analysis as time bar chart
- Analysis TR time and critical path
- Visualisation of service arrangement
- Servicing cost analysis
- Integration of handling strategies
- Verifies compatibility of aircraft and GH equipment
- Speeds up and standardises planning processes
- Test of new procedures
- Planning apron extensions
- Create different service arrangements for new aircraft models
- Test the compatibility between the aircraft and the standardised GH equipment.

7.3 Application of CAST Ground Handling to Airbus A320

Unfortunately, the program will be available after the final date of this project, thus is not possible to create any simulation.

Nevertheless, the CAST Vehicle and CAST Ground Handling were accessible during a CAST training program while writing this project.

The training was focused on the following steps (adapted from **CAST Tr. 2009**):

- Know the basics of the program, main menus and tools bars.

  The tool reflects its complexity with a variety of menus and tools bar. Some of them appear default in the main screen, helping the user with quick buttons to start and build the airside model.

  The menus have the same format in every step of the simulation creation, as well as the dialogues and schemes to define process and objects, hence, if one of the dialogues is well known, the others are known by extension. See Figure 7.12

  However, to work quickly with the program some combination of keys with the keyboard and mouse are necessary (for example, Shift & Left Mouse Button to select one object in concrete), which is easily forgotten if the user is a beginner with the program or is not accustomed to use it often.

- Create a simple airside model with objects like taxiways, aprons, depots, etc.

  To help the user building an infrastructure, it is possible to use an existing .dxf CAD layout.

  The process is very simple: the object required is selected in the "Objects Toolbar" and is modified and moved if necessary with the use of simple menus and dialogues. See Figure 7.12

  Afterwards a relation between the individual object to the others has to be defined.

  At the end a complete infrastructure setup is created defining the relations between the objects. See Figure 7.12

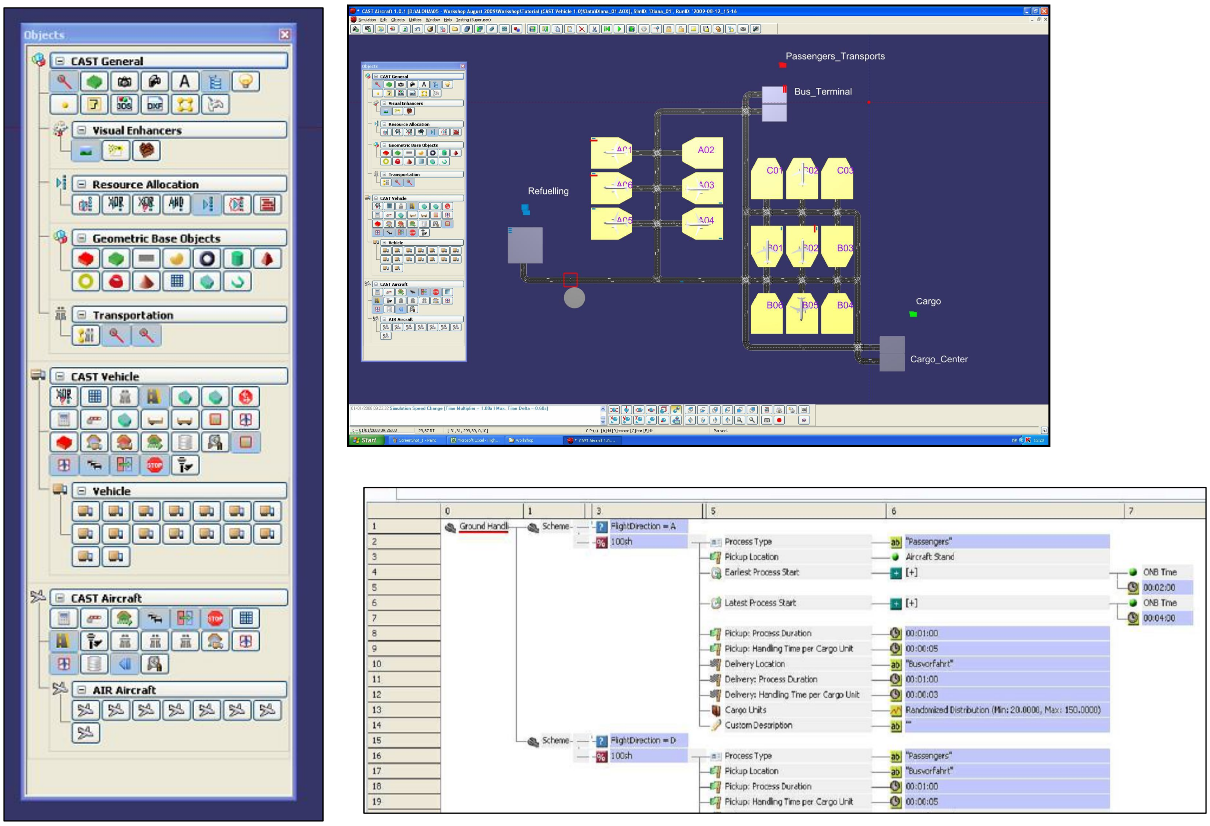

Figure 7.12 CAST Vehicle “Objects Toolbar” (left), network (right top) scheme dialogue (right bottom) (**CAST Tr. 2009** and **EUROCONTROL**)

- Test the network.

The program has the possibility of test the infrastructure created to validate it. Testing the network with random traffic and the origin and destinations relations is possible as well.

- Input a central flight schedule handling system.

The flight schedule can be edited, adding a new flight or deleting one existing.

- Generate the traffic.

The traffic is generated by dispositions. There are three different kinds: dispatching centres, empties and traffic flow, their names imply their functions. Each disposition is responsible for every process related with it by “Ground Handling Schemes”. Figure 7.13

These dispositions must be created in the network, along with “Vehicle Depots” to park vehicles generating for the traffic.

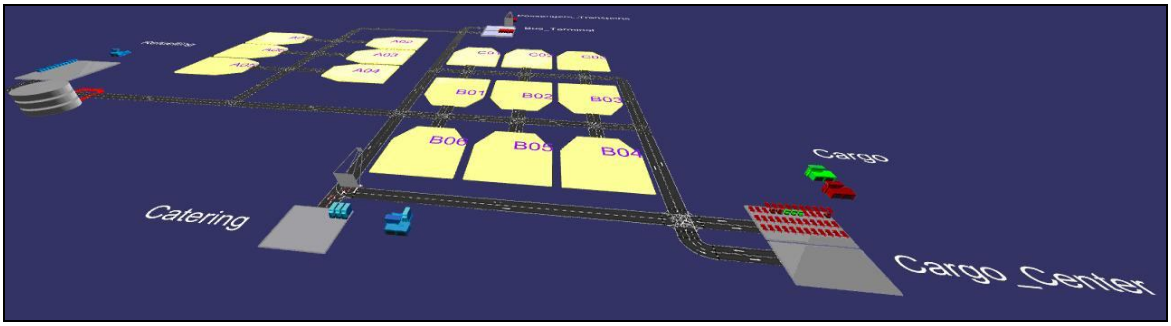

Figure 7.13 CAST Vehicle catering and cargo “dispositions” (**CAST Tr. 2009** and **EUROCONTROL**)

- Creation of specific GH processes defined by the user.

A GH process is defined in the corresponding “Deposit” creating a “Ground Handling Scheme”. See Figure 7.12

The process is generated with several conditions with a simple programming language If-node (if, then, else). The condition is set up by combining some operators such as AND, OR, NOT, =, > … offered in the context menu.

Although the Scheme could seem difficult for a person not accustomed to write language programs, the Scheme is very easy to understand and to handle. In a few minutes, the user is improving his use of the Schemes and with a little bit of practise is defining the same process with fewer lines in the Scheme.

- Define the results will be shown during the simulation such us colour-code.

The data visualisation during the simulation is running enables to gain first impressions about the processes.

The two possible modules to use for simulating time are, graphs showing the chronological sequence and objects that can be colour coded depending on the logged results. The two modules can be activated and edited independently of each other. See Figure 7.14

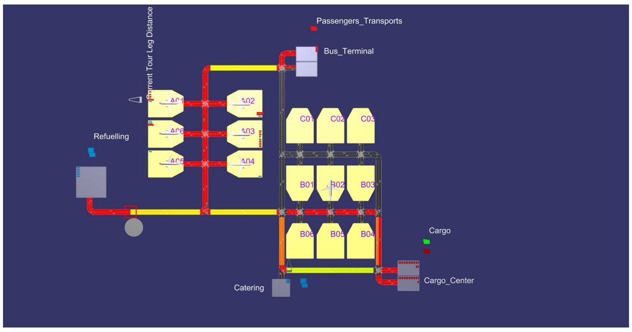

Figure 7.14 CAST Vehicle training. Create of airside (**CAST Tr. 2009** and **EUROCONTROL**)

- Run the simulation

  If the network was tested and all the processes are correctly defined the simulation starts to run.

  It is possible to play and pause the simulation, as well as define the speed of the visualisation until one maximum.

  Depending on the time simulated (one day, a week, month …) and the quantity and variety of vehicles, processes, aircraft and so on, the simulation can be very fast or takes days for running, always considering the use of a general personal computer.

- “LogAnalyser”

  This tool inside the program allows the user to find out results easily at the end of the simulation.

Definitely, once the program will be available, this computer tool is indicated to analyse and test the new configurations created under GH point of view in Chapter 9.

8 Expert interviews

8.1 Reasoning

The voice of experience is always necessary to understand in depth any complex process, even more in aeronautical market, as the efficiency and reliability have to be proven during long time.

One way to take enough knowledge in any process is obviously to work directly within it; however, it is not possible in the most cases. Nevertheless, getting information, ideas and general knowledge from people working within or in close contact with the process will always be possible.

Therefore, expert interviews are a good way to achieve the objective of deep understanding in GH, in combination with simulations and studies.

It is also important to take in consider different points of view and innovative ideas from people with good knowledge about GH.

A good example is the Ryanair Company, who usually has different and innovative procedures to reduce turanround time, for instance not numbered seats, or the idea of passengers carrying their own luggage to the aircraft. Therefore, conduct an interview with an expert in Ryanair of GH may give revolutionary ideas and information to investigate and simulate.

8.2 Set up

The first step to conduct these interviews is to decide who can be considered an expert.

There are many possibilities: workers from Ground Handling Companies, Airlines, Airports, or Aircraft Manufactures Companies, pilots, aircraft cabin staff, aircraft engineers and so on.

To obtain the best results and the most quantity of information possible, the experts have to represent the most of the work positions in relation with GH, such as:

- Operators with different responsibilities working directly in or around the aircraft
- Workers from different Ground Handling Companies in relation with marketing, systems and company costs

- Airline workers responsible for the GH special procedures inside that airline
- Aircraft engineers expert in GH or in simulation programs related as CAST
- Airport experts in GH procedures

The interview should vary in depending of the expert special knowledge and in the information that wants to be obtained.

Nevertheless, some questions should be present in all the different questionnaires:

- Description of GH since the point of view of the expert
- Critical processes in GH and ways to improve it/them
- Aircraft design in relation with GH: service points, external configurations conventional and unconventional, internal configuration and so on
- Costs of GH procedures, equipment, staff, etc
- Time of a normal TR and ways to reduce it
- Handling companies procedures
- Especial or innovative equipment
- Innovative procedures by airlines, handlings companies or airports
- Questions according with the speciality of the expert

Finally, the labour of the interviewer is to transcript the interview and obtaining results with the information.

8.3 Results of Prof. Dr.-Ing. G. Konieczny interview

This interview obtained a general knowledge about GH and a different point of view from Prof. Dr. Konieczny.

The most important conclusions are:

- The GH process is a really higher optimize system difficult to improve

- For each TR process there has to be found the critical part and the modifications in aircraft configuration that could help in the process

- The critical process in GH is the passengers deboarding and boarding procedure and is difficult to improve it as the human factor has to be in account

- Refuelling and unload - load processes could be a bit critical as well, but not all the rest of processes

- Modifying the aircraft with another door only save few minutes with the disadvantage of increase the weigh of the aircraft

- Change service points in the aircraft is not critical, as the processes related with these points are not critical

The entire transcription of the interview is written in Appendix C.

9 Innovative conventional aircraft configurations

9.1 Conventional configuration

During about fifty years, civil aircraft present similar configurations with only few differences related with optimization studies of each aircraft manufactured company. In case of single aisle aircraft these differences are less pronounced, that leads to a conventional configuration which has great advantages over all the other possible choices. (**Gomez 2009b**)

A conventional configuration has all of these three main attributes: fuselage, wing and the empennage at its rear end.

Furthermore, LCA use conventional configurations aircraft with the following characteristics in common: (**Roskam II 1997, Scholz 2009**

- They result from aerodynamic, weight, utility and cost optimization studies
- Fuselage is built as a cylinder with constant circular cross-section to withstand internal pressurization
- Nose and tail parts of semi conical shape
- Two engines most placed under the wing
- Landing gear in tricycle configuration fully retractable. The nose gear into the fuselage, and the main landing gear into the wing or the fuselage in especially fairings
- Horizontal and vertical empennage at the fuselage tail. The most common shapes: conventional tail (70%) or T-tail shape
- Wing optimized for aerodynamic performance and low weight, backswept for high subsonic cruise speed. Positioned under the main cabin deck in low wing arrangement in most of the cases or in high wing arrangement in some cases
- High-lifts system. Trailing edge flaps in 25 % to 30 % of the local wing chord, and slats in 10 %
- Fuel tanks inside the wing and the wing box (central part of the wing)

- For low wing aircraft, extending the wing platform rearward at the inner wing to allow the integration of landing gear and flap

- The low wing divides the fuselage in two decks. The main deck contains cockpit crew and passengers cabin; the low deck, called cargo deck, is cut into two compartments by the wing box, central part of the wing across the fuselage

- Payload of 120 to 180 passengers

But nowadays, other aircraft of similar size makes use of different approach, as the case of business jet or military transports, that have proven their efficiency, reliability and feasibility.
Thus, it is logic try to optimize the configurations with the goal of ground handling costs and TR time optimization.

9.2 Airbus A320 family and Boeing 737 family configurations

The sizes and other features between the different aircraft inside one family change. However, the general configuration, wing, empennage and fuselage diameter remain constant, as it shown in Figure 9.1.

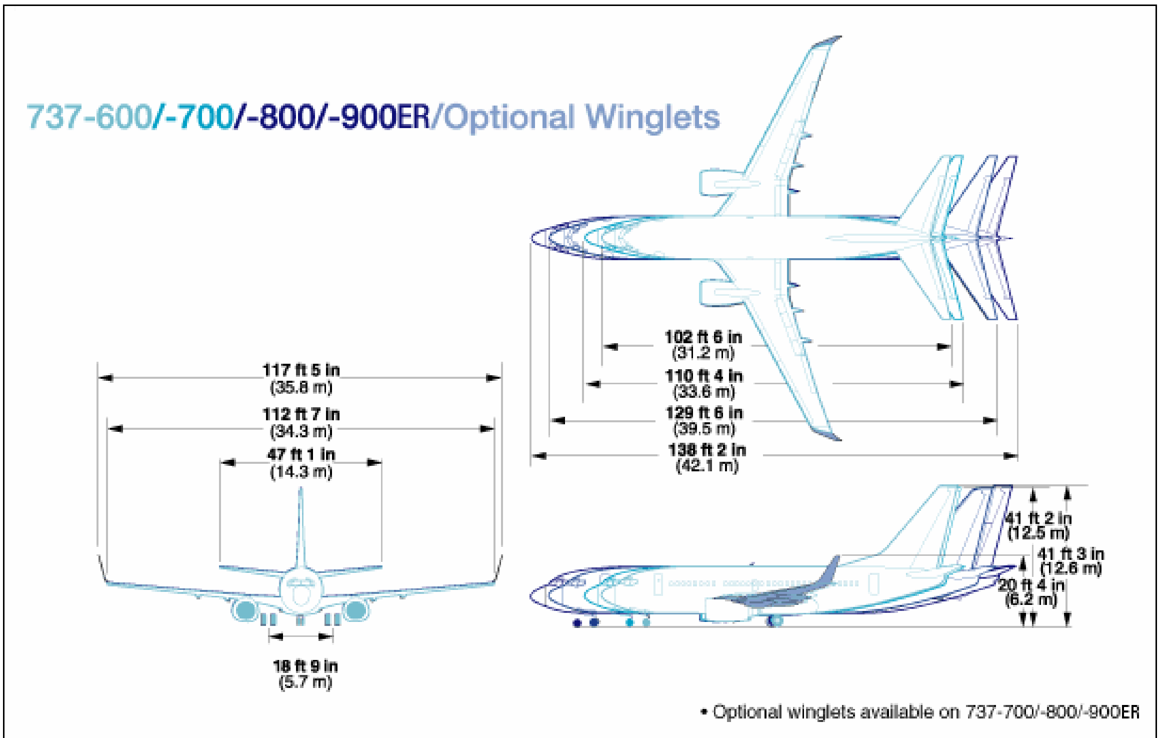

Figure 9.1 General exterior arrangement of the Boeing B737 family (**Boeing 2005**)

Both aircraft families have similar configuration, with the main characteristics discussed on the previous Chapter 9.1:

- Cylindrical fuselage divided in two decks
- Two engines placed under the wing
- Nose and tail parts of semi conical shape
- Low wing position
- Conventional tail
- Tricycle landing gear retractable in the wing (main landing gear)

The general external dimensions of the A320-200 and B737-700 to are shown in Figure 9.2

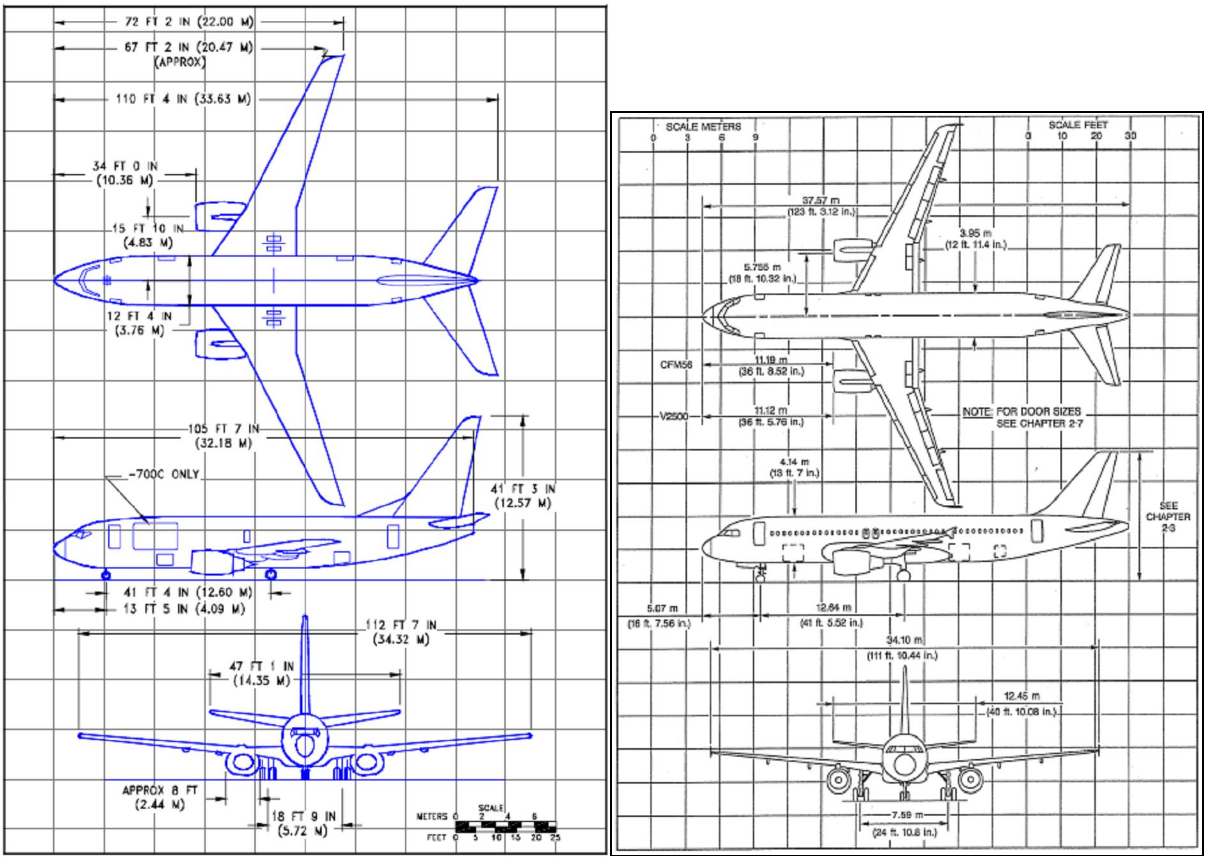

Figure 9.2 General dimensions of the B737-700 (left) and A320-200 (right) (**Boeing 2005, Airbus 1995b**)

9.3 Optimizing for ground handling

The main changes in the external configuration which lead to a better GH aircraft are: (**Gomez 2009b**)

- Placing fuselage closer to the ground
- Easily accessible cargo hold doors and service points
- Service points area clearance. No collision of vehicles with lifting surfaces or engines
- Service points separated to allow the activity of several processes at once
- FWD and AFT cargo holds connected
- Additional door for faster and easier boarding

9.4 Possible modifications

Actually, the number of options to choose is limited by development cost, risk, manufacturing reasons and market acceptance. This Chapter presents the advantages and disadvantages of different aircraft configurations based on the previous Chapters. (From **Roskam II 1997**, **Scholz 2009, Gómez Aircraft)**

9.4.1 Placing fuselage closer to the ground

As can be observed in A320 and B737 aircraft (Figures 9.2), the lowest element of them influencing the undercarriage height are the engines placed below the wing. Nowadays, new engines have higher by-pass ratio which need bigger ground clearance, moving fuselage even further away from the ground.

There are some ways to achieve low height for the aircraft:

- High wing configuration
- Place the engines at fuselage tail
- Place the engines above the wing

<u>High wing configuration</u>

The high wing configuration is typical in the freighter aircraft, especially in the military cargo aircraft.

The advantages are:

- Undisturbed cargo floor
- Low fuselage, close to the ground
- Good load ability, with easy and fast access via tail cargo ramp
- Sufficient space for integration of high by-pass ratio engines
- All engines placements possible with preserving big ground clearance
- Less restriction for wing platform
- Shorter landing gear
- Possibility of placing the third passenger door in the middle of the fuselage
- Well known, proven in many airplanes like military cargo jets: Lockheed C-141 Starlifter, Lockheed C-5 Galaxy, McDonnell Douglas C-17, Antonov An-124 Ruslan; and passenger jets: BAe 146, Do-328JET, Antonov An-148, etc

The disadvantages are:

- Heavier fuselage
- Limited cabin height or large fairing
- Higher drag due to the bulge created by the wing at the top of the fuselage
- Complex landing gear:
  - High mass if is retracted into the wing
  - Retracted into the fuselage the gear track is limited and dependant on fuselage width
  - Bigger fairings which increase the drag
  - Occupying place in the fuselage belly under the passenger cabin floor
- Less ditching capability

<u>Engines at fuselage tail</u>

This configuration is the second most popular among commercial jets, which consists of placing the engines at the both sides of the tail.

It provides sufficient engine ground clearance while the landing gear is most commonly only as long as necessary to prevent flaps from touching the ground.

The advantages are:

- Clean aerodynamic of the wing
- Low wing configuration
- None or favourable influence of the engines on wing cruise efficiency
- Easy balancing of the aircraft with the wing closer to the tail

- Landing gear shorter and lighter, easily integrated in the wing
- Well known solution, proven in many business jets and passengers jets: Embraer ERJ-145 series, Bombardier CRJ, Fokker F-50, Mc Donnell Douglas DC-9, Boeing 727, etc

The disadvantages are:

- More difficult engine access for maintenance purposes
- Weight and balance more careful
- Heavier tail cone
- Higher flexion momentum in the wing fitting. In flight, if the engines are on the wing, their weigh help to compensate the lift force momentum in the wing fitting

Engines above the wing

Another way to place the engines further from the ground is mounting them on the wing, but on pylons shifting them up and behind (Honda Jet N420HA), or directly above the leading edge (Boeing YC-14, McDonnell Douglas YC-15).

The advantages are:

- Potential for using Coanda effect externally blown flaps
- Low wing configuration
- Lower noise level on the ground, while the wing is located between engines and the ground
- Engines at least partially protected by the wing from the debris from the ground
- Landing gear shorter and lighter, easily integrated in the wing

The disadvantages are:

- The engines disturb the external surface of the wing, thus increment the cruise drag, especially in transonic regime, where the local flow speed is higher than the free stream speed
- More difficult engine access for maintenance purposes
- Much less proven than previous configuration

9.4.2 Empennage configuration possibilities

There are many possibilities of empennage shapes. Bellow the most common are described.

Conventional Tail

Approximately 70 % of aircraft are fitted with this empennage configuration.

The advantages are:

- Provides appropriate stability and control
- Most lightweight construction in most cases
- Probably lowest possible cost
- Larger vertical tailplane height
- Well known, proven in many airplanes

The disadvantages are:

- The downwash of the wing is relatively large in the area of the horizontal tailplane
- Rear engines cannot be teamed with conventional tails
- Not possible access via tail cargo ramp
- The horizontal tailplane can be disturbed by the stream of hot high velocity air expelled by the engines

T-tail

In this configuration the horizontal tailplane is mounted at the top of the vertical tailplane.

The advantages are:

- The vertical tailplane can be smaller
- The downwash of the wing has less effect in the horizontal tailplane
- Horizontal tailplane more effective and smaller
- Less tail buffeting in the horizontal tailplane
- Space for the engines at the rear
- Possible access via tail cargo ramp

The disadvantages are:

- Heavier because the vertical tailplane has to support the horizontal
- Problems with the deep stall, in case of high angle of attack the horizontal tailplane can be caught up in the airflow behind the wing and be blanketed

9.5 SUMO software: sketches of aircraft configurations

The three-view drawings for the innovative aircraft configurations have been created with the software program SUrface MOdeling tool for aircraft configurations (SUMO) v.1.9.1

SUMO is free software under the terms of the GNU General Public License. In free software is a matter of the users to run, copy, distribute, change and improve the software. (**GNU 2009)**

The aerodynamic surfaces are developed with geometrical parameters such as NACA airfoil, height, length, rotation, etc, and their positions respect of the aircraft nose. Figure 9.3

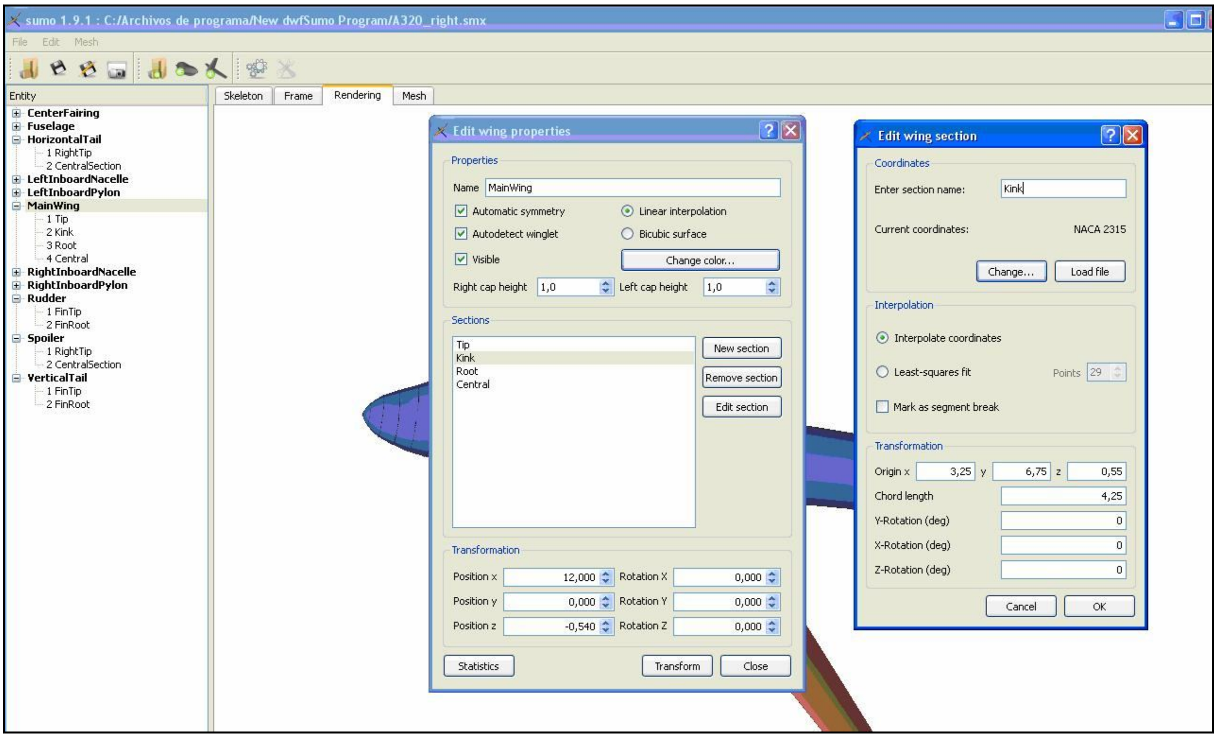

Figure 9.3 Creation of aerodynamic surfaces with SUMO program

The rest of the external surfaces, as the fuselage or the engines, are developed with geometric parameters and sketches of the skeleton and frame are carried out with the mouse. Figure 9.4

The final external structure of the aircraft is created assembling the surfaces.

Therefore, aircraft sketches are quickly originated with this tool.

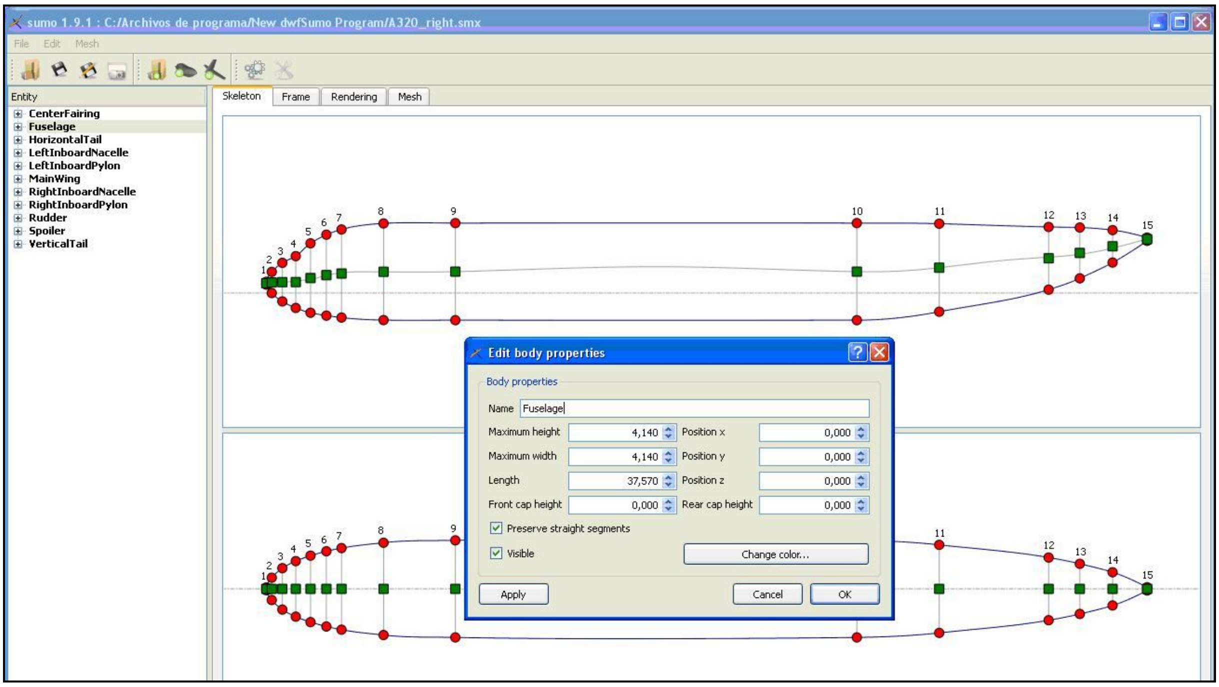

Figure 9.4 Creation of external surfaces with SUMO program

9.6 Analysis of new innovative configurations

Beginning with a reference aircraft with a configuration very similar to the Airbus A320, some changes are made in order to create new configurations in form of sketches within a GH point of view.

The present Chapter describes these new innovative configurations regarding with their GH characteristics.

The configuration and external dimensions of the Airbus A320 are described in Chapter 3 and Appendix D.

The reference aircraft is represented in the following Figure 9.5 in three-view drawings with a perspective camera.

The external surfaces are drawn with grey colour. The changes have been done in the initial configuration are represented by turquoise blue with the purpose of emphasize the difference with the initial configuration.

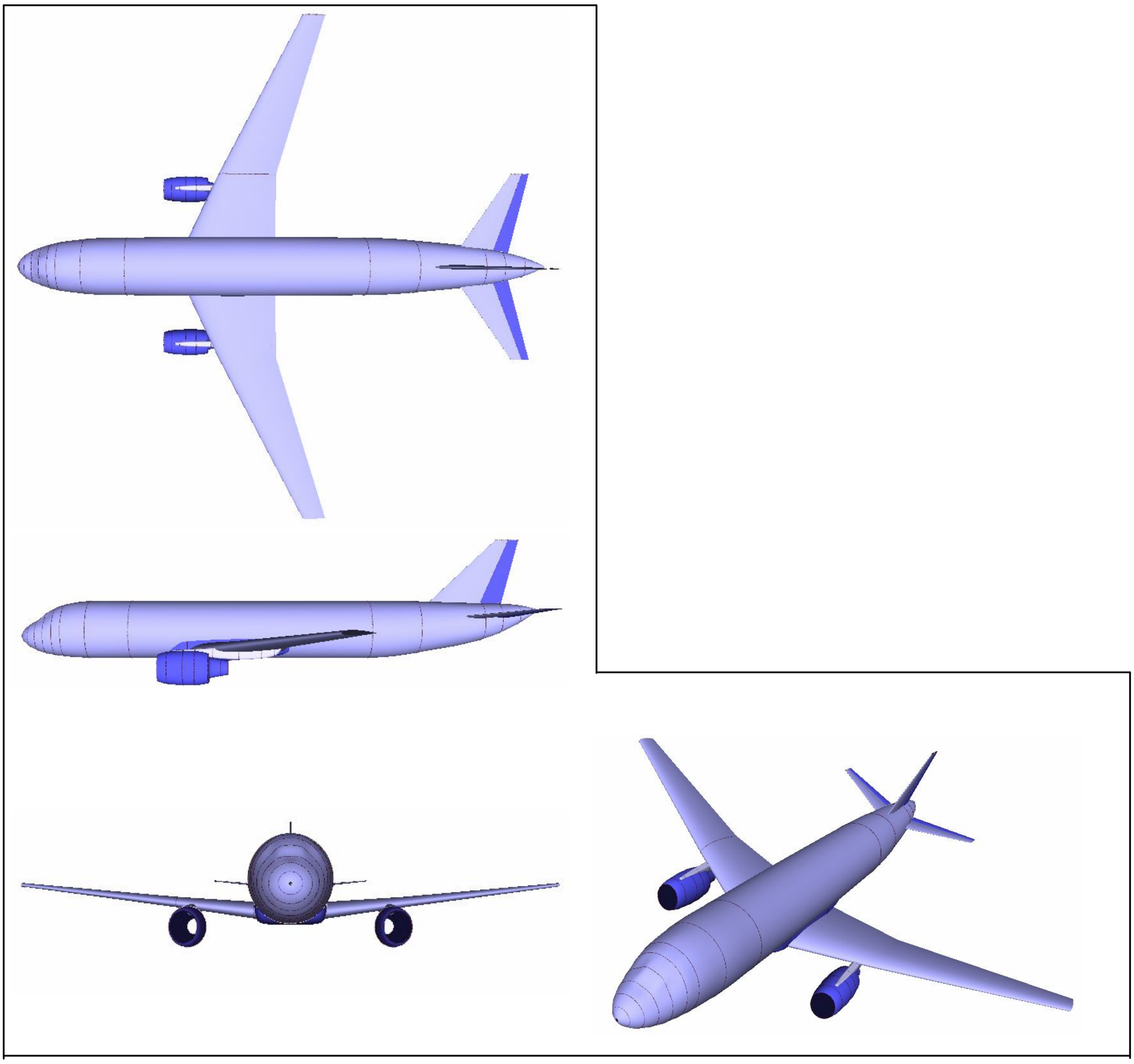

Figure 9.5 Reference aircraft configuration

Configuration 01

The configuration 01 presents a high wing configuration, same conventional tail and engines under the wing. See Figure 9.6

The GH advantages respect the reference aircraft are:

- The fuselage can be placed closer to the ground, but not too much due to the fact the engines are placed under the wing
- Undisturbed cargo floor, good load ability. Only necessary one door and one belt for the cargo process instead of AFT and FWD doors. Easy and fast access via tail cargo ramp
- Big ground clearance
- Less restriction for wing platform

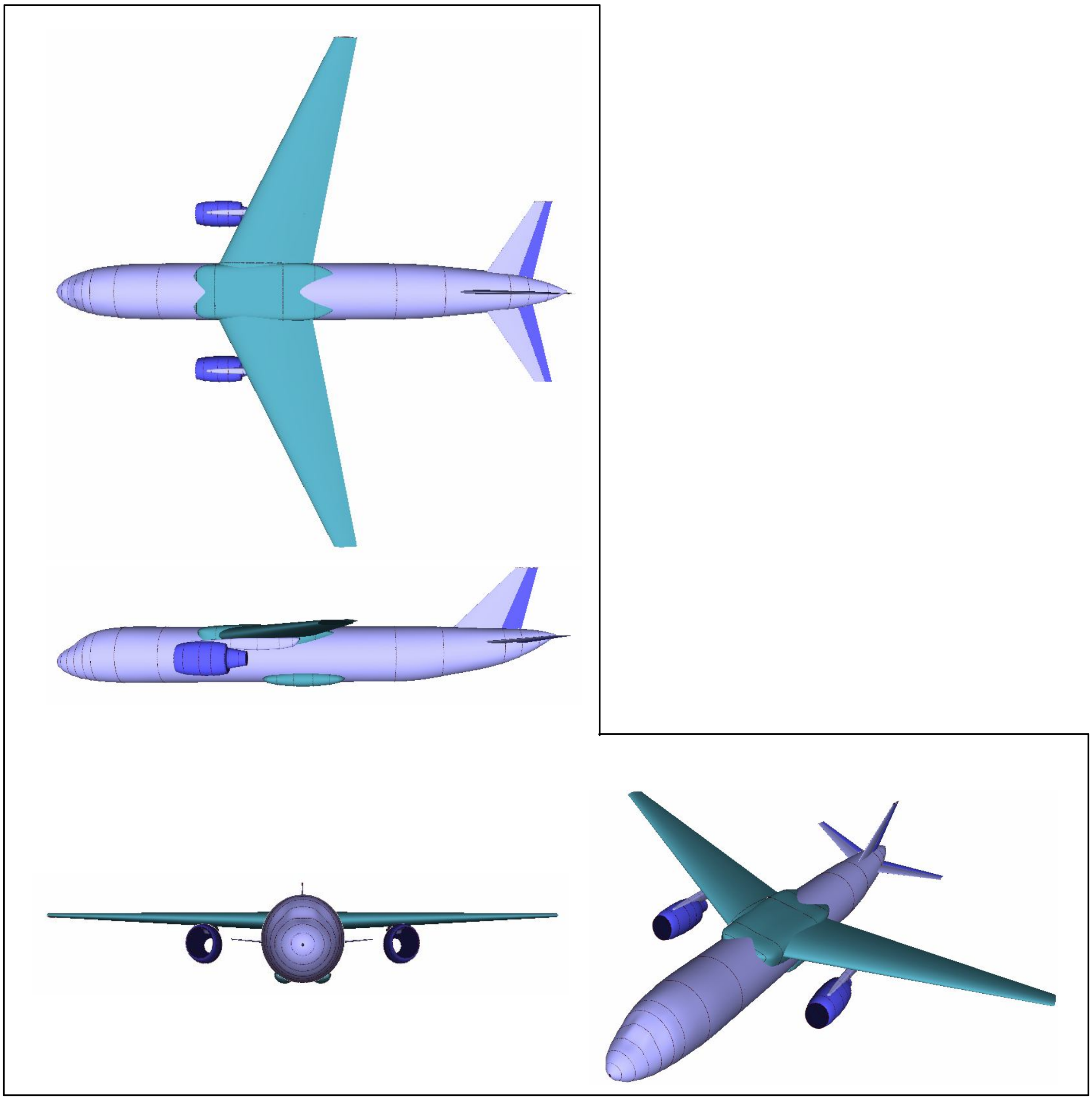

Figure 9.6 Configuration 01

Configuration 02

The configuration 02 presents a high wing configuration and T-tail. The engines are placed under the wing. See Figure 9.7

The GH advantages respect the reference aircraft are:

- Same advantages with high wing configuration as AGHIAC 01
- Possible access via tail cargo ramp
- Bigger cone tail clearance

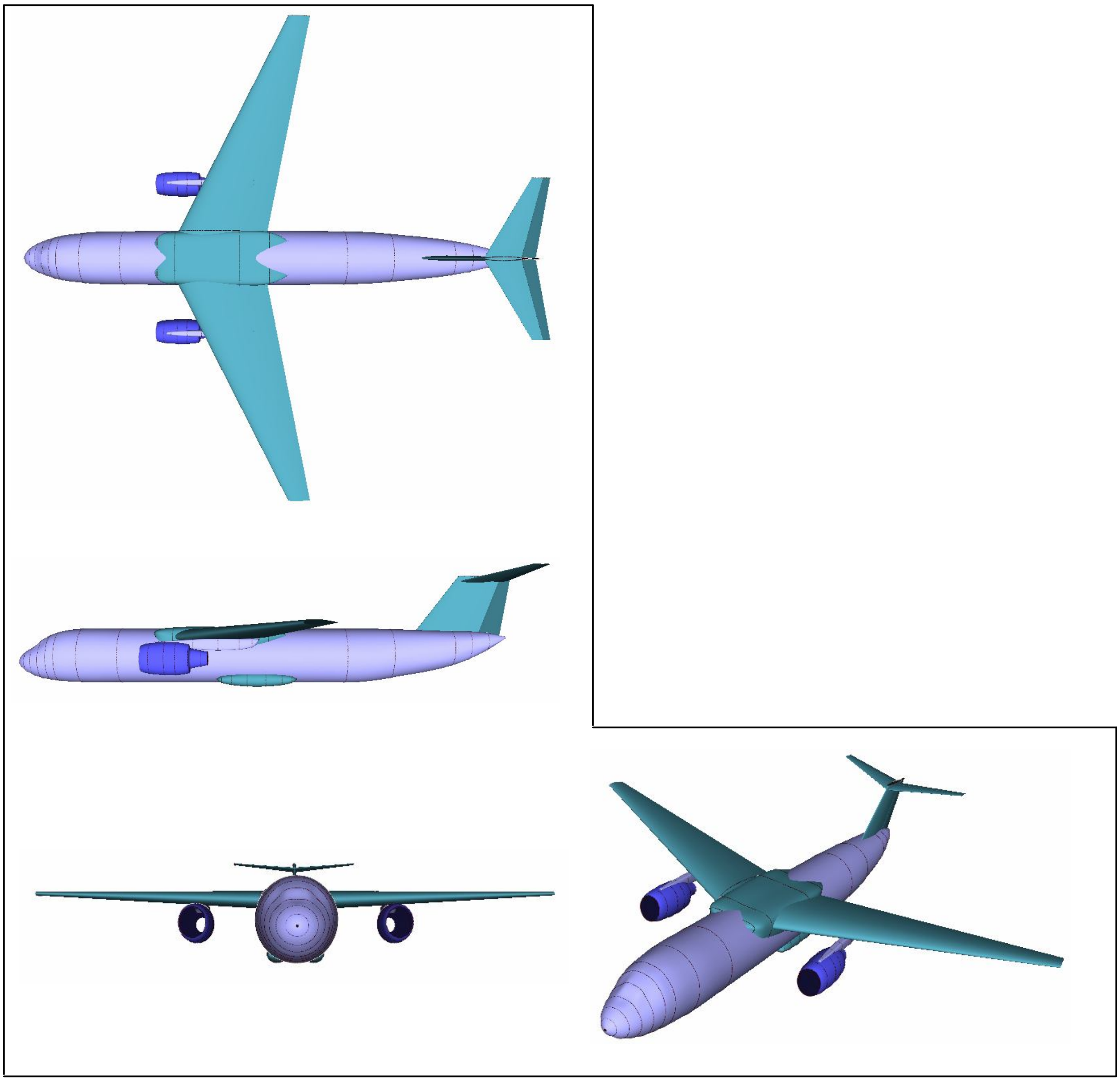

Figure 9.7 Configuration 02

Configuration 03

The configuration 03 presents a high wing configuration, T-tail and engines at fuselage tail. See Figure 9.8

The GH advantages respect the reference aircraft are:

- The fuselage can be placed even closer to the ground
- Same advantages with high wing configuration as AGHIAC 01
- Clearance under the wing. More space for vehicles
- Better handling for cone tail due to bigger cone tail clearance
- Possible access via tail cargo ramp

- Undisturbed cargo floor
- Possibility of placing the third passenger door near to the middle of the fuselage, owing to the wing is closer to the tail

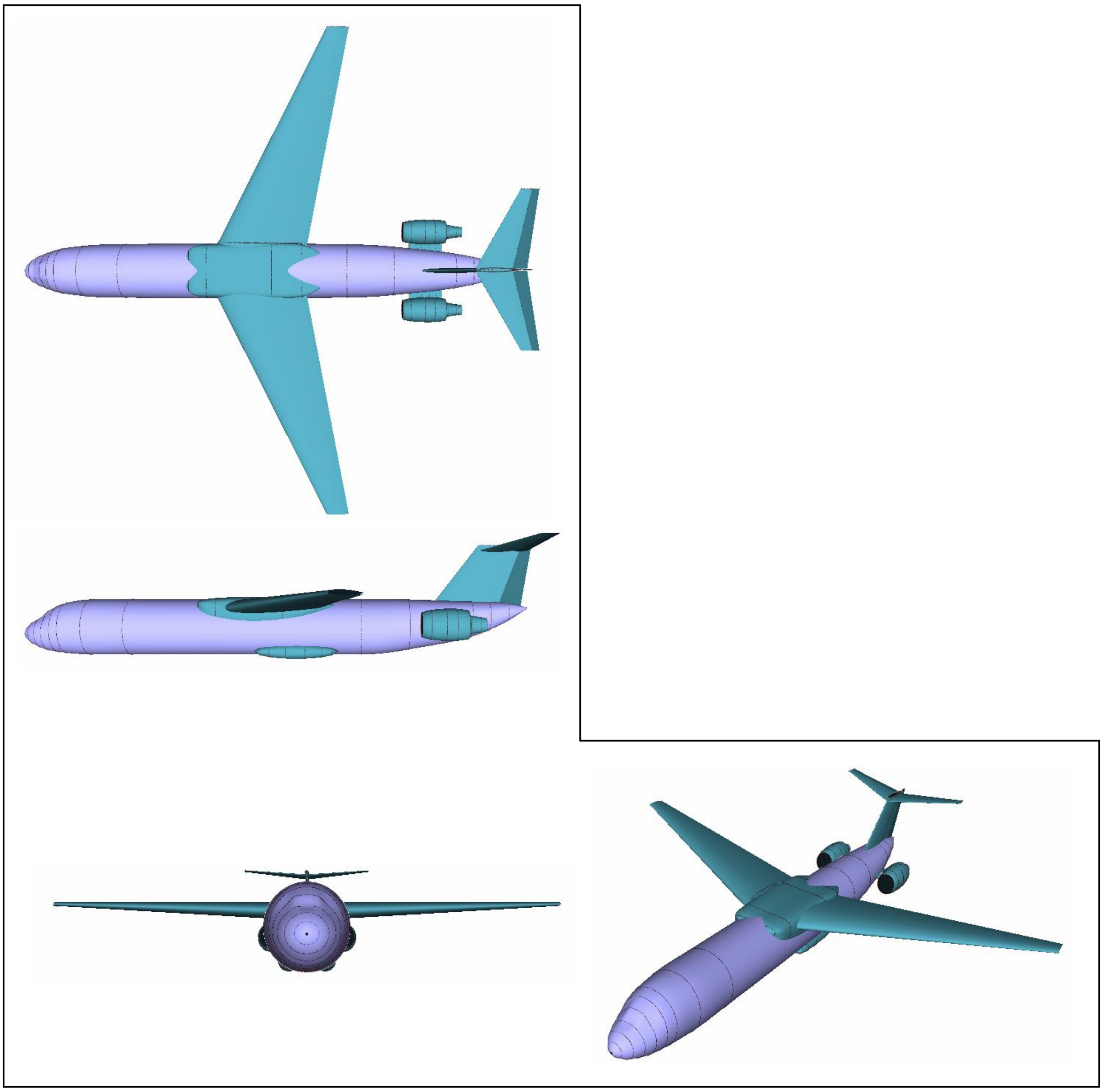

Figure 9.8 Configuration 03

Configuration 04

The configuration 04 presents a low wing configuration, T-tail and engines at fuselage tail. See Figure 9.9

The GH advantages respect the reference aircraft are:

- Better handling for cone tail. Possible access via tail cargo ramp

- Low wing configuration, but also closer to the ground owing to the engines are situated at the fuselage tail
- Same advantages with T-tail configuration as AGHIAC 03
- Even bigger cone tail clearance, as the engines are situated higher than AGHIAC 03
- Possible access via tail cargo ramp
- Longer FWD cargo hold as the wing is positioned closer to the tail
- Possibility of placing the third passenger door in the middle of the fuselage

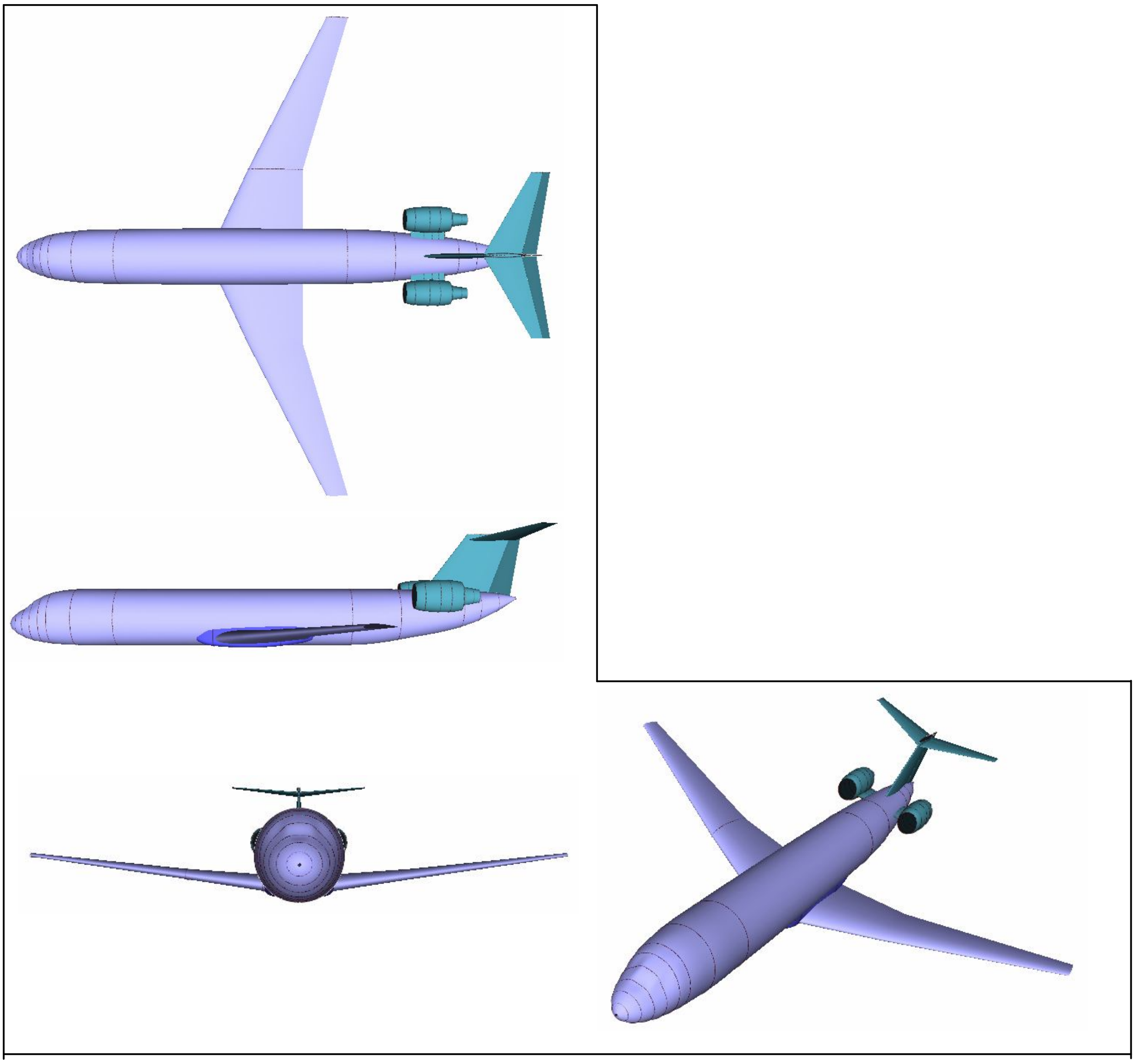

Figure 9.9 Configuration 04

<u>Configuration 05</u>

The Configuration 05 presents an extreme low wing configuration, T-tail and engines over the wing. See Figure 9.10

The GH advantages respect the reference aircraft are:

- Low wing configuration, but also closer to the ground owing to the engines are situated above the wing
- Same advantages with T tail configuration as AGHIAC 03
- Better handling for cone tail due to bigger cone tail clearance
- Possible access via tail cargo ramp
- However, less ground clearance under and around the wing

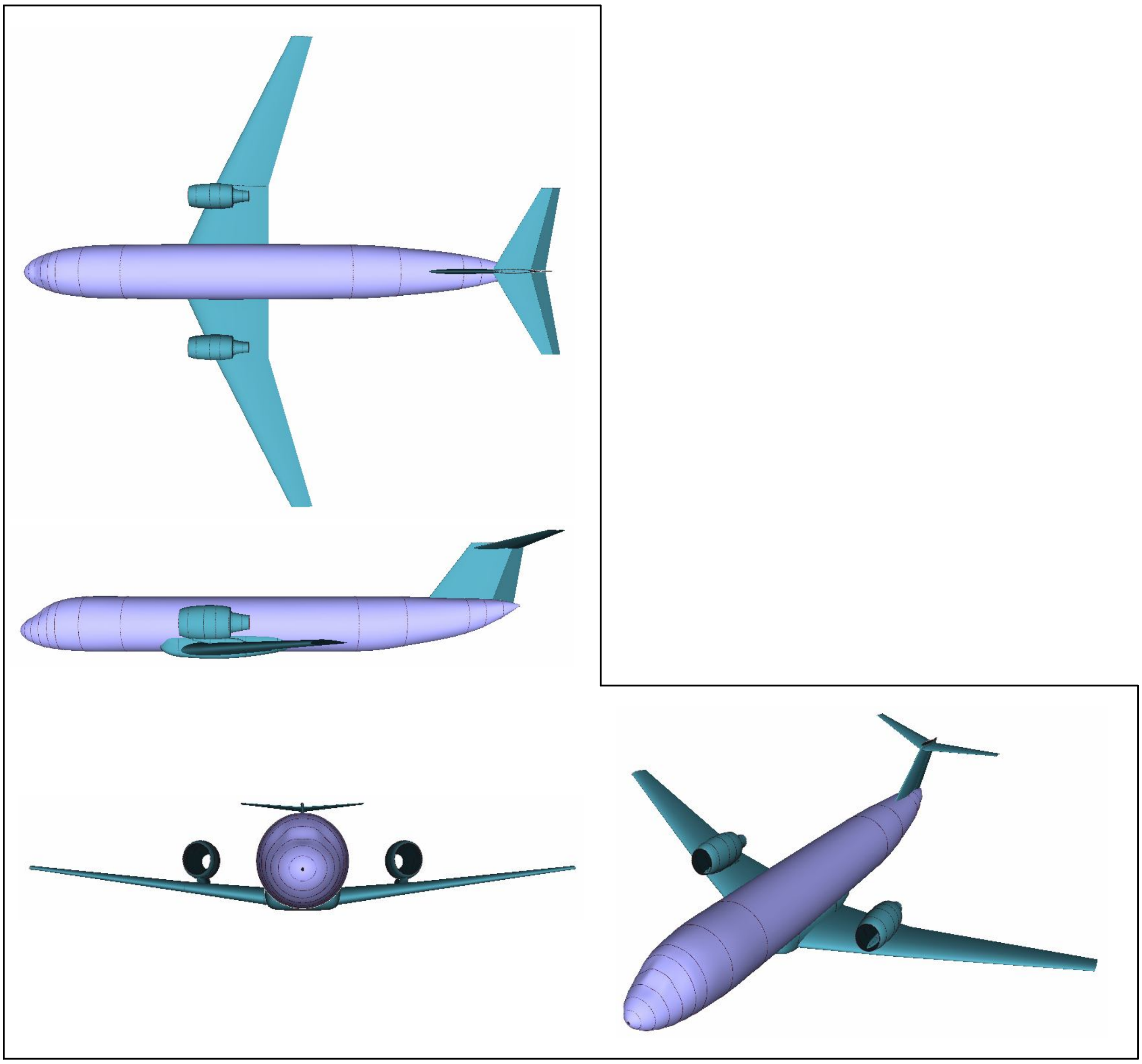

Figure 9.10 Configuration 05

Configuration 06

The configuration 06 presents a Z-wing configuration, T-tail and engines at fuselage tail. See Figure 9.11

The GH advantages respect the reference aircraft are:

- Clearance under the wing. More space for vehicles at the left side.
- Same advantages with T tail configuration as AGHIAC 03.
- Third boarding door possibilities.
- However, the sill height cannot be decrease because the landing gear integration.

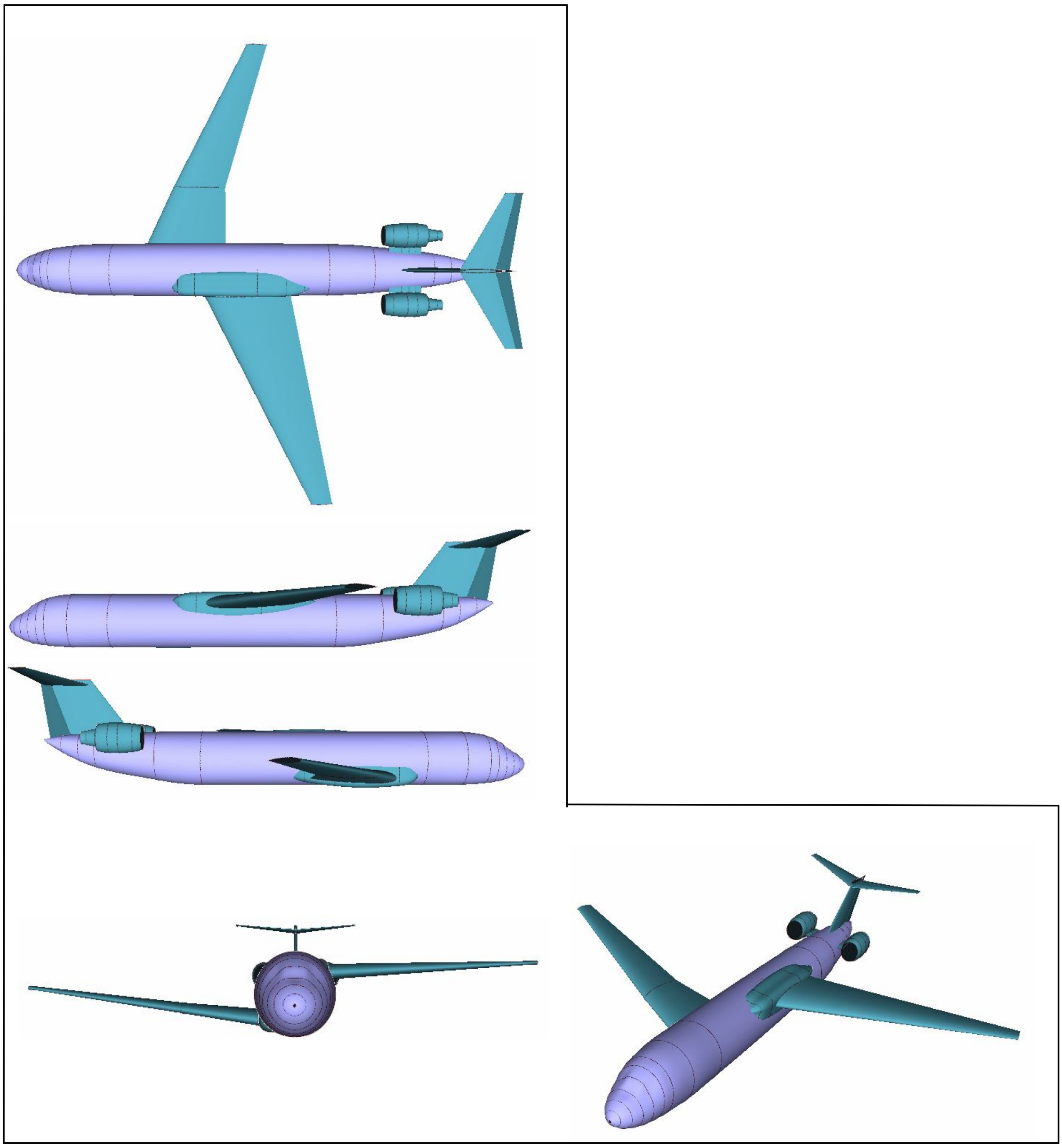

Figure 9.11 Configuration 06

9.7 Innovative aircraft configuration selection

To select one configuration, besides GH point of view, it is necessary to take in account many factors like the aerodynamic, weight, utility, static and dynamic stability, control, costs, and maintenance and so on.

The configuration 05 has big disadvantages in aerodynamic and maintenance characteristics. The configuration 06 has problems in stability and control, and it is probably heavier. Furthermore, they are not enough proved configurations and they are not attractive for the passengers who normally prefer typical configurations. Because of that, configurations 05 and 06 are not selected.

The configurations 01, 02 and 03 present high wing configuration. All of these configurations have different advantages, but with the GH intention, the configuration 03 is the best selection, due to its higher clearance under the wing as the engines are situated at the tail cone, its fuselage is situated closest to the ground than in other cases, and it has T-tail which allows the installation of a cargo tail ramp.

The configuration 04 is a good selection as well. It presents low wing configuration, which is important for passengers transport as the cabin is undisturbed, and the same advantages with the T-tail as configuration 03, but with even bigger cone tail clearance, as the engines are situated higher.

Therefore, configuration 03 and configuration 04 could be good configurations to create a new aircraft design within GH point of view.

10 Discussion and future works

As mentioned in this report, the study of the turnaround features should be considered as a first step in investigation and evaluation of aircraft optimized for ground handling.

The real-time data of turnaround analyzed in this thesis belonged to one airport. However the ground handling procedures are strongly depending on the handling companies practices and operating circumstances which may result in different procedures. Hence, the statistical models should be implemented with more data from other airports and from different handlings companies.

This thesis is focused in LCA which usually prefer the use of secondary airports because of the following main reasons:

- Parking on apron in front of terminal and parallel to the terminal building can be possible. This enables the movement of the aircraft without the utilization of pushback. Thus, there is a cost reduction in terms of equipment and manpower. (**Gomez 2009a**)

- The aircraft can be parked at a walking distance to the terminal gate. Thus the transport of passengers by bus, between the terminal gate and the aircraft, is eliminated. Therefore there is a cost reduction in terms of equipment and manpower. (**Gomez 2009a**)

- The airport fees of secondary airports are usually less cost than for big airports.

- In secondary airports there is more flexibility to change the schedules flights or to create new ones.

Owing to these reasons, the statistical models should be based in secondary airports to represent better turnaround of aircraft operated by LCA.

The level of reliability of the statistical equations is related with the amount of data analyzed, that means the number of airports studied. Therefore, the statistical models created in this thesis should be adjusted and tested with more data from different airports. It is the costumer decision which level is required.

Once the required level of the equations is reached, the ground handling software simulators should use the parameters from the statistical models for the simulations.

Turnarounds of the innovative configurations sketches created based in the Airbus A320 in Chapter 9 have to be tested and simulated with software programs.

Although SIMBA is a good tool to simulate turnaround, it does not give enough results to compare one aircraft to others.

At the writing of this thesis, CAST ground handling is not yet available. But definitely, CAST Ground Handling will be the indicated tool to analyse and test the turnaround of these innovative configurations.

Once the innovative configurations sketches are tested and the most promised selected, it is necessary to conduct a preliminary sizing of them.

The preliminary sizing of the innovative configurations is necessary, because the improve of the ground handling features can become other features of the aircraft worst, for example the weight can be increased, the stability and control can be reduced, etc. Therefore, it is necessary to maintain a holistic view on the aircraft design.

Once the innovative aircraft is selected, it is totally necessary to obtain the aircraft DOC, in order to check that the DOC regarding ground handling operations are reduced, as well as that the other DOC types, as maintenance or fuel costs, are not increased, or just in a quantity less than the reduction of ground handling costs.

11 Summary

This master thesis deals with the analysis of turnaround procedures.

The investigation of turnaround procedures includes the description of the ground handling processes and equipments existing nowadays, as well as a normal turnaround sequences, analyzing the critical paths of it.

The turnaround of an aircraft can be described in terms of separate processes that have to be carried in a chronological order. The main ground handling procedures are the passengers deboarding/boarding, cargo exchange, refuelling, ground power, pushback and pre-flight inspections. Those processes have to be carried out at every aircraft turnaround, except refuelling and pushback which in some cases cannot be necessaries. Furthermore, the passengers deboarding/boarding, the cargo exchange and the refuelling are critical paths of a turnaround.

Continuing with the turnaround investigation, ground handling features of the typical commercial aircraft preferred by LCA have been studied and compared.

Besides, a proper study of turnaround requires an analysis and research of real turnarounds that take place in airports. Therefore the data collected from the videos recorded in Berlin – Schönefeld Airport has been analyzed.

The analysis of this data has allowed the creation of mathematical equations and statistical models which represent typical ground handling procedures. These equations define the time to carry out each process with representative rates.

SIMBA and CAST are software programs which can simulate aircraft turnarounds. Both programs are described and investigated. The utilization of the tools has been explained defining the input data required, how to work with them and the results that could be obtained.

In case of SIMBA, a simulation of a turnaround has been conducted for a reference aircraft based on the Airbus A320. As input data for the simulation, the statistical rates and equations found out from the videos data have been used. The results of the simulation have been analyzed. The simulation results have been the turnaround costs, the turnaround bar chart and the compatibility of the ground handling vehicles movements.

In combination with the simulations and studies, expert interviews are a good way to achieve the objective of deep understanding in ground handling,. An interview to Prof. Dr.-Ing G.

Konieczny was conducted. His point of view about turnaround was given. This information was considered in the studies of this thesis.

The general features of a conventional aircraft configuration are described regarding with ground handling characteristics. The possible modifications of the conventional configuration have been studied in order to improve and optimize the turnaround procedures.

Innovative configurations, in form of sketches, are proposal and described with the assistance of three-view drawings. Their main ground handling features are explained.

Finally, two of these innovative configurations created are selected as the most promising, explaining the reasons of the selection.

12 Conclusions

The following main conclusions are drawn from this thesis:

1. Turnaround processes. The statistical models and mathematical equations which represents the ground handlings process are summarized in the following Table 12.1

Table 12.1 Statistical models

Process	**Rate**	**Equation**
Passengers Deboarding	$k_{pax,outR}$ = 34 pax/min	$t_{pax,deb} = \frac{n_{pax,out}}{k_{pax,outR}}$
Passengers Boarding	$k_{pax,inR}$ = 20 pax/min	$t_{pax,boa} = \frac{n_{pax,in}}{k_{pax,inR}}$
Bulk cargo: Unloading	k_{ULD} = 218.84 kg/min	$t_{ULD} = \frac{m_{cargo}}{k_{ULD}}$
Bulk cargo: Loading	k_{LD} = 132.4 kg/min	$t_{LD} = \frac{m_{cargo}}{k_{LD}}$
Container cargo	k_{LDc} = 0.45 containers/min	$t_{LDc} = \frac{n_{container}}{k_{LDc}}$
Refuelling	-	$t_f = \frac{1}{-0.036} \cdot Ln\left(1 + \frac{V_f \cdot (-0.036)}{1475}\right)$
Catering	k_{CAT} = 0.86 trolleys/min	$t_{CAT} = \frac{n_{trolleys}}{k_{CAT}}$
Ground Power	-	Almost the duration of the TR
Potable Water Service	FR_{PW} = 63.14 l/min	$t_{PW} = \frac{V_{PW}}{FR_{PW}}$
Lavatory Water Service	FR_{WWS} = 38 l/min	$t_{WWS} = \frac{V_{WWS}}{FR_{WWS}}$
Pushback	-	$t_{PB} = \frac{d_{PB}}{v_{PB} \cdot 60}$
Cleaning	No real data available	No real data available

2. The most promising innovative configurations to improve ground handling procedures and turnaround costs are: the configuration 03 which presents high wing configuration, T-tail and engines at fuselage tail; and the configuration 04 which presents low wing configuration, T-tail and engines at fuselage tail.

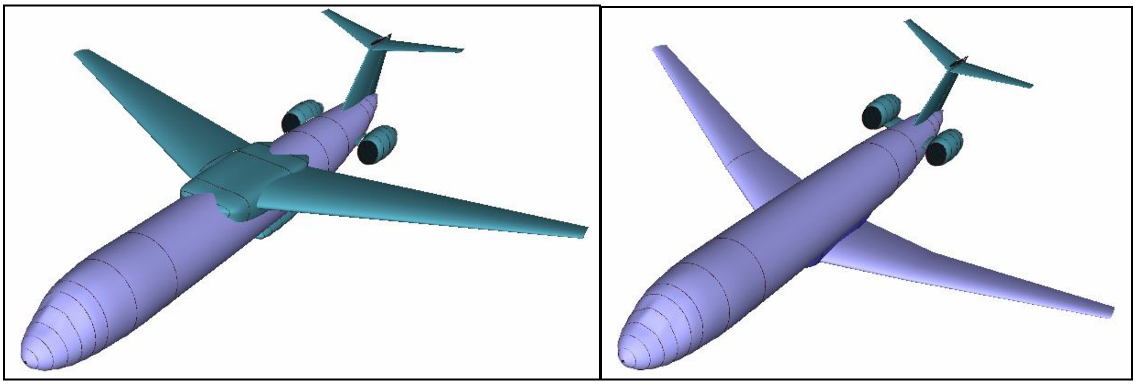

Figure 12.1 Configurations selected for improve the turnaround procedures (03 left, 04 right)

3. Ground Handling Processes comparison of the aircraft preferred by LCA. The time for carry out each ground handling process of those aircraft, based in their technical manuals from manufactures, are summarized in the following Table 12.2

Table 12.2 GH processes of the most popular commercial jets transport

Total time of the GH process min	**Airplane** A319	A320	B737-700	B737-800
Deboarding	9,1	9,4	8	10
Boarding	11,4	15	12	15
Cleaning	13,4	16,8	14	15
Refuelling	15,6	13 (60%)	13	13
Unloading and Loading	29,5	39	26	29
Potable Water Service	6,5	6,5	6	6
Waste Water Service	6,5	6,5	14	14
Turnaround time	30	40	32	38

4. Time bar chart of the SIMBA simulation of a turnaround for a reference aircraft based in the Aribus A320. The ground handling characteristics are based in the statistical models created in this thesis. The total time of the turnaround is 38 minutes.

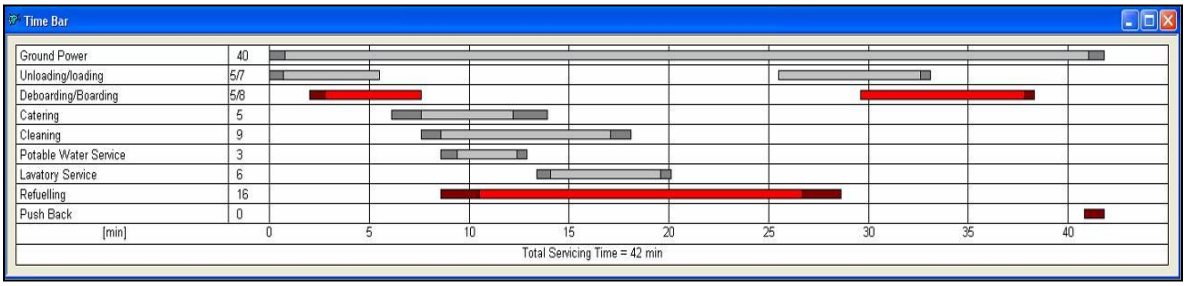

Figure 12.2 SIMBA time bar chart of the reference aircraft simulation

5. Turnaround costs of the SIMBA simulation for the reference aircraft. The input data is taken from Salzburg Airport (**SZG 2007**). The total cost of the turnaround simulated is 560.14 $.

Handling Costs

Activity	Crew size	Time on aircraft [min]	Preparation Time [min]	Man minutes [min]	Labour cost/hour [$/h]	Labour cost [$]	Labour add. cost [$]	Equipment cost/hour [$/h]	Equipment cost [$]	Equipment add. costs [$]	Costs [$]
Ground Power	------------	42	------------	0	0.00	0.00	0.00	38.86	27.20	0.00	27.20
Unloading/loading	3	33	10	129	9.05	19.00	120.00	31.54	22.60	0.00	161.60
Deboarding/Boarding	------------	36	------------	0	0.00	0.00	0.00	145.00	87.00	42.22	129.22
Cleaning	3	10	10	60	11.80	12.00	0.00	0.00	0.00	0.00	12.00
Potable Water Service	1	4	10	14	11.80	3.00	0.00	43.66	10.19	0.00	13.19
Lavatory Service	1	7	10	17	11.80	3.00	0.00	45.73	12.96	0.00	15.96
Push Back	2	1	5	12	9.05	2.00	0.00	19.24	1.92	0.00	3.92
Luggage Transport	1	33	2	35	22.50	13.00	0.00	51.36	29.96	0.00	42.96
Total ramp handling costs										=	406.05
Terminal handling costs										+	90.67
Total ground handling costs										=	496.72
Catering items										+	12.42
Fuel amount										+	51.00
Total costs										=	560.14

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Figure 12.3 SIMBA turnaround costs of the reference aircraft simulation

Acknowledgements

First, I would like to thank my parents for their support, patience, help, advices, and economics efforts to let me study all these years. Without your appreciation and words of encouragement I could never have finished my studies writing my final thesis in Germany.

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Appendix A

Turnaround video data

This appendix summarizes in tables the data obtained with SXF Airport videos and calculations created with it for statistical purposes.

A.1 General data

Table A.1 Flights

Airport Apron	Air Company	Flight	Type of Aircraft	Operation Type
Position 50	Germanwings	4U 012-4013	A319	Low Cost
	Germanwings	4U 014-4015	A319	Low Cost
	Germanwings	4U 016-4017	A319	Low Cost
	Germanwings	4U 8135-8126	A319	Low Cost
	Germanwings	4U 8125-8124	A319	Low Cost
	Germanwings	4U 2002-2003	A319	Low Cost
	Germanwings	4U 2004-2005	A319	Low Cost
Position 51	Germanwings	4U 814T-8124	A319	Low Cost
	Germanwings	4U 2014-2015	A319	Low Cost
	Germanwings	4U 8057-8134	A319	Low Cost
	Germanwings	4U 8987-8128	A319	Low Cost
Position 61	Easyjet	EZY 8414-4593	A319	Low Cost
	Easyjet	EZY 4256-4573	A319	Low Cost
	Easyjet	EZY 4668-4511	A319	Low Cost
	Easyjet	EZY 4580-4613	A319	Low Cost
	Easyjet	EZY 4528-4555	A319	Low Cost
	Easyjet	EZY 4267-4268	A319	Low Cost
Position 62	Ryanair	FR 5492-5493	B737-700 Biz-Jet	Low Cost
	Ryanair	FR 8558-8559	B737-700 Biz-Jet	Low Cost
	Easyjet	EZY 4532-4621	A319	Low Cost
	Easyjet	EZY 1524-1607	A319	Low Cost
	Easyjet	EZY 4622-8417	A319	Low Cost
	Easyjet	EZY 4702-4637	A319	Low Cost
	Ryanair	FR 1305-1306	B737-700 Biz-Jet	Low Cost
	Ryanair	FR 1638-1639	B737-700 Biz-Jet	Low Cost

Position 63	Easyjet	EZY 4674-4633	A319	Low Cost
	Easyjet	EZY 4686-4634	A319	Low Cost
	Easyjet	EZY 6867-6868	A319	Low Cost
	Easyjet	EZY 7223-7224	A319	Low Cost
	Easyjet	EZY 4265-4266	A319	Low Cost
	Easyjet	EZY 4636-4605	A319	Low Cost
	Easyjet	EZY 2107-2108	A319	Low Cost
Position 55B	Macedonian Airlines	IN 320-321	B737-500	Conventional
	Aeroflot Russian Airlines	SU 111-112	A319	Conventional
	Norwegian Air Shuttle	DY 1160-1161	B737-700 Biz-Jet	Conventional
	Aeroflot Russian Airlines	SU 113-114	A319	Conventional
	Aer Lingus	EI 332-333	A320-200	Conventional
	Blue Air	JOR 139-140	B737-300	Conventional

Table A.2 Flights Details

Flight	**From Airport**	**To Airport**	**Last Stage Length** km	**Next Stage Length** km	**Pax out**	**Pax in**
4U 012-4013	Munich (MUC)	Munich (MUC)	464	464	139	120
4U 014-4015	Stuttgart (STR)	Stuttgart (STR)	512	512	130	130
4U 016-4017	Stuttgart (STR)	Stuttgart (STR)	512	512	129	132
4U 8135-8126	Cologne/Bonn (CGN)	Cologne/Bonn (CGN)	470	470	127	114
4U 8125-8124	Cologne/Bonn (CGN)	Munich (MUC)	470	464	118	80
4U 2002-2003	Stuttgart (STR)	Stuttgart (STR)	512	512	140	111
4U 2004-2005	Stuttgart (STR)	Stuttgart (STR)	512	512	142	137
4U 814T-8124	Cologne/Bonn (CGN)	Cologne/Bonn (CGN)	470	470	0	80
4U 2014-2015	Stuttgart (STR)	Stuttgart (STR)	512	512	110	109
4U 8057-8134	Cologne/Bonn (CGN)	Munich (MUC)	470	464	141	137
4U 8987-8128	Moscow (VKO)	Munich (MUC)	1583	464	120	133
EZY 8414-4593	London (LGW)	Riga (RIX)	951	839	148	121
EZY 4256-4573	Barcelona (BCN)	Copenhagen (CPH)	1503	1309	137	110
EZY 4668-4511	Lisbon (LIS)	Madrid (MAD)	2304	1853	153	128
EZY 4580-4613	Pisa (PSA)	Athens (ATH)	994	1797	147	110

EZY 4528-4555	Barcelona (BCN)	Copenhagen (CPH)	1503	364	143	121
EZY 4267-4268	Paris (ORY)	Paris (ORY)	884	884	144	114
FR 5492-5493	Frankfurt-Han (HNN)	Frankfurt-Han (HNN)	513	513	171	96
FR 8558-8559	Dublin (DUB)	Dublin (DUB)	1326	1326	170	149
EZY 4532-4621	Budapest (BUD)	Geneva (GVA)	685	868	145	147
EZY 1524-1607	London (LTN)	London (LTN)	948	948	144	116
EZY 4622-8417	Geneva (GVA)	London (LGW)	868	951	132	139
EZY 4702-4637	Brussels (BRU)	Basel (BSL)	644	682	137	141
FR 1305-1306	Shannon (SNN)	Shannon (SNN)	1511	1511	168	115
FR 1638-1639	East Midlands (EMA)	East Midlands (EMA)	1002	1002	175	136
EZY 4674-4633	Milan (LIN)	Basel (BSL)	827	682	133	91
EZY 4686-4634	Rome (CIA)	Pisa (PSA)	1178	994	146	123
EZY 6867-6868	Glasgow (GLA)	Glasgow (GLA)	1228	1228	122	145
EZY 7223-7224	Liverpool (LPL)	Liverpool (LPL)	1101	1101	139	135
EZY 4265-4266	Paris (ORY)	Paris (ORY)	884	884	143	119
EZY 4636-4605	Basel (BSL)	Tallinn (TLL)	682	1050	137	115
EZY 2107-2108	London (LTN)	London (LTN)	948	948	147	108
IN 320-321	Skopje (SKP)	Skopje (SKP)	1307	1307	35	19
SU 111-112	Bergen (BGO)	Bergen (BGO)	1016	1016	82	61
DY 1160-1161	Bergen (BGO)	Bergen (BGO)	1016	1016	138	117
SU 113-114	Moscow (SVO)	Moscow (SVO)	1595	1595	78	92
EI 332-333	Dublin (DUB)	Dublin (DUB)	1326	1326	154	132
JOR 139-140	Bucharest (BBU)	Bucharest (BBU)	1271	1271	74	37

Table A.3 Turnaround times in SXF airport

Flight	**Turnaround time** min
4U 012-4013	33,3
4U 014-4015	33,5
4U 016-4017	35,5
4U 8135-8126	45,5
4U 8125-8124	56,1
4U 2002-2003	30
4U 2004-2005	36,1
4U 814T-8124	36,5
4U 2014-2015	28
4U 8057-8134	51

4U 8987-8128	83,7
EZY 8414-4593	29
EZY 4256-4573	38
EZY 4668-4511	51,5
EZY 4580-4613	38,3
EZY 4528-4555	26,5
EZY 4267-4268	23
FR 5492-5493	31,2
FR 8558-8559	120
EZY 4532-4621	51,6
EZY 1524-1607	36,2
EZY 4622-8417	28,6
EZY 4702-4637	27,6
FR 1305-1306	40
FR 1638-1639	39
EZY 4674-4633	25,8
EZY 4686-4634	27,2
EZY 6867-6868	33,1
EZY 7223-7224	29,1
EZY 4265-4266	56,3
EZY 4636-4605	25,1
EZY 2107-2108	27,2
IN 320-321	50
SU 111-112	44
DY 1160-1161	38,8
SU 113-114	82
EI 332-333	43,8
JOR 139-140	36
	Average 41,26 **Minimum** 23

A.2 Passengers: deboarding/boarding

Table A.4 Time positioning/removing airstair or airbridge

Flight	**Airstairs/Airbridge**	**Time positioning** sec	**Time removing** sec
4U 012-4013	Two stairs	38	17
4U 014-4015	Two stairs	52	24
4U 016-4017	Two stairs	45	20

4U 8135-8126	Two stairs	43	19
4U 8125-8124	Two stairs	54	16
4U2002-2003	Two stairs	42	20
4U2004-2005	Two stairs	43	19
4U 814T-8124	Two stairs	78	9
4U 2014 - 2015	Two stairs	57	32
4U 8057 - 8134	Two stairs	30	18
4U 8987 - 8128	Two stairs	60	60
EZY8414 - 4593	Two stairs	61	36
EZY4256 - 4573	Two stairs	37	47
EZY4668 - 4511	Two stairs	26	21
EZY4580 - 4613	Two stairs	57	19
EZY4528 - 4555	Two stairs	68	15
EZY4267 - 4268	Two stairs	64	26
FR 5492 - 5493	Two stairs	13	15
FR 8558 - 8559	Two stairs	?	11
EZY 4532 - 4621	Two stairs	63	71
EZY 4532 - 4622	Two stairs	49	60
EZY 4622 - 8417	Two stairs	52	69
EZY 4702 - 4637	Two stairs	33	62
FR 1305 - 1306	Two stairs	22	14
FR 1638 - 1639	Two stairs	14	15
EZY 4674 - 4633	Two stairs	74	38
EZY 4686 - 4634	Two stairs	60	46
EZY 6867 - 6868	Two stairs	60	18
EZY 7223 - 7224	Two stairs	90	21
EZY 4265 - 4266	Two stairs	67	50
EZY 4636 - 4605	Two stairs	83	35
EZY 2107 - 2108	Two stairs	61	43
IN 320 - 321	Bridge	75	49
SU 111 - 112	Bridge	46	30
DY 1160 - 1161	Bridge	58	40
SU 113 - 114	Bridge	52	38
EI 332 - 333	Bridge	58	42
JOR 139 - 140	Bridge	31	39
	Two stairs	**Average** 51.5	**Average** 30.8
	Bridge	**Average** 53.3	**Average** 39.7

Table A.5 Deboarding time

Flight	**Passengers out**	**Deboarding time**	**Passengers out rate**
		min	pax/min
4U 012-4013	139	4,13	33,66
4U 014-4015	130	3,83	33,92
4U 016-4017	129	3,05	42,30
4U 8135-8126	127	3,82	33,27
4U 8125-8124	118	3,48	33,88
4U2002-2003	140	3,63	38,54
4U2004-2005	142	5,65	25,13
4U 2014 - 2015	110	4,75	23,16
4U 8057 - 8134	141	5,00	28,20
4U 8987 - 8128	120	4,07	29,48
EZY8414 - 4593	148	7,45	19,87
EZY4256 - 4573	137	5,35	25,61
EZY4668 - 4511	153	3,97	38,57
EZY4580 - 4613	147	4,95	29,70
EZY4528 - 4555	143	3,67	39,00
EZY4267 - 4268	144	4,25	33,88
FR 5492 - 5493	171	5,38	31,77
EZY 4532 - 4621	145	3,93	36,87
EZY 4532 - 4622	144	2,68	53,67
EZY 4622 - 8417	132	4,70	28,09
EZY 4702 - 4637	137	4,85	28,25
FR 1305 - 1306	168	5,32	31,60
FR 1638 - 1639	175	4,33	40,39
EZY 4674 - 4633	133	4,85	27,42
EZY 4686 - 4634	146	5,13	28,44
EZY 6867 - 6868	122	3,63	33,58
EZY 7223 - 7224	139	2,73	50,86
EZY 4265 - 4266	143	3,90	36,67
EZY 4636 - 4605	137	4,63	29,57
EZY 2107 - 2108	147	3,52	41,80
IN 320 - 321	35	-	-
SU 111 - 112	82	-	-
DY 1160 - 1161	138	-	-
SU 113 - 114	78	-	-
EI 332 - 333	154	-	-
JOR 139 - 140	74	-	-
Average	132,44	4,35	33,57

Table A.6 Boarding time

Flight	**Passengers in**	**Boarding time** min	**Passengers in rate** pax/min
4U 012-4013	120	6,20	19,35
4U 014-4015	130	6,67	19,49
4U 016-4017	132	8,93	14,78
4U 8135-8126	114	8,75	13,03
4U 8125-8124	80	4,95	16,16
4U2002-2003	111	8,48	13,08
4U2004-2005	137	10,10	13,56
4U 814T-8124	80	5,20	15,38
4U 2014 - 2015	109	7,25	15,03
4U 8057 - 8134	137	16,18	8,47
4U 8987 - 8128	133	10,85	12,26
EZY8414 - 4593	121	4,75	25,47
EZY4256 - 4573	110	4,15	26,51
EZY4668 - 4511	128	6,58	19,44
EZY4580 - 4613	110	4,90	22,45
EZY4528 - 4555	121	5,00	24,20
EZY4267 - 4268	114	4,80	23,75
FR 5492 - 5493	96	5,15	18,64
FR 8558 - 8559	149	6,37	23,40
EZY 4532 - 4621	147	5,43	27,06
EZY 4532 - 4622	116	6,88	16,85
EZY 4622 - 8417	139	5,32	26,14
EZY 4702 - 4637	141	6,63	21,26
FR 1305 - 1306	115	4,80	23,96
FR 1638 - 1639	136	5,87	23,18
EZY 4674 - 4633	91	9,97	9,13
EZY 4686 - 4634	123	6,08	20,22
EZY 6867 - 6868	145	6,97	20,81
EZY 7223 - 7224	135	5,10	26,47
EZY 4265 - 4266	119	6,52	18,26
EZY 4636 - 4605	115	5,12	22,47
EZY 2107 - 2108	108	4,73	22,82
IN 320 - 321	19	-	-
SU 111 - 112	61	-	-
DY 1160 - 1161	117	-	-
SU 113 - 114	92	-	-
EI 332 - 333	132	-	-
JOR 139 - 140	37	-	-

Average	113,68	6,71	19,47

A.3 Cargo: unloading/loading

Table A.7 General characteristics of cargo process

Flight				Unloading		Loading	
	Type of Aircraft	Type of cargo	Loader Kind	AFT cargo hold	FWD cargo hold	AFT cargo hold	FWD cargo hold
4U 012-4013	A319	Bulk	Belt	X		X	
4U 014-4015	A319	Bulk	Belt	X		X	
4U 016-4017	A319	Bulk	Belt	X		X	
4U 8135-8126	A319	Bulk	Belt	X		X	
4U 8125-8124	A319	Bulk	Belt	X		X	
4U 2002-2003	A319	Bulk	Belt	X		X	
4U 2004-2005	A319	Bulk	Belt	X		X	
4U 814T-8124	A319	Bulk	Belt	X		X	
4U 2014-2015	A319	Bulk	Belt	X		X	
4U 8057-8134	A319	Bulk	Belt	X		X	
4U 8987-8128	A319	Bulk	Belt	X		X	
EZY 8414-4593	A319	Bulk	Belt	X		X	
EZY 4256-4573	A319	Bulk	Belt	X		X	
EZY 4668-4511	A319	Bulk	Belt	X	X	X	
EZY 4580-4613	A319	Bulk	Belt	X		X	
EZY 4528-4555	A319	Bulk	Belt	X		X	
EZY 4267-4268	A319	Bulk	Belt	X		X	
FR 5492-5493	B73W	Bulk	Belt		X		X
EZY 4532-4621	A319	Bulk	Belt	X		X	
EZY 1524-1607	A319	Bulk	Belt	X		X	
EZY 4622-8417	A319	Bulk	Belt	X		X	
EZY 4702-4637	A319	Bulk	Belt	X		X	
FR 1305-1306	B73W	Bulk	Belt		X		X
FR 1638-1639	B73W	Bulk	Belt		X		X
EZY 4674-4633	A319	Bulk	Belt	X	X	X	
EZY 4686-4634	A319	Bulk	Belt	X		X	
EZY 6867-6868	A319	Bulk	Belt	X		X	
EZY 7223-7224	A319	Bulk	Belt	X		X	
EZY 4265-4266	A319	Bulk	Belt	X		X	
EZY 4636-4605	A319	Bulk	Belt	X		X	X

EZY 2107-2108	A319	Bulk	Belt	X		X	
IN 320-321	B737-500	Bulk	Manually		X		X
SU 111-112	A319	Container and bulk	Container	X	X	X	X
DY 1160-1161	B73W	Bulk	Belt	X		X	X
SU 113-114	A319	Container	Container	X	X	X	
EI 332-333	A320-200	Container	Container	X		X	
JOR 139-140	B737-300	Bulk	Belt		X		X

Table A.8 Time positioning/removing loader vehicle

Flight	Loader	Time to positioning sec	Time to removing sec
4U 012-4013	Belt	33	32
4U 014-4015	Belt	37	27
4U 016-4017	Belt	40	16
4U 8135-8126	Belt	42	110
4U 8125-8124	Belt	41	48
4U2002-2003	Belt	39	70
4U2004-2005	Belt	29	33
4U 814T-8124	Belt	69	32
4U 2014 - 2015	Belt	63	22
4U 8057 - 8134	Belt	49	77
4U 8987 - 8128	Belt	31	76
EZY8414 - 4593	Belt	17	83
EZY4256 - 4573	Belt	19	29
EZY4668 - 4511	Belt	95	28
EZY4580 - 4613	Belt	57	34
EZY4528 - 4555	Belt	54	8
EZY4267 - 4268	Belt	56	19
EZY 4532 - 4621	Belt	93	23
EZY 4532 - 4622	Belt	14	24
EZY 4622 - 8417	Belt	13	19
EZY 4702 - 4637	Belt	25	30
FR 1305 - 1306	Belt	22	36
FR 1638 - 1639	Belt	19	13
EZY 4674 - 4633	Belt	43	17
EZY 4686 - 4634	Belt	58	8
EZY 6867 - 6868	Belt	32	20
EZY 7223 - 7224	Belt	98	?
EZY 4265 - 4266	Belt	13	10
EZY 4636 - 4605	Belt	22	53

EZY 2107 - 2108	Belt	-	14
IN 320 - 321	No loader	12	13
SU 111 - 112	Container	76	24
DY 1160 - 1161	Belt	64	22
SU 113 - 114	Container	53	37
EI 332 - 333	Container	42	50
JOR 139 - 140	Belt	25	31
	Belt	**Average** 40.52	**Average** 32.88
	Container	**Average** 57	**Average** 37

Table A.9 Baggage rate

Flight	Passengers getting out	Passengers getting in	Baggage unload Units	Baggage load Units
4U 012-4013	139	120	62	56
4U 014-4015	130	130	67	77
4U 016-4017	129	132	79	67
4U 8135-8126	127	114	75	70
4U2002-2003	-	111	-	72
4U 2014 - 2015	110	109	52	67
4U 8057 - 8134	141	137	44	48
4U 8987 - 8128	120	133	94	57
EZY8414 - 4593	148	121	80	91
EZY4668 - 4511	153	128	107	73
EZY4580 - 4613	147	110	85	88
EZY4528 - 4555	143	114	78	45
EZY 4532 - 4622	144	116	87	64
FR 1305 - 1306	168	115	77	77
FR 1638 - 1639	-	136	-	83
EZY 4686 - 4634	-	123	-	70
EZY 6867 - 6868	122	145	60	94
EZY 4265 - 4266	143	119	101	72
IN 320 - 321	35	19	39	23
DY 1160 - 1161	138	117	98	114
JOR 139 - 140	74	37	31	37

Table A.10 Unloading characteristics

Flight	Passengers	Baggage (units)	Baggage calculated (units)	Unloading Time min	Load kg	Unloading rate kg /min
4U 012-4013	139	62		3,833	843,2	219,98
4U 014-4015	130	67		4,483	911,2	203,26
4U 016-4017	129	79		5,333	1074,4	201,46
4U 8135-8126	127	75		5	1020	204,00
4U2002-2003	140	-	79	6,67	1142,4	161,08
4U2004-2005	142	-	80	6,783	1088	160,40
4U 2014 - 2015	110	52		4,186	707,2	168,94
4U 8057 - 8134	141	44		3,45	598,4	173,45
4U 8987 - 8128	120	94		6,117	1278,4	208,99
EZY8414 - 4593	148	80		3,85	1088	282,60
EZY4256 - 4573	137	-	78	3,617	1117,92	293,28
EZY4668 - 4511	153	107		10,05	1455,2	144,80
EZY4580 - 4613	147	85		4,8	1156	240,83
EZY4528 - 4555	143	78		5,467	1060,8	194,04
EZY4267 - 4268	144	-	81	4,883	1175,04	225,60
EZY 4532 - 4621	145	87		5,483	1183,2	215,79
EZY 4532 - 4622	144	87		4,917	1183,2	240,63
EZY 4622 - 8417	132	-	76	5,3	1077,12	195,02
EZY 4702 - 4637	137	-	78	3,167	1117,92	334,95
FR 1305 - 1306	168	77		5,183	1047,2	202,05
FR 1638 - 1639	175	105		5,667	1428	251,99
EZY 4674 - 4633	133	-	76	3,65	1085,28	283,18
EZY 4686 - 4634	146	-	82	4,117	1191,36	270,88
EZY 6867 - 6868	122	60		4,583	816	178,05
EZY 7223 - 7224	139	-	79	5,167	1134,24	207,93
EZY 4265 - 4266	143	101		6,117	1373,6	224,55
EZY 4636 - 4605	137	-	78	2,483	1117,92	427,23
EZY 2107 - 2108	147	-	82	4,633	1199,52	240,71
DY 1160 - 1161	138	98		13,07	1332,8	101,97
JOR 139 - 140	74	31		3,133	421,6	134,57
Average	132	76,7		5,113	1042,81	218,84

Table A.11 Loading characteristics

Flight	Passengers	Baggage Units	Baggage calculated Units	Loading Time min	Load kg	Loading rate kg /min

4U 012-4013	120	56		7,15	761,6	106,52
4U 014-4015	130	77		8,3	1047,2	126,17
4U 016-4017	132	67		8,3	911,2	109,78
4U 8135-8126	114	70		6,817	952	139,65
4U2002-2003	111	72		9,683	979,2	101,13
4U2004-2005	137	-	78	9,45	1060,8	112,25
4U 814T-8124	80	34		4,383	462,4	105,50
4U 2014 - 2015	109	67		10,6	911,2	85,96
4U 8057 - 8134	137	48		5,37	652,8	121,56
4U 8987 - 8128	133	57		6,133	775,2	126,40
EZY8414 - 4593	121	91		8,667	1237,6	142,79
EZY4256 - 4573	110	-	66	7,25	897,6	123,81
EZY4668 - 4511	128	73		8,25	992,8	120,34
EZY4580 - 4613	110	88		8,9	1196,8	134,47
EZY4528 - 4555	121	-	71	8,1	965,6	119,21
EZY4267 - 4268	114	45		3,95	612	154,94
EZY 4532 - 4621	147	-	82	7,05	1115,2	158,18
EZY 1524 - 1607	116	64		5,783	870,4	150,51
EZY 4622 - 8417	139	-	79	7,5	1074,4	143,25
EZY 4702 - 4637	141	-	80	4,767	1088	228,24
FR 1305 - 1306	115	77		8,133	1047,2	128,76
FR 1638 - 1639	136	83		7,1	1128,8	158,99
EZY 4674 - 4633	91	51		4,616	693,6	150,26
EZY 4686 - 4634	123	70		4,217	952	225,75
EZY 6867 - 6868	145	94		10,783	1278,4	118,56
EZY 7223 - 7224	135	-	77	10,8	1047,2	96,96
EZY 4265 - 4266	119	72		7,217	979,2	135,68
EZY 4636 - 4605	115	-	68	9,1	938,4	103,12
EZY 2107 - 2108	108	-	65	6,7	884	131,94
IN 320 - 321	19	23		1,867	312,8	167,54
DY 1160 - 1161	117	114		15,633	1550,4	99,170
JOR 139 - 140	37	37		4,617	503,2	108,99
Average	114	68,7		7,41	933,73	132,4

Table A.12 Loading containers characteristics

Flight	Container unload Units	Container load Units	Unloading Time min	Loading Time min	Unloading rate kg /min	Loading rate kg /min
SU 111 - 112	3	4	10,15	7,514	0,30	0,53
SU 113 - 114	2	2	5,867	4,917	0,68	0,41

EI 332 - 333	3	3	7,03	8,716	0,43	0,34
Average	3		7,37		0,45	

A.4 Refuelling

Table A.13 Time positioning, connecting, disconnecting and removing refuelling vehicle

Flight	Type of aircraft	Time positioning sec	Time connecting sec	Time disconnecting sec	Time removing sec
4U 8135-8126	A319	8	76	91	13
4U2002-2003	A319	15	50	38	37
4U2004-2005	A319	12	35	51	21
4U 814T-8124	A319	10	69	24	17
4U 8057 - 8134	A319	55	56	157	30
4U 8987 - 8128	A319	10	219	102	37
EZY8414 - 4593	A319	51	109	120	18
EZY4256 - 4573	A319	22	101	134	27
EZY4668 - 4511	A319	51	91	41	40
EZY4580 - 4613	A319	48	97	73	21
EZY4528 - 4555	A319	-	94	54	23
EZY4267 - 4268	A319	41	79	54	28
FR 5492 - 5493	B737-700 Biz-Jet	25	39	146	39
EZY 4532 - 4621	A319	61	35	24	24
EZY 1524 - 1607	A319	25	35	29	26
EZY 4622 - 8417	A319	34	62	58	17
FR 1305 - 1306	B737-700 Biz-Jet	58	131	167	43
FR 1638 - 1639	B737-700 Biz-Jet	20	86	85	32
EZY 4674 - 4633	A319	14	82	46	17
EZY 4686 - 4634	A319	19	77	136	36
EZY 6867 - 6868	A319	3	114	263	21
EZY 7223 - 7224	A319	28	159	73	42
EZY 4265 - 4266	A319	20	86	83	16
EZY 4636 - 4605	A319	55	87	47	49
EZY 2107 - 2108	A319	15	71	69	16
IN 320 - 321	B737-500	36	88	75	26
DY 1160 - 1161	B737-700 Biz-Jet	6	80	87	40
EI 332 - 333	A320-200	15	15	32	124

JOR 139 - 140	B737-300	76	154	53	23
Average		29,75	85,41	83,17	31,14

Table A.14 Refuelling data

Flight	Last Stage Length km	Next Stage Length km	Refuelling Time min
4U 8135-8126	464	464	12,65
4U2002-2003	512	512	8,12
4U2004-2005	512	512	7,45
4U 814T-8124	470	470	2,65
4U 8057 - 8134	470	464	8,73
4U 8987 - 8128	1583	464	9,57
EZY8414 - 4593	951	839	7,12
EZY4256 - 4573	1503	1309	9,15
EZY4668 - 4511	2304	1853	18,1
EZY4580 - 4613	994	1797	13
EZY4528 - 4555	1503	364	4,83
EZY4267 - 4268	884	884	8,07
FR 5492 - 5493	513	513	3,35
EZY 4532 - 4621	685	868	6,92
EZY 1524 - 1607	948	948	7,37
EZY 4622 - 8417	868	951	11,13
FR 1305 - 1306	1511	1511	7,63
FR 1638 - 1639	1002	1002	4
EZY 4674 - 4633	827	682	7,07
EZY 4686 - 4634	1178	994	8,22
EZY 6867 - 6868	1228	1228	9,75
EZY 7223 - 7224	1101	1101	8,23
EZY 4265 - 4266	884	884	6,97
EZY 4636 - 4605	682	1050	7,03
EZY 2107 - 2108	948	948	6,48
IN 320 - 321	1307	1307	15,13
DY 1160 - 1161	1016	1016	13,13
EI 332 - 333	1326	1326	9,05
JOR 139 - 140	1271	1271	11,22
Average	1015,34	949,38	8,69

A.5 Catering

Table A.15 Time positioning/removing catering vehicle

Flight	Moving vehicle sec	Positioning platform sec	Downing platform sec	Removing Vehicle sec
4U 8135-8126	17	35	53	25
4U 814T-8124	17	171	39	60
4U 8987 - 8128	21	39	52	22
EZY4256 - 4573	35	49	79	70
EZY4668 - 4511	32	92	72	39
EZY4580 - 4613	16	81	63	28
EZY 4532 - 4621	67	44	57	45
Average	31,33	56,67	62,67	38,17

Table A.16 Time for catering

Flight	Trolleys in/out Units	Catering time min	Catering rate Trolleys/min
4U 8135-8126	5	6,52	0,77
4U 8987 - 8128	3	5,05	0,6
EZY4256 - 4573	3	3,97	0,77
EZY4668 - 4511	4	3,85	1,04
EZY4580 - 4613	4	3,82	1,05
EZY 4532 - 4621	5	5,13	0,97
Average	4	4,72	0,86

A.6 Ground power

Table A.17 Time connecting/disconnecting GPU

Flight	Time connecting sec	Time disconnecting sec
4U 8135-8126	53	68
4U 8125-8124	54	40
4U 814T-8124	73	57
4U 8057 - 8134	69	54
4U 8987 - 8128	53	76
EZY8414 - 4593	28	55
EZY4256 - 4573	29	47
EZY4668 - 4511	49	71
EZY4580 - 4613	35	52

EZY4528 - 4555	32	48
EZY4267 - 4268	26	38
FR 5492 - 5493	77	66
EZY 4532 - 4621	46	36
EZY 1524 - 1607	67	57
EZY 4622 - 8417	81	51
EZY 4702 - 4637	59	39
FR 1305 - 1306	53	73
FR 1638 - 1639	54	28
EZY 4674 - 4633	49	38
EZY 4686 - 4634	34	53
EZY 6867 - 6868	28	48
EZY 7223 - 7224	53	41
EZY 4265 - 4266	70	20
EZY 4636 - 4605	47	47
EZY 2107 - 2108	34	38
IN 320 - 321	27	43
SU 111 - 112	-	32
DY 1160 - 1161	16	24
SU 113 - 114	37	70
JOR 139 - 140	91	87
Average	49,10	49,90

A.7 Potable water service

Table A.18 Time connecting/disconnecting potable water vehicle

Flight	Time positioning sec	Time connecting hose (estimated) sec	Time disconnecting hose (estimated) sec	Time removing vehicle sec
4U 814T-8124	31	10	8	28
EZY8414 - 4593	35	10	8	20
EZY4256 - 4573	40	10	8	17
EZY4668 - 4511	60	10	8	23
EZY4580 - 4613	50	10	8	17
EZY4528 - 4555	57	10	8	26
EZY 4532 - 4621	45	10	8	16
EZY 4622 - 8417	31	10	8	22
EZY 4702 - 4637	37	10	8	23
EZY 4674 - 4633	29	10	8	10
EZY 4265 - 4266	12	10	8	5

EZY 4636 - 4605	25	10	8	21
EZY 2107 - 2108	34	10	8	30
IN 320 - 321	27	10	8	48
Average	36,65 Sum: 47	10	8 Sum: 30	21,86

Table A.19 Time pumping potable water

Flight	Type of A/C	Time pumping min	Potable water tank capacity l	Flow rate min
4U 814T-8124	A319	2,95	200	67,80
EZY8414 - 4593	A320	0,73	200	273,97
EZY4256 - 4573	A319	3,82	200	52,36
EZY4668 - 4511	A319	3,68	200	54,35
EZY4580 - 4613	A319	4,95	200	40,40
EZY4528 - 4555	A319	4,6	200	43,48
EZY 4532 - 4621	A319	1,83	200	109,29
EZY 4622 - 8417	A319	3,57	200	56,02
EZY 4702 - 4637	A319	3,5	200	57,14
EZY 4674 - 4633	A319	1,82	200	109,89
EZY 4265 - 4266	A319	2,27	200	88,11
EZY 4636 - 4605	A319	3,45	200	57,97
EZY 2107 - 2108	A319	4,47	200	44,74
IN 320 - 321	B737-500 (735)	5,1	200	39,22
Average		3,54	200	63,14

A.8 Waste water service

Table A.20 Time connecting/disconnecting lavatory service vehicle

Flight	Time positioning sec	Time connecting hose (estimated) sec	Time disconnecting hose (estimated) sec	Time removing vehicle sec
EZY8414 - 4593	24	10	8	35
EZY4256 - 4573	28	10	8	9
EZY4668 - 4511	18	10	8	18
EZY 4532 - 4621	32	10	8	19
EZY 4622 - 8417	23	10	8	12
EZY 4674 - 4633	7	10	8	20
IN 320 - 321	64	10	8	48

Average	28 Sum: 38	10	8 Sum: 31	23

Table A.21 Time emptying waste water

Flight	Type of Aircraft	Time emptying min	Flow rate l/min	Volume drained min
EZY8414 - 4593	A319	2,7	38	102,6
EZY4256 - 4573	A319	1,85	38	70,3
EZY4668 - 4511	A319	4,75	38	180,5
EZY 4532 - 4621	A319	4,03	38	153,14
EZY 4622 - 8417	A319	2,33	38	88,54
EZY 4674 - 4633	A319	3,88	38	147,44
IN 320 - 321	B737-500 (735)	3,98	38	151,24
Average		3,36	38	127,68

A.9 Pushback

Table A.22 Time positioning, removing and preparing pushback tractor

Flight	Type	Time positioning min	Time removing min	Time preparing min
4U 012-4013	Conventional	0,13	1,95	3,82
4U 014-4015	Conventional	0,45	1,52	0,67
4U 016-4017	Conventional	0,12	1,83	4,07
4U 8135-8126	Conventional	0,50	1,45	0,97
4U 8125-8124	Conventional	-	1,77	-
4U2002-2003	Conventional	0,37	1,35	0,38
4U2004-2005	Conventional	0,48	1,23	1,23
4U 814T-8124	Conventional	0,13	1,45	2
4U 2014 - 2015	Conventional	0,28	1,12	2,28
4U 8057 - 8134	Conventional	0,50	1,53	2,28
4U 8987 - 8128	Conventional	0,12	1,22	2,72
EZY8414 - 4593	Conventional	1,50	1,15	0,63
EZY4668 - 4511	Conventional	1,05	1,05	2,1
EZY4528 - 4555	Conventional	0,23	-	2,25
EZY 4622 - 8417	Conventional	0,67	1,6	3,22
EZY 7223 - 7224	Conventional	0,30	-	0,5
SU 111 - 112	Conventional	0,38	1,05	0,45
DY 1160 - 1161	Conventional	1,52	0,75	0,35
SU 113 - 114	Conventional	0,40	1,52	0,87

Average	Conventional	0,51	1,38	1,71
EZY4256 - 4573	Towbarless	0,43	1,08	0,83
EZY4580 - 4613	Towbarless	0,37	1,67	2
EZY4267 - 4268	Towbarless	0,13	-	-
FR 5492 - 5493	Towbarless	0,32	1,87	2,7
FR 8558 - 8559	Towbarless	0,52	1,65	0,37
EZY 4532 - 4621	Towbarless	0,33	-	1,18
EZY 1524 - 1607	Towbarless	0,25	2,83	0,183
EZY 4702 - 4637	Towbarless	0,55	1,25	0,73
FR 1305 - 1306	Towbarless	0,42	1,42	0,18
FR 1638 - 1639	Towbarless	0,67	1,15	0,28
EZY 4674 - 4633	Towbarless	0,48	1,22	1,93
EZY 4686 - 4634	Towbarless	0,10	1,7	0,2
EZY 6867 - 6868	Towbarless	0,70	1,12	0,38
EZY 4265 - 4266	Towbarless	-	-	2,32
EZY 4636 - 4605	Towbarless	0,18	1,03	1
EZY 2107 - 2108	Towbarless	0,15	1,55	0,35
IN 320 - 321	Towbarless	0,37	0,92	1,02
EI 332 - 333	Towbarless	0,20	1	0,23
JOR 139 - 140	Towbarless	0,27	1,03	0,3
Average	Towbarless	0,36	1,41	0,90

Table A.23 Pushback time

Flight	Type	Pushback Time min	**Flight**	Type	Pushback Time min
4U 012-4013	Conventional	1,17	EZY4256 - 4573	Towbarless	2,62
4U 014-4015	Conventional	1,27	EZY4580 - 4613	Towbarless	1,45
4U 016-4017	Conventional	1,58	FR 5492 - 5493	Towbarless	1,33
4U 8135-8126	Conventional	1,18	FR 8558 - 8559	Towbarless	1,93
4U 8125-8124	Conventional	1,25	EZY 4532 - 4621	Towbarless	3,8
4U 2002-2003	Conventional	1,67	EZY 1524 - 1607	Towbarless	1,3
4U 2004-2005	Conventional	1,28	EZY 4702 - 4637	Towbarless	1,23
4U 8057 - 8134	Conventional	1,57	FR 1305 - 1306	Towbarless	1,3
4U 8987 - 8128	Conventional	1,47	FR 1638 - 1639	Towbarless	1,67
EZY8414 - 4593	Conventional	2	EZY 4674 - 4633	Towbarless	1,67
EZY4668 - 4511	Conventional	1,42	EZY 4686 - 4634	Towbarless	1,18
EZY4528 - 4555	Conventional	1,9	EZY 6867 - 6868	Towbarless	0,85
EZY 4622 - 8417	Conventional	1,22	EZY 4265 - 4266	Towbarless	1,32

EZY 7223 - 7224	Conventional	2,07	EZY 4636 - 4605	Towbarless	1,08
SU 111 - 112	Conventional	1,4	EZY 2107 - 2108	Towbarless	1,45
DY 1160 - 1161	Conventional	1,25	IN 320 - 321	Towbarless	1,27
SU 113 - 114	Conventional	1,6	EI 332 - 333	Towbarless	0,82
			JOR 139 - 140	Towbarless	1,3
Average	Conventional	1,49	**Average**	Towbarless	1,53

Appendix B

Turnaround statistics

This appendix summarizes in Figures the statistical models obtained in Chapter 5.

B.1 Passengers: deboarding/boarding

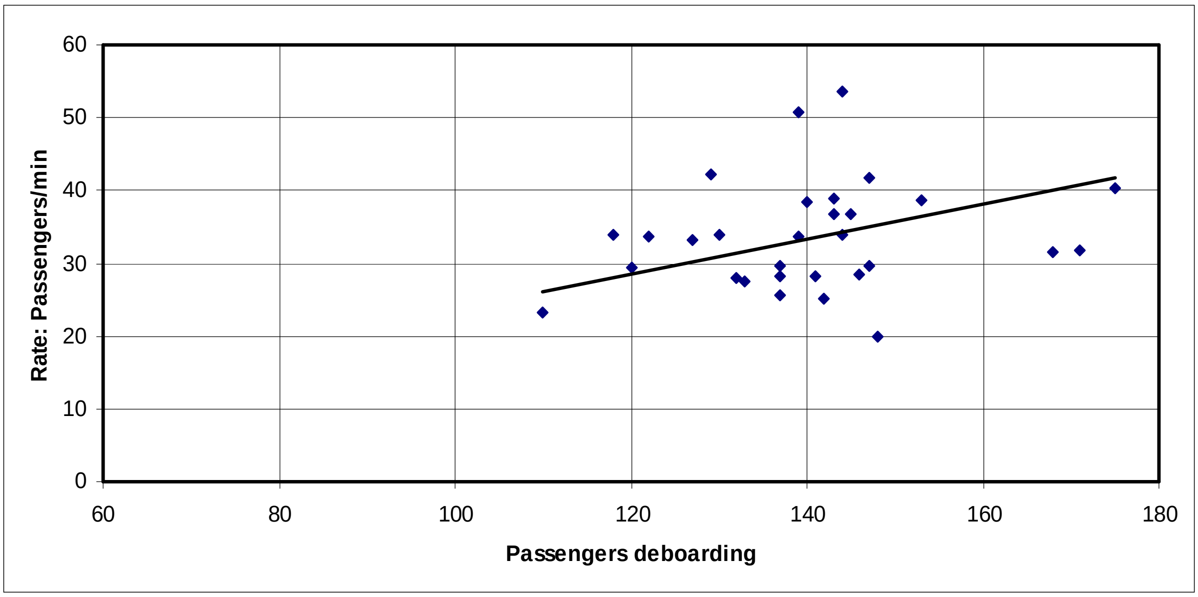


Figure B.1 Rate of passengers deboarding

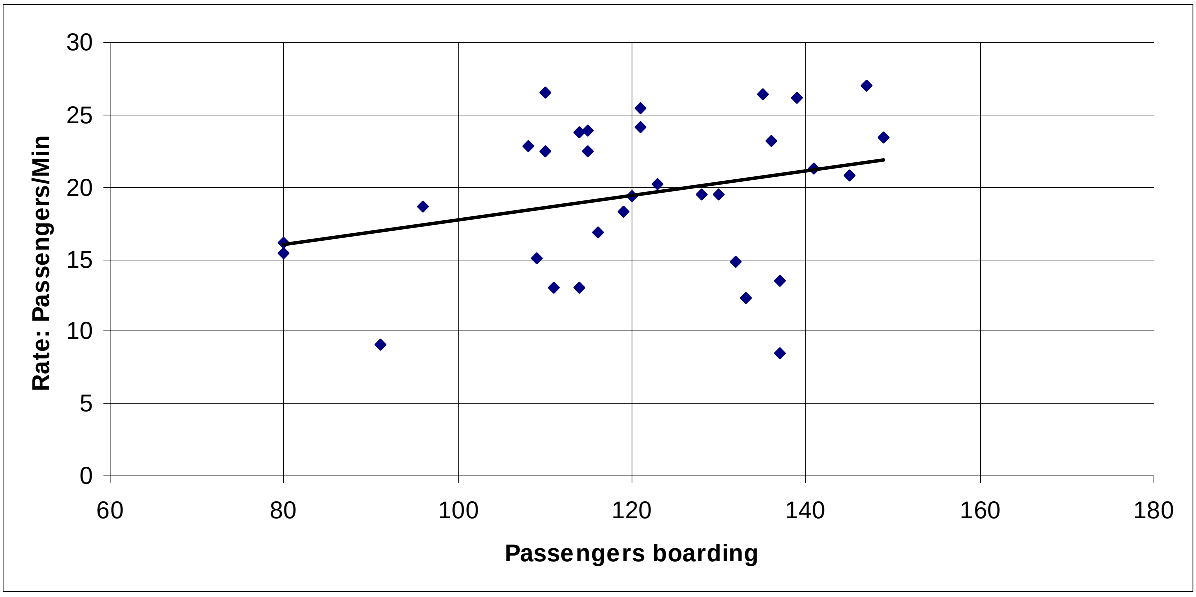


Figure B.2 Rate of passengers boarding

B.2 Cargo: unloading/loading

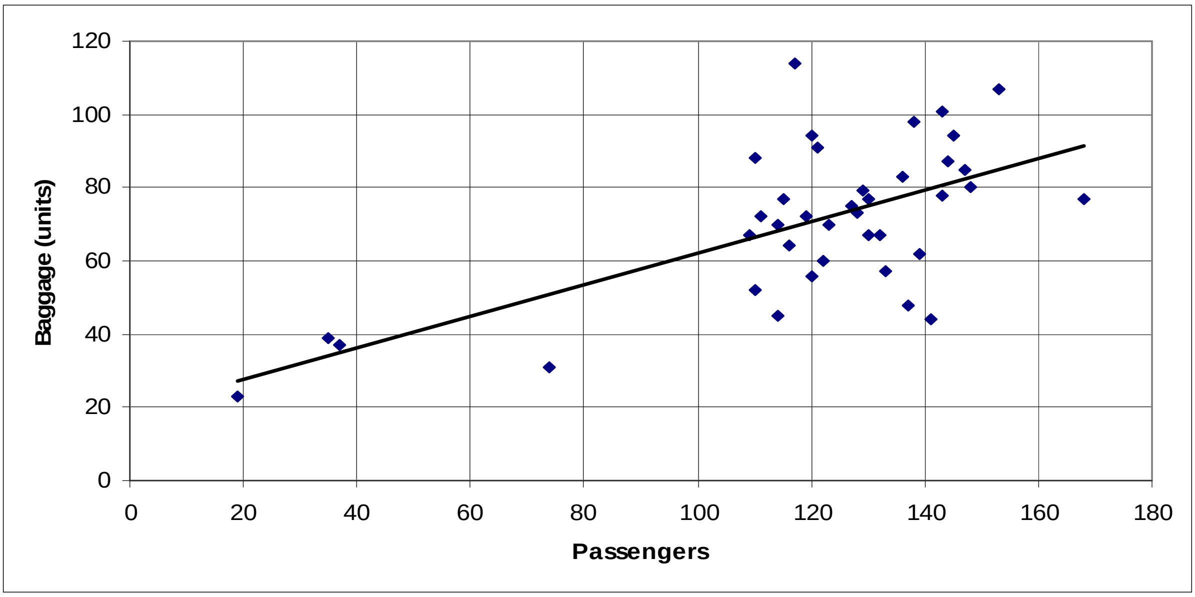


Figure B.3 Baggage (units) per passengers

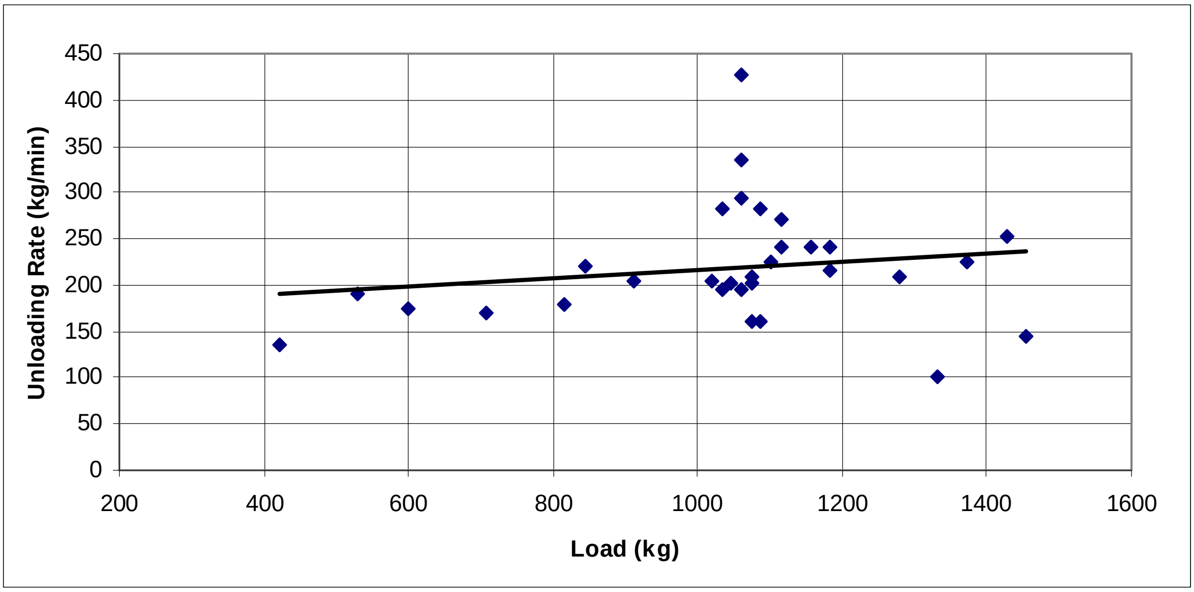


Figure B.4 Unloading rate

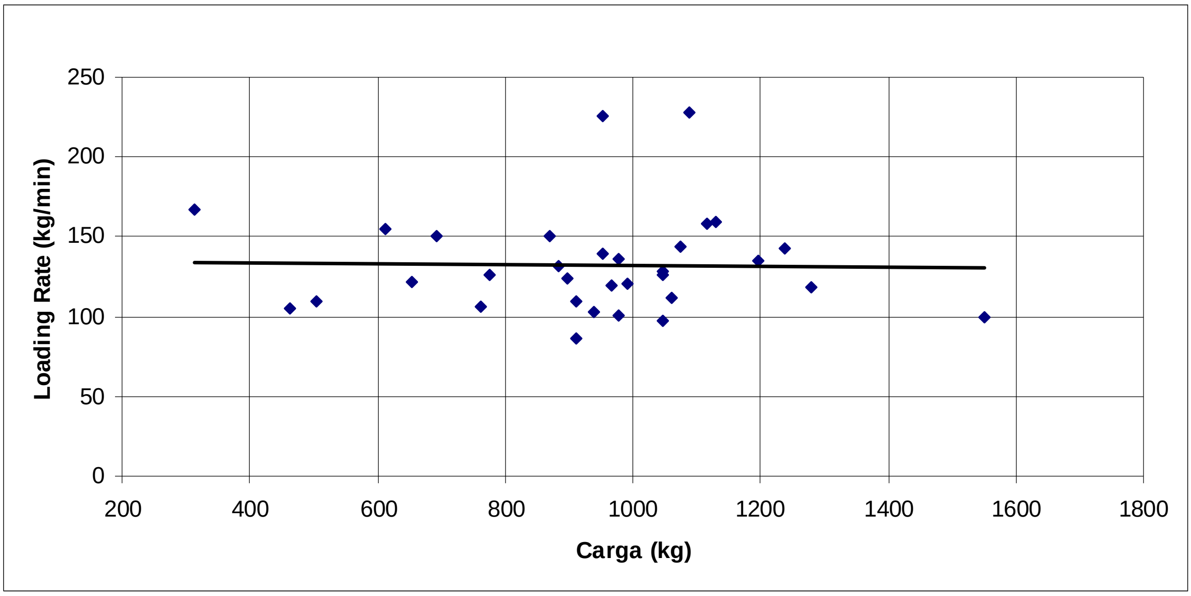


Figure B.5 Loading rate

B.3 Refuelling

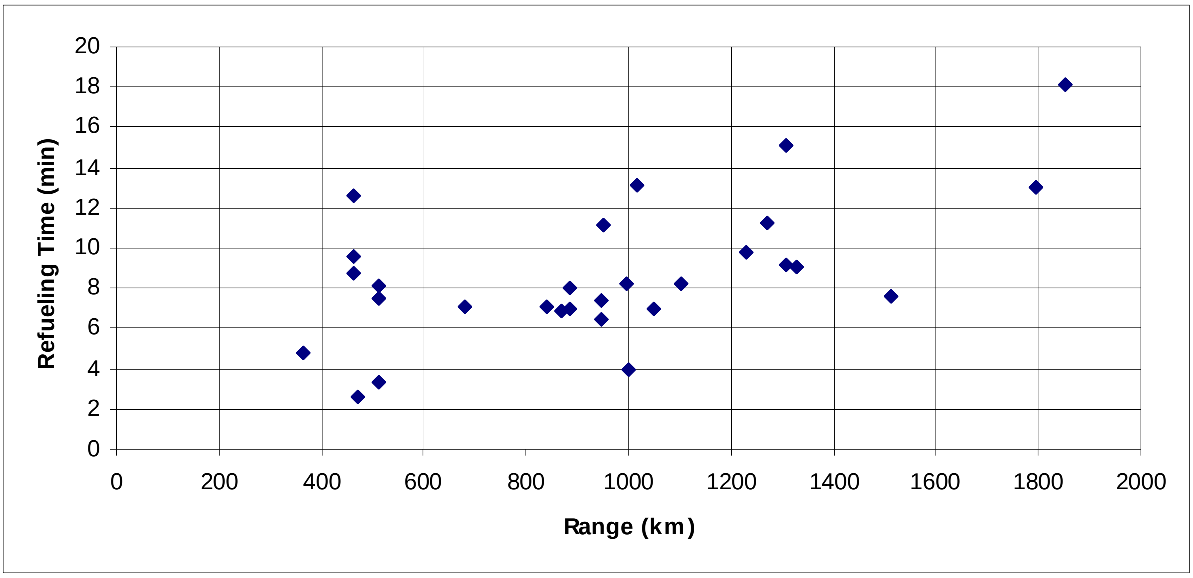


Figure B.6 Refuelling time

Appendix C

Expert interview

C.1 Data

Expert
Prof. Dr.-Ing. Gordon Konieczny

Interviewer
Diana Rico Sánchez

Time and location
Monday, 13.04.2009, 16:00 - 16:45
HAW University

Prof. Dr.-Ing Gordon Konieczny's professional career:

- Since 2007 Professor for cabin/cabin systems, HAW Hamburg.
- 2003 - 2007 Airbus Deutschland GmbH, Overall Cabin Concepts/Human Factors
- 2002 – 2003 Fraport AG, Airport Development
- 2001 Ph.D. TU Dresden
- 2001 EADS CRC, research assistant
- 1997 – 2001 Daimler-Benz (Chrysler) AG, research assistant
- 1995 - 1996 Hamburg Airlines
- 1995 Diplom, TU Berlin

C.2 Transcription of the interview

- **Interviewer**: Can you describe the Ground Handling Process?
- **Dr. Konieczny**: The Ground Handling Process (GHP) of the aircraft… the question is which kind of process you want to study: the passengers handling, cargo handling, potable water and waste water handling, cleaning of the aircraft, fuel, pilots check or the maintenance. This is quite a lot, but you have to take it in consideration.

- **Interviewer**: There are too many activities, so which one do you think is the critical process for GH?

- **Dr. Konieczny**: The time is the most critical issue. I means, you have ninety minutes for large aircraft, like the Boeing 747 or Airbus A380, and you have like half and hour, forty or twenty minutes for single aircraft like the Airbus A320, a single aisle family (1:30) or the Boeing B737 family, so actually you say, ok, is twenty minutes or twenty five minutes. If you go to companies is not what they expect to have, they say, I would like to happily have ground handling of two minutes. They want short turnarounds. (…)

- **Interviewer**: That brings me to another question: how the companies select one or other kind of GH process, for example, Ryanair has a short TR time, how do the companies select this time?
- **Dr. Konieczny**: Actually, the airlines make money when the aircraft is flying, so they want to keep the time at the airport small and quickly as possible. With Ryanair for example, they say…ok, 50 to 20 minutes is the next time for turnaround, so everything, every activity has to be harmonize and organize or even avoided. Cleaning the aircraft, for example, you get the passengers out of the aircraft, and so the flight attendant will come from the rear of the aircraft to the front of the aircraft, and look if everything is all right. That would not really clean the aircraft, but just check if the safety briefing cards were available. For Ryanair they are in front of the seats, so this is not a problem. So actually, for all the airlines is the same time for turnaround, so then, you take singles operations and then you evaluate your operation time for each operation, and you can have a net plan or something like that and determine critical path. Then is up to the aircraft, for example, most critical thing, time-wise, is the deboarding and boarding of passengers, because it takes time according to the cultural background for example. Depending on the type of passenger, the boarding can be fast or slow (...). Or, if you have the problem, for example, that you can only operate one door, in all of the cases in aircraft, every passenger left the aircraft only across front left door. (…)

  The thing is, ok someone say give me fifteen minutes for boarding-deboarding, basically is the human factor issue, normally is not the technical issue, even if you would have, for example, three full operating doors on aircraft, you would not significantly decrease the TR time, to my attitude, because you would need more staff at the gates in the terminal to arrange all the passengers for the boarding. This is the issue. I understood your project is about the question of the technical supports.

- **Interviewer**: Yes, but not really. My project is also focused on trying to find new configurations from the point of view of aircraft design, not only in the ground equipment or processes on land. So for this, do you have some ideas, or what do you think is necessary to change nowadays for trying to optimize the GH process?
- **Dr. Konieczny**: You have to look into the net plan for the aircraft TR and it is for example the fuelling that is critical, because the airport operating guys with the ground

operation manual of the airlines that says you are only allowed to fuel the aircraft if all the passengers are off board. That must be the rule. So you are good with your three doors when you get all the passengers off the aircraft, but you are only allowed to board the aircraft when is not fuelling, according to the airports operating procedures, then there is not so much benefit (…)

For me is the most critical issue: passengers boarding and deboarding, to get all the passengers to the seats. I think there is not a really relation between widen the airline by one or two inches and the boarding time, that is not the issue. It's more about the expectation of passengers for flight, they do not want to be cattle, like cows, into the aircraft, and this: imagine that you are American and you fly to the south of Ireland. Because they have TR times of twenty minutes, they would think, because they'll do, that all the passengers are treated like cattle (…), like cows say, running into the aircraft. We know that is only because the factor that they are fast, and are getting fast into the aircraft, and they can reduce TR time, they can have this low tickets fares for example, this is the mind of this people. But if you have tourists going in a charter flight, they don't want to be in hurry, they don't want to be rushed up of the aircraft, they just want to have the time.

So for me, the most important thing is a passenger, for me it is also the critical time for every aircraft. I think you cannot go under that turnaround (TR) time.

- **Interviewer**: And what do you think about loading and unloading?
- **Dr. Konieczny**: Loading and unloading is not critical, but it's depends if you have containerized bulk or not.

- **Interviewer**: Then, containers or bulk?
- **Dr. Konieczny**: It's depends what is cheaper for the airline. For example if you operate an aircraft like single aisle aircraft, they have mostly containers, baggage or cargo. For example, Lufthansa operates with ULD's with the containers. The good think is every airport has these containers. German Wings operates also aircraft A320 or 319 and they have bulk load, because of them rather estimate one piece of luggage per two passengers, (…) fourteen to fifteen kilograms per one baggage.

- **Interviewer**: About the refueling regulations you commented, can you describe the different ways that there are?
- **Dr. Konieczny**: It's depends on the airport authority, because they have these airport rules, and this rules tell you what it's allowed and what it's not allowed. The best times, you have to refuel the aircraft with passengers on board, then all the doors have to be open, all the passengers are not allowed to block the aisle, to pass the seat, boarding and deboarding, only in groups, by the guide of flight attendant more or less, and then if the aircraft have to be refueled, the fire brigade have to be there. Pilot airlines try to avoid the aircraft amount of money, 45 minutes flight, the passengers out and in aircraft, and fly again (…)

But it depends on the local airport regulations operating procedures. They tell you exactly what to do or not to do.

- **Interviewer**: Continuing with refueling, some airports use hydrant systems with vehicles dispensers, and others use fuel trucks. Which is the best system?
- **Dr. Konieczny**: Actually I have no idea what the refuel recommend, if dispenser or truck, but actually to my attitude is not a big difference for single aircraft.

- **Interviewer**: What do you think about devices, like on board stairs, which try to improve the GH?
- **Dr. Konieczny**: They are not comfortable for the aircraft. The onboard stairs must be low for the boarding and deboarding process, because for the passengers is more complicate to go into the aircraft (than with airbridge).

- **Interviewer**: About cleaning, catering, water removal, and so on, those are not carried out every TR. There is another rule for that, for example after three flights the aircraft has to be cleaning?
- **Dr. Konieczny**: It's depends of the airline. For example, they select between total cleaning and basic cleaning (…). If it's a low cost airline in a normal TR select a basic cleaning.

- **Interviewer**: Can you describe how does the type of aircraft influence in GHP? For example the height, like Boeing 737-500, that is really low and the operators, do not need a belt loader for load the luggage, or for refueling do not need a stairs to reach the valve in the wing.
- **Dr. Konieczny**: For fuelling this is not a big different. For baggage handling is also not a big different because you need a baggage loader to operators can work without damage in their backs when they move the baggage between the cars to the cargo hold.
  You have to find out what is not a critical part for TR. If is for the passengers I don't know if height it's so important, ok you have to climb up stairs 1,5 meters further I don't know if that makes a big difference, the climb for go on or off the aircraft take longer, but actually for the boarding process do not make any difference.
  For refueling all the fuelling truck has a ladder, so is also not the issue, it's take thirty seconds longer maybe, but this is not important, at the end this is not the issue.
  I think for TR process you have to look in each process, which is our critical part. The deboarding is another door operating. Today most of the airlines board only for one door, the first on the left.

- **Interviewer**: What is the reason for use only one door?
- **Dr. Konieczny**: The arrangement of the airports is only have one boarding finger or boarding bridge, and especially for single aircraft use only one bridge. For example in

Amsterdam Airport, normally they have for the jumbos 747 two airbridges for the two front doors, or for Airbus A380 there are three, they have a bridge over the wing, and finally get to the cross door at the rear of the wing.

- **Interviewer:** So finally you can use only the two doors in secondary airports or remote aprons.
- **Dr. Konieczny:** Yes this is the issue. Like the Airbus 321, which can take all three doors for boarding and deboarding, but then you have to make sure that you have enough buses, for example, for the all staff. If you have three doors, use three doors to decrease the TR time.

- **Interviewer**: Do you have some idea for optimize the aircraft for some GH process? Something to change, for example, the service points in the aircraft.
- **Dr. Konieczny**: This is not critical. Waste water service is not critical, potable water service is not critical, ground power is not critical.
  For example for the Airbus A380, that you have three decks, you have the cargo deck, the main deck and upper deck, so you have to organize the sub-processes there. For the A320, or a single aisle family for example, you have two decks: the cargo deck, that is totally independent what you are doing there from the operation optimizing, because also, as far I remember, the cargo doors are not exactly below the entry and exit doors, that means you can put trucks on the wide side of the aircraft. At the moment, is like on the left side you see the boarding and deboarding of the aircraft, on the right side you can dedicate to the aircraft. So review to check this, if you come with two bridges, but the problem is the one single aisle, over the field length you need two aisles getting two doors.
  I think you have to see, you have to investigate the aircraft like big and wide, and you have to see if the cargo is the only area, but is not the only critical path. Fuelling into my attitude also is not a critical path, even if you go to totally fuel, like 70 tons of fuel, in a B737. Water waste is not a critical issue. Critical issue is boarding and deboarding, then it gets to cleaning and catering, because these are like for sub-processes on a main deck are also only two doors.

- **Interviewer**: But do you think is possible optimizing the GH process changing something?
- **Dr. Konieczny**: The thing is this is a really higher optimize system. Everything is adjusted to be very fast. I think now you only can be close to, I don’t know, what kind of goal. I think you cannot jump that far. And if you say ok, I have a fuselage, or aircraft cabin, I can put out and in the passengers into the aircraft, according to my opinion.
  I think you could board the aircraft for different side, I mean, third door from the left, second from the right, first from the left or something like this, the problem is you have the passengers, the human being.

You have half of passengers on board for the three, four door to operate the staff, but no one really do this because doors increase weight. So I do not think that TR time will improve with an increase on passenger doors.

- **Interviewer**: Can the cleaning procedure be improved?
- **Dr. Konieczny**: Sometimes strange things happen for example, you get the passengers out from the front door, the guy handling will clean or will give the feedback to check the clean, and the passengers will board to the rear door, all happens at the same time. So the first passengers get out of the aircraft, the agents go behind to clean the aircraft, and new passengers come from the rear of the aircraft. But this process is not so good because create a lot of stress.

- **Interviewer**: About costs, how to calculate GH cost?
- **Dr. Konieczny**: For GH cost there is a book. There are some studies about costs for Peter Morrell (Cranfield University). He did an investigation in GH and he also had some looks for all the GH costs. But it's from ninety's. But that not change too much. Nevertheless, every airport has the list of the fees for landing and for handling one aircraft. But this is quite complicate it, you use a catalog and you select different services packages. But it depends on the airport.

- **Interviewer**: What is the most expensive process? The refueling?
- **Dr. Konieczny**: It's depends. The thing is how to look the GH costs, for example in Germany most of the airports are operated by the airport company, the most of the handling is also most operated by handling company or by the airport, so they have all the capital cost if it's right. In United States for example, every airline has its own terminal more or less, and all equipments, so the capital costs is faced by the airlines. Finally the gross costs are the same but the question of who has the capital cost in US is another story. In Germany the airports are operated by the companies (like Fraport) so they have their operation plans and they handling most of aircraft, but due to the European commercial law you can look if you have more than 2 billions passengers per year, at least too handling agencies must be at the airports to guarantee a competition prices. In Hamburg I think you have Swissport, Luftansa, and totally you have four or five, and they competent against each other.
  But the most expensive thing is the landing. But anyway look Peter Morrell book, edited by Cranfield University.

- **Interviewer**: For end the interview, what do you think must be the goal of my project? New configurations? Improve procedures?
- **Dr. Konieczny**: You are writing your thesis for aircraft in special operation, like European operations or United States from the East to the West Cost, yes? Which aircraft in concrete?

- **Interviewer**: A319 family or A320 family.
- **Dr. Konieczny**: Yes, like that for example. So I would see ok what is the net plan, to critical path analysis and all staff. And if you know one is a critical path you can get this TR time and reduce this to estimated technical fifteen minutes. I think below fifteen minutes is not possible. (…)

- **Interviewer**: Are impossible TR times below fifteen minutes?
- **Dr. Konieczny**: It's depends. Two segments flight: Germany to France and return. You consider the TR in France: you don't have to fuel, you already get the passengers off board, and the passengers on board. So if you go to this, if you make proper use of the people, you configure your TR process. (…)

- **Interviewer**: Do you want to add something more that I have to know?
- **Dr. Konieczny:** Actually, the thing is really, really, optimized. For fifteen minutes really have to looking about each condition. If you say, I need an additional door for example, airlines don't get an additional door, the door weight tons. You have to estimate the costs-benefits analysis and that additional amount add to capital costs and DOC is been used that benefit that you all need it, like in five minutes less the boarding time.

  The issue is why the German or why Europe try to reduce TR time. For example you are allowed to take off on the morning at 6 and should be here until 10 o'clock pm, which means that if you even to operate the aircraft from Germany to Mallorca-Germany, you could do this three times, but then you have a limited time for ground handling. That is why to try to reduce TR time (…) , just to get three times Mallorca per day for example.

- **Interviewer:** Thank you very much for your time. This interview has been very interested.
- **Dr. Konieczny**: You are welcome, and don't hesitate to contact me again if you have more questions.

Appendix D

LCA aircraft ground handling features

This appendix collects the data, in tables and figures, of the Aircraft Manual of Airbus A319 and A320, and Boeing 737-700 and 737-800.

Table D.1 General airplane characteristics (**Jane's 2008**)

	A319	**A320**	**B737-700**	**B737-800**
Aircraft dimensions m				
Overall length	33,84	37,57	33,63	39,47
Height	11,76	11,76	12,57	12,55
Fuselage diameter	3,95	3,95	3,53	3,53
Wingspan (geometric)	34,10	34,10	34,3	34,3
Wheelbase	11,04	12,64	12,60	15,60
Basic operating data				
Engines (two)	CFM56-5 or IAE V2500	CFM56-5 or IAE V2500	CFM56-7	CFM56-7
Single class layout	134	164	140	175
Range km	3350 (6800)	4800 (5700)	6230	5665
Maximum operating Mach number	0.82	0.82	0.785	0.785
Bulk hold volume m^3	27,62	37,41	28,4	45,1
Design weight Kg				
Maximum taxi weight	64400	73900	70307	79243
Maximum takeoff weight	64000	73500	70080	79016
Maximum landing weight	61000	64500	58604	66361
Maximum zero fuel weight	57000	60500	55202	62732
Maximum operating empty weight	39225	41345	37648	41413
Maximum structural Pay Load	16836	19256	17554	21319
Maximum fuel capacity litres	23860	23859	26022	26020

D.1 Airbus 320

The manual provide three examples to analyse the turnaround time based in different cabin layouts: high-density layout, single class layout and two classes layout.

<u>Main characteristics</u> (**Airbus 1995b**)

The following Figures D.1 to D.4 describe visually the main characteristics that have to be taken in account for ground handling: number of passengers, quantity of ULDs containers, the arrangements for ground service equipment and the ground service connections.

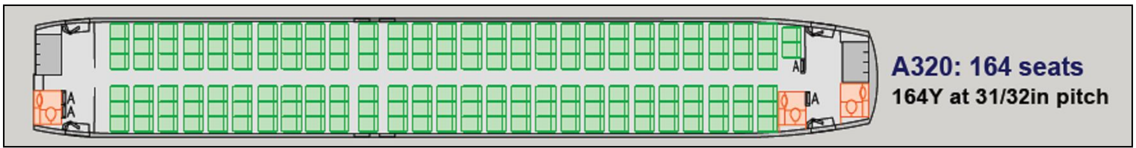
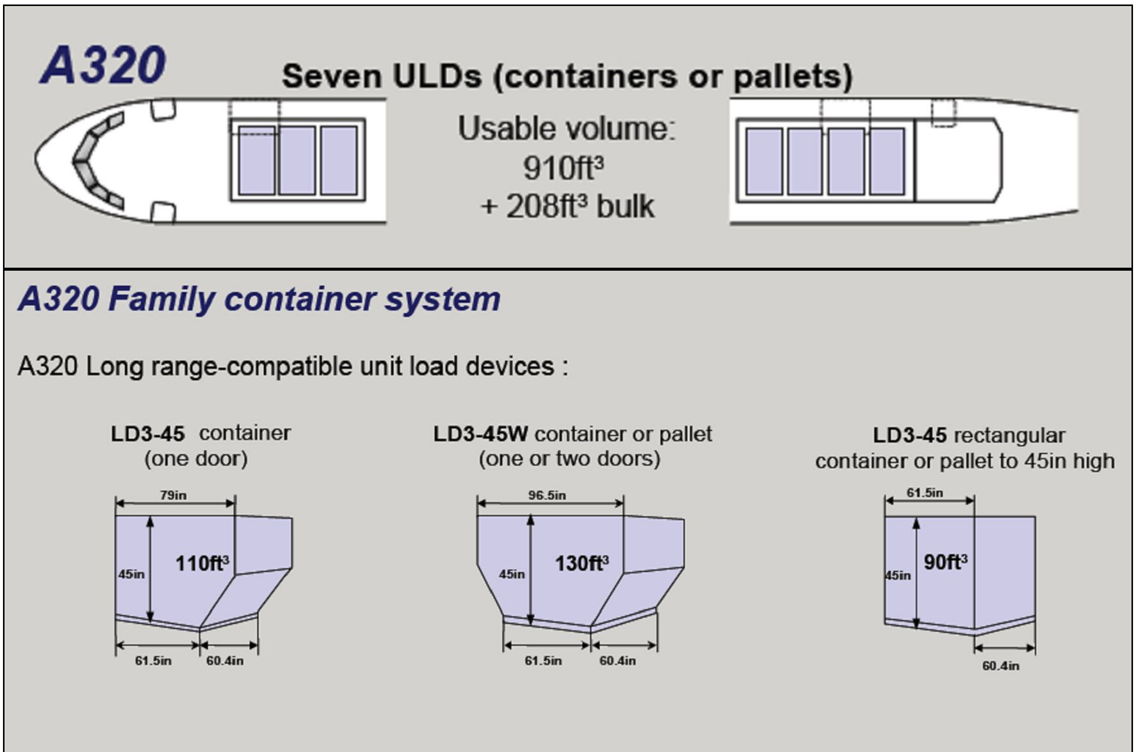
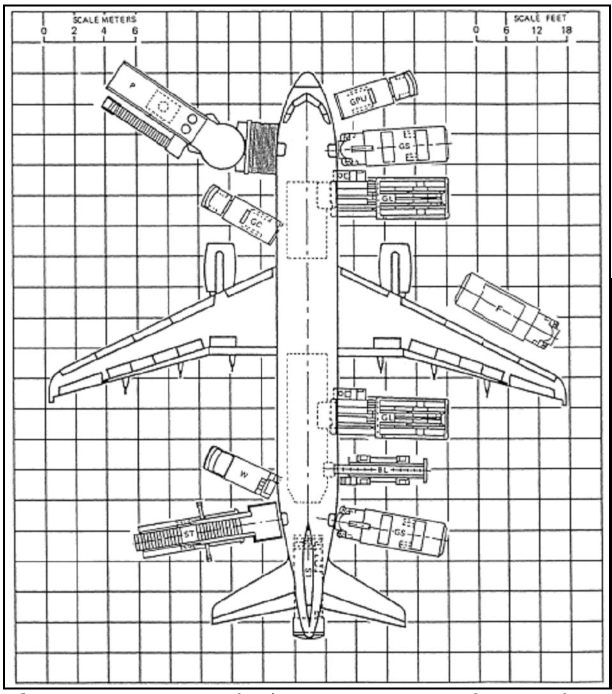


Figure D.1 Single-class layout A320. 164 passengers. (**Airbus 1995b**)



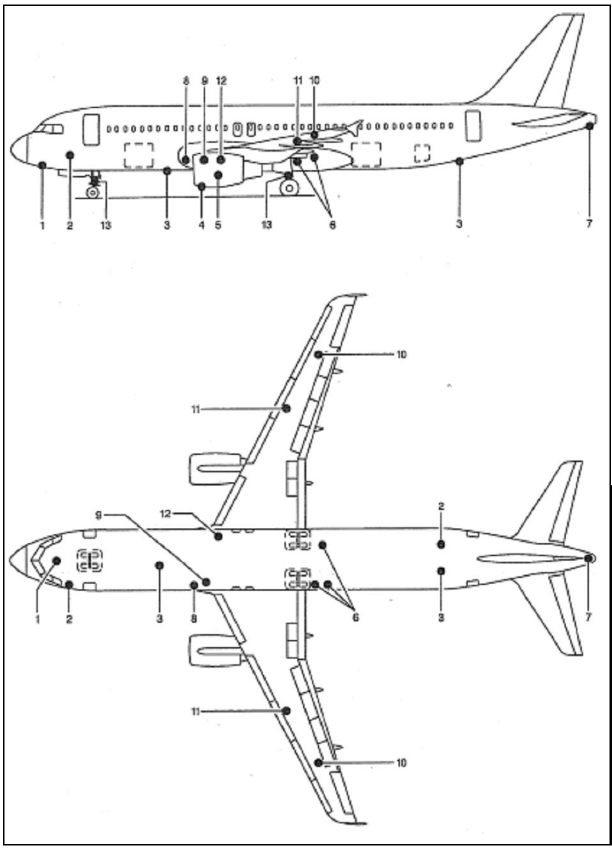
		LD3-45	LD3-45W			LD3-45 rectangular		
Max. gross weight	kg	1134	container	1134	pallet	container	1134	pallet
	lb	2500		2500			2500	
Internal volume	m³	3.1	3.6		3.6	2.5		2.4
	ft³	110	130		130	90		84

Figure D.2 Lower deck compartments A320. (**Airbus 1995b**)



AS	-	AIR STARTING UNIT
BL	-	BULK LOADER
D	-	DOLLY
F	-	FUEL TANKER
GL	-	GROUND LOADER
GPU	-	ELECTRICAL GROUND POWER UNIT
GS	-	GALLEY SERVICE TRUCK
P	-	PASSENGER LOADING BRIDGE
ST	-	STAIRWAY
T	-	TRANSPORTER
LS	-	LAVATORY SERVICE TRUCK
W	-	WATER SERVICE TRUCK
GC	-	GROUND AIR PRECONDITIONING UNIT

Figure D.3 Typical arrangements of ground support equipment during turnaround A320. (**Airbus 1995b**)



1	-	GROUND ELECTRICAL POWER RECEPTACLE
2	-	TOILET SERVICING
3	-	WATER FILLING AND DRAINAGE
4	-	IDG OIL FILLING CONNECTOR
5	-	ENGINE OIL FILLING CONNECTOR
6	-	HYDRAULIC
7	-	APU OIL FILLING CONNECTOR
8	-	GROUND SERVICE CONDITIONED AIR CONNECTOR
9	-	GROUND AIR CONDITIONING AND AIR START CONNECTOR
10	-	GRAVITY FILLING PANELS
11	-	REFUEL/DEFUEL CONNECTOR
12	-	REFUEL/DEFUEL PANEL
13	-	AIRCRAFT GROUNDING

Figure D.4 Ground service connections A320 (**Airbus 1995b**)

<u>GHP times</u>

The following Tables show the data of the GH procedures for the Airbus A320.

Table D.2 Deboarding/boarding times A320 (**Airbus 1995b**)

	Cabin Section		
	High density layout	Single class layout	Two classes layout
Passengers number	180	164	150
Time positioning/removing bridge/stairs min	1	1	1
Doors used	2	1	1
Deboarding Pax/(min*door)	15	20	20
Boarding Pax/(min*door)	9	12	12
Total time deboarding min	7	9,4	8,5
Total time boarding min	11	15	13,5

Table D.3 Catering A320 (**Airbus 1995b**)

	Cabin Section		
	High density layout	Single class layout	Two classes layout
Passengers number	180	164	150
Time positioning vehicle min	-	2	2
Time removing vehicle min	-	1	1
Number of catering vehicles	-	1	1
Time exchange AFT galley min	-	4	7
Time exchange FWD galley min	-	4	7
Total time min	-	14	20

Table D.4 Cleaning A320 (**Airbus 1995b**)

High density layout	Nº seats/ Time seat seats/min	180/0,5
	Nº Toilets/Time toilet toilets/min	-
	Time seats (5 agents) min	18

	Time toilets (1 agent) min	-
Single class layout	Nº seats/ Time seat seats/min	164/0,5
	Nº Toilets/Time toilet toilets/min	3/5,0
	Time seats (5 agents) min	16,8
	Time toilets (1 agent) min	15
	Quick cleaning without vacuum min	8
Two classes layout	Nº seats/ Time seat seats/min	150/0,5
	Nº Toilets/Time toilet toilets/min	3/5,0
	Time seats (5 agents) min	15
	Time toilets (1 agent) min	15
	Quick cleaning with vacuum min	14

Table D.5 Refuelling A320 (**Airbus 1995b**)

	Cabin Section		
	High density layout	Single class layout	Two classes layout
Passengers number	180	168	150
Positioning device min	3	3	3
Removing device min	2	2	2
Fuel capacity litre	23860	23860	23860
Flow Rate per connection l/min	1475	1475	1475
Time refuelling min	6 (20 %)	13 (60 %)	13 (60 %)
Total time min	11	18	18

Table D.6 Unloading/loading A320 (**Airbus 1995b**)

		Cabin Section		
		High density layout	Single class layout	Two classes layout
General Data	Passengers number	180	168	150

	Kg per passenger	13	20	20
	Positioning time min	2	2	2+3+3
	Removal time min	1	1	1
	Loading rate Kg/min	110	110	1,5 Containers/min
AFT Bulk compartment exchange	Additional freight or bulk	NO	600	300
	Baggage and Bulk load kg	1500	2400	1800
	Containers	-	-	4
	Operators	3	3	1
	Time unloading min	11	18	6
	Time loading min	11	18	6
	Total time min	25	39	29
FWD Bulk compartment Exchange	Baggage and Bulk load kg	900	1600	1200
	Containers	-	-	3
	Operators	2	2	1
	Time unloading min	11	18	4
	Time loading min	11	18	4
	Total time min	25	39	13

Table D.7 Water service A320 (**Airbus 1995b**)

	Potable water	**Waste water**
Tanks capacity litre	200	200
Time connecting min	2,5	2,5
Time disconnecting min	2	2
Time pumping/aspirating min	2	2
Total time min	6,5	6,5

Other procedures

Other activities are not specified because they are considered not critical-time activities.

Turnaround Chart

The following Figures D.5 to D.7 resume in turnaround charts the characteristics times for each terminal process.

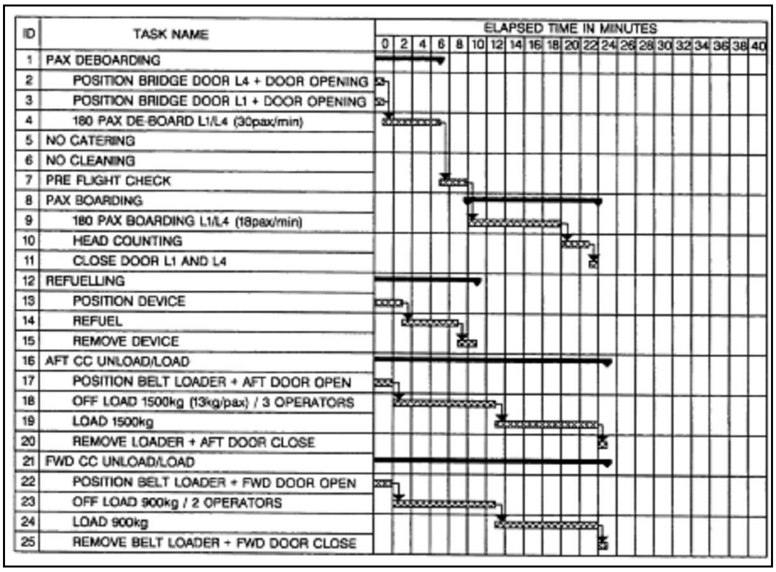


Figure D.5 Turnaround chart A, A320. (**Airbus 1995b**)

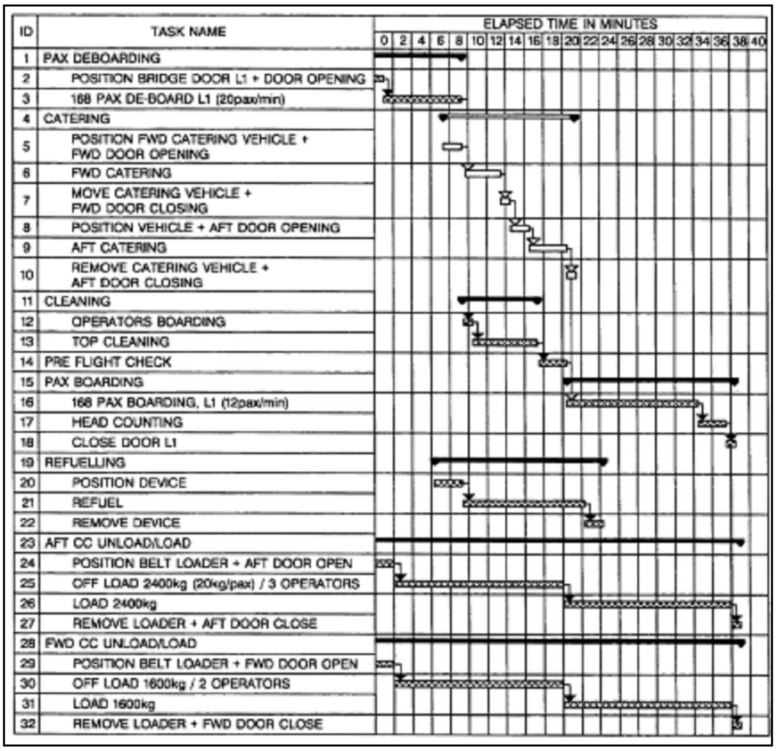


Figure D.6 Turnaround chart B, A320. (**Airbus 1995b**)

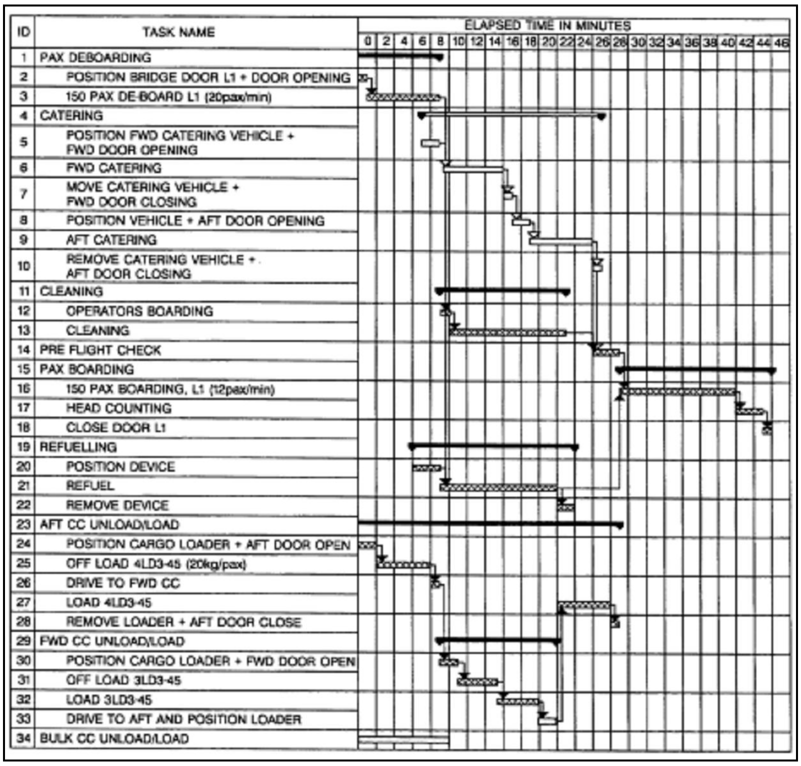


Figure D.7 Turnaround chart C, A320. (**Airbus 1995b**)

D.2 Airbus 319

<u>Main characteristics</u> **(Airbus 1995a)**

The following Figures D.8 to D.11 describe visually the main characteristics to take in account for ground handling: number of passengers, quantity of ULDs containers, the arrangements for ground service equipment and the ground service connections.

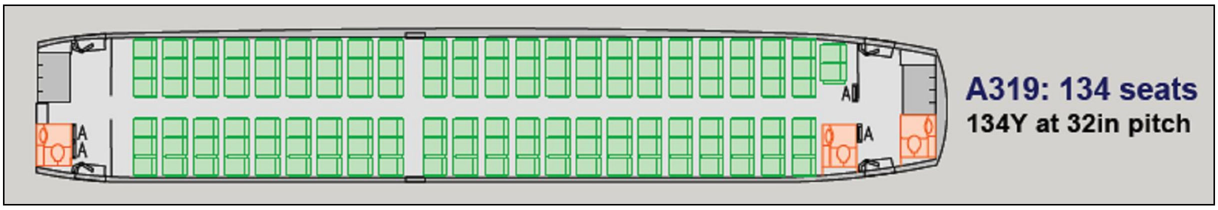
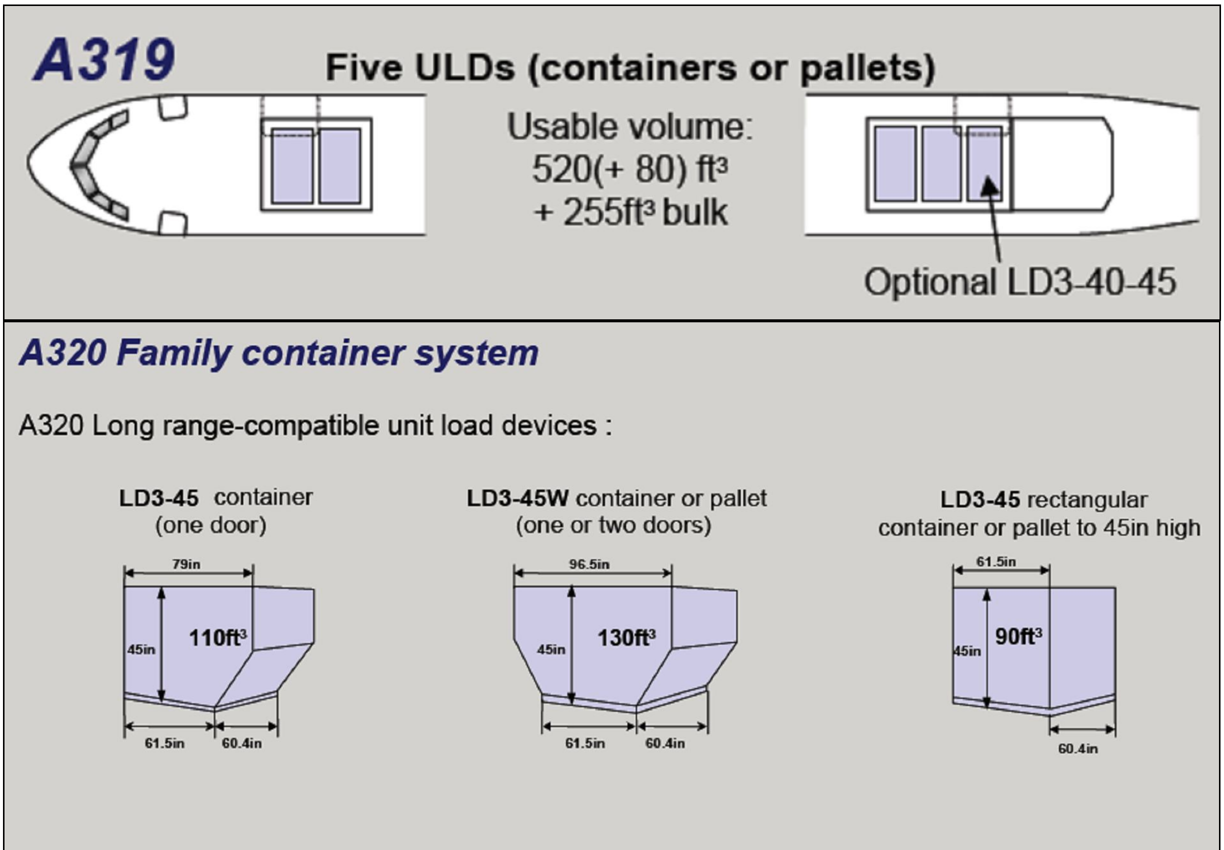


Figure D.8 Single-class layout A319. 164 passengers. (**Airbus 1995a**)



		LD3-45	LD3-45W			LD3-45 rectangular		
			container		pallet	container		pallet
Max. gross weight	kg	1134		1134			1134	
	lb	2500		2500			2500	
Internal volume	m^3	3.1	3.6		3.6	2.5		2.4
	ft^3	110	130		130	90		84

Figure D.9 Lower deck compartments A319. (**Airbus 1995a**)

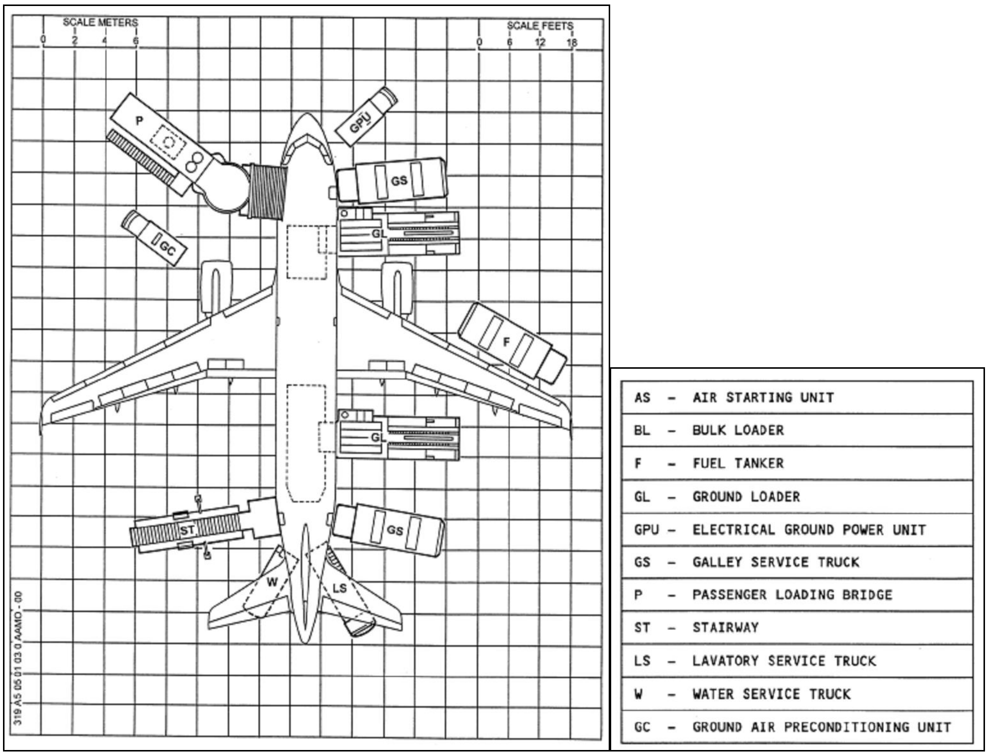


Figure D.10 Typical arrangements of ground support equipment during turnaround A319. (**Airbus 1995a**)

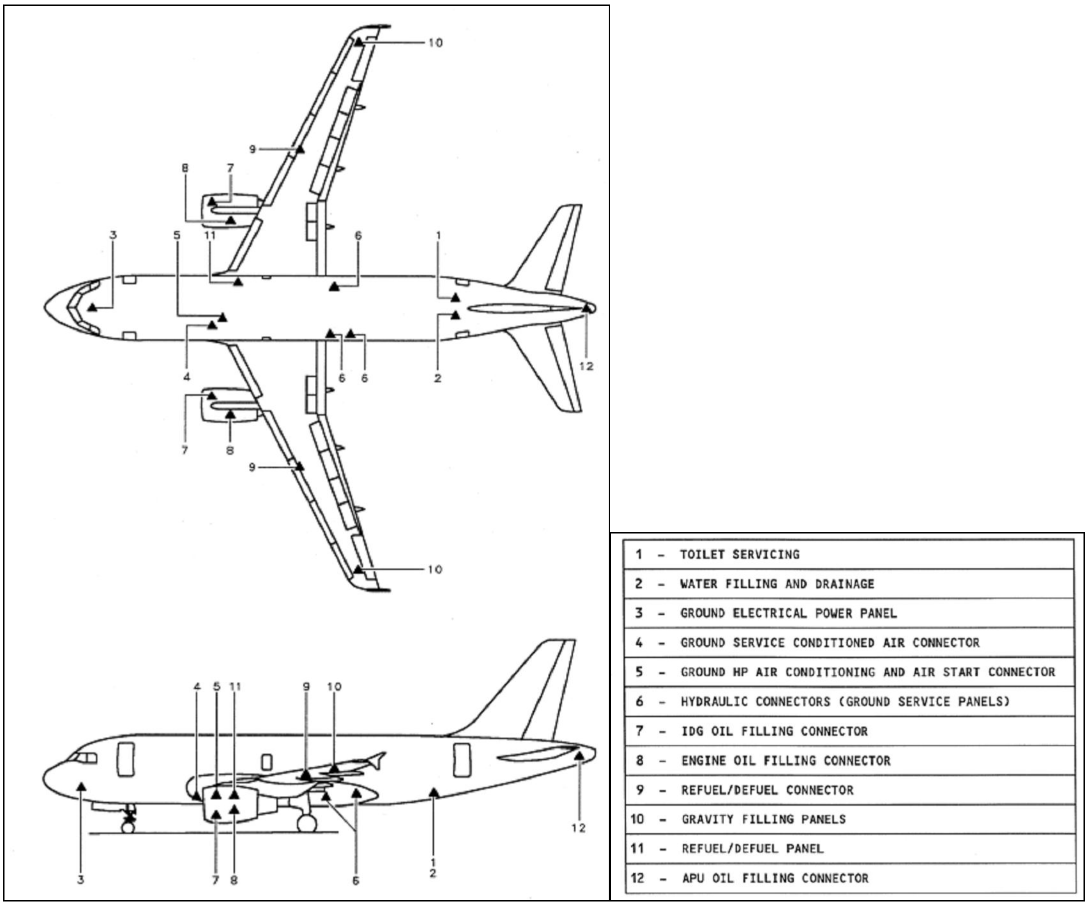


Figure D.11 Ground service connections A319. (**Airbus 1995a**)

GHP times

The following Tables show the data of the GH procedures for the Airbus A319.

Table D.8 Deboarding/boarding times A319 (**Airbus 1995a**)

Cabin section	Passengers number	Positioning /removing bridge/stair min	Doors used	Deboarding Pax/min·door	Boarding Pax/min·door	Total time deboarding min	Total time boarding Min
Single class	134	3	1	22	16	9,1	11,38

Table D.9 Catering A319 (**Airbus 1995a**)

Cabin section	Time positioning vehicle min	Time removing vehicle min	Time exchanging galleys min	Total time min
Single class	2	1	6	9

Table D.10 Cleaning A319 (**Airbus 1995a**)

Cabin section	Nº seats/ Time seat seats/min	Nº Toilets/ Time toilet toilets/min	Time seats (5 agents) min	Time toilets (1 agent) min	Quick cleaning without vacuum min
Single class	134/0,5	2/5	13,4	10	8

Table D.11 Refuelling A319 (**Airbus 1995a**)

Positioning device min	Removing device min	Fuel capacity litre	Flow Rate per connection l/min	Time refuelling min	Total time min
4	3,5	23860	1475	8,1	15,6

Table D.12 Unloading/loading A319 (**Airbus 1995a**)

General data	Cargo	Containers	Baggage and bulk
	Quantity Units or kg	4 LD3-46	2400
	Time positioning min	3	3
	Time removing min	2,5	2,5
AFT Bulk compartment exchange	Baggage and bulk load kg	-	1200
	Containers	2	-

	Time unloading min	5,5	11,5
	Time loading min	4	12,5
	Total time min	15	29,5
FWD Bulk compartment exchange	Baggage kg	-	1200
	Containers	2	-
	Time unloading min	4	11,5
	Time loading min	4,5	12,5
	Total time min	14	29,5
	Total time min	23,5	29,5

Table D.13 Water service A319 (**Airbus 1995a**)

	Potable water	**Waste water**
Tanks capacity litre	200	200
Time connect min	2,5	2,5
Time disconnect min	2	2
Time pumping/aspirating min	2	2
Total time min	6,5	6,5

Other procedures

Other activities are not specified because they are considered not critical-time activities.

Turnaround Chart

The following Figures D.12 and D.13 resume in TR charts the characteristics times for each terminal process.

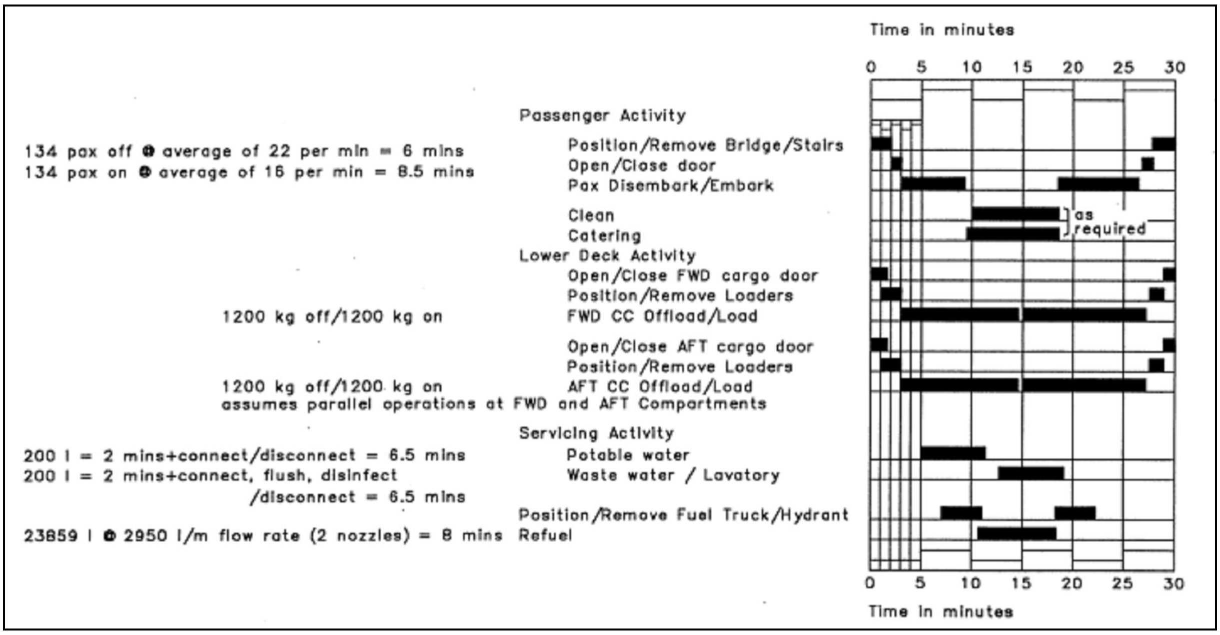


Figure D.12 Turnaround chart A, A319. (**Airbus 1995a**)

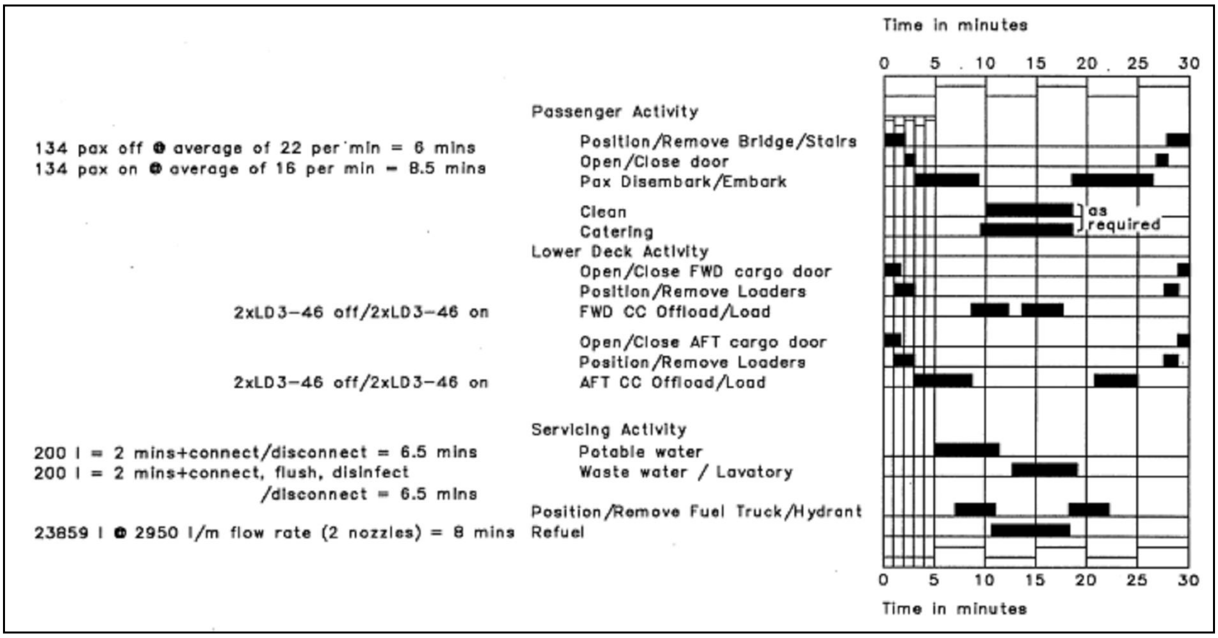


Figure D.13 Turnaround chart B, A319. (**Airbus 1995a**)

D.3 Boeing 737-700

Main characteristics (**Boeing 2005**)

The following Figures D.14 to D.17 describe visually the main characteristics to take in account for ground handling: number of passengers, quantity of ULDs containers, the arrangements for ground service equipment and the ground service connections.

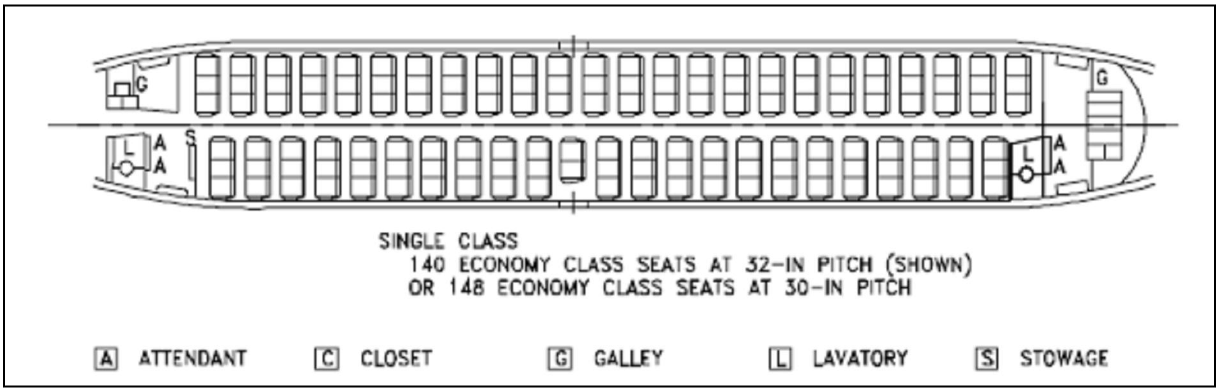


Figure D.14 Single-class layout B737-700. 140 passengers. (**Boeing 2005**)

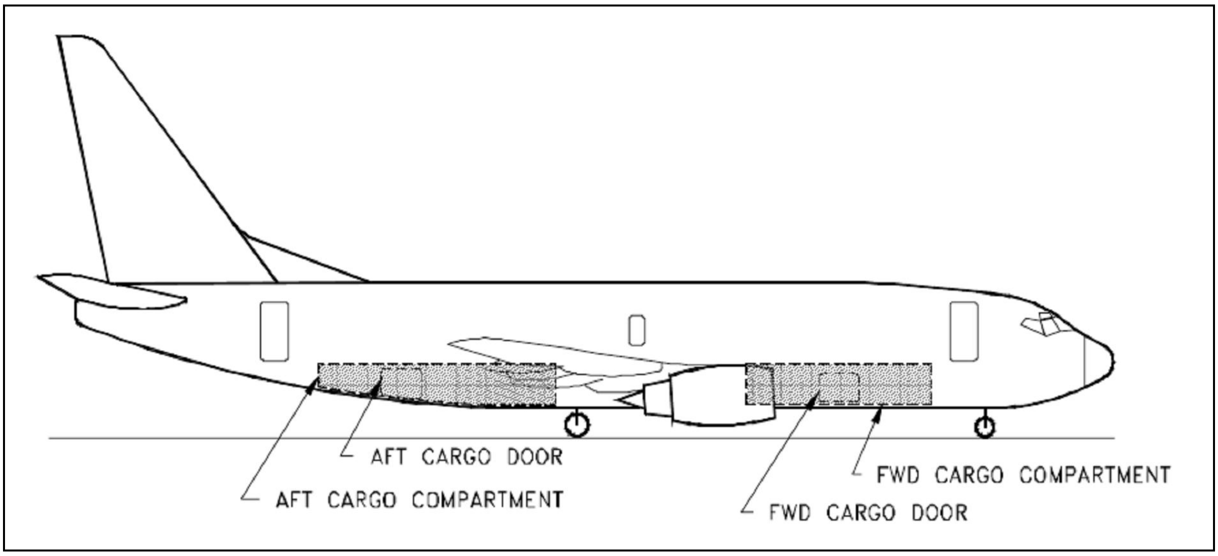


Figure D.15 Lower deck compartments B737-700. (**Boeing 2005**)

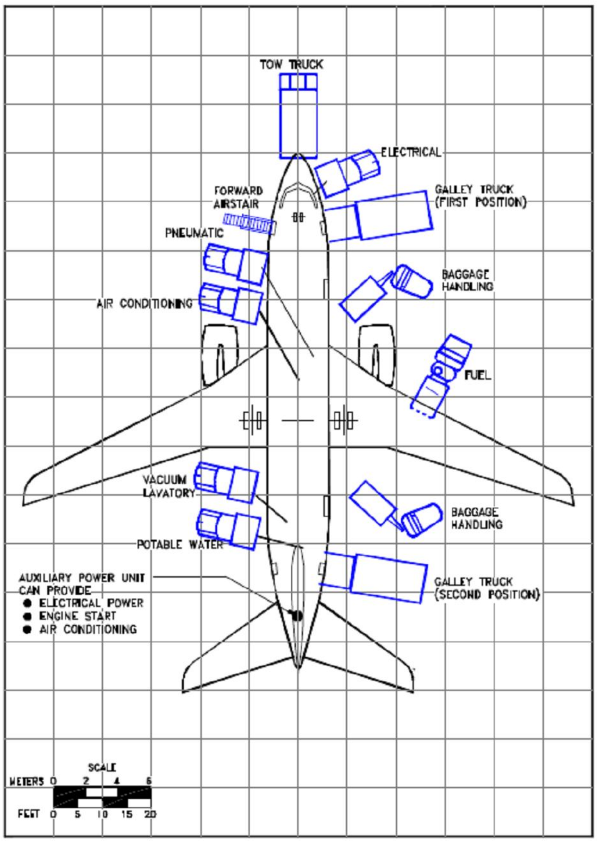


Figure D.16 Typical arrangements of ground support equipment during turnaround B737-700. (**Boeing 2005**)

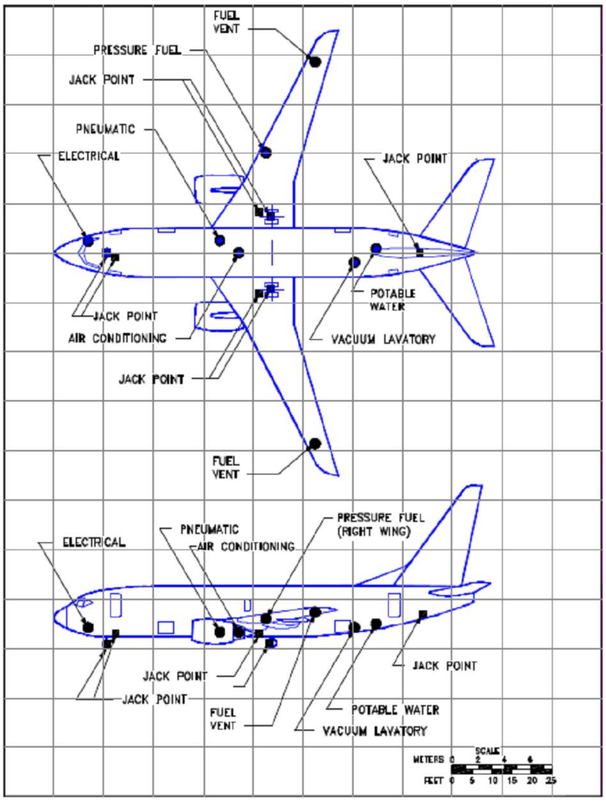


Figure D.17 Ground service connections B737-700. (**Boeing 2005**)

GHP times

The following Tables show the data of the GH procedures for the Boeing 737-700.

Table D.14 Deboarding/boarding times B737-700 (**Boeing 2005**)

Cabin section	Passengers number	Positioning /removing bridge/stair min	Doors used	Deboarding Pax/min·door	Boarding Pax/min·door	Total time deboarding min	Total time boarding Min
Single class	140	1	1	18	12	8	12

Table D.15 Catering B737-700 (**Boeing 2005**)

Cabin section	Time positioning vehicle min	Time removing vehicle min	Time exchanging galleys min	Total time min
Single class	2	2	18	22

Table D.16 Cleaning B737-700 (**Boeing 2005**)

Cabin section	Cleaning Agents boarding min	Cleaning Agents deboarding min	Time seats and Toilets (2 agents) min	Total time min
Single class	2	2	10	14

Table D.17 Refuelling B737-700 (**Boeing 2005**)

Position device min	Removing device min	Fuel capacity litre	Flow Rate per connection l/min	Time refuelling min	Total time min
2	2	26000	1136	9	13

Table D.18 Unloading/loading **B737-700 (Boeing 2005)**

General data	Cargo	Baggage and bulk
	Quantity Units or kg Time positioning min Time removing min	2400 2 2
	Unloading rate Baggage/min Loading rate Baggage/min	15 10

AFT Bulk compartment exchange	Baggage and bulk load Units	83 Baggage
	Containers	-
	Time unloading min	6
	Time loading min	8
	Total time min	18
FWD Bulk compartment exchange	Baggage Units	57
	Containers	-
	Time unloading min	4
	Time loading min	6
	Total time min	14
	Total time min	26

Table D.19 Water service B737-700 (**Boeing 2005**)

	Potable water	**Waste water**
Tanks capacity litre	200	200
Time connecting min	2	2
Time disconnecting min	2	2
Time pumping/aspirating min	2	10
Total time min	6	14

<u>Other procedures</u>

Other activities are not specified because they are considered not critical-time activities.

<u>Turnaround Chart</u>

The following Figure D.18 resumes in turnaround chart the characteristics times for each terminal process.

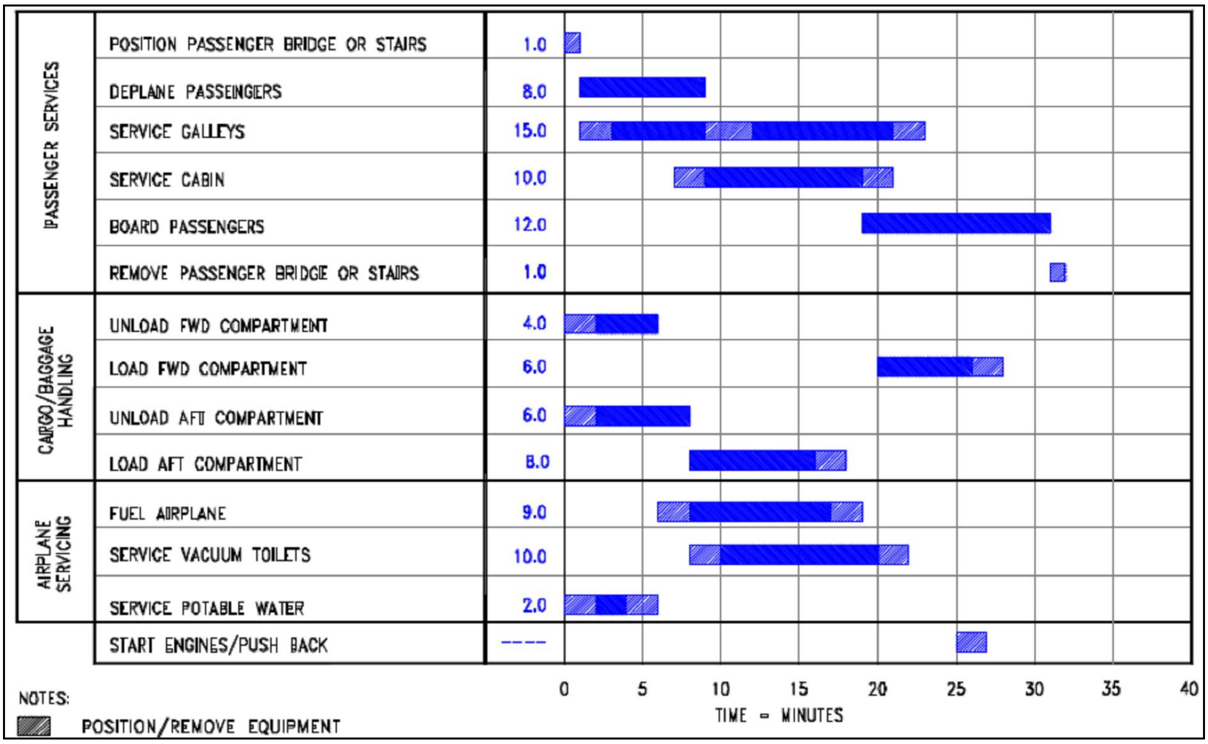


Figure D.18 Turnaround chart, B737-700. (**Boeing 2005**)

D.4 Boeing 737-800

Main characteristics (**Boeing 2005**)

The following Figures D.19 to D.22 describe visually the main characteristics to take in account for ground handling: number of passengers, quantity of ULDs containers, the arrangements for ground service equipment and the ground service connections.

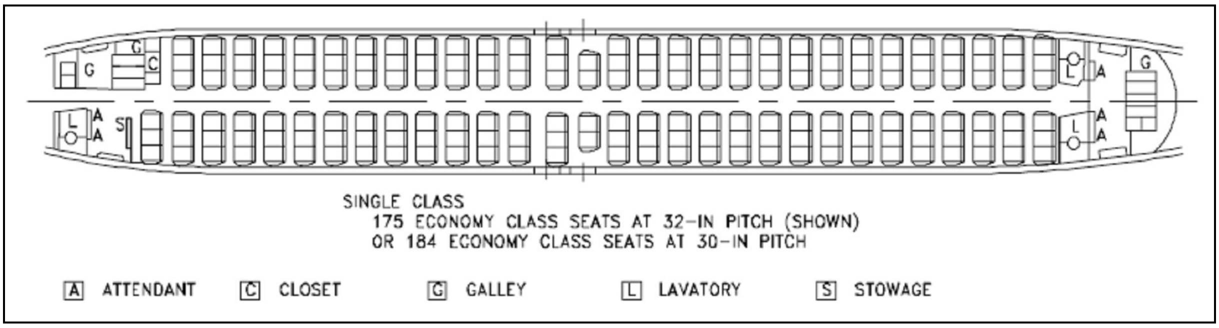


Figure D.19 Single-class layout B737-800: 175 passengers. (**Boeing 2005**)

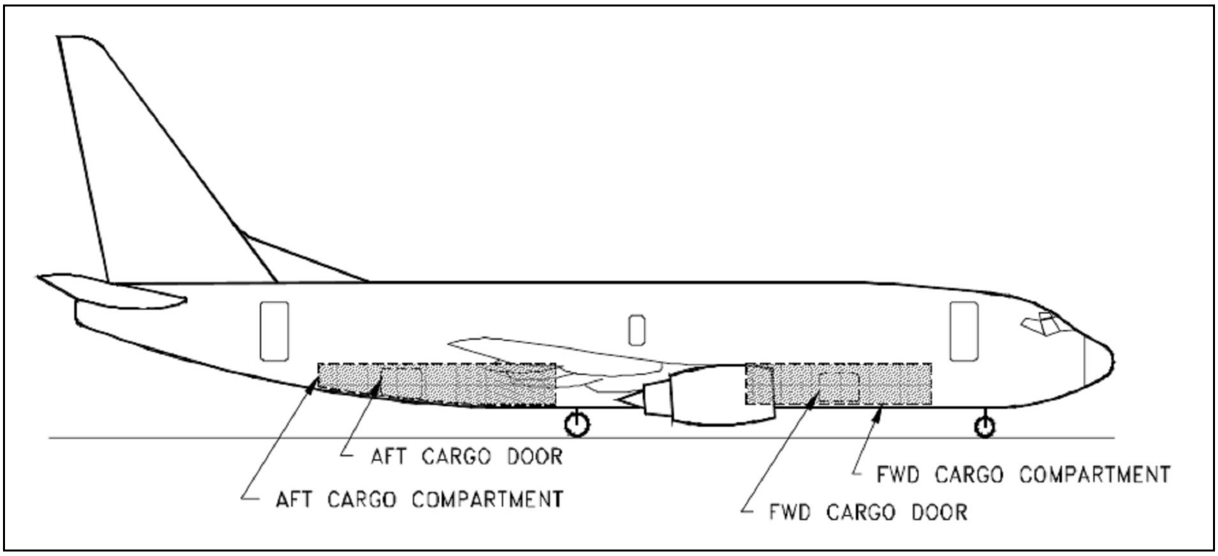


Figure D.20 Lower deck compartments B737-800. (**Boeing 2005**)

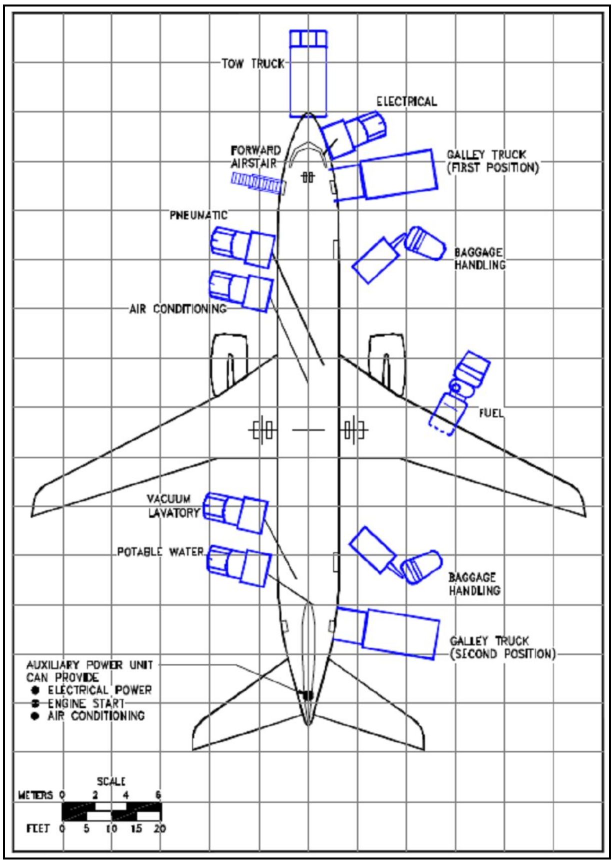


Figure D.21 Typical arrangements of ground support equipment during turnaround B737-800. (**Boeing 2005**)

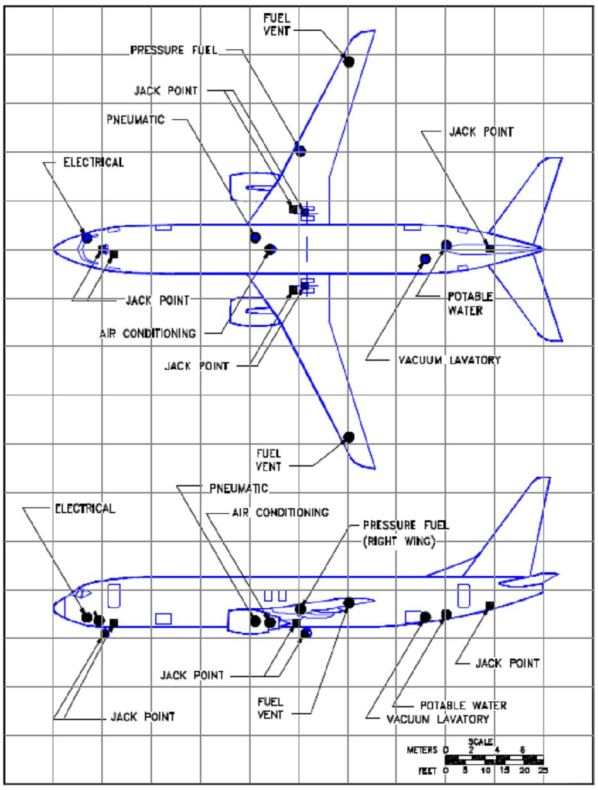


Figure D.22 Ground service connections B737-800. (**Boeing 2005**)

GHP times

The following Tables show the data of the GH procedures for the Boeing 737-800.

Table D.20 Deboarding/boarding times B737-800 (**Boeing 2005**)

Cabin section	Passengers number	Positioning /removing bridge/stair min	Doors used	Deboarding Pax/min·door	Boarding Pax/min·door	Total time deboarding min	Total time boarding Min
Single class	175	1	1	18	12	10	15

Table D.21 Catering B737-800 (**Boeing 2005**)

Cabin section	Time positioning vehicle min	Time removing vehicle min	Time exchanging galleys min	Total time min
Single class	2	2	18	22

Table D.22 Cleaning B737-800 (**Boeing 2005**)

Cabin section	Cleaning Agents boarding min	Cleaning Agents deboarding min	Time seats and toilets (2 agents) min	Total time min
Single class	2	2	11	15

Table D.23 Refuelling B737-800 (**Boeing 2005**)

Position device min	Removing device min	Fuel capacity litre	Flow Rate per connection l/min	Time refuelling min	Total time min
2	2	26000	1136	9	13

Table D.24 Unloading/loading B737-800 (**Boeing 2005**)

General Data	Cargo	**Baggage and bulk**
	Quantity Units or kg	2400
	Time positioning min	2
	Time removing min	2
	Unloading rate Baggage/min	15
	Loading rate Baggage/min	10

AFT Bulk compartment exchange	Baggage and bulk load Units	91
	Containers	-
	Time unloading min	6
	Time loading min	9
	Total time min	19
FWD Bulk compartment exchange	Baggage Units	69
	Containers	-
	Time unloading min	5
	Time loading min	7
	Total time min	16
	Total time min	29

Table D.25 Water service B737-800 (**Boeing 2005**)

	Potable water	**Waste water**
Tanks capacity litre	200	200
Time connect min	2	2
Time disconnect min	2	2
Time pumping/aspirating min	2	10
Total time min	6	14

Other procedures

Other activities are not specified because they are considered not critical-time activities.

Turnaround Chart

The following Figure D.23 resumes in TR chart the characteristics times for each terminal process.

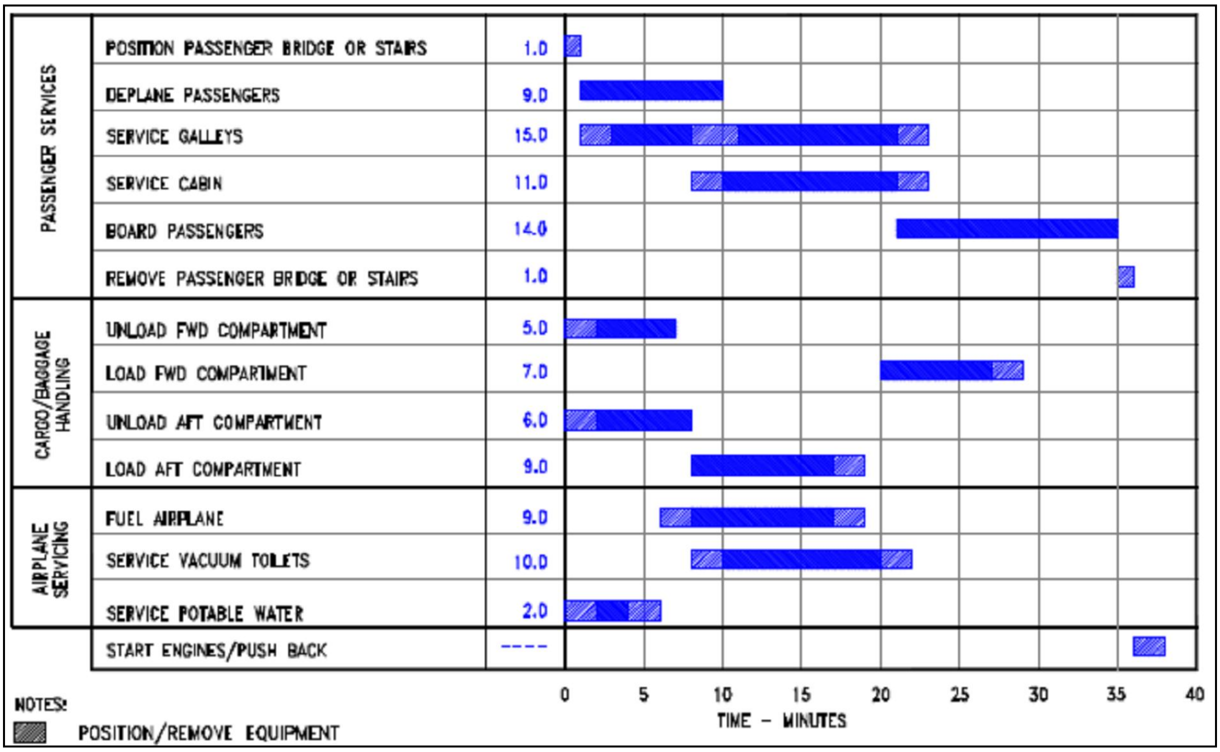


Figure D.23 Turnaround chart, B737-800. (**Boeing 2005**)