UNIVERSIDAD POLITÉCNICA DE MADRID

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA AERONÁUTICA Y DEL ESPACIO

DOCTORAL THESIS

Airline cost methodology for analyzing biofuel usage feasibility

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LOS VOCALES

EL SECRETARIO

*Nada te turbe,
nada te espante.
S.T.J.*

*A mi padre,
Antonio*

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Resumen

Las emisiones de CO₂ de la aviación están creciendo junto con el crecimiento del tráfico. Las organizaciones internacionales están preocupadas y están implementando reglas de incentivos para reducirlas. IATA ha declarado un Carbon Neutral Growth (CNG) de las emisiones a partir de 2020 dentro de su hoja de ruta. Este documento tiene como objetivo analizar las medidas adecuadas que podrían ayudar a alcanzar este objetivo y se centra en su impacto en las finanzas de 15 diversas aerolíneas españolas.

Con estos objetivos, se diseña un modelo de estimación para realizar un pronóstico del mercado aéreo español 2017-2025. Está compuesto por tres submodelos: (i) el modelo de tráfico estima el rendimiento anual de los transportistas españoles en cada una de sus rutas, (ii) el modelo de biocombustible se encarga de estimar los precios, las emisiones y las regulaciones de los biocombustibles (con especial atención a porcentaje de mezcla) y (iii) el modelo de costo operativo estima la estructura de gastos del transportista. Los datos de varias fuentes (con respecto a las estadísticas de tráfico de 2016 y las previsiones de crecimiento y precios de los combustibles, por nombrar solo dos) se recopilan y fusionan para alimentar el modelo.

Los resultados agregados muestran que se debe aplicar un aumento promedio de 3% / año del porcentaje obligatorio de mezcla para un GNC 2020 en el escenario base. Con respecto a las diferentes materias primas de biocombustibles investigadas, el rendimiento de camelina presenta un buen compromiso con respecto a los precios, las emisiones y los problemas de producción. Un estudio adicional sobre la estructura de costos de las aerolíneas muestra que las diferencias en el modelo operativo (tradicional, bajo precio...) pueden generar grandes diferencias en términos de impacto de la introducción de biocombustibles en los costos totales de las aerolíneas. Además, se observa una alta sensibilidad a los cambios en el precio del combustible común y el crecimiento del tráfico.

Keywords: Carbon Neutral Growth (CNG); biofuel; tráfico; costs operativos; aerolíneas españolas; prognosis.

Abstract

Aviation CO₂ emissions are growing along with traffic growth. International organizations are concerned and are implementing incentive rules in order to reduce them. IATA has stated a Carbon Neutral Growth (CNG) of emissions from 2020 forward within its roadmap. This paper aims to analyze suitable measures that could help to reach this target and focuses on their impact on the finances of 15 varied Spanish airlines.

With these goals, an estimation model is designed in order to carry out a forecast of the 2017-2025 Spanish air market. This is comprised by three submodels: (i) the traffic model estimates the annual performance for Spanish carriers in each of their routes, (ii) the biofuel model is in charge of estimating the biofuel prices, emissions and regulations (with special attention to mandatory blending percentage) and (iii) the operating cost model estimates the carrier's expenses structure. Data from several sources (regarding 2016 traffic statistics and forecasts of growth and fuel prices to name but two) is gathered and merged in order to feed the model.

Aggregated results show that an average 3%/year increase of mandatory blending percentage should be applied for a 2020 CNG in the base scenario. Regarding the different biofuel feedstocks investigated, camelina's performance presents a good compromise in respect to price, emissions and production issues. A further study on the airline's cost structure show that differences in the operating model (legacy, low cost...) can lead to big differences in terms of impact of biofuels introduction on the total airline costs. In addition, high sensibility to changes in common fuel price and traffic growth is observed.

Keywords: Carbon Neutral Growth (CNG); biofuel; traffic; operating cost; Spanish carriers; forecast.

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List of Acronyms

A4A	Airlines for America
AAGR	Average Annual Growth Rate
AC	Aircraft
AENA	Aeropuertos Españoles y Navegación Aérea
AESA	Agencia Estatal de Seguridad Aérea
AF	Airline Factor
AGR	Annual Growth Rate
AOC	Air Operator's Certificate
AOCTF	Airline Operational Cost Task Force
AOOE	All Other Operating Expenses
APP	Aircraft Purchase Price
ASM	Available Seat Mile
ASTM	American Society for Testing and Materials
ATA	Air Transport Association of America
ATAG	Air Transport Action Group
ATFM	Air Traffic Flow Management
ATM	Available Tonne Mile
BAU	Business As Usual
BH	Block Hours
BOE	Boletín Oficial del Estado
BTS	Bureau of Transportation Statistics
CAGR	Compound Annual/Average Growth Rate
CAPEX	Capital Expenditures
CASM	Cost per ASM
CNG	Carbon Neutral Growth
COP	Conference of Parties

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CR	CRuise
CY	Calendar Year
DA	Depreciation and Amortization
DB	Database
DDDD	Dull, Dangerous, Dirty and Deep
DOC	Direct Operating Costs
DOT	Department Of Transportation (US)
DP	Depreciation Period
EC	European Comission
EEA	European Environment Agency
EEX	European Energy Exchange
EU	European Union
EUA	European Allowance
EUR	European Euro
ETS	Emissions Trading System
FAA	Federal Aviation Administration
FC	Flight Crew
FH	Flight Hours
FO	Fuel & Oil
FT	Fischer-Tropsch
FY	Fiscal Year
GDP	Gross Domestic Product
GHG	GreenHouse Gas
HEFA	Hydroprocessed Esters and Fatty Acids
HRJ	Hydrotreated Renewable Jet
IAG	International Airlines Group
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILUC	Indirect Land Use Change
INS	Insurance

IOC	Indirect Operating Expenses
ITAKA	Initiative Towards sustainable Kerosene for Aviation
KPI	Key Performance Indicator
LCC	Low-Cost Carrier
LNF	Landing Fees
MLW	Maximum Landing Weight
MNT	Maintenance
MSR	Market Stability Reserve
MTOW	Maximum TakeOff Weight
NAYSA	Navegación Y Servicios Aéreos canarios
OFO	Other Flying Operations
OPEX	Operating Expenditures
PS	Passenger Service
RASM	Revenue per ASM
RF	Region Factor
RofAOOE	Rest of AOOE
RPM	Revenue Passenger Mile
RTM	Revenue Tonne Mile
RV	Residual Value
SFC	Specific Fuel Consumption
SPK	Synthetic Paraffinic Kerosene
ST	Service Type factor
SWAFEA	Sustainable Way for Alternative Fuel and Energy in Aviation
TAOE	Total Aircraft Operating Expenses
TH	Trip Hours
TNC	Terminal Navigation Charges
TO	TakeOff
TOE	Total Operating Expenses
TR	Transport Related
TtW	Tank-to-Wake

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UAV	Unmanned Aerial Vehicle
UN	United Nations
UNEP	United Nations Environment Program
US	United States
USD	United States Dollar
WtT	Well-to-Tank
WtW	Well-to-Wake

Chapter 1. Introduction

1.1. Background

Emissions of Greenhouse Gases (GHGs) have become a worldwide concern due to the critical climate change and global warming the Earth is suffering during the last decades. This has motivated several establishments and governments to initiate different measures with the objective of reducing the overall polluting emissions. Transport constitutes a very important piece in this regard and, in particular, aviation organizations are searching for alternatives to diminish the environmental footprint. In fact, a resolution to maintain CO₂ emissions from 2020 forward and reach a 50% decrease by 2050 has been already acquired (Figure 1). This is the so-called Carbon Neutral Growth (CNG). The development of alternative and cleaner biofuels and incentive economic measures are key factors that are being under study due to the insufficient results of the pure technological actions (Alonso, et al., 2014).

As it has been stated in (Morrell, 2007), airlines financial results are highly sensitive to small changes in either costs or revenues because of the historically high level of operational and gearing that has prevailed. A change due to the introduction of biokerosene may then cause a relevant impact on the cost structure due to its uncertainties derived from the main differences with current Jet-A1 fuel. Some of them are non-scaled facilities and supply chain, production directly linked to climate changes, regulatory constraints, specifications or engines and related systems performance and maintenance.

Figure 1 IATA's schematic CO₂ emissions reduction roadmap. Source: (IATA, 2013). © 2013 International Air Transport Association (IATA). All Rights Reserved.

Within the Initiative Towards sustainable Kerosene for Aviation (ITAKA) consortium of leading aerospace and fuel companies (ITAKA, 2017), and its initiative to produce sustainable biofuels for use in aviation, the aim of this paper was to develop an airline industry cost calculating methodology for analyzing feasible normal flight operations in Europe by dropping biofuels.

Sustainable Way for Alternative Fuel and Energy in Aviation (SWAFEA) project (Novelli, 2011) developed a wide research for drop-in biofuels feasibility in which, after considering all the required constraints and incentives for reducing a 50% the CO₂ emissions of the aviation sector in 2050 with respect to 2005 levels, focusing on short-term feasible biofuels (BTL and HRJ) and only in Europe, four relevant drivers were provided as main accelerators for future biofuels usage in aviation:

- Jet fuel demand increase
- Air transport growth
- Aircrafts fuel efficiency improvement

- Biofuels positive impact in global sustainability

Prior studies have analyzed data from previous years regarding the evolution of air traffic and its emissions (Amizadeh, et al., 2016). Others have estimated the future growth of CO₂ emissions in the next decade (Kousoulidou & Lonza, 2016) and the required quantity of biofuels in order to meet an emission reduction (Deane, et al., 2015). Nevertheless, the literature lacked from a detailed forecast of the impact of the biofuels implementation focusing on the airlines finances, which are expected to be the main drivers of this development (Smith, et al., 2017). All these factors were direct and/or indirectly inserted in the model scheme, whether through inputs or cost equations constants.

1.2. Aviation research framework

Due to the difficulties and the challenges the aviation business will face in the next decades, a new research framework within an aviation industry – university chair would be beneficial for both sides. Similar ventures have been developed in the aeronautical industry but oriented mainly to technical issues, not managerial ones.

This project aims to be the first result of this framework. Furthermore, future collaboration projects will continue the work carried out here and develop new studies based on the economic impact of biofuels in the business. Particularly, the scope of this work is aimed to be extended to Europe, other continents and, eventually, worldwide analyses will be carried out. This framework's structure is broken down in Figure 2.

Organizations and commercial companies from the aviation industry (airlines, consultancy firms, air transport agencies...) and universities (departments related with air transport, air management...) are the main pillars of this collaboration. Their joint cooperation in topics regarding air traffic (demand, offer, evolution along time...), biofuels (production process, usage feasibility, emissions...) and management (operating costs, legal framework...) would lead to the procurement of several research and commercial outcomes.

Figure 2 Aviation research framework scheme.

In addition, another research line regarding Unmanned Aerial Vehicles (UAVs) is also expected to be outlined in the short-term. The rapid growth the market of this kind of air vehicles has suffered in the last decades is boosting several conflicts with traditional air transport. This is especially critical in airport terminal areas where approach or climb manoeuvres have been disturbed by small UAVs. Local and international institutions are currently working on a common legal framework in order to address this type of issues and some radical changes are expected in the forthcoming years.

On the other side, UAVs' prospects are huge and a lot of applications are suitable for them due to their characteristics. Missions which are dull, dangerous, dirty and/or deep (DDDD) are particularly appropriate for UAVs. Some of these missions will be highly automated in the future and a lot of research will be needed in order to achieve the desired technological development.

1.3. Scope

Under the auspices of the aforementioned research framework, the motivation of this investigation is to carry out a prognosis of the forthcoming years (2017-2025) in order to estimate suitable incentive rules that should be imposed for a CNG and their economic influence on the Spanish carriers. In this regard, an estimation model has been designed including three components: traffic, biofuel and costs. Data from 2016 is used as starting point for the forecast along with different forecasts related with traffic growth or fuel prices from different sources explained in the correspondent sections. This case study focuses on Spain, which is an example of a middle-sized and oil-importer country. Furthermore, it holds a long air transport tradition and its assorted airlines exploit several markets, (domestic, European and Latam specially) thus allowing their cross-comparison and the procurement of diverse outcomes.

Special attention deserve the bibliographic review carried out in some cases. Particularly, due to the nature of this project, an estimation of future events, several sources of diverse outlooks have been consulted. This happens in the case of the fuel price, European Allowances (EUAs; from the European carbon market) value or the traffic evolution along the forthcoming years. The comparison of various sources and the final verdict regarding which option to choose is not a trivial decision. In fact, the review of recent forecasts also evidences the lack of certainty about some matters.

There are some issues whose analysis is out of the scope of this investigation such as the estimation of non-operating costs of the airlines or the micro-environmental impact of cultivation of biofuel feedstocks or Indirect Land Use Change (ILUC). This has been analyzed regionally, jointly with some logistic issues, in (Herr, et al., 2016) and (Smith, et al., 2017). As aforementioned, only Spanish airlines are included in this analysis, considering all their domestic and international operations but excluding those flights carried out by foreign carriers, even if they take place within the Spanish territory.

The scope does not include specifications from any biofuel candidate/s but a scheme and related methodology, which may require further customization in case a biofuel usage considerably differs, from an airline cost structure perspective, from current jet and biofuels, for example, non drop-in biofuels. Cargo operators are also out of this thesis' scope.

1.4. Arrangement

This thesis is organized following the main flow of the design process of the forecasting model. Firstly, data from databases (DBs) is analyzed in Chapter 2. There, their merging process is also carefully described. Global operation outcomes or KPIs such as RPM or ASM are displayed for each of the analyzed airlines. Secondly, the model is developed in Chapter 3. As stated before this is comprised by 3 main parts: the one regarding the estimation of air traffic is explained in section 3.1; the biofuel calculations including their properties and incentive policies that are or could be in force are gathered in section 3.2 and, in last place, the operating cost model is depicted in section 3.3. The outcome of the model is shown in Chapter 4. There, two different analyses are carried out. From a macro point of view, the overall fuel consumption, costs and regulations that should be imposed are presented. On the other hand, from a micro point of view, an exhaustive analysis regarding each carrier costs is displayed. Eventually, Chapter 5 gathers a series of conclusions extracted from the careful observation of the aforementioned results.

Appendixes in this thesis include relevant information for meticulous readers but not necessary for the understanding of the main flow of the research. They are ordered in order of appearance. In particular, tables in Appendix A present the different DBs employed and the fields they contain. The units used in the analysis and some conversion factors are gathered in Appendix B. ICAO and IATA codes for several aircraft types are shown in Appendix C. In Appendix D, some properties from the aircraft that constitute the Spanish fleet are tabulated, which set up the aircraft DB used within the model. In addition to the AC DB, several airports worldwide were gathered in their own DB. A sample of the Spanish ones (peninsula, canarian and

balear archipelagos) can be found in Appendix E. The history behind the flights using biofuels is commented in Appendix F. Regarding previous work carried out in the operating cost models design two different appendixes are presented: firstly, the IATA's Airline Cost Management Group background is disclosed in Appendix G; secondly, the ATA's standard model for calculating operating costs is described in Appendix H. In both cases, a brief introduction to those organizations and their efforts in designing cost models and trials to conform a bloc of airlines in order to improve costs and their management is there briefly explained. Some definitions concerning airlines' costs and related issues can be consulted in Appendix I. As it is explained in section 3.3, the American DB collected by its Department of Transportation (DoT) and made public online is an important piece of this project; Appendix J is dedicated to its overall description. Finally, some outcomes from the model not included within the main body due to space reasons are presented in Appendix K.

Chapter 2. Data analysis

In this chapter, a description of the used databases and an initial analysis of the traffic data obtained from Spanish carriers during 2016¹ is presented. This represents the original statistics that are used as baseline in the forecast model described in Chapter 3.

2.1. Databases

A core piece of this project was the handling of great amounts of data from several databases (DBs). Information such as operations, passengers, aircraft features or airport locations was extracted from them and carefully merged. Three main types of DBs were used regarding their information: traffic, aircraft and airports.

They were all gathered and managed using Microsoft Excel. On the other hand, the processing of them along with the calculations carried out inside the estimation model were done developing Matlab scripts. The most important DBs are briefly described below. Appendix A can be consulted for further information since it gathers and details the different fields from each of the DBs. In addition, Appendix B shows the units used by default in this study and the conversion factor for them.

¹ The financial year (FY) of Spanish Airlines is equivalent to the calendar year (CY), from January to December. For this reason, this difference will not be specified in the remaining of the document. Data referred to one year will refer to the January-December period.

2.1.1.Traffic

For running the proposed model, four different aviation industry DBs were used in order to obtain accurate information regarding 2016 European air traffic. Aviation DBs have been provided for determining both European network and revenue performance. Key aviation industry players have been chosen for this purpose. The first 3 were purchased while the last one is publicly available.

- (Sabre, 2013). Data range is all the flights arriving/departing to/from EU on September 2013, because is assumed to be the most representative month. Relevant data from this DB are the revenue passengers per carrier and route.
- (Innovata, 2013). Same range as mentioned before. In this case, number of flights per carrier and route were used.
- (EUROCONTROL, 2016). Same range as mentioned before but during the third week of June 2016 instead. Available data comprises flight's carriers, schedules and aircraft.
- (AENA, 2016). In this case only data from Spanish airports is available. It includes overall annual and monthly operations and passengers carried out by airlines within the peninsula and the islands (separated or aggregated).
- (US BTS, 2016). Information from this website was used in order to develop and fit the operating cost model, which has been carried out in section 3.3.

In particular, the DBs used as information sources and the process followed to obtain the traffic from 2016 is described in this paragraph. Firstly, route-divided data from two purchased databases, number of flights from (Innovata, 2013) and revenue passengers from (Sabre, 2013), were merged in order to obtain an averaged load factor for the different routes that each airline operates. Then, city pairs and their correspondent annual departures were computed by merging route-divided data from acquired database (EUROCONTROL, 2016) and overall Spanish operations from public database (AENA, 2016). In section 2.2 the airlines included within this analysis are briefly described using significant data extracted from these databases as a summary.

2.1.2. Aircraft and airports

Apart from the aforementioned traffic databases, other two were used within the model (Figure 9 in Chapter 3 shows the global scheme of the estimation model and there it can be observed how these databases are introduced):

- **Aircraft.** Structural, aerodynamic and propulsive features from aircraft used by the analyzed airlines. Data was mainly obtained from (Harris, 2005) but other sources of information had to be analyzed in order to obtain relevant data from several aircraft. Worldwide aircraft nomenclature (ICAO and IATA codes) are gathered in Appendix C while particular data from Spanish carriers fleet can be consulted in Appendix D.
- **Airports.** Political and geographical location of 7200 airports worldwide was obtained from (OpenFlights, 2017). This was later used for calculations such as route length. A data sample from Spanish airports is found in Appendix E.

2.2. Spanish carriers

As specified beforehand, commercial airlines from Spain with AOC type A2 are the target of this analysis. In fact, an important piece of the estimation model (the one which is related with the traffic, see section 3.1) is based on data from these carriers reported in previous years. It must be pointed out that the only Spanish freighter with AOC type A, Swiftair, was removed from this analysis.

Table 1 shows a brief summary of the carriers analyzed including their market niche and their fleets. There it can be observed the great variety of the Spanish airlines regarding their economic model or type of operation, market niche and overall fleet size. Data has been aggregated from different sources such as (AESA, 2017), (AIRFLEETS, 2017), (Planespotters, 2017) and websites of airlines.

² Air Safety State Agency (AESA) is the Spanish national aviation authority which approves and grants the Air Operator Certificates (AOCs). Those AOCs which are type A allow the correspondent carrier to carry out commercial services without limits regarding maximum number of passengers or tonnage. More information can be found in (AESA, 2017).

Table 1. Summary of Spanish carriers analyzed in the forecast. Fleet data is illustrative; renting aircraft not considered.

Carrier	ICAO	IATA	Group	Business Model	Main Destinations	No.	Fleet Model
Iberia	IBE	IB	IAG	Legacy	Europe Latam	16	A319
						14	A320
						12	A321
						10	A330-2
						8	A330-3
						17	A340-6
Vueling	VLG	VY	IAG	Low-cost	Europe	5	A319
						84	A320
						11	A321
Iberia Express	IBS	I2	IAG	Low-cost	Spain	18	A320
					Europe	3	A321
Air Nostrum	ANE	YW	IAG	Regional	Spain	5	ATR-72-6
					Europe	9	CRJ-200
						29	CRJ-900
Air Europa	AEA	UX	-	Regular	Europe Latam	12	A330-2
						2	A330-3
						19	B737-8
						5	B787-8
						3	ATR-72
						1	EMB-145
						7	EMB-190
Volotea	VOE	V7	-	Low-cost	Europe	5	A319
						17	B717-2
Evelop	EVE	E9	-	Low-cost	Europe	1	A320
					Caribbean	2	A330-3
Alba Star	LAV	AP	-	Low-cost	Mediterranean	4	B737-4
Privilege	PVG	P6	-	Charter	Portugal	1	B767-3R
Plus Ultra	PUE	PU	-	Regular	Latam	2	A340-3
Wamos	PLM	EB	-	Tour operator	Caribbean	1	A330-2
						3	B747-4
Binter	IBB	NT	Binter	Regional	Canary Is.	9	ATR-72-5
					Africa	1	CRJ-900
Naysa	NAY	ZN	Binter	Regional	Canary Is.	11	ATR-72-5
Canair	RSC	-	Binter	Regional	Canary Is.	5	ATR-72-5
Canaryfly	CNF	PM	-	Regional	Canary Is.	4	ATR-72

As extracted from Table 1, Vueling has the bigger fleet with 100 Airbus aircraft. It takes advantage of the commonality provided by the A320 family. In fact, these are the most repeated aircraft type along the Spanish carriers (Iberia, Vueling, Iberia Express, Volotea and Evelop). On the other hand, the regional ATR-72 is the most used aircraft for short-haul routes (Air Nostrum, Air Europa, Binter, Naysa, Canair and Canaryfly). Air Europa shows the most assorted fleet with 7 different aircraft types. Not for nothing, it is one that exhibits a high number of different routes (see Figure 3 below).

2.2.1. Data per airlines

As stated before, data from 15 Spanish carriers is extracted from different databases. In this section, that information is postprocessed and shown in different formats, which allow a clear comparison between the different types of carriers and the economic models that are used in each case. A similar representation of this data can be found in K.1 (Appendix K).

Table 2 Traffic data from Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016).

Carrier	Annual PAX	Annual operations	Average distance [mi]	City pairs
Vueling	27538222	188745	777	356
Iberia	13708519	86605	2240	79
Air Europa	10790589	84634	1384	126
I Express	4627967	32294	840	43
A Nostrum	4390960	89036	444	88
Volotea	3001392	33216	569	190
Naysa	1358393	25546	107	12
Canair	832202	15200	116	9
Evelop	582176	3179	1768	25
Binter	528658	9307	520	18
Canary Fly	343256	10897	96	4
Alba Star	315999	3011	724	44
Wamos	175350	405	3452	3
Privilege	147307	2165	990	5
Plus Ultra	49388	284	3152	2
Total	68390378	584524	917	1004

Figure 3 Traffic data from Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016).

The 15 operators shown in Figure 3 are ordered from left to right following the number of passengers carried during 2016. It can be observed that the IAG group (Vueling, Iberia, Iberia Express and Air Nostrum) constitutes the vast majority of the Spanish market (50M PAX and 400k ops; 73% and 68% of market share). Air Europa has a big relevance in the Spanish air traffic (10.8M PAX and 85k ops; 16% and 14% of market share). The group comprised by Binter airlines (Naysa, Canair and Binter) have also a great number of flights (2.7M PAX and 50k ops; 4% and 9% of market share) which reveals the relevant paper of the air transport within the islands.

An interesting datum is the fact that a huge averaged distance (greater than 3000 statute miles) is achieved by Plus Ultra and Wamos with only 2 and 3 different city pairs respectively. Both of them fly routes over the Atlantic to Mexico and Latam. These destinations are very important due to touristic and ethnic reasons for Spain. On the other side, Naysa, Canair and Canary Fly show the smaller distance, 100 miles approximately, the characteristic longitude between islands in the Canary archipelago.

Another significant fact is that Volotea, although in the 6th place in the PAX ranking, is the 2nd carrier in terms of number of routes with 190 different connections (only surpassed by Vueling which operates 356 city pairs). This evidences the low-cost

operation model of this carrier whose founders are the same who created Vueling in 2004.

Table 3 KPIs from Spanish carriers in 2016. Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

Carrier	ASM	RPM
Iberia	36352168758	29066907391
Vueling	20931803894	17237564482
Air Europa	16395581969	12844396364
I Express	4625677755	3646736445
A Nostrum	2179122860	1317601278
Volotea	2014032720	1599666800
Evelop	1624533950	1364608517
Wamos	572550363	549648348
Privilege	412926120	144524142
Alba Star	343134432	234641426
Plus Ultra	331212160	155669715
Naysa	194070300	139146284
Binter	160528830	127554939
Canair	130669575	95388792
Canary Fly	81435825	34203047
Total	86349449511	68558257970

Figure 4 Key Performance Indicators from Spanish carriers in 2016. Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

As Table 3 and Figure 4 show, Iberia is the biggest carrier in terms of ASM (Available Seat Mile) and RPM (Revenue Passenger Mile) due to its combination of big number of operations and long range routes over the Atlantic (see Figure 3). Comparing both figures, it can be observed how the four Canary carriers (Naysa, Binter, Canair and Canaryfly) achieve the lowest ASM and they are pushed into the background in Figure 4 due to their inter-insular short routes.

2.2.2. Data per aircraft

As previously made in section 2.2.1, postprocessed data from different databased is presented here. This time it is organized using aircraft as categories instead. Annual operations, overall block hours and average route distance are shown in Table 4 and Figure 5 to begin with.

Table 4 Traffic data from aircraft of Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016)

AC	Annual operations	Block hours	Av. Dist. [mi]
A345	60	77020	286
A346	8907	451183	4792
AT43	1504	56317	177
AT72	10574	79577	141
AT75	55761	46421	162
AT76	18543	13471	185
B712	27544	71	538
B733	211	93128	737
B734	2236	1805	705
B735	600	11110	627
B738	32612	56049	1046
B744	405	21928	3457
B763	433	45380	875
B788	661	15688	2978
CRJ2	14641	4330	428
CRJ9	64365	36855	533
E145	1324	70005	273
E190	25869	2509	501
F100	38	948	995
Total	58524	1232696	917

Figure 5 Traffic data from aircraft of Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016)

As the figure shows, the A320 is the most used aircraft within the Spanish carriers in term of both overall operations and block time. This is due to the great A320 fleet owned by Iberia, Vueling and Iberia express. The next most used aircraft in terms of operations are the CRJ9 and the AT75 due to their extended usage among the canarian short-haul routes airlines. On the other hand, the most used aircraft in terms of block hours are the B735 and the B712. Finally, the biggest average distance is flight by the A340 series, the jumbo B744 and the Dreamliner B788 from Air Europa that joins Madrid with Miami.

More information regarding the information related to aircraft is gathered in Table 5 and Figure 6. There, the ASM and RPM per aircraft are presented. This time, after the A320, the A346 is the aircraft with more ASM/RPM flight probably caused by its long-haul routes.

Table 5 Key Performance Indicators from aircraft of Spanish carriers in 2016. Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

AC	ASM	RPM
A319	3443002968	2738709634
A320	27660786840	22545992900
A321	3636479510	2796191733
A332	10876545075	7949939395
A333	8620928960	6848038300
A343	2511173350	1899638667
A345	6349200	5968248
A346	17484172770	13987338216
AT43	11979360	11260598
AT72	102080850	65543721
AT75	476918325	364372963
AT76	236508825	148679110
B712	1528587280	1210003820
B733	21304459	18960969
B734	235619712	160221404
B735	44487300	36240405
B738	4781251080	4227138537
B744	572550363	549648348
B763	95476500	33416775
B788	673126740	632739135
CRJ2	260604800	147952642
CRJ9	1819071090	1127741015
E145	18072600	16988244
E190	1229082084	1032901615
F100	3289470	2631576
Total	86349449511	68558257970

Figure 6 Key Performance Indicators from aircraft of Spanish carriers in 2016. Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

2.2.3. Data per region

As stated before, Spanish airlines comprehend a great variety of economic ways of carry out that business. This also leads to several markets whose destinations are fed by those carriers. With the aim of showing the different regions where the Spanish airlines fly, this section shows traffic data segregated by 7 different regions:

- Iberia: inter-peninsular Spanish flights.
- Canary: inter-insular Spanish flights.
- Ib-Canary: peninsula-Canary Islands Spanish flights.
- Iberia-EU: peninsula-rest of EU Spanish flights.
- Canary-EU: Canary Islands-rest of EU Spanish flights.
- Iberia-Intl: peninsula-rest of the world Spanish flights.
- EU-EU: Spanish airlines flights within the rest of the European Union.

The reason behind the segregation of the peninsular and Canarian regions relies on historic and traditional issues. Due to the big distance between islands in that archipelago and the big number of inhabited islands a big inter-insular air market has been developed giving rise to 4 important airlines (Binter, Naysa, Canair and Canaryfly; see Table 1). Regarding the rest of regions, the inter-European flights are mainly carried out by point-to-point low-cost carriers (LCCs) and the international flights are mainly Atlantic flights towards both Latam and US carried out by traditional airlines and tour-operators.

All of the described seven bins are selective, in other words, given a route (airports of origin and destination), it can only be included within a determined bin. The outcome of the analysis of all the flights carried out by the 15 Spanish airlines described at the beginin of section 2.2 are gathered in Table 6 and Figure 7.

Table 6 Traffic data from exploited regions of Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016).

Region	Departures	Annual BH	Av. Distance
Iberia	165	245908	325
Canary	34	57408	106
Ib-Canary	66	86477	1125
Iberia-EU	398	466851	879
Canary-EU	37	17474	1496
Iberia-Intl.	45	216441	5145
EU-EU	259	142137	590
Total	1004	1232696	917

Figure 7 Traffic data from exploited regions of Spanish carriers in 2016. Source: (AENA, 2016) and (EUROCONTROL, 2016).

As the graph from Figure 7 shows, the most of the Spanish carriers' flights join an Iberian city with another European (398 city pairs). The second most-exploited market in terms of departures is the inter-European (259 city pairs). This is due to the point-to-point flights of the LCCs Volotea (152 flights), Vueling (71 flights) and Alba Star (22 flights).

The Iberia-EU market is also the biggest in terms of cumulated BH. However, the second market in this case is the inter-peninsular region, instead of the inter-European. This may be caused because the Iberian flights show a faster frequency than the latters; thus cumulating more BH along the year.

Regarding the average distance, as expected, the intercontinental flights are the ones which show the largest range. An interesting observation can be made in this regard, the Iberia-EU flights show a shorter average longitude than those from the Iberia-Canary region. This could indicate that the most of the routes from the peninsula to Europe joint cities from near countries such as Portugal, France and Italy. In fact, even London or West-Germany cities are closer to Madrid that the Canary Islands.

Following a similar analysis to that carried out in the airlines and aircraft sections (sections 2.2.1 and 2.2.2), Table 7 and Figure 8 show the RPM and ASM classified by the regions explained at the beginning of this section.

Table 7 Key Performance Indicators from exploited regions of Spanish carriers in 2016.
Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

Region	ASM	RPM
Iberia	7286161844	5722862745
Canary	460074603	308640768
Ib-Canary	6219648230	4863103142
Iberia-EU	28617527158	23357440212
Canary-EU	1126492065	970614424
Iberia-Intl.	37076273774	28799646389
EU-EU	5563271837	4535950290
Total	86349449511	68558257970

Figure 8 Key Performance Indicators from exploited regions of Spanish carriers in 2016.
Source: (AENA, 2016), (EUROCONTROL, 2016), (Innovata, 2013) and (Sabre, 2013).

In this case, due to the high distances, the intercontinental flights (Iberia-Intl.) are the ones with the biggest values of Available Seats Mile (ASM) and Revenue Passenger Mile (RPM). However, the Iberia-EU region is close to it due to the fact that is the one which contains the biggest amount of departures as shown in Figure 7. LCCs such as Volotea, Vueling or some routes from Air Europa are the ones which feed this European city-pairs.

When comparing this graph against Block Hours (BH) results in Figure 7 it can be seen how the region order is the same except from one pair. The two regions who have the less both BH and ASM are switched in Figure 8 in respect to the previous one. In other words, Canary and Canary-EU are the 6th and 7th regions respectively in terms of BH (Figure 7) but the 7th and 6th in terms of ASM (Figure 8). This is due to a couple of factors which are in fact related with the kind of routes and aircraft used within flights from those regions:

- Aircraft capacity. In the Canary-EU flights, aircraft are bigger thus increasing the seats of the flight and therefore making the ASM grow. Inter-insular flights (Canary region) are usually feed with airplanes manufactured by Embraer, Canadian Regional Jet (CRJ) or ATR, whose capacity varies from only 40 to 90 seats. On the other hand, Canary-EU flights are usually flown with small or medium airliners (Airbus A320 family or Boeing 737) from 120 up to 200 seats.
- Velocity. Within Inter-insular flights, the overall velocity of the trip is commonly much slower than longer trips. This, even considering short distances, gives rise to slower trips and a bigger volume of BH. This item is affected in two different ways:
 - Short distances. In inter-insular routes aircraft can hardly reach their cruising speed since a big part of the flight are the climb and the airport approach.

- Small airplanes. Generally, Canarian airlines use regional aircraft whose cruising speed is much smaller than bigger airliners; 500 mph in the A320 case and 320 mph in the ATR case, see Appendix D for detailed information in this regard. In any case, these velocities are not normally reached due to the fact explained in the previous bulleted item.

Chapter 3. Methodology (model design)

Once the 2016 data from Spanish carriers has been broken down, this section aims to describe the model which carries out the future estimation of traffic (section 3.1), biofuel price and regulations (section 3.2) and, eventually, the operating expenses suffered by the airlines (section 3.3). These three pillars constitute the basis of the prognosis. Figure 9 summarizes its main pieces and their interconnections.

Figure 9 Global scheme of the estimation model and its main components: traffic, biofuel and costs models.

As explained before (section 2.1) several DBs are needed in order to feed the model. This can be observed in Figure 9, where traffic data is inserted into the Traffic model block jointly with the airport DB which is used mainly to determine the distances. On the other hand, the aircraft DB is embedded into the three different models due to the relevance of the aircraft properties (see Appendix D).

3.1. Traffic model

Several organizations and consulting companies try to estimate the air transport volume evolution in order to help airlines and related corporations to take accurate decisions such as which market must be considered as a potential target or which route could be affected due to demand oscillations. In this case the model is based in the estimated growth rate, a method included within the so-called *time-series projections* in (Doganis, 2002).

3.1.1. Forecast

Following the premises stated in (IATA, 2016) and (AIRBUS, 2016), this industry has shown a strong resiliency to external shocks (especially critical were the Gulf crisis in the 90's beginning, the 11-S and the financial crisis of 2008) and it has outperformed the historical world Gross Domestic Product (GDP) growth. As seen in Figure 10, the world traffic has doubled within the last couple of 15-year periods and it is expected to repeat this behavior in the following 15-year period. In fact, a 3.5%-4.5% Compound Annual Growth Rate (CAGR)³ has been forecast until 2035. Nevertheless this values could be affected by several uncertainties. For example. They could be decreased if the protectionism level of governments' regulations grows, hence difficulting the trade between states. An example of this can be found in the economic policies that are been announced in the US since the Donald Trump election in 2016.

³ CAGR, also known as Compound Average Growth Rate or Average Annual Growth Rate (AAGR), is the mean Annual Growth Rate (AGR) along a certain period of time (years in this case):

$$CAGR = \frac{\sum_{i=1}^N AGR_i}{N} \quad i = 1, 2, \dots, N \text{ years.}$$

This indicator represents the AGR expected if the growth rate was steady. In terms of beginning and ending values, V_i , it can be calculated as follows:

$$CAGR = \sqrt[N]{\frac{V_1}{V_N}} - 1.$$

Figure 10 World annual traffic: historic and Airbus forecast. Source: (AIRBUS, 2016).

Asia (mainly represented by China, India and Indonesia), see Figure 11, is going to be the fastest growing region in the next two decades (CAGR of 4.7%). In fact, China and India are supposed to displace USA and UK for the 1st and 3rd place respectively of biggest markets ranking during the 2020's. On the other hand, the aforementioned outlooks guess that Europe will be the slowest region with a 2.5% CAGR.

Figure 11. Passenger journeys (millions) forecast of the top ten markets worldwide. Source: (IATA, 2016).

A Europe focused analysis is carried out in (EUROCONTROL, 2013) which also includes some remarks regarding the development of alternative fuels. This report considers special factors such as airport capacity, high-speed train network development (very relevant for northern Spain routes) and environmental impact. Its most-likely scenario, *Regulated growth*, indicates that European flights will suffer a 1.8% CAGR been higher during the first decade (about 2.1% from 2015 to 2025). However, this Europe's development is based on eastern countries such as Bulgaria, Romania, Ukraine and Belarus while western states will face a below-2% CAGR, as shown in Figure 12.

Figure 12 European countries CAGR (2012-2035) in the most-likely scenario as stated in (EUROCONTROL, 2013).

Particularly, traffic zones of Spain and Canary Islands are expected to grow at AGRs between 1.5-2.0% in the next two decades. In fact, (EUROCONTROL, 2013) states a 1.7% annual growth between 2015 and 2025 within its *Regulated growth* scenario. Its worst scenario, *Fragmenting world*, estimates a null growth instead. This is based on the idea of higher tensions between regions and increasing fuel prices.

Despite of these data, recent investigations have increased the traffic estimation for the next decade (EUROCONTROL, 2017). This analysis includes considerations regarding special events such as the EURO2020 (European football cup) or the switch of tourism towards Iberia due to south-eastern (Tunisia, Egypt and Turkey) threats. All of this jointly with the fall of oil prices has made analysts update their forecasts for Spain up to a 2.0-3.0% AGR for 2015-2025.

With all of this in mind, the two main inputs of the traffic estimation model are described in the following bullets:

- Traffic of Spanish carriers in 2016. Data from 4 different databases ((EUROCONTROL, 2016), (AENA, 2016), (Innovata, 2013) and (Sabre, 2013)) has been merged in order to obtain the annual routes, frequencies, passengers and fleets from each of the airlines analyzed. This process was summarized and its results analyzed in Chapter 2.
- Traffic forecasts. Data from (EUROCONTROL, 2017) is used since it is the most recent and accurate source, it is focused in Europe and its estimations are made with a very detailed forecast method. Different AGRs are used for Iberian, Canary or European flights. As shown in Table 8 and Figure 13, represented on the following page, three different scenarios are also available: High (optimistic), Baseline and Low (pessimistic). As the reader may observe, estimations suffer from lack of information for the last 4 years (from 2023 onwards) thus producing linear trends (constant AGRs) in that period. The higher AGRs for Spain and Canary islands in 2016-2018 is due to the aforementioned threats in conflictive countries from the south-east that are moving tourism through south-west.

Table 8 Forecast for Annual Growth Rates (AGRs) in Spain, Canary Islands and Europe.
Three different scenarios are represented: High, Base and Low. Source:
(EUROCONTROL, 2017).

	Spain			Canary Islands			EU		
2013	-1.9			-3.4			-1.1		
2014	3.9			6.9			1.7		
2015	3.3			-0.9			1.6		
2016	7.7			11.0			2.8		
	High	Base	Low	High	Base	Low	High	Base	Low
2017	7.1	5.5	3.9	7.8	6.2	4.7	4.3	2.9	1.5
2018	4.4	2.8	1.4	3.8	2.2	0.7	3.1	1.9	0.6
2019	4.6	2.0	-0.5	4.4	1.6	-0.7	3.7	1.8	-0.2
2020	4.0	2.3	0.7	3.8	1.7	0.0	3.9	2.1	1.2
2021	3.3	1.4	-0.2	3.2	1.2	-0.6	3.0	1.4	-0.1
2022	3.3	1.6	0.0	3.5	1.4	-0.3	3.0	1.6	0.2
2023	3.2	1.7	0.2	3.5	1.4	-0.3	3.0	1.6	0.2
2024	3.2	1.7	0.2	3.5	1.4	-0.3	3.0	1.6	0.2
2025	3.2	1.7	0.2	3.5	1.4	-0.3	3.0	1.6	0.2
CAGR₁₇₋₂₅	4.0	2.3	0.7	4.1	2.1	0.3	3.3	1.8	0.4
Total_{25/16}	42.7	22.6	6.0	43.6	20.0	2.8	34.3	17.8	3.9

Figure 13 Forecast for Annual Growth Rates (AGR) in Spain, Canary Islands and Europe.
Three different scenarios are represented: High, Base and Low. Source:
(EUROCONTROL, 2017).

3.1.2. Model

In the following lines the model is briefly described. It is in charge of estimating the traffic inputs of the cost model for each airline, year and route (see Figure 9) using as reference the aforementioned AGR.

3.1.2.1. Departures, flown miles and ASM

Firstly, the departures are directly extracted arising from available data from 2016 and the estimations explained in section 3.1.1 by the equation

$$Departures_{year} = Departures_{2016} \cdot \prod_{i=2017}^{year} (1 + AGR_i).$$

Once the number of departures is known, the flown miles per year can be simply obtained by multiplying then by the route distance and then the Available Seats Mile (ASM) is computed using the aircraft capacity (seats).

3.1.2.2. Route times

Another input of the model is the number of hours that the fleet has been used that year (both block and flown hours; BH and FH). This was supposed to be computed based on the formulation developed in (Ssamula, et al., 2006). The model developed there takes into account the route distance and the cruise speed of the airliner that flies it.

On the other hand, one of the DBs used in this study (see section 2.1), (Innovata, 2013), included an estimation of the flight time (see section A.1.2). In order to compare and validate both formulations, some actual BH gathered from the Vueling website were compared. Table 9 and Figure 14 show the results of this validation on the following page.

Table 9 BH function validation results. The actual BH shown by Vueling are compared against BH estimated by improved Ssamula (Ss^*) and (Innovata, 2013) (Inn).

City pair	Vueling BH	Ssamula*		Innovata	
		BH	Diff [%]	BH	Diff [%]
Barcelona-P. Mallorca	51	54	5.3	45	-11.8
Paris-London	63	61	-2.5	70	11.1
Barcelona-Bilbao	70	73	4.4	65	-7.1
Valladolid-Barcelona	80	81	1.6	80	0.0
Barcelona-Jerez	95	102	7.6	110	15.8
Rome-Munich	100	92	-7.8	95	-5.0
Vigo-Barcelona	103	104	1.1	100	-2.9
Barcelona-La Coruna	105	104	-1.1	100	-4.8
Barcelona-Zurich	105	101	-3.4	105	0.0
Barcelona-Bari	130	129	-1.1	120	-7.7
Barcelona-Prague	140	138	-1.3	140	0.0
Santander-Tenerife	200	189	-5.4	195	-2.5
Banjul-Barcelona	305	302	-0.9	330	8.2

Figure 14 BH function validation results. The actual BH shown by Vueling are compared against BH estimated by improved Ssamula, Ss^* , and (Innovata, 2013), Inn.

Both estimates from (Innovata, 2013) and an improved Ssamula function are compared against the actual values obtained from the Vueling airline in Figure 14. It must be pointed out that, the original formulation in (Ssamula, et al., 2006) showed a certain bias in their BH estimations. For this reason a fitting step was made. In this process, a constant time factor was applied to the original estimation in order to

minimize the overall Mean Absolute Error (MAE). This new formulation is the so-called improved Ssamula, Ss^* , in that graph.

In Figure 14 it can be checked how the improved Ssamula method, Ss^* , presents a better behavior than the Innovata, Inn, when compared against actual BH from Vueling. In fact, it can be observed how the light blue line (the one that represents the Ss^* error) has smaller values than the light green one (the one that represents the Inn error). Ss^* estimations present a MAE of 2.5 %. For these reasons, the improved Ssamula formulation was used within the traffic model applied in this study.

3.1.2.3. Fleet size

Finally the number of aircrafts used per route is estimated supposing a diary utilization of 10h for each plane⁴ as the following equation shows:

$$\text{No. of } AC_{year} = \frac{\text{Trip time} \cdot \text{Departures}_{year}}{AC \text{ daily utilization}}$$

where the trip time is also estimated using the improved formulation in (Ssamula, et al., 2006) which considers the previously estimated BH and a servicing time which involves refueling, checking engines and other ground handling activities while the airplane is parked.

3.2. Biofuel model

This section presents the basis of the biofuel model that is in charge of feeding the costs model as shown in Figure 9. Two main parts are differentiated: the kerosene and biofuel prices and the regulations. The first piece is used to estimate the price of both common kerosene and alternative biofuels during the decade that is under study (2017-2025). The second piece attempts to replicate the possible measures

⁴ The mean aircraft daily utilization was set to 10 hours following the results shown in (Amizadeh, et al., 2016) and (MIT ICAT, 2014). These analyses, which use data from the last years, agree that both European and American airlines achieve this value for their fleets in average.

adopted by international organizations and governments in order to incentive the usage of cleaner energy sources.

3.2.1. Price forecast

The first piece of the biofuel model is in charge of estimate the value for both common kerosene as well as different biofuel types considered in this project. This is carried out using previous research and forecast as information source.

3.2.1.1. Kerosene

Even though fuel price is one of the most analyzed commodity values its forecasts are not able to estimate its future value with enough accuracy due to unpredicted disturbances in the geopolitical and economic situation. Particularly, the dramatic fall of the second half of 2014 was not expected at all and most of the previous outlooks have become useless. As an example, the estimation made in (NY State, 2009) could not even predict the rise suffered by the fuel price in 2010-2011, as shown in Figure 15.

Figure 15 West Texas price forecast. Source: (NY State, 2009).

Another obsolete analysis, (Lukoil, 2013), was not able to foresee the dramatic fall of 2014. In fact, their scenarios expected a rising price of the barrel from 2013 until 2025. This is depicted in Figure 16.

Figure 16 Brent price forecast. Source: (Lukoil, 2013).

Nevertheless, in more recent studies, most of the analysts agree that minimum from January 2016 represents a relatively clear turning point (LeBlanc, 2015) and that fuel price is likely to remain within 30-130 for the next 5 years (Yergin, 2015). In fact, the so-called *rivalry* scenario mentioned in that report is the closest to resemble the actual situation. This can be observed in Figure 17.

This *rivalry* scenario is based on the idea that different energy sources will clash for the market share in the forthcoming years. Four circumstances are pointed as the drivers for this competition:

- Price signals. Last adjustments within the commodities market could force the producers diminish their production hence inflating the fuel prices.
- Environmental concerns. Fossil-fuels-based energies are disadvantaged by global plans such as those agreed in Kyoto 1997 or Paris 2015. Carbon markets or pro-clean-resources projects, which are the main outcome of

these agreements, ease and promote the development of renewable energy in detriment of fuel.

- Technology improvements. Nowadays new sources of energy are been found and old energy production processes are been enhanced using technological research.
- Energy security. Countries try to be as independent as possible in terms of energy production. In oil-importer countries, this means the development of other sources for energy generation.

Figure 17 Brent price forecast. Source: (Yergin, 2015).

The FAA forecast for the next 20 years, (FAA, 2016), also estimates a similar oil price to that foreseen in the *rivalry* scenario. The fuel climb as of 2016 can be observed in Figure 18 on the next page.

Figure 18 Brent price forecast. Source: (FAA, 2016).

Making a very accurate and precise prediction of the fuel price is not the goal of this paper so a couple of general scenarios (see Table 14) are considered:

- **Stability (S):** 50 USD/barrel. This scenario supposes a continuation of the present situation of production surplus and prices war between producers. This is similar to the *autonomy* scenario described in (Yergin, 2015), see Figure 17. It is based on the assumption that actions carried out by the society and improvement achieved by the technology will regionalize the worldwide energy scheme. One of the facts that is supposed to maintain the fuel price low in this scenario is the adjustment of production costs and the rise of gas demand.
- **Rising (R):** 10 USD per year increase from 50\$ in 2017 up to 130USD in 2025. This is the forecast predicted by the FAA in its 2016 report (FAA, 2016) where the fuel price reaches again its level of 2011. This is similar to the aforementioned *rivalry* scenario from (Yergin, 2015), see Figure 17.

The *vertigo* scenario is discarded because, as of 2016, its price evolution is obsolete and such a fast price recovery seems difficult to reach nowadays. The premise behind this outlook is the expectation of a hesitant and erratic economic evolution.

Fuel and jet kerosene data is taken from (IndexMundi, 2016), see Figure 19. In order to transfer fuel prices from the previous scenarios into jet kerosene a +20% factor

has been applied using an average of data since 1990. Fitting for last years' market has been checked as well as it can be seen in the red line of Figure 19. This 20% factor has only been violated in punctual situations such as dramatic price falls (2008 or 2014) or in times of very volatile exchanges (2011-2012).

Figure 19 Historic prices of West Texas and Jet fuel barrels. Source: (IndexMundi, 2016).

3.2.1.2. Biofuel

Several different kinds of alternative fuels are under development in the last years. From cultivated microalgae to forestry residues, the pros and cons of a great variety of feedstocks are being currently analyzed. Some prior studies have analyzed the biofuel extraction process from microorganisms (Breil, et al., 2016) or cultivated plants (Hood, 2016). In (Gössling & Upham, 2009) further information can be obtained in this regard. Since this research focuses in the short period when their implementation is expected to begin, relatively already-developed biofuels are chosen as alternatives to common kerosene. As recent studies show (de Jong, et al., 2015) (IRENA, 2017), it seems that the most suitable option for a biofuel immediate introduction into the aviation industry is the one that come from the synthetic process called Hydrotreated Renewable Jet (HRJ) fuel⁵.

⁵ This method consists basically in the treatment (deoxygenation and isomerization) of vegetal oils or animal or waste fats. They are also known as bio-SPK (Synthetic Paraffinic Kerosene) or Hydroprocessed Esters and Fatty Acids (HEFA).

The methodology to estimate the prices of different biofuel feedstocks is taken from (Escobar, et al., 2016). The prices for 2017 are shown in Table 10. Two plants (Camelina and Jatropha) are considered within the different scenarios analyzed in section Chapter 4 (see Table 14). Used cooking oil is also considered as a potential resource due to its competitive production price and low emissions. Nevertheless its usage as a real alternative could be constrained by some production issues (Talebia_Kiakalaieh, et al., 2013).

The technological suitability of these three feedstocks has been already proven in commercial flights Figure 20. Salicornia is discarded because, in addition to its higher price, its use as biofuel feedstock can be in conflict with culinary usage. Other sources such as microalgae constitute a prohibitive alternative to kerosene since the economic measures needed to overcome the gap between them seem overwhelming, at least with present technology.

Date	Carrier	Route	Feedstock
22 June 2011		Amsterdam – Paris (B737)	Used cooking oil
15 July 2011		Hamburg – Frankfurt (A321)	Mix of feedstocks
18 July 2011		Amsterdam – Helsinki (A321)	Used cooking oil
21 July 2011		Mexico City – Tuxtla Gutierrez (A320)	Jatropha
1 August 2011		Mexico City – Madrid (B777)	Jatropha
3 October 2011		Madrid – Barcelona (A320)	Camelina
6 October 2011		Birmingham – Arrecife (B757)	Used cooking oil
13 October 2011		Toulouse – Paris (A321)	Used cooking oil

Figure 20 First commercial flights using biofuel. Source: (ICAO, 2011).

Information about demonstration flights and commercial flights carrying passengers in the last years (not only the first ones shown in Figure 20) is gathered in Table 36 and Table 37 within Appendix F.

As may be observed from Table 37, there has been an intensive use of UCO as an alternative feedstock to traditional kerosene. In addition, camelina and jatropha have been also burned in several flights.

On the other hand, regarding the different carriers that have test the usage of biofuels within their scheduled flights, KLM stands out among the others. In fact it has feed their fleet with biofuel on a regular basis several times. These demonstrations are under the ITAKA program and their outcome can be found in (Dean, 2014).

3.2.2. Emissions

The emission of Greenhouse Gases (GHG) is the main concern behind the global efforts that are being implemented with the goal of reducing atmosphere pollution. Regarding this, complex models are being developed to compute the whole life-cycle emissions of different feedstocks and refining processes. This is called the Well-to-Wake (WtW) path. In addition, this can be divided into two parts. Firstly, the Well-to-Tank (WtT), which includes GHG emitted during the fuel production and delivery and secondly, the Tank-to-Wake (TtW), which refers to the GHG emitted due to the jet combustion. The latter, TtW, is the allocation where biofuels take advantage over conventional fossil fuel (Novelli, 2011).

When dealing with life-cycle emissions assessment, a great dispersion in values is found along the literature (Novelli, 2011), (Agusdinata, et al., 2011), (Staples, et al., 2014) and (Stratton, et al., 2010). In this analysis, recent results from (de Jong, et al., 2017), see Figure 21, are used and displayed in Table 10. In that article, the author recommends the usage of the energy allocation method as a standard for determining the WtW emissions and its results are the most conservative when compared against prior studies.

Table 10 Feedstock properties for HRJ biofuels.

Feedstock	2017 Price [USD/fuel ton] (Escobar, et al., 2016)	Emissions [gCO _{2eq} /MJ] Prior studies	Emissions [gCO _{2eq} /MJ] (de Jong, et al., 2017)	ΔBio/Fossil [%]
Fossil fuel	430	-	88	0
Used cooking oil	830	17-21	28	-68
Camelina	925	37-55	55	-38
Jatropha	1065	18-47	47	-47

Figure 21 WtW GHG emission performance of biofuel conversion pathways. Source: (de Jong, et al., 2017).

Other biofuels seem to show a better behavior in terms of WtW emissions. In particular, the emissions of the well-known Fischer-Tropsch (FT) mixtures are in the range of 10 gCO_{2eq}/MJ. However, its current cost and the complexity of their mass production make their immediate implementation (the goal of this research) not much probable.

3.2.3.Regulation

During the last decades a global concern relating CO₂ emissions has grown among certain institutions all around the world. The climate change has become an international problem. Several actions are being taken in order to reduce those emissions involving all sectors (UNEP, 2015). The graph in Figure 22 shows the past and potential evolution of GHG emissions in two different scenarios.

Air transport represents a very important industry that contributes to this effect severally. In fact, a 2% of the global 2015 CO₂ emissions (12% of the transportation sector) were produced by aviation as reported in (ATAG, 2016). For this reason, IATA is leading a global plan to react to this trend (IATA, 2016).

Among all the possible incentives that have been carried out in different countries and industries, as stated in (Hazariah, et al., 2016), the approach that seems to be the most suitable is the combination of a mandatory blending percentage with subsidies through tax management or offset mechanisms. In the following sections, the other two mitigation policies or measures, emissions surcharge and mandatory blending percentage, are described according to its implementation in the estimation model developed for the forecast in this analysis.

¹ Data for 2014 are available from EDGAR and PRIMAP, see Chapter 2.

² The six greenhouse gases covered by the UNFCCC/Kyoto Protocol — carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Here aggregated with 100-year Global Warming Potentials (GWPs) of the IPCC Second Assessment Report.

³ Based on the final released IPCC AR5 scenarios database data.

Figure 22 Historical GHG emissions and projections until 2050. Source: (UNEP, 2015).

Tax management policies were discarded in this study. The reason is that Spanish government frees from taxes airlines whose international operations ratio is bigger than 50%. This holds true for all of the Spanish carriers except for the Canary ones. Nevertheless, within the Canary Islands legal framework, a different normative must be followed. In that case, neither the maritime nor the air transport is forced to pay

taxes as stated in (BOE, 2007). Summarizing, all of the Spanish airlines are already freed from tax payments.

3.2.3.1. Emissions surcharge

During the year 2005, the EU launched the so-called EU Emissions Trading System (ETS). This scheme is based on a cap-and-trade principle: each participant is assigned a cap limit for its GHG emissions and then the surplus or lacking emissions are traded in a secondary market through the so-called European Allowances (EUAs). This program has been divided into different phases which are been designed on the fly:

1. Phase I (2005-2007). At the beginning (European Commission, 2005), only CO₂ from industries such as energy production, mining and processing of ferrous metals were included into the scheme.
2. Phase II (2008-2012). In the following years, more activities and gases were attached to the system and more countries joined it. In fact, aviation was included in 2012.
3. Phase III (2013-2020). During this period some changes, explained below, to the program were proposed due to the lack of effectiveness of the program and the fall of the EUAs' price.
4. Phase IV (2021-2028). This phase is expected to increase the pace of emissions cuts in order to achieve the EU 2030 target (40% emissions reduction from 1990) agreed in the 21th Conference of Parties (COP) held in Paris in 2015.

Despite the fact that inter-EU flights were included in this scheme in 2012, long-haul routes departing or arriving EU were not surcharged in order to avoid overlaps with counterpart mechanisms and other trust issues. This decision, also known as *stop-the-clock*, has caused a lot of controversy in the industry along the years and it has been revised several times. In fact, recently in July 2017, its revocation delay has been backed by the EU Panel until 2021. At that time, another meeting will be carried

with the aim of discuss the *stop-the-clock* revocation if global carbon markets (which are expected to be developed by aviation international organizations by that time) are not on the expected way or do not achieve their desired effectiveness regarding emissions surchargement and reduction.

With the goal of estimate the future prices of the EUAs, an analysis of historical values and forecasts from different experts is carried out in the following paragraphs. Historical values of the EUAs come from (EEX, 2002) and are represented in Figure 23.

Figure 23 Historic price of EUA [EUR/tCO₂]. Source: (EEX, 2002).

This low prices are the consequence of the backward movement of the economy since the 2008 crisis; industry decreased their GHG production hence causing an excess of EUAs in the market.

Forecast carried out during the Phase II of the EU ETS (Koop & Tole, 2011) expected a major increase of the prices. Analysts predicted different situations in those years. One possibility was the scenario where the EU ETS were to be ended in 2020 without a Phase IV; in that case the prices of the EUAs were expected to fall to zero price in 2018. In the other possibilities, all of the outlooks (depending on the measures adopted by the EC; short or long term) expected a biggest growth of prices than the one that has been produced in the actual prices (more than 10 EUR/tCO₂ by 2017 and more than 20 EUR/tCO₂ by 2028).

Other example of these failed forecast is shown in Figure 24. There, the author, (Yunyi Chen, 2012), reflected 5 different scenarios considering Business as Usual (BAU) or different potential developments of the energy and market indexes (high and low for each one). In any case, none of them was able to predict the prices of the 2014-2016 period.

Figure 24 EUAs' price forecast. Source: (Yunyi Chen, 2012).

EU is trying to recover levels around 20 EUR/tCO₂ via two market policies: backloading and Market Stability Reserve (MSR). The first one consists in a delay of EUAs sales. During the 2013-2015 period, 900 million EUAs were withheld from auctions in the primary market. These are expected to be reintroduced in 2019-2020 auctions. In fact, as analyzed in (ICIS, 2016), this policy did had an impact in 2014-2015 when volume of traded EUAs decreased and their price increased, see Figure 25. Nevertheless their value has returned to 2013 levels in 2016 (as already seen in Figure 23).

Figure 25 Backloading effect on EUAs price 2014-2015. Source: (ICIS, 2016).

The second measure planned by the EC to force an increase in the EUAs' price is the MSR, to be launched in 2019. It consists in reserving surplus EUAs within a special fund. The volume of this withheld allowances can be observed in Figure 26.

Figure 26 Market Stability Reserve (MSR) planned for 2019 onwards. Source: (ICIS, 2016).

However, these strategies have not had a noticeable impact yet and the EUA's price remains considerably low to the EU expectations. Perhaps due to this reason forecasts from past years were too optimistic in this regard and they are far from the actual current prices. For example, in (ICIS, 2016), Figure 27, the rally caused by the backloading measure in 2014-2015 was expected to be continued and further accelerated in 2019 due to the MSR. Nevertheless, 2017 prices are far below the price in that estimation, around 12 EUR/tCO₂.

Figure 27 EUAs' price forecast. Source: (ICIS, 2016).

Finally, In order to estimate the effect of this program a model similar to that described in (Girardet & Spinler, 2013) was implemented here. The method consists in calculating the amount of CO₂ emitted arising from the mass of fuel burned and applying an estimated value for the emissions cost as show in the following equation

$$ETS \text{ Expenses} = m^f \cdot e \cdot c^{CO_2}$$

where m^f represents the mass of fuel used (computed by the operating costs estimation model described in section 3.3), e is the exchange factor of CO₂ tones emitted for each fuel ton ($e = 3.15 \text{ m}^{CO_2}/\text{m}^f$ according to (IPCC, 2007)) and c^{CO_2} stands for the price of CO₂ emissions.

Since forecasts found in the literature were outdated as explained before this price is estimated using the approximate average from last three years before 2016 ($c^{CO_2} = 6 \text{ €/tCO}_2$). During this period the EUA value seems stabilized if compared against the huge fluctuations of the first ETS phases (2005-2012), see Figure 23.

3.2.3.2. Mandatory blending

The second regulatory method that is going to be analyzed is the application of certain levels of mandatory blending of biofuels by governmental organizations. This measure has not been put into practice yet in the EU. However, if a reduction of carbon is desired, it will be necessary since difference between biofuel and kerosene price are far bigger than the cost of the emissions surcharge explained in section 3.2.3.1.

Medium-short term biofuels analyzed in this study are designed as drop-in fuels. This means that they can be used within the current aircraft technology without any changes in the fuel and engines systems. In fact, these biofuels can be used mixed with traditional kerosene. This is what happened in the most of the flights gathered in Table 37 and the reasons are the flight safety and the biofuel available stock.

In this case, this regulation has been simulated by means of a certain percentage that is applied to the whole mass of fuel burnt. Depending on the different scenarios analyzed (see Table 14) this percentage is forced to grow faster or slower in order to fit the CNG for the desired year. This way, the impact on the carriers' economy will be higher or lower as analyzed in Chapter 4.

3.3. Operating costs

The core piece of this analysis' model is the estimation of the carriers' operating costs. As stated in (Stratford, 1973), these costs are not usually used as an estimate of true costs but as a comparative measure. The main reasons behind their calculations are:

- Aircraft optimization during the design process.

- Comparative analysis of fleet and route planification in airlines' projects.
- Operation optimization in terms of flight equipment development, integration of services and components life extension.

Several work has been done through the aviation history with the goal of compute these costs and, eventually, define strategy lines to diminish them. In fact, in the last years, IATA has created a workgroup dedicated to this tasks. The so-called Airline Cost Management Group (ACMG) is trying since the last decade to join aviation industry players into a common framework to analyse the airlines' expenses and enhance their operations. More information about this task force has been collected in Appendix G.

3.3.1. Model trade-off

Some literature was reviewed in order to choose a suitable model for this purpose. In this regard, historically, the article (Mentzer & Nourse, 1940) is considered as the precursor of methodologies for the airlines cost estimation. They used data from the Douglas DC-3 in that study.

Initially, the model gathered in (ATA, 1967), whose publication was made by the Air Transport Association of America jointly with the three biggest manufacturer companies in the US at that time (Boeing, Douglas and Lockheed Martin). There, a standardized method was developed with a similar aim to the one mentioned in the previous paragraph: compare airplane competitiveness and suitability for a given route. However, given its date of development and its calculations based on empirical regressions it seemed somewhat outdated. A summary of this model can be found in Appendix H.

Other also consulted information sources regarding econometric models were (Stratford, 1973) and (Doganis, 1989). Nevertheless, the former suffered from similar handicaps to those explained in the previous paragraph and the latter was not as detailed as desired for this thesis' purposes.

Another option taken into account was the approach of (Ssamula & Del Mistro, 2004) in determining a realistic and feasible cost model for route economic analysis. Its authors develop a model in order to understand route economics and, eventually, compare the OPEX of different fleets along certain African routes. This was carried out jointly with the development of a model for the estimation of traffic from a route in (Ssamula, et al., 2006).

In (Harris, 2005), an operating expenses model is developed for the NASA. Although published in 2005, its author used data from 1999 gathered by the US DoT Form 41 in order to fit the model equations and validate its results. In this thesis, most of the cost calculating equations were imported from this study for two main reasons: (i) its relatively recent publication date and (ii) its usage of easily available data from BTS Form 41 DBs.

3.3.2. Model description

As explained in the previous section, In this case the methodology developed in (Harris, 2005) was used as a reference and baseline. The main structure of the cost allocations used there can be observed in Figure 28. As shown in the scheme, TOE are divided into TAOE and AOOE. As explained in Appendix I, TAOE appears to have a higher management control in shorter terms than AOOE due to a shorter-term escapability.

Figure 28 Accounting tree as followed in (Harris, 2005).

Its author designs there a model based on data of US carriers⁶ from 1999. Since this paper's analysis is intended to be focused in the next decade (up to 2025) a model fitting and validation was carried out in order to update the model parameters using data from 2015. The layout of this model fitting is displayed in Figure 29.

Figure 29 Model fitting and validation scheme. Operating costs allocations.

⁶ See Appendix J for more information regarding data gathered by the US Department of Transportation (DoT) in general and the financial Form 41 in particular.

Commercial aviation has always been a dynamic industry and its cost structure has suffered great changes within short periods of time. Examples of this are the labor cost reduction carried out by LLCs specially or the sharp increase of fuel cost in the 2011-2014 period (and its consequent decrement from that year onwards).

In addition, costs (at least those which are within the carrier's control) have been suffering a gradual reduction in the last decades (Torrejón Plaza & Celemín Pedroche, 2013) due to reasons such as:

- LLCs efficiency regarding expenses. This has force traditional airlines to carry out strict adjustments in their accounts.
- Liberalization of air transport worldwide, which increased competency.
- Privatization of traditional carriers.

For all these reasons explained in the previous paragraphs the model was fitted and adjusted, since some of its factors were expected to be outdated.

It must be taken into account that the model is not intended to be too exhaustive since input data that is eventually used lacks for some detailed information such as exact purchase prices, maintenance costs, airline employees... The operating costs model inputs can be found in the following list. Three main sources are differentiated:

- Traffic. It was obtained from the T2 schedule (see footnote 6) that summarizes data reported by US carriers. It is compiled by aircraft types and entities. During the Spanish carriers forecast information described in section 3.1 processed as explained in section 3.1.2 was used. Traffic inputs are basically: overall number of operations, flight and block hours, distance flown, ASM and RPM.
- Aircraft. An aircraft database was built gathering all the relevant specifications regarding each airplane characteristics. Older aircraft specs were found in (Harris, 2005). Other sources such as manufacturer's websites had to be

consulted in order to achieve information for newer aircraft. Some of the specs used within the model are: Maximum Takeoff Weight (MTOW), Maximum Landing Weight (MLW), Takeoff thrust, cruise Specific Fuel Consumption (SFC), Aircraft Purchase Price (APP)...

- Fuel. The price of both kerosene and biofuels with their correspondent blending percentage if applicable are introduced in the cost model as inputs.

The outputs of the operating costs model are the expenses associated to each allocation (fuel and oil, maintenance, passenger service...; these can be found in Figure 29). A high level operational cost structure was the first basis for aggregating operating costs. During the validation phase, this output was compared against data from different financial reports gathered in (US BTS, 2016) (see footnote 6).

During the model design the original methodology of (Harris, 2005) was also analyzed. It was found that for some cost allocations (flight crew, flight equipment maintenance and rest of AOOE) an *airline factor* (AF) was applied. This constant fitted to each airline (or entity, the report is not clear about that) is in charge of adequate the model output to the actual values. This does not seem to be a suitable method to design an estimation model since its scope is then constrained to that particular year and to the included airlines. In fact, this was verified while comparing results from years 1999 and 2015. In most cases, the appropriate airline factor was completely different from one year to the other, showing even inverse values. In other words, given an entity, the model estimated a lower cost than the actual one in 1999 but a higher cost in 2015. For this reason the usage of this parameter was discarded and the errors of the model are bigger even for the year 1999.

It must be pointed out that expenses estimated here are supposed to represent the costs suffered by an already operational airline and they do not intend to include any kind of introduction expenses, those items which cost arise on a once only basis due to introduction into service (Stratford, 1973).

In the methodology and the following figures, a classification regarding the airline entity region is done. For some allocations, a *region factor* (RF) is applied depending on which market the entity operates: Domestic, Atlantic, Latam, Pacific and International as differentiated in (US BTS, 2016).

3.3.3.Allocations

In this section, four allocations (Flight crew, Flight equipment maintenance and Depreciation and amortization jointly with Insurance) are commented as examples of the model fitting and validation procedure carried out in this study.

3.3.3.1. Direct costs (TAOE)

This category, as explained in Appendix I, includes expenses dependent on the type of aircraft being operated.

Fuel and oil

This allocation has not undergone any change, in respect to that explained in (Harris, 2005), other than the change of fuel price (see section 3.2.1) for each correspondent year. Nevertheless, its validation comparison is shown in Figure 30 since it is the most relevant piece regarding the estimation of the prices of both common kerosene and innovative biofuels.

Figure 30 Fitting and validation results: Fuel and oil expenses.

Flight crew

This cost allocation was computed using the fleet block hours and MTOW as inputs.

$$\text{Flight Crew Expenses} = K (\text{MTOW})^{0.40} (\text{BH})$$

where K is a constant that adjust the results for each region. Once the results for 2015 the constant K was adjusted for each region. The results of this fitting can be found in Figure 31. As explained before, in this analysis the AF applied in (Harris, 2005) was omitted.

Figure 31 Fitting and validation results: Flight crew expenses.

Insurance

This allocation uses the Aircraft Purchase Price (APP) as input for its estimation. Since data for the entire fleet of years 1999 and 2015 was not available, validation of this section of the model was substituted by a new procedure. For the Spanish carriers, the APP estimation was carried out using the manufacturer's portfolio prices with an average discount of 10% (considering that the catalogue price shown to the public is larger than the actual APP when sold to airlines).

Other flying operations

This is a quite small allocation that includes marginal expenses such as fees and other taxes. The minor amount of costs that are gathered here in contrast with other allocations can be observed in Figure 37. In any case, Figure 32 shows the outcome of the fitting and validation of the model applied to 2016 data. In fact, a lower dispersion to that shown for the 1999 data is obtained.

Figure 32 Fitting and validation results: Other flying operations expenses.

The fitting of this allocation was carried out varying the values of the *region factors* which aim to consider dissimilarities in OPEX due to differences between the different regions. The original and modified values are shown in Table 11.

Table 11 Region factors fitting for Other flying operations.

Region	1999	2015
Domestic	1.2	0.5
Atlantic	0.5	0.2
Latam	0.5	0.4
Pacific	0.3	0.1
Intl.	0.3	0.3

These *region factors* affect linearly to the results. The decrement of their values for the 2015 case could be due to an overall reduction of cost achieved by the airlines. Nevertheless, it must be pointed out that the 1999 values already had an oversized values; it can be observed how the blue estimations from Figure 32 show certain positive bias.

Flight equipment maintenance

A similar procedure to that explained in the previous section was carried out for the fitting of the flight equipment maintenance allocation. A constant that affects the results in the original methodology was modified in order to capture the increase of maintenance expenses suffered by the airlines in the last years. Estimation results in Figure 33 seem to appropriately fit the actual cost reported by the carriers except from three outliers.

Figure 33 Fitting and validation results: Flight equipment maintenance expenses.

Depreciation and amortization

As explained in the section dedicated to the allocation Insurance, the APP was estimated using the manufacturer's portfolio prices with an average discount of 10%. Furthermore, the depreciation period (DP) was set to 20 years according to (IATA, 2016). In addition, following this report, a 5% was used as residual value (RV) at the end of the aircraft's life instead of the 15% used in (Harris, 2005) for the fleet in 1999. The following equation summarizes this calculus:

$$\text{Depr. \& Amort.} = APP \frac{(1 - RV)}{DP}$$

3.3.3.2. Indirect costs (AOOE)

This category, as explained in Appendix I, includes expenses independent on the type of aircraft being operated.

Passenger service

This allocation includes expenses such as flight attendants salaries, passenger's food and other in-flight costs. In fact, in (Harris, 2005), it is modelled as a function of the flight attendant expenses as the following equation shows:

$$\text{Passenger Service Expenses} = 1.6 (55,500)(\text{Number of Flight Attendants})$$

where an averaged salary of 55.5k USD per flight attendant is estimated. Furthermore, the number of stewardesses was estimated using the following equation:

$$\text{Nr. FA} = \left[\left(\frac{AC \text{ BH}}{\text{Attend. Hours per Year}} \right) \left(\frac{\text{Nr. Attendants}}{AC} \right) \right] \left(1,3647 + 0,02351 \frac{BH}{\text{Departure}} \right)$$

where an important hypothesis is that the average stewardess works 1200 BH per year. The result of applying this method to the 1999 and 2015 fleet is shown in Figure 34. The fitting of the model consisted in an increase of 25% in the constant factor applied to the equation. This is probably due to the inflation in the flight attendants' salary and the latter addition of new passenger services such as inflight internet and multimedia or entertainment services, which are each time more common in scheduled flights.

Figure 34 Fitting and validation results: Passenger service expenses.

The difficulty here was that the error for small carriers (those whose expenses are lesser) is positively biased while the error for large carriers (with bigger expenses) is negatively biased. This can be noticed in Figure 34 where symbols in the bottom of the chart are on the right side of the black dashed line while symbols in the middle top are on the left side of the black dashed line. This could indicate, and could be further analyzed, that the model could be further improved via inputting other parameters or using other relations between them

Landing fees

In (Stratford, 1973), it is stated that landing fees are included as an operating expense and are of significance in actual and comparative aircraft cost estimates. They are based on the gross weight of the aircraft, but a number of exceptions to this exist and international flights and short sector flights are in some cases liable to special rates for landing fees. Parking fees are also charged depending on the weight of the aircraft per 24-hour period, after a specific time period.

For this cost, (Harris, 2005) works with the general equation:

$$\text{Landing Fees} = 0.00147 * ST * RF * MLW * Departures$$

the ST being a Service Type Factor (Passenger 1.0, Cargo 0.89), the RF a Region Factor (Domestic 1.0, Atlantic 2.36, LatinAmerica 1.64, Pacific 4.28) and the MLW the Maximum Landing Weight. In this case, Route Factors had to be fitted to results from 2015 resulting in an average 30% increase depending on the region. The outcome of its validation is shown in Figure 35.

Figure 35 Fitting and validation results: Landing fees expenses.

As the chart shows, there exists a great dispersion in the results. This was also a problem in the original model and the cargo airlines were blamed for it. This issue was partially fixed by adding the so-called region factors. Their values are shown in Table 12.

Table 12 Region factors fitting for Landing fees.

Region	1999	2015
Domestic	1.0	2.1
Atlantic	2.4	4.0
Latam	1.6	2.5
Pacific	4.3	6.0
Intl.	2.8	2.8

In this case, changes are not so evident. Most of the factors had to be increased unless the one for international routes which stayed the same.

This model to estimate the landing fees could be further developed in order to consider the actual fees compelled by each airport. In any case this would require a big amount of work regarding the gathering of information from different airports all around the world. Eventually this terminal charge, which is levied upon the departing flight only, would have to be related to the aircraft weight (MTOW usually) as it is commonly ruled.

Rest of AOOE

This category was created since several minor allocations shown a great difficulty to be estimated. They were joined under this term, Rest of AOOE. Some accounts included within it are reservation, sales, advertising, promotion or maintenance and depreciation of ground equipment. Figure 36 shows the result of fitting the model to 2015 data, in this case, since overall bias was very accurate, the fitting process consisted in diminishing the standard deviation of the error. This was carried out via modifying Regional Factors. This can be observed in the difference between the red and yellow circles (Latam) in that figure. The former correspond to the non-fitted model while the latter, nearer to the target or actual value, correspond to the fitted one. The constant for the Pacific routes (diamonds) was also diminished while Domestic (cross) and Atlantic (triangles) factors stayed the same. Another issue is that this allocation was designed to be computed using the aforementioned Airline Factor twice (in two different equations). As stated in the first paragraphs of section

773.3, this factor is not used here as it represents a non-legit way to fit the data in the author's opinion.

Figure 36 Fitting and validation results: Rest of AOOE expenses.

In this allocation, using data from 2015 (red symbols), a clear bias was found for Latam (circles), Pacific (diamonds) and Intl. (squares) flights. For this reason the regional factor was applied though not used in the original formulation. The final values can be found in Table 13. A fairly agreement was achieved using this factors as Figure 36 shows.

Table 13 Region factors fitting for Rest of AOOE.

Region	1999	2015
Domestic	1.0	1.0
Atlantic	1.0	1.0
Latam	1.0	0.6
Pacific	1.0	0.8
Intl.	1.0	1.2

Transport related

This is an allocation with a high level of uncertainty and deviation along all the airlines (from 99% to 0% of AOOE in 1999). The reason behind this is that each airline allocates here different expenses and a standard account is not followed in this schedule. For this reason, a constant ration related to the Rest of AOOE expenses was fixed.

3.3.4. Overall estimation

With the aim of providing a general overview of the expenses estimation method, the order of magnitude of the different allocations of the model and the effectiveness of the model validation and fitting with 2015 data, Figure 37 represents the estimated values for the airlines' expenses structure against the actual values.

Figure 37. Results from operating costs model validation. Comparison of actual (2 outer circles) versus estimated (2 inner circles) aggregated expenses for years 1999 and 2015. Values in USD billions ($\times 10^9$).

First of all, comparing both graphs in Figure 37 it can be observed that the aviation industry in US has increased its 60% costs during those 15 years: from 110 USD billions in 1999 to 180 USD billions in 2015. This agrees with (IATA, 2015) where an average Annual Growth Rate (AGR) of 5% is indicated for that period. Looking at the allocations themselves the ones which error is bigger are the Passengers Services and the Transport Related. In fact, the author in (Harris, 2005) admits this is the most difficult allotment to estimate since carriers do not share the same criteria when distributing their expenses in this bin. On the other hand, the Fuel and Oil

allocation is well estimated by the model with an error lower than 4 % in 2015. This is the most important piece since the forecast is going to be based on modifications in the fuel price.

It must be pointed out that expenses derived from Depreciation and Amortization and Insurance are not shown in this graphic since the data needed for their calculation was not available. In addition, the estimation of these allocations for the forecast carried out in this study was developed with a different procedure as explained before. The actual value of these fields was also of a smaller order than the rest of allocations in 2015 (1.5 and 0.1 USD billions respectively).

Chapter 4. Results

In this section, the outcome of the forecast carried out with the model described in Chapter 3 is analyzed. Four different scenarios (which in fact comprise several more inside) are described and later analyzed.

4.1. Scenarios

When forecasting future events it is a common practice considering different circumstances or situations which can be expected in order to gather the possible uncertainties of the estimation. In this case, four scenarios have been designed in view of the possible variations of the three models previously described.

Table 14 Scenarios used during the estimation.

Name	CNG Year	Fuel Scenario	Biofuel feedstock	Traffic Scenario
CNG17S	2017	Static	Used cooking oil	High
CNG17R	2017	Rising		Base
CNG20S	2020	Static	Jatropha	Low
CNG20R	2020	Rising		

Although the CNG plan is expected to be implemented in 2020, two extra scenarios doing it in 2017 are analyzed with the aim of comparing both situations and their consequences. Explanations regarding the different fuel scenarios can be found in section 3.2.1.1; the biofuel feedstock in section 3.2.1.2 and the traffic forecast in section 3.1.1.

4.2. Macroanalysis (aggregated results)

Resulting data is presented in different formats in order to obtain clear conclusions. Firstly, Figure 38 shows possible emissions for the next decade for the three different traffic scenarios considered.

Figure 38 CO₂ emissions progress for Spanish carriers. Two possible CNG time horizons and three traffic scenarios.

Results show an estimate of 14.5 million tonnes for the analyzed Spanish carriers in 2016. In (EEA, 2016), see Figure 39, 151 million tonnes of CO₂ are calculated for the entire Europe; in (Eurostat., 2015) and (EUROCONTROL, 2017) it is shown that Spanish traffic corresponds to a 19% of the European one in terms of both passengers and operations; in (AENA, 2016) it can be calculated that carriers from this analysis constitute the 40% of Spanish traffic and that 10% of the Spanish carriers traffic is between abroad city pairs. If the AGR from 2015 to 2016 (EUROCONTROL, 2017) is added to this information, the result resembles very well the one made by the model developed in this research:

$$\begin{aligned}
& 151 \text{ CO}_2 \text{ Mton EU 2014} \cdot 19\% \frac{\text{Spanish market}}{\text{EU market}} \cdot 40\% \frac{\text{Spanish carriers}}{\text{Spanish market}} \\
& \cdot (1 + 3.3\% \text{AGR}_{2015}) \cdot (1 + 7.7\% \text{AGR}_{2016}) \\
& \cdot \left(1 + 10\% \frac{\text{Spanish carriers abroad market}}{\text{Spanish carriers total market}}\right) \\
& = 14 \text{ CO}_2 \text{ Mton Spanish carriers 2016}
\end{aligned}$$

Figure 39 CO₂ emissions from aviation industry in Europe. Source: (EEA, 2016).

Blue lines indicate a remote implementation of the CNG in 2017. Comparing it against the red lines the increment of emissions that is expected in the following 3 years can be assessed. Depending on the traffic scenario this varies from an almost null growth in the pessimistic one to an about 10% in the optimistic one which means 0.5 million tonnes per year. This figure also shows the great sensibility of the CNG cap to traffic circumstances.

Figure 40 Mandatory blending needed for a CNG applied in 2017 and 2020.

With the aim of estimate the mandatory blending percentage that should be imposed for a CNG, Figure 40 represents it in relation to different traffic forecasts and the three biofuels analyzed. Since cooking oil presents the lowest life-cycle emissions, it is the feedstock whose mandatory percentage, given a particular scenario, is the lowest; vice versa for Jatropha. However, camelina presents some upsides regarding the production process (Moser, 2010) that could ease its introduction as the main alternative biofuel.

The almost linear growth is due to the almost constant AGR forecasted in (EUROCONTROL, 2017). Less accuracy of the traffic prognosis is considered for the most distant years. While a 3%/year increment is needed in the Base scenario in average for the 3 feedstocks, a great dispersion is found when comparing the extreme traffic scenarios, High and Low. The former seems to ask for an average 6%/year increase of blending percentage. On the other hand, an almost null growth is presented in the pessimistic traffic scenario.

Another relevant observation is the amount of biofuel needed to achieve the CNG. In the Base scenario for camelina biofuels, an average 0.5 million tonnes/year increase of biofuel would be needed. This seems a difficult goal to reach and the real production will determine the eventual suitability of this program. In any case, it must be also taken into account that a mixture of feedstocks could be also carried out within the market, thus reducing the produced quantity of each of them.

The impact of this mandatory blending on the ensemble of Spanish airlines is outlined in Figure 41. There 2 different fuel scenarios (Static, S, and Rising, R; see 3.2.1.1) are considered for each CNG time horizon (2017 and 2020).

Figure 41 Impact on costs (absolute, left axis, and relative to TOE, right axis) of CNG implementation in 4 different scenarios.

An extraordinary difference is found between the two fuel scenarios. This is due to the fact that the fuel in the Rising (R) scenario reaches the estimated biofuels prices around 2022 (depending on the feedstock considered). At that point, that would cause big couplings and interferences in prices and results from this study become out of scope. In the Static case, the behavior of the increment of cost is similar to the blending percentage increase. Depending on the traffic development and the feedstock, a range of TOE increments from almost 0% up to 10% is expected 5 years after the CNG implementation.

4.3. Microanalysis (carriers)

This section's goal is twofold: (i) the impact of the policies within the airlines costs structure is assessed and (ii) the results of the cost estimation model are presented in more detail. For this purpose, the chosen scenario is an intermediate one: CNG20S with the Base estimation of traffic from (EUROCONTROL, 2017) and the usage of Camelina as biofuel feedstock (see continuous red line from CNG20S in Figure 41).

Figure 42 Biofuels impact on TOE in 2025. Scenario: CNG20S, Base, Camelina. Legend: lower bound of route distance bins.

The relative influence of the mandatory blending imposition can be found for each carrier in Figure 42. It must be pointed out that this value is directly proportional to the ratio of Fuel and oil expenses within the whole cost structure. Firstly, a big difference in percentage is found between different airlines (Air Nostrum doubles the Canaryfly ratio). Air Nostrum seems to be the most harmed carrier with an average 3.7% of increment in its TOE. Regarding the route distance, as expected, longer city pairs suffer bigger percentage increases than short flights (see the Evelop case). In fact, the Canary airlines (Naysa, Canair and Canaryfly) are located at the end of the list. The reason why these carriers are less sensitive is that other expenses allocations such as Landing fees are more relevant for short-haul routes than for longer ones (see Figure 43). This could indicate that, if CNG is implemented, perhaps the design of distance-specific financial helps would be desirable.

The overall impact of the mandatory blending application can be visually assessed in Figure 43. There, six different airlines from those included in this investigation (see Table 1) are broken down into their different allocations. This selection's criteria is based on the economic model followed by the carriers. Particularly, the chosen ones are a legacy with long-haul routes (Iberia), an Atlantic tour-operator (Wamos), two European LCCs (Vueling and Volotea), an Iberian regional (Air Nostrum) and a regional airline from the Canary Archipelago (Canaryfly).

Figure 43 Cost allocations for 4 representative Spanish carriers. Scenario: CNG20S, Base, Camelina.

Some differences can be observed, Figure 43, in relation to the economic model carried out by each of the represented airlines (cost from other airlines can be found in Appendix K). The main difference is the extraordinary ratio of Iberia and Wamos for RofAOOE. This allocation includes expenses such as sales, advertising, maintenance and depreciation of ground equipment... As pointed out in (Harris, 2005), its ratio tends to be considerably higher for legacy carriers. Regarding the landing fees expenses, these depend on the number of departures. This is the reason which causes regional carriers (Binter) show a larger ratio than those which operate long-haul routes (Wamos and Iberia). The Flight crew costs are also bigger in short-haul carriers because this allocation is highly dependent on the BH to FH ratio, thus penalizing regionals.

In order to better compare the budget volume of each of the analyzed carriers, Table 15 and Figure 44 show their overall expenses. The baseline year and the last year of the prognosis (2016-2025) have been selected for representation.

Table 15 Overall expenses for Spanish carriers (2016-2025). Scenario: CNG20S, Base, Camelina.

Carrier	2016	2025	Δ [%]
IBERIA	4289	5383	25.5
VUELING	3085	3776	22.4
AIR EUROPA	2122	2668	25.8
I EXPRESS	600	740	23.2
VOLOTEA	459	569	24.1
A NOSTRUM	426	541	26.9
EVELOP	209	257	23.2
WAMOS	76	96	25.7
NAYSA	74	90	22.5
ALBA STAR	54	64	17.6
CANAIR	46	57	22.6
PRIVILEGE	42	52	23.1
BINTER	41	50	22.9
PLUS ULTRA	32	40	25.7
CANARY FLY	29	36	22.0
TOTAL	11585	14419	24.5

Figure 44 Overall expenses for Spanish carriers (2016-2025). Scenario: CNG20S, Base, Camelina.

Firstly, it should be noted that the increment percentage shown here (red crosses) is different from that shown in Figure 42. There the percentage refers to the increment due to biofuels only while here, the increment is in total terms. On average, that increment is circa 24%, similar to the total relative traffic growth expected for those years, which is 22.6% (as shown in Table 8) with a CAGR₁₇₋₂₅ of 2.3%.

The mode regarding this increment is around 23% which is shared by the LCC Vueling, Iberia Express, Volotea and Evelop, the charter Privilege and the Canarian quartet. Apart from this intermediate band, the most affected carrier is Air Nostrum, 26.9%, as it happened with the biofuel impact. On the other hand, Alba Star represents by far the less affected airline with a 17.6% increment. This was also one of the operators with a smaller biofuel impact.

Another group of Atlantic companies can also be deduced from the expenses increment values. Iberia, Air Europa, Wamos and Plus Ultra are highly sensitive to the traffic increase due to their long routes through America.

Comparing this chart with the one included in Figure 4 (ASM and RPM from Spanish carriers in 2016) a clear correlation can be found. Nevertheless, some airlines' positions are switched. Special attention deserves Naysa and Canair that are the 12th and 14th in terms of ASM while 9th and 11th in terms of costs.

The previous expenses but this time broken down into allocations and in terms of percentage (this eases the cost structures comparison) are displayed in Table 16 and Figure 45. Once again, two years (the baseline 2016 and the last estimated 2025) are shown for each airline.

Analyzing CNG and biofuel impact

Table 16 Costs breakdown for Spanish carriers (16-25). Scenario: CNG20S, Base, Camelina.

Carrier	Y	DA	ΔBio	FC	FO	INS	LNF	MNT	OFO	PS	RofA	TR
Iberia	16	18	0	10	15	2	2	3	0	6	37	7
	25	17	3	9	18	1	1	3	0	5	35	7
Vueling	16	22	0	11	11	6	3	8	1	6	31	2
	25	22	2	10	13	5	3	7	1	6	30	2
Air Europa	16	18	0	11	16	4	2	4	0	6	33	5
	25	17	3	10	19	3	2	3	0	5	31	5
I Express	16	22	0	11	12	4	2	8	0	6	33	2
	25	21	2	10	14	3	2	7	0	6	32	2
Volotea	16	12	0	16	16	11	2	11	1	12	19	1
	25	11	3	16	18	9	2	10	1	11	18	1
A Nostrum	16	24	0	17	19	4	4	7	1	6	17	1
	25	23	4	16	21	3	4	6	1	6	16	1
Evelop	16	16	0	9	14	9	1	3	0	5	36	7
	25	16	3	8	16	7	1	3	0	5	34	7
Wamos	16	10	0	7	17	4	1	7	0	5	40	9
	25	9	3	6	19	3	1	7	0	4	37	8
Naysa	16	22	0	18	10	2	5	22	1	9	10	1
	25	21	2	18	12	2	5	22	1	8	10	1
Alba Star	16	13	0	9	10	29	2	6	1	5	24	1
	25	13	2	9	12	25	2	6	1	5	24	1
Canair	16	21	0	18	10	3	5	22	1	8	11	1
	25	20	2	17	12	2	5	21	1	8	11	1
Privilege	16	28	0	13	13	8	3	9	1	8	19	1
	25	26	3	12	15	6	3	8	1	7	18	1
Binter	16	18	0	16	13	8	4	15	1	7	17	1
	25	18	3	15	15	7	3	15	1	7	16	1
Plus Ultra	16	18	0	10	18	9	2	2	0	7	27	7
	25	17	4	10	21	7	2	2	0	6	25	6
Canary Fly	16	23	0	20	9	2	5	24	1	9	6	0
	25	23	2	19	11	2	5	23	1	9	6	0

Figure 45 Costs breakdown for Spanish carriers (16-25). Scenario: CNG20S, Base, Camelina.

The different cost structures for each airline can be observed in Figure 45. Some particularities can be analyzed. Air Nostrum and Plus Ultra are the carriers which are more influence by Fuel & oil (FO) expenses (circa 20% TOE). This explains why they are two of the most charged in Figure 42. Air Nostrum represents an extraordinary case because long-haul carriers were expected to be the most affected ones (as it is in the first places in Figure 42. In addition, Air Nostrum shows one of the biggest percentages of Depreciation and amortization (DA) expenses (circa 24% TOE) probably because its fleet is mainly composed by CRJ900, one of the most expensive aircraft among the regional category (see Appendix D). This should diminish the importance of FO allocation. Nevertheless, the fact that can be the cause why Air Nostrum is the most affected by FO (and hence biofuels) is that it has low RofAOOE expenses in comparison with long-haul carriers and low Maintenance (MNT) costs in comparison with short-haul carriers. In fact, Binter has a similar costs structure but its MNT costs percentage is two times that of Air Nostrum (15% and 7% respectively).

In general terms, long-haul carriers have big percentages of FO and RofAOOE while short-haul carriers show big percentages of FC and MNT. Other remarkable facts are the great percentage of Insurance (INS) shown by Alba Star, Passenger service (PS by Volotea) or the low amount of DA allocated to Wamos.

Chapter 5. **Conclusions**

In this project, a model to estimate the mandatory blending percentage that should be imposed for a Carbon Neutral Growth (CNG) and the impact of the biofuel introduction on the Spanish carriers' costs and emissions has been developed. It includes three main pieces: biofuel (emissions, regulations and price), traffic (operations, RPM/ASM...) and the Total Operating Cost (TOE, direct and indirect). A total of 15 assorted Spanish airlines have been analyzed on the basis of data from 2016 merged from different databases.

The examination of this model's output (a prognosis from 2017 to 2025) allows the reader to extract some conclusions and makes available relevant information for possible future regulations. As results show, due to the expected traffic growth a 3%/year increase of mandatory blending should be imposed from 2020 forward in the base scenario. Nevertheless, extreme scenarios indicate percentages varying from null to 7%/year increases depending on the traffic growth and biofuel emissions.

The common fuel price has been confirmed as a key factor that influences the impact of the biofuels introduction on the airlines costs. Nowadays, the price fall suffered in 2014 makes biofuel prices far less competitive. However, if crude rises and recovers levels from 2011, biofuels could even enter a price war.

The biofuels selected as possible candidates are the HRJ (Hydrotreated Renewable Jet) because of their maturity and emissions/price ratio compared against other

biofuel processes. The different feedstocks analyzed were used cooking oil, camelina and jatropha due to their proven capabilities. Cooking oil seems to show the best behavior since its estimated price and emissions are the lowest; vice versa with jatropha, the worst. Nevertheless, the capacity to mass production is expected to be a key factor that will determine the final potential of each biofuel implementation. Cooking oil has presented some issues regarding this so camelina could represent a feasible short-term alternative.

A breakdown of the carriers' operating cost structure has also been studied. Long-haul routes are more prone to undergo bigger increments in TOE due to biofuel mandatory blending because of their higher ratio of fuel cost within the TOE. In fact, remarkable differences are found between Spanish carriers cost increments (from 1.8% to 3.7% of TOE for a base scenario in 2025). Perhaps the design of distance-specific financial helps would be desirable.

5.1. Future development

It must be mentioned that the model suffers from certain uncertainty in various aspects. The most relevant in terms of order of impact in the results may be the one related with the traffic forecast. This has been surpassed by the definition of various scenarios but this leads to great variations in the results. Other sources of uncertainty are the biofuel both price and emissions. These are not clear at this point of their development and several aspects can have a noteworthy impact on them.

With the aim of overcoming all these uncertainties possible future development are mentioned in this paragraph. Firstly, the traffic forecast will be in continuous modification and this results should be corrected in agreement. Secondly, some concerns regarding the biofuels development and price should be further considered (production capacity and costs, impact of tickets price and general demand...). Thirdly, the operating cost model could be improved if data from European carriers was publicly available as North-Americans do with their financial reports. Particularly, certain pieces of the cost model could be improved such as the landing or navigation

fees. Finally, other innovative techniques such as data mining and machine learning could be applied to all this fields in order to obtain more accurate estimations.

5.2. Aviation research framework

As stated at the beginning of this thesis (section 1.3), this work aims to represent the inception of a new research framework within an aviation industry – university chair. For this reason, future collaboration projects between commercial companies, air navigation agencies and universities will continue the work carried out here and develop new studies based on the economic impact of biofuels within the business. Particularly, the scope of this work is aimed to be extended to Europe, other continents and, eventually, worldwide analyses will be carried out.

Appendix A. Databases

In this appendix the main fields that constitute the used databases are shown. It must be pointed out that not all of them have been used in this project.

A.1. Traffic

This section gathers the 5 DBs used for traffic data collection whose usage was explained in section 2.1.1.

A.1.1. SABRE

The (Sabre, 2013) database was purchased containing all flights arriving/departing to/from Europe on September 2013. The fields included in it are shown in Table 17.

Table 17 Fields from SABRE database.

Origin	Cabin Class
Destination	Passengers
Operating Airline	RevenueInUSD
Connecting points	Avg One Way Fare In USD
Segments airlines	

Although not used in this study, the different cabin classes shown in this database were: First, Discount First, Business, Discount Business, Coach and Discount Coach.

A.1.2. INNOVATA

The (Innovata, 2013) database was purchased containing all flights arriving/departing to/from Europe on September 2013. The fields included in it are shown in Table 18.

Table 18 Fields from INNOVATA database.

Carrier	Departure City	Aircraft Types
Depart Airport	Departure Time Pub.	Stops
Arrive Airport	Departure Time Actual	Stop Code
Depart City	Departure UTC Var.	Flight Distance
Arrive City	Arrival Airport	Elapsed Time
Carrier	Arrival Time Pub.	Codeshare
Flight number	Arrival Time Actual	Wet lease
Code Share Flag	Sub Aircraft Code	Codeshare
Code Share Carrier	Group Aircraft Code	Operational Suffix
Service Type	Arrival Country	ASM
Date From	Arrival City	Aircraft Tonnage
Date To	Traffic Restriction	Total Seats
Departure Airport	Extra Day	
Departure Country	Classes	

In this case, apart from ASM, flight distance and elapsed time were field of special relevance because they were used for the validation of the functions that were created with the aim of computing this values (using the airport and aircraft databases).

A.1.3. EUROCONTROL

The (EUROCONTROL, 2016) database was acquired containing all flights arriving/departing to/from Europe on the third week of June 2016. The fields included in it are shown in Table 18. A total of 230 000 flights were recorded that week.

Table 19 Fields from EUROCONTROL database.

Num	ATFM Delay	Late Updater	Revised Taxi Time
Origin	Rerouting State	N Atlantic Flight	TIS
Destination	Most Pen Reg	COBT	TRS
Not Used	Type	EOBT	To Be Sent Slot
AC Type	Equipment	Flight State	To Be Sent Proposal
Rfl	ICAO Eq	Prev Flight State	Last Sent Slot
Zone Ori	Com Eq	Suspension State	Last Sent Proposal

Zone Dest	Nav Eq	Tact Id	Last Sent Slot M
Flight Id	Ssr Eq	Sam Ctot	Last Sent Proposal M
Date Dept	Survival Eq	Sam Sent	Flight Count Op
Time Dept	Persons On Board	Sip Ctot	Normal Flight Tact
Time Arr	Top Fl	Sip Sent	Proposal Flight Tact
Callsign	Max Rfl	Slot Forced	Op Ac Oper. Icao Id
Company	Flt Pln Source	Most Penal Regul	Rerouting Why
Univ Unique Id	Aobt	Regul Affected	Rerouted Flight State
Flips Cloned	Ifps Id	Excluded From Ins.	Runway Visual Range
Flight Saamid	lobt	Last Received Atfm	Ftfm Airac Cycle
Flight Samadid	Ori Flight Data Q	Last Received	Ftfm Env Base
Tact Id	Flight Data Q	Last Sent	Rtfm Airac Cycle
Ssr Code	Source	Manual Exemption	Rtfm Env Base
Registration	Exem. Reason Ty	Sensitive Flight	Ctfm Airac Cycle
Planned Date Dept	Exem. Reason Dis	Ready Improvem.	Ctfm Env Base
Plan Time Dept	Late Filer	Ready Dept	Last Receiv. Progress

A.1.4. AENA

The (AENA, 2016) database was obtained from its website containing all flights arriving/departing to/from Spanish airports. Annual and monthly data is available. The fields included in it are shown in Table 20.

Table 20 Fields from AENA database.

Passengers	Freight	Airline
Transit passengers	Transit freight	Airline group
Operations	Mail	Airport

A.1.5. US DoT Form 41

The fields gathered within the most important schedules of the US Form 41 (see Appendix J for more information) used in this thesis are presented in the following subsections.

A.1.5.1. Common identification fields

There is a series of fields that are common to the different schedules available in the BTS database, see Table 21. They are useful in order to identify the different airlines, entities, regions or aircraft types. Their codes are gathered in the so-called *support tables*, which include the different acronyms used to refer the several carriers or aircrafts.

Table 21 Common identification fields from BTS database.

Airline Id	Carrier	Aircraft Group
Unique Carrier	Carrier Name	Aircraft Type
Unique Carrier Name	Carrier Group	Aircraft Config
Unique Carrier Entity	Carrier Group New	Service Class
Carrier Region		

A.1.5.2. T2 Schedule

This schedule is the one which includes the information used as input for the operating costs estimation model. Its items, see Table 22; include fields such as the revenue passengers or the distance flown.

Table 22 Fields from T2 schedule (BTS database).

ASM	RTM mail	Rev. Hours Airborne	Air Days Equipment
RPM	ATM	Non Rev. Hours Airborne	Air Days Route
RTM	Miles Flown	Hours RampToRamp	Fuels
RTM Freight	Departures	Hours Airborne	Num. Months

A.1.5.3. B43 schedule

This schedule includes useful information about the fleet from the different carriers, see Table 23.

Table 23 Fields from B43 schedule (BTS database).

Serial Number	Operating Status	Model
Tail Number	Number Of Seats	Capacity In Pounds
Status	Manufacturer	Acquisition Date

A.1.5.4. P51 schedule

This schedule includes detailed operating costs for large, medium and regional carriers. Some of its fields are expenses derived from Flying Operations (FO) or Maintenance, see Table 24.

Table 24 Fields from P51 schedule (BTS database).

Pilot Expense	Maintenance	Traffic	Total Op Expense
Fuel	Depand Rental	Departure	Total Air Hours
Other Expenses	Total Direct	Capacity	Air Days Assign
Total Direct Less Rent	Flight Attendants	Total Indirect	Air Fuels Issued

A.1.5.5. P52 schedule

The content of this schedule is similar to the P51 one, but only for large carriers. In addition, the information is more detailed, see Table 25.

Table 25 Fields from P52 schedule (BTS database).

Pilot FO	Incident FO	Airframe Allow	Oth Flt Equip Dep
Oth Flt FO	Pay Tax FO	Airframe Overhauls	Oth Flt Equip Dep Grp I
Train FO	Oth Tax FO	Engine Allow	Flt Equip A Exp
Pers Exp FO	Other Exp FO	Engine Overhauls	FO Exp I A
Pro FO	Total FO	Tot Dir Maint	Tot Air Op Expenses
Interchg FO	Airframe Labor	Ap Mt Burden	Dev N Preop Exp
Fuel FO	Engine Labor	Tot Flt Maint Memo	Oth Intangibles
Oil FO	Airframe Repair	Net Obsol Parts	Equip N Hangar Dep
Rental FO	Engine Repairs	Airframe Dep	G Prop Dep
Other FO	Interchg Chrg	Engine Dep	Cap Leases Dep
Ins FO	Airframe Materials	Parts Dep	Total Air Hours
Benefits FO	Engine Materials	Eng Parts Dep	Air Days Assign

A.1.5.6. P12 Schedule

The profit and loss statements of large carriers are here gathered. It includes fields such as operating revenues and expenses or depreciation, see Table 26.

Table 26 Fields from P12 schedule (BTS database).

Net Income	Total Misc Rev	Promotion Sales	Cap Gains Other
Op Profit Loss	Res Cancel Fees	General Admin	Other Income Net
Trans Rev Pax	Misc Op Rev	General Services	Non Op Income
Mail	Pub Svc Revenue	Deprec Amort	Income Pre Tax
Total Property	Trans Revenue	Trans Expenses	Income Tax
Prop Freight	Op Revenues	Op Expenses	Income Before Oth
Prop Bag	Flying Ops	Interest Long Debt	Discont Ops
Total Charter	Maintenance	Interest Exp Oth	Extra Items
Charter Pax	Pax Service	Foreign Ex Gains	Income Tax Extra
Charter Prop	Aircft Services	Cap Gains Prop	Income Tax Credits

A.1.5.7. P6 schedule

This schedule gathers operating expenses by objective grouping, Table 27. Some of its items are the salaries and the materials purchased.

Table 27 Fields from P6 schedule (BTS database).

Salaries Mgt	Benefits Payroll	Advertising	Landing Fees
Salaries Flight	Benefits	Communication	Rentals
Salaries Maint	Salaries Benefits	Insurance	Depreciation
Salaries Traffic	Fuel	Outside Equip	Amortization
Salaries Other	Maint Material	Commisions Pax	Other
Salaries	Food	Commissions Cargo	Trans Expense
Benefits Personnel	Other Materials	Other Services	
Benefits Pensions	Materials Total	Services Total	

A.1.5.8. P7 schedule

This schedule gathers operating expenses by functional grouping, Table 28. Some of its items are passenger services and the advertising and publicity expenses.

Table 28 Fields from P7 schedule (BTS database).

Air Op Expense	Air Svc Expense	Res Expense	Transport Exp
Flight Att Expense	Traffic Exp Pax	Advert. Exp Pax	Total Op Expense
Food Expense	Traffic Exp Cargo	Advert. Exp Cargo	Maint Prop Equip
Oth In Fl Expense	Traffic Exp Oth	Advert. Exp Inst	Depr Prop Equip
Pax Svc Expense	Traffic Expense	Advert. Expense	Maint Depr
Line Svc Expense	Res Exp Pax	Admin Expense	Svc Sales Op Exp
Control Expense	Res Exp Cargo	Depr Exp Maint	
Landing Fees	Res Exp Oth	Amortization	

A.2. Aircraft

The aircraft database was obtained mainly from (Harris, 2005) although several manufacturers' websites were also consulted for information such as the recommended selling price. The fields included in it are shown in Table 29. Data for fleets from Spanish carriers is gathered in Appendix D.

Table 29 Fields from aircraft database.

AC Model	TakeOff SFC
No. Engines	Cruise SFC
Eng. TakeOff Power	Cruise L/D
Eng. TakeOff Thrust	L/D Divided By SFC
Total TakeOff Thrust	Engine type
MTOW	Purchase Price
MLW	Num Of Seats

OEW
Eng. Weigth

Cruise Speed

A.3. Airports

The airports database was obtained from (OpenFlights, 2017). The fields included in it are shown in Table 18. A total of 7200 airports are gathered there.

Table 30 Fields from airports database.

Airport ID	Latitude
Name	Longitude
City	Altitude
Country	Timezone
IATA	Daylight Saving Time
ICAO	

Appendix B. Units

The units and conversion factors used in the thesis are gathered in this appendix. Both financial and technical data are collected in separated sections. This is of special relevance due to the fact that methodologies used in this work were designed in different unit systems.

B.1. Forex exchange

The expenses and other financial data are expressed in USD (United States Dollars). At the time this thesis was written (early 2017), the exchange rate from USD to EUR (European Euro) was close to parity. Table 31 gathers the exchange rates between the USD and the other 5 most traded currencies in the world.

Table 31 Forex exchange rates. Retrieved 24/07/2017.

Currency	Code	Sym	Rate	Sym	Code	Currency
EU Euro	EUR	€	1.16	\$	USD	US Dollar
US Dollar	USD	\$	111.21	¥	JPY	Japanese Yen
Pound Sterling	GBP	£	1.30	\$	USD	US Dollar
US Dollar	USD	\$	1.26	A\$	AUD	Australian Dollar
US Dollar	USD	\$	1.25	C\$	CAD	Canadian Dollar

B.2. Physical units

In this section, some conversion factors (focused on kerosene properties) are gathered (Table 32).

Table 32 Physical conversion factors.

Unit	Symbol	Factor	Symbol	Unit
US gallon	gal	3.7854	l	Litre
Kerosene litre	l ^k	0.8	kg ^k	Kerosene kg
Kerosene ton	ton ^k	3.15	ton ^{CO2}	Ton CO ₂
Imperial gallon	lgal	1.201	gal	US gallon
Pound	lb	0.4536	kg	Kilogram
Short ton	ston	0.9072	ton	Metric ton
Long ton	lton	1.0161	ton	Metric ton
Statute mile	mi	1.6093	km	Kilometer
Nautical mile	nmi	1.8520	km	Kilometer
Foot	ft	0.3048	m	Metre
Inch	in	2.540	cm	Centimeter
Miles per hour	MPH	1.609	km/h	Kilometer per hour
Knot	kn	1.852	km/h	Kilometer per hour

Appendix C. Aircraft list

In this appendix, Table 33 gathers the information from several aircraft. For each of them, their ICAO, IATA and common name are shown.

Table 33 Aircraft nomenclature.

ICAO	IATA	Name
A124	A4F	Antonov AN-124 Ruslan
A140	A40	Antonov AN-140
A148		Antonov An-148
A158	A58	Antonov An-158
A225	A25	Antonov An-225 Mriya
A310	310	Airbus A310 all pax models
A310	312	Airbus A310-200 pax
A310	313	Airbus A310-300 pax
A318	318	Airbus A318
A319	319	Airbus A319
A310	31F	Airbus A310 Freighter
A310	31X	Airbus A310-200 Freighter
A310	31Y	Airbus A310-300 Freighter
A320	320	Airbus A320-100/200
A321	321	Airbus A321-100/200
n/a	32S	Airbus A318/319/320/321
A330	330	Airbus A330 all models
A332	332	Airbus A330-200
A333	333	Airbus A330-300
A338	338	Airbus A330-800
A339	339	Airbus A330-900
A340	340	Airbus A340 all models
A342	342	Airbus A340-200
A343	343	Airbus A340-300
A345	345	Airbus A340-500
A346	346	Airbus A340-600
n/a	380	Airbus A380 pax
n/a	38F	Airbus A380 Freighter
A30B	AB3	Airbus A300 pax
A30B	AB4	Airbus A300B2/B4/C4 pax
A306	AB6	Airbus A300-600 pax
A3ST	ABB	Airbus A300-600ST Beluga Freighter
A30B	ABF	Airbus A300 Freighter
A30B	ABX	Airbus A300C4/F4 Freighter
A306	ABY	Airbus A600-600 Freighter
A350	350	Airbus A350
A358	358	Airbus A350-800
A359	359	Airbus A350-900
A35K	351	Airbus A350-1000[2]
A388	388	Airbus A380-800
A748	HS7	Hawker Siddeley HS 748
AC68	ACP	Gulfstream/Rockwell (Aero) Comm.
AC90	ACT	Gulfstream/Rockwell (Aero) Turbo
AN12	ANF	Antonov AN-12
AN24	AN4	Antonov AN-24
AN26	A26	Antonov AN-26
AN28	A28	Antonov AN-28
AN30	A30	Antonov AN-30

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AN32	A32	Antonov AN-32	B736	736	Boeing 737-600 pax
AN72	AN7	Antonov AN-72 / AN-74	n/a	737	Boeing 737 all pax models
AP22		Aeroprakt A-22 Foxbat / A-22 Valor	B738	738	Boeing 737-800 pax
AS32	APH	Eurocopter AS332 Super Puma	B739	739	Boeing 737-900 pax
AS50	NDE	Eurocopter AS350 Écureuil	n/a	73F	Boeing 737 all Freighter models
AT43	AT4	Aerospatiale/Alenia ATR 42-300 / 320	B737	73G	Boeing 737-700 pax
AT45	AT5	Aerospatiale/Alenia ATR 42-500	B738	73H	Boeing 737-800 (winglets) pax
AT46	ATR	Aerospatiale/Alenia ATR 42-600	B732	73M	Boeing 737-200 Combi
AT72	AT7	Aerospatiale/Alenia ATR 72	B737	73W	Boeing 737-700 (winglets) pax
AT73	ATR	Aerospatiale/Alenia ATR 72-200 series	B732	73X	Boeing 737-200 Freighter
AT75	ATR	Aerospatiale/Alenia ATR 72-500	B733	73Y	Boeing 737-300 Freighter
AT76	ATR	Aerospatiale/Alenia ATR 72-600	B741	741	Boeing 747-100 pax
ATL	ATL	Robin ATL	B742	742	Boeing 747-200 pax
ATP	ATP	British Aerospace ATP	B743	743	Boeing 747-300 pax
B105	MBH	Eurocopter (MBB) Bo.105	B744	744	Boeing 747-400 pax
B190	BEH	Beechcraft 1900	n/a	747	Boeing 747 all pax models
B212	BH2	Bell 212	B742	74C	Boeing 747-200 Combi
B412	BH2	Bell 412	B743	74D	Boeing 747-300 Combi
B429	BH2	Bell 429	B744	74E	Boeing 747-400 Combi
B461	141	BAe 146-100	n/a	74F	Boeing 747 all Freighter models
B462	142	BAe 146-200	B744	74J	Boeing 747-400 (Domestic) pax
B463	143	BAe 146-300	N74S	74L	Boeing 747SP
B703	703	Boeing 707-300 pax	n/a	74M	Boeing 747 all Combi models
n/a	707	Boeing 707/720 all pax models	B74R	74R	Boeing 747SR pax
B703	70F	Boeing 707 Freighter	B741	74T	Boeing 747-100 Freighter
B703	70M	Boeing 707 Combi	B743	74U	Boeing 747-300 / 747-200 Freighter
B712	717	Boeing 717	B74R	74V	Boeing 747SR Freighter
B721	721	Boeing 727-100 pax	B742	74X	Boeing 747-200 Freighter
B722	722	Boeing 727-200 pax	B744	74Y	Boeing 747-400 Freighter
n/a	727	Boeing 727 all pax models	B752	752	Boeing 757-200 pax
B721	72B	Boeing 727-100 Mixed Configuration	B753	753	Boeing 757-300 pax
B722	72C	Boeing 727-200 Mixed Configuration	n/a	757	Boeing 757 all pax models
n/a	72F	Boeing 727 Freighter (-100/200)	B752	75F	Boeing 757 Freighter
n/a	72M	Boeing 727 Combi	B752	75M	Boeing 757 Mixed Configuration
B722	72S	Boeing 727-200 Advanced pax	B762	762	Boeing 767-200 pax
B721	72X	Boeing 727-100 Freighter	B763	763	Boeing 767-300 pax
B722	72Y	Boeing 727-200 Freighter	B764	764	Boeing 767-400 pax
B731	731	Boeing 737-100 pax	n/a	767	Boeing 767 all pax models
B732	732	Boeing 737-200 pax	n/a	76F	Boeing 767 all Freighter models
B733	733	Boeing 737-300 pax	B762	76X	Boeing 767-200 Freighter
B734	734	Boeing 737-400 pax	B763	76Y	Boeing 767-300 Freighter
B735	735	Boeing 737-500 pax	B772	772	Boeing 777-200 / Boeing 777-200ER

B77L	77L	Boeing 777-200LR / Boeing 777F	CN35	CS5	CASA/IPTN CN-235
B773	773	Boeing 777-300	CONC	SSC	Aerospatiale/BAC Concorde
B77W	77W	Boeing 777-300ER	CONI	L49	Lockheed L-1049 Super Constellation
n/a	777	Boeing 777 all pax models	COUC	HEC	Helio H-250 Courier / H-295 / 385
B783	783	Boeing 787-3[3]	CRJ1	CR1	Canadair Regional Jet 100
B788	788	Boeing 787-8[3]	CRJ2	CR2	Canadair Regional Jet 200
B789	789	Boeing 787-9[3]	CRJ7	CR7	Canadair Regional Jet 700
B78X	78J	Boeing 787-10	CRJ9	CR9	Canadair Regional Jet 900
BA11	B11	British Aerospace (BAC) One Eleven	CRJX	CRK	Canadair Regional Jet 1000
BCS1	CS1	Bombardier CS100	CVLP	CV4	Convair CV-240 & -440
BCS3	CS3	Bombardier CS300	CVLT	CV5	Convair CV-580, Convair CV-600
BE58		Beechcraft Baron / 58 Baron	D228	D28	Fairchild Dornier Do.228
BELF	SHB	Shorts SC-5 Belfast	D328	D38	Fairchild Dornier Do.328
BER2		Beriev Be-200 Altair	DC10	D10	Douglas DC-10
BLCF	74B	Boeing 747 LCF Dreamlifter	DC3	D3F	Douglas DC-3
BN2P	BNI	Pilatus Britten-Norman BN-2A/B	DC6	D6F	Douglas DC-6
C130	LOH	Lockheed L-182 / 282 / 382 (L-100)	DC85	D8T	Douglas DC-8-50
C162	CN1	Cessna 162	DC86	D8L	Douglas DC-8-62
C172	CN1	Cessna 172	DC87	D8Q	Douglas DC-8-72
C72R	CN1	Cessna 172 Cutlass RG	DC9	DC9	Douglas DC-9
C77R	CN1	Cessna 177 Cardinal RG	DC91	D91	Douglas DC-9-10
C182	CN1	Cessna 182 Skylane	DC92	D92	Douglas DC-9-20
C208	CN1	Cessna 208 Caravan	DC93	D93	Douglas DC-9-30
C210	CN1	Cessna 210 Centurion	DC94	D94	Douglas DC-9-40
C212	CS2	CASA / IPTN 212 Aviocar	DC95	D95	Douglas DC-9-50
C25A	CNJ	Cessna Citation CJ2	DH2T	DHR	De Havilland Canada DHC-2 Turbo
C25B	CNJ	Cessna Citation CJ3	DH8A	DH1	De Havilland Canada DHC-8-100
C25C	CNJ	Cessna Citation CJ4	DH8B	DH2	De Havilland Canada DHC-8-200
C46	CWC	Curtiss C-46 Commando	DH8C	DH3	De Havilland Canada DHC-8-300
C500	CNJ	Cessna Citation I	DH8D	DH4	De Havilland Canada DHC-8-400
C510	CNJ	Cessna Citation Mustang	DHC2	DHP	De Havilland Canada DHC-2 Beaver
C525	CNJ	Cessna CitationJet	DHC3	DHL	De Havilland Canada DHC-3 Otter
C550	CNJ	Cessna Citation II	DHC4	DHC	De Havilland Canada DHC-4 Caribou
C560	CNJ	Cessna Citation V	DHC5	DHC	De Havilland Canada DHC-5 Buffalo
C56X	CNJ	Cessna Citation Excel	DHC6	DHT	De Havilland Canada DHC-6 Twin
C650	CNJ	Cessna Citation III	DHC7	DH7	De Havilland Canada DHC-7 Dash 7
C680	CNJ	Cessna Citation Sovereign	DOVE	DHD	De Havilland DH.104 Dove
C750	CNJ	Cessna Citation X	E110	EMB	Embraer EMB 110 Bandeirante
CL2T		Bombardier 415	E120	EM2	Embraer EMB 120 Brasilia
CL30		Bombardier BD-100 Challenger 300	E135	ER3	Embraer RJ135
CL44	CL4	Canadair CL-44	E135	ERD	Embraer RJ140
CL60	CCJ	Canadair Challenger	E145	ER4	Embraer RJ145

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E170	E70	Embraer 170	J328	FRJ	Fairchild Dornier 328JET
E175	E75	Embraer 175	JS31	J31	British Aerospace Jetstream 31
E190	E90	Embraer 190	JS32	J32	British Aerospace Jetstream 32
E190	E90	Embraer 195	JS41	J41	British Aerospace Jetstream 41
E35L	ER3	Embraer Legacy 600 / Legacy 650	JU52	JU5	Junkers Ju52/3M
E545		Embraer Legacy 450	L101	L10	Lockheed L-1011 Tristar
E190	E90	Embraer Lineage 1000	L188	LOE	Lockheed L-188 Electra
E50P	EP1	Embraer Phenom 100	L410	L4T	LET 410
E55P	EP3	Embraer Phenom 300	LJ35	LRJ	Learjet 35 / 36 / C-21A
EC20		Eurocopter EC120 Colibri	LJ60	LRJ	Learjet 60
EC25		Eurocopter EC225 Super Puma	LOAD	ALM	Ayres LM200 Loadmaster
EC35		Eurocopter EC135 / EC635	MD11	M11	McDonnell Douglas MD-11
EC45		Eurocopter EC145	MD81	M81	McDonnell Douglas MD-81
ECHO		Tecnam P92 Echo / P92 Eaglet	MD82	M82	McDonnell Douglas MD-82
EV97		Evektor SportStar / EV-97 Harmony	MD83	M83	McDonnell Douglas MD-83
EXPL	MD9	MD Helicopters MD900 Explorer	MD87	M87	McDonnell Douglas MD-87
F100	100	Fokker 100	MD88	M88	McDonnell Douglas MD-88
F27	F27	Fokker F27 Friendship	MD90	M90	McDonnell Douglas MD-90
F28	F21	Fokker F28 Fellowship	MI8	MIH	MIL Mi-8 / Mi-17 / Mi-171 / Mil-172
F2TH	D20	Dassault Falcon 2000	MI24		Mil Mi-24 / Mi-25 / Mi-35
F50	F50	Fokker 50	MU2	MU2	Mitsubishi Mu-2
F70	F70	Fokker 70	N262	ND2	Aerospatiale (Nord) 262
F900	DF9	Dassault Falcon 900	NOMA	CD2	Government Aircraft Factories N22B
FA7X	DF7	Dassault Falcon 7X	P06T		Tecnam P2006T
G159	GRS	Gulfstream Aerospace G-159 G I	P28A		Piper PA-28 Cherokee
G21	GRG	Grumman G-21 Goose	P68	PN6	Partenavia P.68
G280	GR3	Gulfstream G280	PA31	PA2	Piper PA-31 Navajo
G73T	GRM	Grumman G-73 Turbo Mallard	PA46	PAG	Piper PA-46
GL5T	CCX	Bombardier BD-700 Global 5000	PC12	PL2	Pilatus PC-12
GLEX	CCX	Bombardier Global Express	PC6T	PL6	Pilatus PC-6 Turbo Porter
GLF4	GJ4	Gulfstream IV	RJ1H	AR1	Avro RJ100
GLF5	GJ5	Gulfstream V	R200		Robin HR200/R2000, Alpha160A
GLF6	GJ6	Gulfstream G650	RJ70	AR7	Avro RJ70
HERN	DHH	De Havilland DH.114 Heron	RJ85	AR8	Avro RJ85
H25B	H25	British Aerospace 125 series	RX1H	AX1	Avro RJX100
H25C	H25	British Aerospace 125-1000 series	RX85	AX8	Avro RJX85
I114	I14	Ilyushin IL114	S210	CRV	Aerospatiale (Sud Aviation) Se.210
IL18	IL8	Ilyushin IL18	S58T	S58	Sikorsky S-58T
IL62	IL6	Ilyushin IL62	S601	NDC	Aerospatiale SN.601 Corvette
IL76	IL7	Ilyushin IL76	S61	S61	Sikorsky S-61
IL86	ILW	Ilyushin IL86	S65C	NDH	Eurocopter (Aerospatiale) SA365C
IL96	I93	Ilyushin IL96	S76	S76	Sikorsky S-76

S92	S92	Sikorsky S-92
SB20	S20	Saab 2000
SC7	SHS	Shorts SC-7 Skyvan
SF34	SF3	Saab SF340A/B
SH33	SH3	Shorts SD.330
SH36	SH6	Shorts SD.360
SU95		Sukhoi Superjet 100
T134	TU3	Tupolev Tu-134
T144		Tupolev Tu-144
T154	TU5	Tupolev Tu-154
T204	T20	Tupolev Tu-204 / Tu-214
TB20		Socata TB-20 Trinidad
TL20		TL Ultralight TL-96 Star / TL-2000
TRIS	BNT	Pilatus Britten-Norman BN-2A Mk III
VISC	VCV	Vickers Viscount
WW24	WWP	Israel Aircraft Industries 1124
Y12	YN2	Harbin Yunshuji Y12
YK40	YK4	Yakovlev Yak-40
YK42	YK2	Yakovlev Yak-42
YS11	YS1	NAMC YS-11

Appendix D. **Aircraft database**

The table included on the following page, Table 34, gathers relevant information from the aircraft analyzed within the fleets of the Spanish carriers. That technical properties are needed in order to feed the operating costs estimation model (section 3.3). There, subindex TO refers to TakeOff conditions and CR to CRuise conditions. Some of them were extracted from (Harris, 2005).

Table 34 Aircraft database of technical properties.

AC	IATA	Engine	Eng. Qty.	Eng. Wgt. [klb]	MTOW [klb]	MLW [klb]	OEW [klb]	T _{TO} [klb]	SFC _{TO}	SFC _{CR}	L/D _{CR}	Seats	VCR [MPH]	APP [USDM]
A319	319	CFM56-5A4	2	5.0	141.1	134.5	88.5	44.0	0.32	0.60	14.1	134	511	89.6
A320	320	CFM56-5B4/P	2	5.3	162.0	142.2	93.0	54.0	0.34	0.60	14.6	180	511	98.0
A321	321	IAE V2500	2	5.3	206.0	172.0	107.0	60.0	0.34	0.60	14.6	185	511	114.9
A330-200	332		2	13.0	530.0	400.0	265.0	140.0	0.34	0.60	14.6	275	541	231.5
A330-300	333	PW4000	2	13.5	533.5	412.0	270.0	134.0	0.34	0.60	14.6	370	541	256.4
ATR-42	AT4	PW 120	2	0.9	34.7	34.2	22.0	18.0	0.39	0.65	9.6	45	322	19.5
ATR-72	AT7	PW 124B	2	1.1	47.4	47.1	27.6	21.6	0.47	0.55	9.6	75	318	24.7
B717-200	717	BMW/RR BR715	2	4.6	114.0	102.0	89.0	37.0	0.37	0.79	12.0	110	504	37.3
B737-400	734	CFM56-3C1	2	4.3	138.5	121.0	72.7	47.0	0.39	0.67	13.7	144	567	47.8
B737-800	738	CFM56-7B27	2	5.3	174.2	146.3	90.7	54.6	0.38	0.60	14.9	180	543	96.0
B747-400	744	RR RB211-524G	4	9.7	800.0	574.0	400.7	232.0	0.57	0.57	13.9	451	565	197.0
B757-200	752	PW 2037	2	7.3	220.0	210.0	128.7	76.5	0.34	0.56	14.1	210	527	76.5
B767-300/R	763	PW 4060	2	9.2	400.0	320.0	199.6	120.0	0.35	0.54	14.9	252	567	197.1
B777-200	772	GE90-76B	2	16.7	515.0	445.0	306.5	152.8	0.39	0.52	17.0	288	564	186.5
B787-800	788	RR Trent 1000	2	13.3	502.5	38.0	264.5	128.0	0.37	0.50	13.4	276	564	224.6
CRJ-2/4	CR2	CF34-3B1	2	1.7	51.0	47.0	30.9	17.5	0.33	0.70	8.0	50	488	21.0
CRJ-900	CR9	CF34-8C5	2	2.5	80.5	73.5	47.3	26.7	0.33	0.70	8.0	90	514	46.5
EMB-120	EM2	PW 118	2	0.9	25.4	24.8	15.2	18.0	0.52	0.61	8.2	30	362	11.0
EMB-145	ER4	AE3007A	2	1.6	45.4	41.2	25.8	14.5	0.33	0.70	8.0	50	518	21.0
EMB-190	E90	CF34-10E	2	3.7	105.4	94.8	61.2	40.0	0.33	0.70	8.0	106	554	32.0

Appendix E. Airports database

In this appendix, Table 35 gathers the information from 62 Spanish airports used in the analysis. A total of 7200 airports worldwide were included in the database but the rest of foreign airports are not shown here due to space reasons.

Table 35 Spanish airports database. Source: (OpenFlights, 2017).

NAME	CITY	NATION	IATA	ICAO	LAT [°]	LON [°]	ALT [ft]
Albacete-Los Llanos Air.	Albacete	Spain	YN	LEAB	38.949	-1.864	2302
Alicante International Air.	Alicante	Spain	ALC	LEAL	38.282	-0.558	142
Almería International Air.	Almeria	Spain	LEI	LEAM	36.844	-2.370	70
Lanzarote Airport	Arrecife	Spain	ACE	GCRR	28.945	-13.605	46
Asturias Airport	Aviles	Spain	OVD	LEAS	43.564	-6.035	416
Badajoz Airport	Badajoz	Spain	BJZ	LEBZ	38.891	-6.821	609
Barcelona International Air.	Barcelona	Spain	BCN	LEBL	41.297	2.078	12
Bilbao Airport	Bilbao	Spain	BIO	LEBB	43.301	-2.911	138
Burgos Airport	Burgos	Spain	RGS	LEBG	42.358	-3.621	2945
Castellón-Costa Azahar Air.	Cast. de la Plana	Spain	CDT	LEDS	40.214	0.073	1145
Ciudad Real Central Airport	Ciudad Real	Spain	CQM	LERL	38.856	-3.970	0
Córdoba Airport	Cordoba	Spain	ODB	LEBA	37.842	-4.849	297
La Cerdanya Airport	Das i Font. de Cer.	Spain	YN	LECD	42.386	1.867	3586
Fuerteventura Airport	Fuerteventura	Spain	FUE	GCFV	28.453	-13.864	85
Girona Airport	Gerona	Spain	GRO	LEGE	41.901	2.761	468
Gran Canaria Airport	Gran Canaria	Spain	LPA	GCLP	27.932	-15.387	78
Armillá Air Base	Granada	Spain	YN	LEGA	37.133	-3.636	2297
Federico Garcia Lorca Air.	Granada	Spain	GRX	LEGR	37.189	-3.777	1860
Hierro Airport	Hierro	Spain	VDE	GCHI	27.815	-17.887	103
Huesca/Pirineos Airport	Huesca	Spain	HSK	LEHC	42.076	-0.317	1768
Ibiza Airport	Ibiza	Spain	IBZ	LEIB	38.873	1.373	24
Jerez Airport	Jerez	Spain	XRY	LEJR	36.745	-6.060	93

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A Coruña-Airport	La Coruna	Spain	LCG	LECO	43.402	-8.377	32
La Gomera Airport	La Gomera	Spain	GMZ	GCGM	28.030	-17.215	716
Leon Airport	Leon	Spain	LEN	LELN	42.589	-5.656	3006
Lleida-Alguaire Airport	Lleida	Spain	ILD	LEDA	41.728	0.535	1170
Logroño-Agoncillo Airport	Logroño-Agoncillo	Spain	RJL	LELO	42.461	-2.322	1161
Logrono Airport	Logroño-Agoncillo	Spain	RJLXXX	LERJ	42.461	-2.320	1161
Getafe Air Base	Madrid	Spain	\N	LEGT	40.294	-3.724	2031
Adolfo Suárez Mad-Barajas	Madrid	Spain	MAD	LEMD	40.472	-3.563	1998
Torrejón Airport	Madrid	Spain	TOJ	LETO	40.497	-3.446	2026
Cuatro Vientos Airport	Madrid	Spain	ECV	LECU	40.371	-3.785	2269
Málaga Airport	Malaga	Spain	AGP	LEMG	36.675	-4.499	53
Melilla Airport	Melilla	Spain	MLN	GEML	35.280	-2.956	156
Menorca Airport	Menorca	Spain	MAH	LEMH	39.863	4.219	302
San Javier Airport	Murcia	Spain	MJV	LELC	37.775	-0.812	11
Alcantarilla Air Base	Murcia	Spain	\N	LERI	37.951	-1.230	250
Ocaña Airport	Ocana	Spain	\N	LEOC	39.938	-3.503	2405
Palma De Mallorca Airport	Palma de Mallorca	Spain	PMI	LEPA	39.552	2.739	27
Pamplona Airport	Pamplona	Spain	PNA	LEPP	42.770	-1.646	1504
Reus Air Base	Reus	Spain	REU	LERS	41.147	1.167	233
Rota Naval Station Airport	Rota	Spain	\N	LERT	36.645	-6.349	86
Sabadell Airport	Sabadell	Spain	QSA	LELL	41.521	2.105	485
Salamanca Airport	Salamanca	Spain	SLM	LESA	40.952	-5.502	2595
San Luis Airport	San Luis	Spain	\N	LESL	39.862	4.258	197
San Sebastian Airport	San Sebastian	Spain	EAS	LESO	43.356	-1.791	16
La Palma Airport	S. C. De La Palma	Spain	SPC	GCLA	28.626	-17.756	107
Santander Airport	Santander	Spain	SDR	LEXJ	43.427	-3.820	16
Santiago de Compostela Air.	Santiago	Spain	SCQ	LEST	42.896	-8.415	1213
Fuentemilanos Airport	Segovia	Spain	\N	LEFM	40.889	-4.238	3307
Pirineus - la Seu d'Urgel Air.	Seo De Urgel	Spain	LEU	LESU	42.339	1.409	2625
Moron Air Base	Sevilla	Spain	OZP	LEMO	37.175	-5.616	285
Sevilla Airport	Sevilla	Spain	SVQ	LEZL	37.418	-5.893	112
Son Bonet Airport	Son Bonet	Spain	\N	LESB	39.599	2.703	157
Tenerife South Airport	Tenerife	Spain	TFS	GCTS	28.045	-16.573	209
Tenerife Norte Airport	Tenerife	Spain	TFN	GCXO	28.483	-16.341	2076
Teruel Airport	Teruel	Spain	TEV	LETL	40.403	-1.218	3380
Valencia Airport	Valencia	Spain	VLC	LEVC	39.489	-0.482	240
Valladolid Airport	Valladolid	Spain	VLL	LEVD	41.706	-4.852	2776
Vigo Airport	Vigo	Spain	VGO	LEVX	42.232	-8.627	856
Vitoria/Foronda Airport	Vitoria	Spain	VIT	LEVT	42.883	-2.724	1682
Zaragoza Air Base	Zaragoza	Spain	ZAZ	LEZG	41.666	-1.042	863

Figure 46 Spanish airports map. Source: (AENA, 2016).

Appendix F. Biofuel powered flights

As many other technological innovations within the aerospace industry, biofuels practical implementation has been needed to be proven in real conditions before its certificated usage in passenger airliners. Test flights used for this purpose are the so-call demonstration flights. First of them were carried out in 2007-2008, see Table 36 for more information.

Table 36 Demonstration flights using biofuels. Adapation from: (ATAG, 2017).

Date	Operator	Aircraft	Feedstock
Oct-07	GreenFlight Intl.	Aero L-29 Delfín	Waste vegetable oil
Feb-08	Virgin Atlantic	Boeing 747	Coconut and babassu
Dec-08	Air New Zealand	Boeing 747	Jatropha
Jan-09	Continental Airlines	Boeing 737	Algae and jatropha
Jan-09	Japan Airlines	Boeing 747	Camelina, jatropha, algae
Nov-09	KLM	Boeing 747	Camelina
Apr-10	US Navy	F/A-18	Camelina
Mar-10	US Air Force	A-10	Camelina
Jun-10	Dutch Military	Ah-64 Apache Heli.	Waste vegetable oil
Jun-10	EADS	Diamond D42	Algae
Nov-10	US Navy	MH-60S Seahawk	Camelina
Nov-10	TAM	Airbus 320	Jatropha

Jun-11	Boeing	Boeing 747-8F	Camelina
Jun-11	Honeywell	Gulfstream G450	Camelina
Aug-11	US Navy	T-45	Camelina
Sep-11	US Navy	AV-8B	Camelina
Oct-11	Air China	Boeing 747-400	Jatropha
Nov-11	Continental Airlines	Boeing 737-800	Algae
Nov-11	Alaska Airlines	Boeing737	Algae
Nov-11	Alaska Airlines	Bombardier Q400	Algae
Jan-12	Etihad Airways	Boeing 777-300ER	Waste vegetable oil
Jan-12	LAN	Airbus 320	Used cooking oil
Apr-12	Qantas Airways	Airbus A330	Refined cooking oil
Apr-12	Porter Airlines	Bombardier Q400	Camelina, brass. carinata
Oct-12	NRC	Dassault Falcon 20	Brassica carinata
Mar-13	Paramus Flying Club	Cessna 182 Skylane	Waste vegetable oil

On July 2011, the American Society for Testing and Materials (ASTM) approved the usage of HEFA renewable fuels within commercial and military flights (ICAO, 2011). Nevertheless, the biofuel must be blended jointly with at least 50% of traditional fuel. The feedstock analyzed were camelina, jatropha and animal fats to name but a few.

Since this ASTM approval, several airlines have wanted to show their environmental compromise by using biofuels in some scheduled routes. In some cases alternative fuels have been used during a certain period of time instead of in a single flight. Several examples of these two cases are shown in Table 37.

Table 37 Commercial flights using biofuels. Adaptation from: (ATAG, 2017).

Date	Operator	Route	Aircraft	Feedstock
Jun-11	KLM	Amsterdam - Paris	Boeing 737-800	Used cooking oil
Jul-11	Lufthansa	Hamburg - Frankfurt	Airbus A321	Jatro. cam. & fats
Jul-11	Finnair	Amsterdam - Helsinki	Airbus A319	Used cooking oil
Jul-11	Interjet	Mexico DF - Tuxtla Gut.	Airbus A320	Jatropha

Aug-11	AeroMexico	Mexico DF - Madrid	Boeing 777-200	Jatropha
Oct-11	Iberia	Madrid - Barcelona	Airbus A320	Camelina
Oct-11	Thomson Airways	Birmingham - Arrecife	Boeing 757-200	Used cooking oil
Oct-11	Air France	Toulouse - Paris	Airbus 321	Used cooking oil
Nov-11	Continental Airl.	Houston - Chicago	Boeing 737-800	Algae fuel
Nov-11	Alaska Airlines	Seattle - Portland	Boeing 737	Used cooking oil
Nov-11	Alaska Airlines	Seattle - Washington	Bomb. Q400	Used cooking oil
Dec-11	Thai Airlines	Bangkok - Chiang Mai	Boeing 777-200	Used cooking oil
Jan-12	Lufthansa	Frankfurt - Washington	Boeing 747	Mix
Apr-12	Jetstar Airways	Melbourne - Hobart	Airbus A320	Used cooking oil
Jun-12	Air Canada	Toronto - Mexico	Airbus 319	Used cooking oil
Jun-12	AeroMexico	Mexico DF - Sao Paulo	Boeing 777	Mix
Mar-13	KLM	New York - Amsterdam	Boeing 777-206	Used cooking oil
Aug-13	LAN	Bogota - Cali	Airbus 320	Camelina
May-14	KLM	Oranjestad - Amsterdam	Airbus A330-200	Used cooking oil
Aug-14	Gol TA	Rio Santos - Brasilia	Boeing 737-700	Corn oil and UCO
Sep-14	Lufthansa	Frankfurt - Berlin	Airbus 320	Farnesan sugar
Sep-14	Finnair	Helsinki - New York	Airbus 330	Used cooking oil
Nov-14	Scandinavian Airl.	Stockholm - Östersund	Boeing 737-600	Used cooking oil
Nov-14	Scandinavian Airl.	Trondheim - Oslo	Boeing 737-700	Used cooking oil
Nov-14	Norwegian Airlines	Bergen - Oslo	Boeing 737-800	Used cooking oil
Mar-15	Hainan Airlines	Shanghai - Beijing	Boeing 737-800	Used cooking oil
May-17	Singapore Airlines	Singapore - S. Francisco	Airbus A350-900	HEFA

Appendix G. **IATA Airline Cost Management Group**

The IATA owns its own department committed to carriers expenses: the Airline Cost Management Group (ACMG), knew as Airline Operational Cost Task Force (AOCTF) before 2014. This workgroup is comprised by an operations team and a steering committee formed by up to 15 airline representants.

The ACMG tries to disseminate the cost management best practices along the members and to provide a standard method to ease the industry financial assessment. They are focused on air transport only and some of their benefits are the identification of cost drivers and the jointly collaboration of industry players. In fact, they boast than the participation in this program has proven to help airlines to curtail their costs.

An example of the outcome included within their reports can be observed in Figure 47. That graph, obtained from the 2014 enhanced report (ACMG, 2014), shows the cost volume of the 55 contributing airlines that year. Abscissas and oordinates axes are Cost per ASK (CASK) and Revenue per ASK (RASK) respectively.

Figure 47 Revenue size indicated against RASK and CASK. Source: (ACMG, 2014).

One important thing this workgroup promotes is the confidentiality. In fact, their reports are only delivered to participating airlines (only small excerpts are publicly available) and results are aggregated and de-identified. Nevertheless, this diminish its value since, for example, BTS data from US is highly detailed and without any censorship regarding carrier confidentiality.

The number of airlines participating in this plan has risen in the last years from the 22 carriers analyzed in the FY2012 (the first year the annual report was delivered) to the 60 operators included within the FY2014 analysis.

Their reports also include a section where data is segregated in different aircrafts. The number of models whose information is deeper detailed has also grown in the last years. At the beginning only the A320 family and the B737 NG were further analyzed while in the 2014 report the A330 and the B777 were studied as well.

They follow a yearly schedule in order to develop the carrier's data analysis. Firstly data is collected in the first quarter. They collect data regarding expenses, traffic and capacity from IATA members on a similar basis to that carried out in the Form 41 from US. A preliminary report is published before summer. Finally, around September they hold a conference and publish an enhanced annual report. Regional or customized reports are also tailored to request but not for free.

G.1. Form 41 comparison

The ACMG usually uses data from US DoT Form 41 for comparison purposes in their annual reports. The KPIs from the majors from America are compared against the calculated KPIs from participating airlines.

In addition, they sometimes prepare extraordinary reports using Form 41 data. In fact, they published a report analyzing data from FY 2008-2009 (ACMG, 2011). In that study, they focus on the 11 majors and scrutinize data looking for trends regarding cost and operation techniques. In general, both revenue and cost statistics decreased due to the crisis started in mid 2008.

There exists two similarities between this thesis and their report:

- They use data from similar Form 41 schedules (see Appendix J) which is broken down in similar cost allocations.
- They also analyze data grouping it into different carriers and aircraft families.

On the next paragraphs a summary from the results obtained by the ACGM from the 2008-2009 Form 41 data comparison is presented. This statement of the main points is focused on cost factors.

As mentioned before, cost statistics decreased year over year due to the financial crisis and the fuel price devaluation (in fact, decrements excluding fuel expenses is not as evident). The most dramatic outcome was the fall of the CASM: around -21% in respect to 2008 values. Similar conclusions were found regarding freight and FH.

It must be remarked the observation made by the ACMG who indicates that network carriers usually operate more expensive mixed fleets and routes (with unit costs above the average); nevertheless, this allows them to achieve bigger cost reductions. On the other hand, LCCs have lower unit costs but they grow as their market niche gets complex due to internationalization (forced by US air transport saturation).

A slight decrement in the fuel consumption was also found and the explained reason was the increment of both fleet and operations efficiency.

In global terms, both expenses and revenues diminished (circa 17%; see Figure 48) but also their difference: losses in 2008 were 6 BUSD while 0.1 BUSD the following year. As mentioned before, the driving force in 2009 was the reduction of fuel expenses that became only the 23% of the cost structure while it had been the 32% in the previous year.

Figure 48 Revenue and expense evolution by airline (2009 vs. 2008). Source: (ACMG, 2011).

At the end of the report, the ACMG also carried out an analysis considering aircraft models. Regarding the category of aircraft used, narrow body AC (bigger than 100 seats) constituted the 50% of the whole market share (85% in the majors' case) followed by the regionals, 24%, and wide-body ACs with two engines, 11%.

A similar distribution of percentages was found in terms of AC manufacturers, Boeing was the biggest one with a 50% of the whole market share (80% in the majors' case). Then Bombardier, 16%, and Airbus, 14%, were behind. In this case, geopolitics of the large industrial conglomerates has a powerful influence. This manufacturer distribution may not be taken as a reference but as a comparison with the European fleet composition, which is mainly constituted by Airbus ACs.

The most relevant discovery was that majors retired in 2009 a considerably amount of their oldest fleet. Particularly the B737 Classic fleet was reduced a 24% that year and the DC9 a 14%. No potential explanations to this fact were proposed although the fuel cost depreciation (the main driver in that year) should have been a pro to the old high-consuming fleet preservation.

Appendix H. **ATA standard cost model**

It was in 1940 when comments regarding operating costs of transport airplanes were published in (Mentzer & Nourse, 1940). Part I of this article was dedicated to the development of equations for calculating the costs derived from the *“flight of the airplane or those affected by variation of airplane size, power, initial cost and aerodynamic efficiency”*. In parts II and III the authors present the airplane characteristics and other factors *“not associated with design and performance”*.

This methodology was the baseline for the Air Transportation Association of America (ATA) to develop a method for estimating DOC. In the following section some background regarding the ATA is presented and later further details about the model history and its structure.

H.1. Air Transportation Association / Airlines for America

ATA is in charge of working jointly with carriers and the US Administration in order to organize collaboration and develop a legal framework for the suitable development of an economic and technological environment that would allow the improvement of air travel for all the involved parts.

This organization was founded in 1936 and it has been involved in several government decisions such as the deregulation process that took part in 1978. The main topics where A4A is involved are: reduction of tax on airlines operation, support

improvement of air traffic control system and a general deregulation in the aviation sector.

Members of ATA are a conglomerate of US majors. During October 2015, Delta Air Lines made public its intention to leave its membership due to disagreements regarding the aforementioned topic related with the traffic control system. This was the last change within the ATA structure and after that Delta's exit, Table 38 gathers the current members of this organization.

Table 38 ATA members as of 2016.

Alaska Airlines	Jetblue Airways Corp.
American Airlines	Southwest Airlines
Atlas Air	United Continental Holdings
Federal Express Corp.	United Parcel Service
Hawaiian Airlines	Air Canada (associate)

At the end of 2011, ATA informed of a new corporational brand: Airlines for America (A4A). With this change, a wider support to US carriers was declared to be aimed considering the global challenges of American air transport.

H.2. ATA Model

As explained before, ATA was one of the first contributors to the definition of a standard method for estimating DOC for piston driven engine aircraft in 1944. This model had a great acceptance and success along the industry and this forced several updates in the following decades. In particular, the following versions were published:

- 1944. First version. Based on (Mentzer & Nourse, 1940) with DC-S airplanes (twin-engine, piston driven engine) and extrapolated to larger aircraft.
- 1949. Revision of statistical data and inclusion of four-engined airplanes.
- 1955. Inclusion of turboprop and turbojet airplanes.

- 1960. Revision of turboprop and turbojet statistical data.
- 1967. Revision of formulation in aims of a better understanding and inclusion of supersonic transport.

The last model update (ATA, 1967) was published jointly by leader manufacturers Boeing, Douglas and Lockheed. The following list enumerates the different allocations included within this last revision:

1. Flying operations. This item was constituted by three parts:
 - a. Flight crew. In this case, a differentiation was made between flights which needed two or three people as crew.
 - b. Fuel and oil. Block fuel, a sum of the fuel consumed during the different flight phases (taxi, climb, cruise and descent; detailed calculations not described there), was used along with some assumed oil consumption in order to estimate this allocation.
 - c. Hull insurance. Since in this revision supersonic transport was added to the model, an aclaration was made regarding the fact that during the first phases of new types of aircrafts their insurance cost is usually too high.
2. Direct maintenance. Expenses related with overhaul, servicing and inspection of the aircraft and the engine were included here.
 - a. Labor (airplane).
 - b. Material (airplane).
 - c. Labor (engine).
 - d. Material (engine).

- e. Maintenance burden. This item was calculated as a linear dependence from the airplane and engine labor expenses.
- 3. Depreciation. In this case, different depreciation periods were proposed for subsonic (12 years) and supersonic (15 years) aircraft while both were considered with a non-existent residual value.

Appendix I. Definitions

This section includes some definitions concerning not only operative costs (which is the first and most relevant section) but other things related to air transport and its management. A big amount of the information gathered in this appendix has been adapted from (ACMG, 2014).

I.1. Total Operating Expenses (TOE)

Following the ICAO classification, the expenses of an airline can be broken down as follows (see Figure 49):

- Operating costs⁷. Those regarding the company operation and related to the offered product or service. They can be divided into:
 - Direct⁸. Regarding the aircraft operation. For this reason they are also referred as Total Aircraft Operating Expenses (TAOE). Following the approach from (Doganis, 2002), they can in turn be divided into:
 - Fixed. They are usually related to the fleet size and its escapability is medium term.

⁷ Also known as Operating Expenses (OPEX) or Total Operating Expenses (TOE).

⁸ Also known as Direct Operating Expenses (DOC) or Total Aircraft Operating Expenses (TAOE).

- Variable. This category gathers cost related to operations and their escapability is short term.

A different division is carried out in (Stratford, 1973), where DOC are classified in three elements: standing costs (depreciation and insurance), flying costs and other costs. On the other hand, the ACMG (see Appendix G) divides the DOC into three different categories: aircraft operation, aircraft maintenance and aircraft servicing.

- Indirect⁹. Regarding the payload and general activities. Following the approach from (Doganis, 2002), they can in turn be divided into:
 - Route specific. Expenses such as fees, services and communication are here gathered and their escapability is long or medium term.
 - Non-route specific. This item includes costs such as those that arise from the staff or finance whose escapability is long term.
- Non-operating costs. Those which are purely related with the bussines, not with the company operations. In this item interests and results of subsidiaries are usually introduced.

Figure 49 Scheme of the total costs of a typical airline.

⁹ Also known as Indirect Operating Expenses (IOC), All Other Operating Expenses (AOOE) or airline related expenses.

This study is based on the operating cost or Total Operating Expenses (TOE). The TOE comprises the total of Flight Operations, Ground Operations and System Operating Expenses (which are broken down in the following three subsections). This line should essentially reconcile to the management accounts *Operating Costs* except for those items that are to be excluded, or otherwise reported, as per the definitions. E.g. the direct, indirect or overhead costs of third party businesses carried out by the reporting airline. TOE does not include any element of 'capital charges', such as interest on loans, the interest element of lease payments, or replacement cost provisions.

I.1.1. Flight operations expenses

This category gathers very important both variable and fixed costs derived from the flight operations carried out by the airline.

Fuel and oil: Here are included expenses for all aircraft fuel and oil consumed by the aircraft, non-refundable duties and taxes pertaining thereto. It includes fuel throughput charges levied by the airports and “fuel-into-plane” costs. Lastly, some techniques have become usual in the industry with the aim of hedging against volatile movements of fuel costs; “Financial Hedging” or Forward Cover transactions associated with fuel purchase must be also considered here. In some cases oil costs are not calculated because the oil to fuel expenses ratio is usually negligible.

Flightdeck crew: pay¹⁰ and allowances¹¹ of flightdeck staff (see section I.2.1), including training whether in the air (training flights) or on the ground (instructors, simulators...). Their management and scheduling is also included in this item.

Flight equipment insurance: this item includes insurance for damage to the airframe, power unit and all their parts, mechanisms and devices and insurance

¹⁰ Pay as outlined above includes all; payroll, overtime, shift pay, sector pay and any other bonus or productivity related pay connected with environment. It also includes employer social insurance costs, contributions to pension funds and any other employment related costs, which are the responsibility of the employer.

¹¹ Allowances as outlined above include all expenses incurred in connection with commercial flight operations, including accommodation, subsistence, meals, per diem allowances, transport and uniform costs, etc.

regarding third party liability. In addition, costs derived from uninsured issues is also gathered here. However, passenger or cargo liability insurance is not.

Flight equipment depreciation: full allowances for depreciation of owned flight equipment such as airframe, power unit and all their parts, mechanisms and devices are included in this category. Each company has its own methodology for the Aircraft Purchase Price (APP), Depreciation Period (DP) and Residual Value (RV). The calculations followed in this thesis are explained in section 3.3.3 (Depreciation and Amortization allocation).

Leasing: this item includes expenses derived from all types of possible lease conditions: financial, dry, wet or all-included leasing.

Navigation fees: this includes en-route and approach (airport arrival or departure; also known as Terminal Navigation Charges (TNC)) charges.

I.1.2. Ground operating expenses

This heading includes costs derived mostly from the maintenance operations. However, other kind of expenses such as the airport charges due to the aircraft and the passengers are also included here.

I.1.2.1. Maintenance

This allocation includes the cost of maintenance for keeping airframe, power unit and all their parts, mechanisms and devices in an optimal condition. The following types of maintenance are defined regarding its goals:

- **Hard time:** fixed-period actions. Period is understood as a certain time (using component age, BH, or FH) or as a certain number of cycles (number of departures...) depending on the component. They are divided into 4 categories: A, B, C and D. The latter is constituted by major revisions such as the overhaul or the Intermediate layover.

- **On condition:** actions that are carried out occasionally in order to check the components state. They are intended to detect potential failures, which are the physical conditions that indicates an impending functional failure.
- **Failure finding:** actions that are carried out occasionally in order to check the components state. They are intended to detect functional failures, which are the ones that prevent the component from functioning within the specified limits.

Regarding the place where the maintenance task are carried out, two different categories are described: line and base.

- **Line maintenance:** this can be done in the ramp. It includes aircraft reception, inspection, troubleshooting (*go* and *no go* faults) and clearance.
- **Base maintenance:** this is done in the hangar while the AC is out of service. Normally this is comprised within the hard time type, including reparision or replacement.

In addition to the expenses arisen from the aforementioned categories, other costs such as aircraft maintenance management and support are also included within this item.

I.1.2.2. Airport Charges

This item includes aircraft related fees and passenger and freight charges. Methods for determining these charges are region and airport dependent. Eventually, customers pay them through the booking price.

- **Aircraft related:** the usage of runways, taxiways and ramp areas are the main reasons behind this item. Other charges are due to noise and emissions fees, towing actions, night surcharges and hangar rentals.

- **Payload related:** this item includes charges related to the usage of terminals and other airport facilities. Security charges can also be charged by the airport to the carrier.

I.1.2.3. Station and ground

This item is mainly constituted by the following two sources of expenses:

- **Ground crew:** this item includes pay (see footnote 10), allowances (see footnote 11) and costs of all station staff engaged (see section I.2.2 for more information regarding airline ground personnel).
- **Facilities:** Maintenance and insurance of airport facilities.

In addition, other smaller pieces are included such as handling fees sometimes outsourced to third party companies and expenses derived from meteorology information acquisition.

I.1.3. System operating expenses

This allocation includes the items explained in the following paragraphs.

Cabin attendants: this item includes pay (see footnote 10), allowances (see footnote 11) and costs (training and supervision) derived from cabin attendants (see section I.2.1 for more information regarding airline air personnel).

Passenger service: items such as general services provided for passengers, meals and accommodation for staff and cost derived from delayed or cancelled departures (refunds, hotel...) are included within this allocation.

Payload insurance: insurance costs regarding freight and passenger liability are included in this item. See flight equipment insurance in section I.1.1.

Marketing: this item includes pay (see footnote 10), allowances (see footnote 11) and costs of all marketing staff (see section I.2.2 for more information regarding

airline ground personnel). It also gathers commissions that are paid by the operating carrier to the marketing carrier when using a free flow code share arrangement.

Information Technology (IT) and communications: this item comprises IT (web related, hardware, software, development of new systems, outsourced services, data warehousing...) and communications (data, telephone, satellite communications...) expenses.

I.2. Staff

Different types of personnel are here described. A major classification could be made considering air and ground labor:

I.2.1. Air staff

Here staff who works aboard the aircraft during revenue flights is gathered.

- **Flightdeck crew:** personnel who is in charge of operating the aircraft and are usually located within the AC flightdeck or cockpit.
 - **Pilots.** Personnel who is responsible of the aircraft operation involving airplane control and some decisions regarding safety issues. It usually includes one captain and a first officer at least.
 - **Flight engineers¹²:** they used to be the ones who monitored aircraft data retrieved from the cockpit control panels. The number of staff from this category is decreasing due to technological developments in aircrafts and air management systems.
- **Flight attendants¹³:** personnel who is in charge of passenger service, comfort and safety during the flight.

¹² Also known as air engineer or air mechanic.

¹³ Also known as cabin attendants, cabin crew, stewards or air hosts.

I.2.2. Ground staff

This staff does not work inside the aircraft during normal revenue flight operations.

- **Maintenance:** all the personnel that keeps airframe, propulsion units and all of their parts, mechanisms and devices in optimal conditions. All types of maintenance (overhaul, hard time, in line..; see section I.1.2.1) are included here.
- **Station staff:** personnel that is involved in servicing and loading the aircraft during its service time (see section I.4). It also includes passenger and cargo handling or ramp planning.
- **Terminal services:** this item is comprised by workers at airport terminals. They provide some services (deaf or blind passenger assistance, wheelchair assistance, oxygen bottle assistance, unaccompanied minors...) and information (travel information, baggage claim, delay or overbooking refunds, check-in and gate agents...) to passenger and customers.
- **Marketing:** personnel in charge of sales management, bookings, management, advertising and publicity.
- **General and administrative:** this item includes the rest of staff that is required to administer the business and not comprised by the aforementioned categories. Some of their tasks are accounting, consulting or office supplies.

I.3. Fleet

There exist some ways of measuring a carrier's fleet. These are the most commonly used parameters regarding this:

Total number of aircraft: This category encompasses both active and non active aircraft, which are detailed below.

- **Active aircraft:** this item includes all the fleet that is in service or in maintenance (but which are expected to return into normal operation).
- **Non-active aircraft:** aircraft which have been removed from operations due to economic reasons (not for maintenance reasons) but still remain as airline's assets are included in this category.

Average Fleet Age: This considers the average age of all active aircraft considering their commissioning date as initial date.

I.4. Operation times

Some time definitions have been used along the thesis. These are commonly used in order to calculate issues such as aircraft utilization. Some of the most popular are here described:

Trip Hours (TH): This value includes the time spent in a whole trip: taxing, flying and servicing.

Block Hours (BH): This term includes the period from the moment the AC pushes back from its parking gate until its arrival in the destination gate. Non-revenue flights such as training ones are not included in this category. BH are equivalent to taxi time plus flight time.

Flight Hours (FH): It is computed as the time from the moment the aircraft leaves the ground until it touches the runway again at the destination airport. It is also known as takeoff to touchdown or wheels-off to wheels-on.

Average aircraft daily utilization (hours per day): Averaged BHs that an AC is used each day. See footnote 4.

Appendix J. US DoT Form 41

The Form 41 has been used in this thesis in order to validate and fit the operating expenses estimation model. In this appendix, some background regarding this well-known American form is gathered and described.

J.1. Bureau of Transportation Statistics

The Bureau of Transportation Statistics (BTS) is one of the federal statistical agencies which comprises data from transportation economics, multimodal freight and commercial aviation. Its main objective is to provide accurate information on different transportation systems throughout the US.

Apart from its continuous data collection and the several infographics and information they publish along the year, their annual report, (BTS, 2016), gathers relevant information regarding passenger and freight movements and transportation performance, economics, safety and environmental impact. For instance, Figure 50 shows the biggest airports in terms of emplaned passengers during 2015.

Notes: Includes passengers enplaned on U.S. carrier scheduled domestic and international service and foreign carrier scheduled international service from the United States.

Figure 50 Enplanements at the top 50 US airports in 2015. Source: (BTS, 2016).

As mentioned before, the BTS DB gathers a great variety of schedules. Some of the modes covered are aviation, maritime, highway or rail transport. The main topics are finance, traffic, on-time performance, travel nature and issues related with safety and accidents.

J.2. The Form

US carriers are compelled by the US Department of Transportation (DoT) to notify their financial accounts on a basis of some predetermined forms. In particular, the US DoT Form 41 is periodically reported by US AOCs through series of 16 schedules containing detailed operational and financial data rigorously collected (some of them and their fields can be consulted in section A.1.5). Once this information is gathered,

it is published on the Bureau of Transportation Statistics (BTS) webpage (US BTS, 2016).

The main topics included within this form are listed in the following lines:

- Traffic. Data from US and foreign carriers is available. This item includes fields such as transported passengers, freight and mail, departures performed, flight hours, available capacity...
- Finance. In this case only US carriers report this information. This item includes mainly expenses (operating expenses) and incomes (transport revenue, foreign exchange gains...) but also gathers information about employees or the airlines equipment inventory.

A useful introduction to these resources is gathered in (Durso, 2007). There the author explains how to get used to work with the Transtats DB and later enters into detail breaking down the different schedules included within the Form 41 (both financial and traffic related). Eventually a study regarding the breakeven load factor from different carriers and the potential use of BTS data for analyzing the bankruptcy risk of United at the end of 2002.

Appendix K. Additional results

In this appendix, additional results from those shown within the thesis' main body are gathered. Two different sections are presented: the Spanish carriers data and the microanalysis results from the prognosis.

K.1. Spanish carriers data

Here, results from section 2.2 are represented using individual plots and non-logarithmic scale in order to provide a different interpretation.

Figure 51 Annual PAX from Spanish carriers in 2016.

Figure 52 Annual operations from Spanish carriers in 2016.

Figure 53 Average route distance from Spanish carriers in 2016.

Figure 54 City pairs from Spanish carriers in 2016.

K.2. Forecast microanalysis

In this section, the graphs showing the outcome of the forecast for each of the airlines are presented. Each plot gathers the expenses from the allocations explained in section 3.3 as estimated along the 10 years of the prognosis. The selected scenario is the CNG implemented in 2020, Static fuel price, BASE traffic forecast and Camelina as feedstock.

Figure 55 Cost allocations timeline: Iberia. Scenario: CNG20S, Base, Camelina.

Figure 56 Cost allocations timeline: Vueling. Scenario: CNG20S, Base, Camelina.

Figure 57 Cost allocations timeline: Iberia Express. Scenario: CNG20S, Base, Camelina.

Figure 58 Cost allocations timeline: Air Nostrum. Scenario: CNG20S, Base, Camelina.

Figure 59 Cost allocations timeline: Air Europa. Scenario: CNG20S, Base, Camelina.

Figure 60 Cost allocations timeline: Volotea. Scenario: CNG20S, Base, Camelina.

Figure 61 Cost allocations timeline: Evelop. Scenario: CNG20S, Base, Camelina.

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Figure 62 Cost allocations timeline: Alba Star. Scenario: CNG20S, Base, Camelina.

Figure 63 Cost allocations timeline: Privilege. Scenario: CNG20S, Base, Camelina.

Figure 64 Cost allocations timeline: Plus Ultra. Scenario: CNG20S, Base, Camelina.

Figure 65 Cost allocations timeline: Wamos. Scenario: CNG20S, Base, Camelina.

Figure 66 Cost allocations timeline: Binter. Scenario: CNG20S, Base, Camelina.

Figure 67 Cost allocations timeline: Naysa. Scenario: CNG20S, Base, Camelina.

Figure 68 Cost allocations timeline: Canair Scenario: CNG20S, Base, Camelina.

Figure 69 Cost allocations timeline: Canaryfly. Scenario: CNG20S, Base, Camelina.

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