INSTITUTO SUPERIOR TÉCNICO
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Regional Airline's Operational Performance Study and Appropriate Enhancement Techniques

PGA – Portugália Airlines as a case study

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"I have offended God and mankind because my work did not reach the quality it should have"

Leonardo da Vinci

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As a unique exception on this entire work, the remaining paragraphs of this chapter will be written in the author's mother tongue, Portuguese. Several reasons motivate this choice, however just one of them is left to be known, which is perhaps the most reasonable one, that is all the persons to whom this work is dedicated to or that are considered to be worth of mention, share the same mother tongue, o meu querido Português.

Em lugar cimeiro, porque genesíaco, este documento que representa o culminar de uma etapa de um, por mim próprio desejado, longo percurso académico e profissional é dedicado a meus pais. Seu fruto próprio, e fruto da sua cultura, da sua inteligência, do seu superior saber estar, e da sua incontornável, porque geneticamente condenados a tal, dedicação e espírito de sacrifício, é ao autor, eu, também dedicado este trabalho. Cuja abnegação de muito, na procura de retorno muito maior, não será nunca esquecido.

Este tipo de texto é propício à enumeração de nomes, entidades e outras identidades, contudo quaisquer nomes dignos de nota, não serão necessariamente numerosos, e apenas constarão do final do presente capítulo, pois são os últimos os mais facilmente lembrados, e é precisamente por esse motivo que constarão deste texto.

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Abstract

Today’s airline industry is a particularly fragile business. Crude prices, world crisis, economy recession, new globalization challenges, green-thinking markets, marginal profits… These are some of the ingredients of what is, for many airline operators, a fatal recipe. The only solution for survival is optimization. A transverse and well-thought optimization.

That is why PGA – Portugália Airlines, a Portuguese Regional Airline, aiming to continuously reach higher efficiency values, initiated a series of studies, based on a scholar-industry cooperation model.

This work is the result of one of these studies. Initially single oriented to fuel conservation strategies, it developed itself to a broader study. Different optimization tools and solutions are described and an operational performance study is performed covering the various aspects of flight operation, by defining a series of metrics, useful to more accurately understand the company’s nature. With the same original data, the company’s operational characteristics are then studied in a more statistical perspective. This work also contemplates a savings analysis, taking into account different scenarios more related with flying itself, hence a more practical approach to optimization procedures.

Resumo

Actualmente, as linhas aéreas atravessam uma situação particularmente difícil. Preço do crude, crise mundial, recessão económica, novos desafios da globalização, mercados de eco-consciência, receitas marginais... São ingredientes do que é, para muitos operadores, uma receita fatal. A sobrevivência reside na optimização. Uma optimização transversal e bem pensada.

É por isso que a PGA – Portugália Airlines, uma companhia aérea regional portuguesa, procurando sempre alcançar os mais elevados níveis de eficiência, encetou uma série de estudos, baseados numa cooperação escola-indústria.

Este trabalho é o resultado de um desses estudos. Orientado inicialmente para estratégias de conservação de combustível, desnvolveu-se num leque maior de assuntos. São apresentadas diferentes ferramentas e soluções de optimização e é desenvolvido um estudo do desempenho operacional da companhia, cobrindo vários aspectos operacionais e definindo métricas, úteis para um melhor entendimento da natureza da companhia. A partir dos mesmos dados, as características operacionais da companhia foram estudadas numa perspectiva mais estatística. Este trabalho contempla ainda uma análise de poupança, tendo em conta diferentes cenários mais relacionados com o próprio voo, sendo assim, uma abordagem mais prática a procedimentos de optimização

Keywords: Fuel Consumption; Fuel Conservation; Operational Performance; Performance Optimization; Regional Airline.

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Acronyms, Abbreviations and Units

ACMI	– Aircraft, Crew, Maintenance and Insurance
AFM	– Aircraft Flight Manual
AMSL	– Above Mean Seal Level
AS	– Available Seats
ASK	– Available Seat Kilometre
APU	– Auxiliary Power Unit
BCAR-N	– British Civil Airworthiness Requirements - Noise
BH	– Block Hours
BOD	– Beginning of Descent
BOW	– Basic Operating Weight
C	– Business Class
CDU	– Control-Display Unit
CG	– Centre of Gravity
CI	– Cost Index
DFC	– Distance- based Fuel Consumption
DME	– Direcção de Manutenção e Engenharia – *“Maintenance and Engineering Department”*
	– Distance Measuring Equipment
DOV	– Direcção Operações de Vôo - *“Flight Operations Department”*
E&M	– Engineering and Maintenance
EASA	– European Aviation Safety Agency
EGT	– Exhaust Gas Temperature
ETA	– Estimated Time on Arrival
ETE	– Estimated Time En Route
ETS	– Emissions Trading System
EU	– European Union
FAA	– Federal Aviation Administration

FADEC – Full Authority Digital Engine Control

FAR – Federal Aviation Regulations

FC – Fuel Consumption

FDR – Flight Data Recorder

FH – Flight Hours

FIR – Flight Information Region

FL – Flight Level

FMS – Flight Management System

Gal – Gallon

GOT – Ground Operation Time

GPS – Global Positioning System

GPU – Ground Power Unit

GSV – Gabinete de Segurança de Voo – *“Fligh Security Gabinet”*

HR/hr – Hour – 3600s

IATA – International Air Transport Association

ICAO – International Civil Aviation Organization

INS _ Inertial Navigation System

IPCC – International Panel on Climate Change

ISA – International Standard Atmosphere

kg – Kilogramme – Base unit of mass in SI

l – Litre

lb – Pound

M – Mach Number

MEL – Minimum Equipment List

MMEL – Master Minimum Equipment List

MLW – Maximum Landing Weight

MRW – Maximum Ramp Weight

MSL – Mean Sea Level

MTOW – Maximum Take-Off Weight

MZFW – Maximum Zero Fuel Weight

N	– Newton – Base unit of force in SI
NAVAID	– Navigation Aid
OAT	– Outside Air Temperature
OEW	– Operational Empty Weight
Pax	– The same as passengers
PGA	– Portugália Airlines – Case-study of a Regional Airline
R&D	– Research and Development
RJ	– Regional Jets – In this exposition a Regional Jet is assumed to be an aircraft capable of flying up-to medium-haul routes, carrying no more than 100 passengers.
RR	– Rolls Royce
s	– Second – Base unit of time in SI
SAR	– Search and Rescue
SI	– International System of Units – "*Système International d'Unités*"
SID	– Standard Instrument Departure
SL	– Sea Level
SNA	– John Wayne Airport IATA code
SOP	– Standard Operating Procedure
STAR	– Standard Terminal Arrival Route
TAP Portugal	– Major Portuguese Airline
TFC	– Time-based Fuel Consumption
TOC	– Top of Climb
TOD	– Top of Descent
TOW	– Take-Off Weight
TMA	– Terminal Area
TSFC	– Thrust Specific Fuel Consumption
TP	– Turbo Props
US	– United States
VFR	– Visual Flying Rules
VHF	– Very High Frequency (30MHz – 300MHz)

VOR	–	VHF Omnidirectional Range
Y	–	Coach Class
ZFW	–	Zero Fuel Weight

Glossary of Terms

Airborne	– Sustained flight. Staying aloft. Actually being in the air.
Air Distance	– Distance travelled in relation to the air. Distance related to the TAS.
Autoland	– System that fully automates the landing phase of an aircraft's flight, with the human crew merely supervising the process.
Citypair	– Flight connection between two different airports with commercial purposes.
Destination Alternate	– Airport contemplated in a flight plan as an alternative destination.
Direct Ground Distance	– Shortest distance between two different points on the ground.
En-route Alternate	– Airport contemplated in a flight plan as an alternative destination for an in-flight diversion.
Ground Distance	– Total length of a flight plan or travelled route, projected on the ground.
Induced drag	– Drag force that occurs whenever a moving object redirects the airflow passing by it.
Jet Streams	– Fast flowing, narrow air currents found in the atmosphere of planets at the tropopause.
Livery	– The special design or set of colours with which a company is associated, present on its products and possessions.
Localizer	– Component of the Instrument Landing System that provides runway centerline guidance to aircraft.
Mach	– The speed of an object moving through air, or any fluid substance, divided by the speed of sound as it is in that substance.
Medium-haul	– Flights with a length no longer than 5000NM.
Off blocks	– Instant when the aircraft leaves, or is about to leave, a gate or stand in an airport.
On blocks	– Instant when the aircraft arrives at a gate or stand in an airport.
Overhaul	– Major inspection/maintenance action
Payload	– Amount of weight carried by the aircraft with a certain commercial value.
Pushback	– Maneuver made by an aircraft still on ground to vacate a gate or stand.
Tankering	– Called to the operational decision of carrying extra fuel, loaded on a place where the fuel price is more financially viable.

Winds Aloft	– Forecast of specific atmospheric conditions in terms of wind and temperature at certain altitudes.

CHAPTER 1

1 Introduction

The world as we know it is in itself an out-of-date concept. The world is in a continuous changing process. We now live in the so-called global village, boundaries and frontiers are now free from a geographic definition and there's a global accountability for Human action. This globalization has come upon us almost undetected but in a very decisive and definitive manner. It's partly because of it that it makes so much sense talking about a global crisis. The crisis has hit us and hit us hard, the oil prices peak in mid-2008 has left its toll, global economy is in recession, the increasing demand of resources by emerging countries is unbalancing the trade balance and companies around the world are struggling to remain afloat with only marginal profits.

The aviation industry is particularly sensitive to this economic scenario. While aviation was a key element for the advent of globalization, connecting any point of the Earth to another in a day's time; it is now one of the most vulnerable industries since there's a considerable worldwide drop in the demand for tickets. This induces an excessive offer of airlines, hence a stronger competition among them, being the natural response lowering fares and reducing costs, resulting in a marginal operation and in some cases poor passenger satisfaction.

With all these concerns in mind, PGA – Portugália Airlines, a Portuguese Regional Airline is, like many of its pairs, aiming to optimize its operation. This optimization is only reasonable if applied in a transverse manner through all of its departments. That's why PGA, by the end of 2008, started to plan a series of studies which were to focus on performance analysis, optimization tools and procedures and operational costs reduction. These studies were to be conducted based on an academic model, enhancing scholar-industry cooperation and developing human resources, while helping the company to achieve higher standards of efficiency.

The present work is the result of one of these studies. Initially single oriented to fuel conservation strategies, it developed itself to a broader study, reaching from recent green policies to efficiency enhancing maintenance operations, while still making a deep performance analysis with numerous efficiency indicators on both PGA's fleets. This broader range of studies explains this work's title: "Regional Airline's Operational Performance Study and Appropriate Enhancement Techniques"; the series of subjects discussed in this work aim for the economic performance optimization of PGA. Economic performance gains relevance due to the appalling situation of today's markets which is giving airlines a hard nut to crack. Cost reduction and green policies make headlines and with the implementation of Emissions Trading System they will walk side by side, in the quest for Economic Performance Optimization, with neither of them ever being left behind.

CHAPTER 2

2 Motivations

2.1 Economic Scenario

Today's airline industry worldwide faces one of the most difficult economic backgrounds since the beginning of commercial aviation. In addition to the serious economical crisis the world has fallen to, the latter years also witnessed ferocious competition among airlines leading to ever minor profit margins, making it more and more difficult for newcomers to succeed and old-timers to remain afloat.

With this negative economic scenario, airline operators deserve a special emphasis, since they have the leading role in commercial aviation, hence being, most of the times, the first link of the chain to brake apart, which is to say, vulnerable to company financial collapse.

Since the year 2000 literally hundreds of airlines filed for bankruptcy, resulting in either suspending all flight operations or in strategic mergers between airlines and global code-sharing alliances.

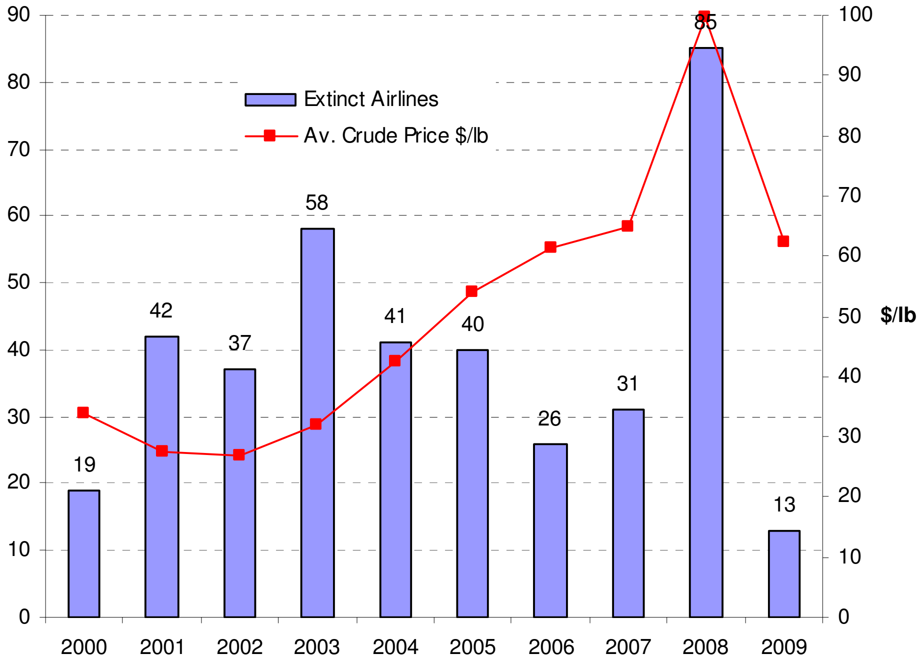

Figure 2-1 - Number of extinct airlines and historical evolution of crude prices since 2000 (source: www.justplanes.com)

The statistics regarding the extinction or merging of airlines is not exclusive to small and/or recent companies, as it also applies to major national airlines. Economic protection is often assured to some companies since their bankruptcy would have a serious and unaccountable impact in the economy as literally thousands would become unemployed. Perhaps the most flagrant example of economic protection in the airline industry is the American law commonly known as *Chapter 11*[1], in accordance with which major North American airlines, like Continental Airlines, Delta Airlines and United Airlines, filed for bankruptcy.

However, and counteracting this type of political efforts to minimize the impact of the world crisis on the economy, more specifically in the airline business, the phenomenon of *credit crunch*[2], recurrent in such economic conditions, arises thus hindering potential investments in fleet renewals or in other strategic sectors of the company reducing its competitive strength.

The growing tendency of the crude prices associated with their high volatility and susceptibility to political, economic and other human factors worldwide make fuel prices perhaps the most decisive cost in an airline operation, hence in its financial health as well.

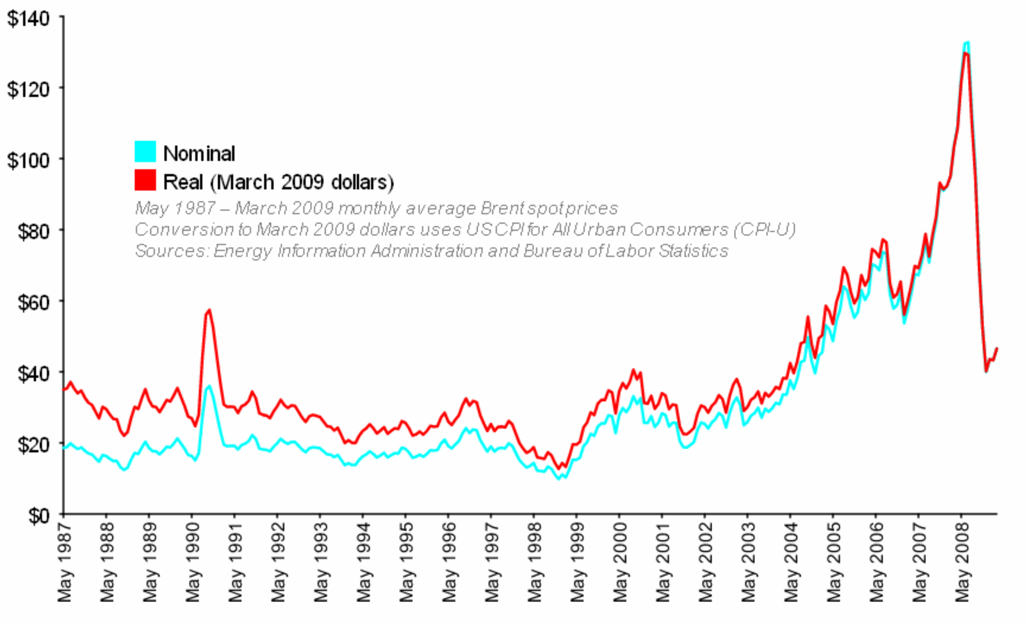

Figure 2-2 - Brent prices (Nominal and Real) since 1987

It is quite obvious the relation between the huge peak in the crude price in mid-2008 (**Figure 2-2**) and the record number of extinct airlines in the same year (**Figure 2-1**). One can also notice the peak occurred in late 1990 coincident with the first war in Iraq, event that shook the crude market worldwide, since Iraq is one of the most significant crude producers; and the continuous rise in crude prices since mid-2001 upon the New York terrorist attacks. These facts

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[1] Chapter 11 – A chapter of the United States Bankruptcy Code, which contemplates the reorganization of a corporation under the bankruptcy laws of the United States. In Chapter 11, in most instances, the debtor remains in control of its business operations *as debtor in possession*, and is subject to oversight and jurisdiction of the court.

[2] Credit Crunch – A reduction in the general availability of loans or a sudden tightening of the conditions required to obtain a loan from the banks.

are clear examples of how human conflicts can determine the fate of world economy, not excluding of course the fate of airline industry, which is one of the highest fuel consumers.

2.2 Aviation, Environment and Health

Air transport performs many important functions in modern societies. Aviation facilitates economic and cultural exchanges and is a significant source of employment and growth in many regions. However, aviation also contributes to global climate change, and its contribution is increasing. While the EU's total greenhouse gas emissions fell by 3% from 1990 to 2002, emissions from international aviation increased by almost 70 %. Even though there has been significant improvement in aircraft technology and operational efficiency this has not been enough to neutralise the effect of increased traffic, and the growth in emissions is likely to continue in the decades to come. In addition, the fact that modern jets operate at high cruise altitudes worsens the effects of engine emissions on higher levels of the atmosphere.

Air pollution can cause a range of health effects including breathing difficulties, heart disease and cancer. Historically, the main air pollution problem has typically been high levels of smoke and sulphur dioxide arising from the combustion of fossil fuels such as coal and oil. The major threat to clean air is now posed by traffic emissions. Motor vehicles emit a wide variety of pollutants, principally carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and particulates (PM10), which have an increasing impact on urban air quality. In addition, photochemical reactions resulting from the action of sunlight on nitrogen dioxide (NO_2) and VOCs from vehicles leads to the formation of ozone, a secondary long-range pollutant, which impacts in rural areas often far from the original emission site. Acid rain is another long-range pollutant influenced by vehicle NO_x emissions. Aircraft and airport-related traffic and activities produce the same types of pollutants as road traffic, domestic and industrial sources. Near to airports, airport activities may form a major or even the dominant source of pollution.

The atmosphere contains certain elements which by a natural process allow the sunlight to cross it while absorbing the heat that is radiated by the Earth. This process is the so called greenhouse effect that supports life as we know it, since it is the natural way that the Earth keeps its temperature. However, human activities such as the burning of fossil fuels and the destruction of forests are increasing the levels of carbon dioxide, water vapour and other heat-trapping gases in the atmosphere. The addition of these greenhouse gases is enhancing the natural greenhouse effect, making the Earth warmer and changing the climate.

The solution lays in reducing global emissions of the greenhouse gases, in particular carbon dioxide. This means making better use of natural resources. Fossil fuels — oil, gas and coal for electricity, heating, cooling and transport — are major sources of greenhouse gas emissions. We need to burn less of them and burn them more efficiently. Emissions of CO_2 from all transport sectors currently account for about 22% of all global emissions of CO_2 from fossil fuel use. In 1990, aviation was responsible for about 12% of CO_2 emissions from the transport sector (**Figure 2-3**).

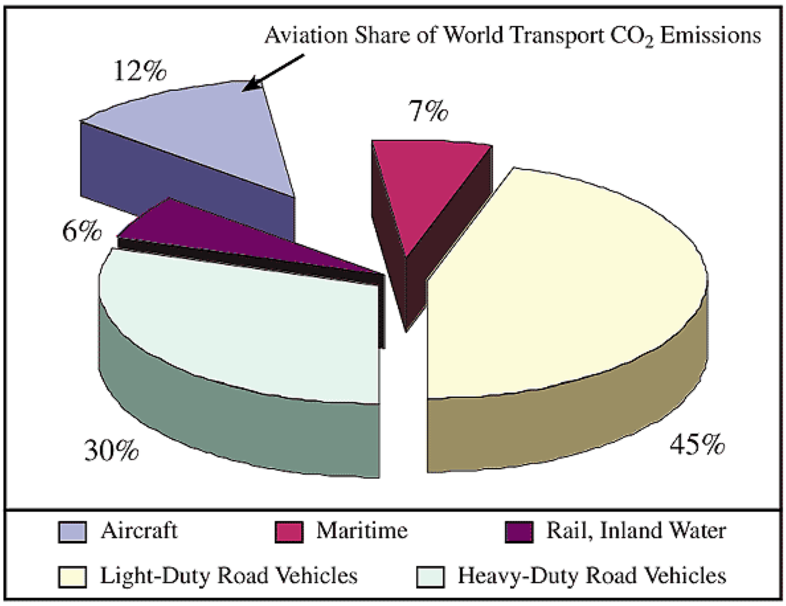

Figure 2-3 - Aviation share of world transport CO2 emissions in 1990

However, since aviation has such an important role to mankind, the most radical solution of stopping all sorts of flights is out of the picture, so Men has to work ways of significantly reducing the toxic gas and particles emissions, whether by a substantial reduction in fuel consumption or by creating alternative propulsion technologies. The latter is presently a distant reality so we have to focus our attention in effective and realistic fuel conservation strategies.

Presently these strategies lay on four main pillars:

- **Technology**
  - New airframes and engines
  - Cleaner bio-fuels and new energy sources
- **Infrastructure**
  - Improved air routes, air traffic management and airport procedures
- **Aircraft Operations**
  - Aim for maximum efficiency and minimum weight
- **Economic instruments**
  - Taxes
  - Incentives to finance technology and R&D
  - ETS

2.3 Fuel Conservation Strategies

The general trend in aircraft engine technology development over the past few decades has been to reduce TSFC[1]. Besides reducing fuel consumption, this trend has resulted in lower emissions of carbon dioxide (CO_2) and water vapour (H_2O) and most other exhaust gases per unit of thrust. Advances in combustor technology have resulted in considerable reduction of NO_x emissions at a given pressure ratio.

Developments in communication, navigation, and surveillance technology, as well as air traffic management systems have enabled more efficient use of the air traffic system. This also brought in some considerable fuel savings. The complete transformation that is, modernization of the air traffic system is expected to generate significant safety, operational, and environmental benefits. Air traffic innovations for present and future systems offer potential for reduced fuel consumption, hence emissions, through improvement in the overall capacity and efficiency of the air traffic system.

Operational improvements consist of establishing more efficient SOPs like engine out taxiing, better APU management, CI optimization, exploiting the FMS flight efficiency tools, CG fine tuning, and several E&M potential savings like, BOW reduction, engine compressor water wash and good airframe surface trimming and washing. Potential environmental benefits to be gained from operational measures within the current air traffic system, though important, are thought to be smaller than those that may be gained through modernization of the air traffic system. The environmental effect will depend on the rate at which these measures are adopted.

Several economic instruments may be considered as fuel conservation strategies, however none is thought be as effective as the ETS. ETS is sustainable and manageable in a global scheme, allows the continuous expansion of the aviation industry and is non-discriminatory.

2.3.1 Emissions Trading System

The Emissions Trading System is an economic tool created with the purpose of reducing the emission of greenhouse gases to the atmosphere, with special emphasis in carbon emissions. In the author's perspective the Emissions Trading System is a key element in a global strategy to reduce the greenhouse effect and to minimize climate change with the potential to be the most significant fuel conservation strategy enhanced by a truly global awareness. That's the reason why it is emphasized by means of a dedicated sub-section on this work.

The main principle behind ETS is considering carbon as a good itself, with a market-driven cost and a customized trading system. According to ETS, carbon is equivalent to permits

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[1] TSFC – Engineering measure of an engine's efficiency; it represents the mass of fuel needed to provide the specific net thrust for a given period of time, given in kg/N.s.

in the sense that a company can only consume the amount of carbon (by means of burnt fuel) for which it is allowed whether by auctioned or purchased permits.

The mechanics of this system is based on a cap and trade concept. Under a *cap* and *trade* system, a *cap* must be set, deciding the total amount of emissions that will be allowed. Next, companies are issued credits, essentially permits, based on how large they are and how broad their operation is, and so forth. If a company comes in below its cap, it has extra credits which it may *trade* with other companies. Companies which come in below their caps can sell their extra credits, profiting while reducing their pollution trail. Companies which exceed their caps are penalized for their excess pollution while still bringing overall pollution rates down. In a sense, the need to purchase credits acts as a fine, encouraging companies to reduce their emissions.

The EU is somewhat a pioneer on this matter introducing its model of ETS (EU ETS) in 2012. The EU ETS assumes that certain conditions are met by the airlines and national regulators. From January 1st 2012, airlines must annually file their, externally audited, emissions report. This report contains the information regarding the company's emissions and tonne-km figures gathered and calculated according to a previously accredited Monitoring and Reporting Plan (MR Plan) without which the company will not be granted with any free permits.

The key dates of the EU ETS are as follows:

- **August 1st 2009** - Operators submit MR Plan which must be reviewed by January 1st 2013
- **January 1st 2010** - Beginning of the annual emissions monitoring
- **March 31st 2011** [*] - Operators submit a verified emissions report to regulator for emissions in the year 2010 (and years thereafter)
- **January 1st 2012** - Beginning of the EU ETS (3% deduction from the original 2004/5/6 baseline emissions)
- **January 1st 2013** [*] - Continuing the EU ETS (w/ 5% deduction from the original 2004/5/6 baseline emissions)

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[*] And each year thereafter

With **Figure 2-4** and **Figure 2-5**, one can have a clear notion of the cap and trade concept. The cap is calculated with the years 2004, 2005 and 2006 baseline emissions' being reduced by 3% in 2012 (first trading period) and 5% in 2013 and years thereafter (second trading period). To the cap value, 3% is taken as a special reserve to new entrants and fast growing operators and from the remaining (net cap) only 85% are free and 15% are auctioned. Any permits above the cap value must be purchased.

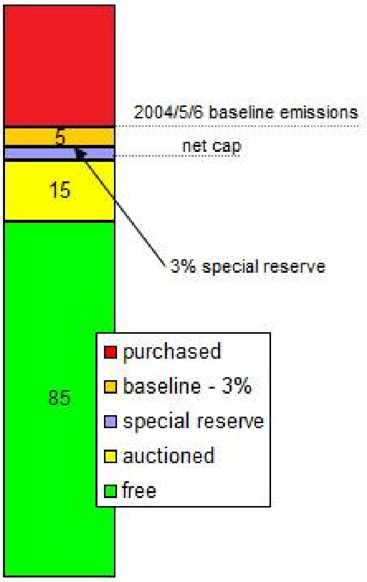

Figure 2-4 - EU ETS Mechanics (year 2013 and so fourth)

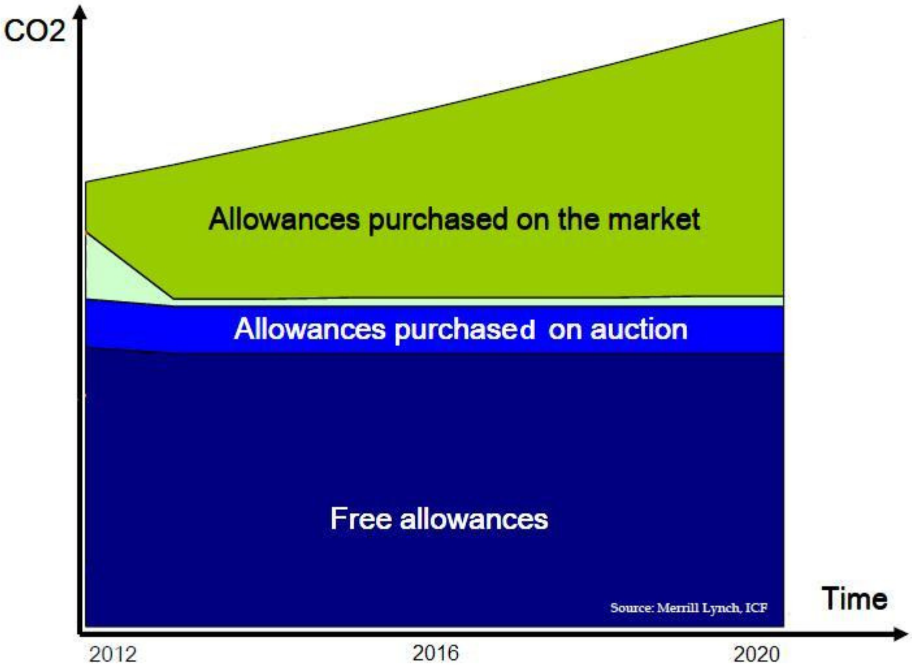

Figure 2-5 - EU ETS timeline

Exemptions to the EU ETS apply to operators flying less than 243 flights per 3 periods of 4 months, operators emitting less than 10000 tons of CO_2 per year, flights carrying non-EU Heads of State, Monarchs and Government Ministers, military flights, SAR flights, fire fighting flights, humanitarian and medical emergency flights, VFR, circular and training flights.

CHAPTER 3

3 PGA Portugália Airlines: Regional Airline Case Study

The development of this thesis would not be possible without a case study of a Regional Airline. PGA Portugália Airlines is an exceptionally well suited example of such a case study due to its size and strict regional operation profile and it was with this company's valuable collaboration that the author could gather all the information needed to conclude this thesis and get to the final conclusions on this subject. All the data analyzed in this thesis is collected from PGA DOV's records.

PGA Portugália Airlines is a Portuguese Regional Airline based at Lisbon International Airport operating scheduled international and domestic routes from Lisbon and Oporto. Established on the 25th July 1988, it began its operation only two years later with domestic routes, due to the delay of the liberalization of the airline industry. In June 1992 PGA flew for the first time an international route. By 1993 the total fleet of six Fokker F28 Mk 100 was completed and by 1997 PGA started receiving the first of the total eight aircraft Embraer ERJ-145.

Aircraft Type	Tail Number	Name
Fokker F28 Mk 100	CS – TPA	Albatroz
	CS – TPB	Pelicano
	CS – TPC	Flamingo
	CS – TPD	Condor
	CS – TPE	Gavião
	CS – TPF	Grifo
Embraer ERJ145	CS – TPG	Melro
	CS – TPH	Pardal
	CS – TPI	Cuco
	CS – TPJ	Chapim
	CS – TPK	Gaio
	CS – TPL	Pisco
	CS – TPM	Rola
	CS – TPN	Brigão

Table 3-1 - PGA fleet

Figure 3-1 - Fokker F28 Mk 100 – CS-TPE "Gavião"
(source: www.planespotters.net)

Figure 3-2 - Embraer ERJ-145 - CS-TPH "Pardal"
(source: www.planespotters.net)

Throughout the years, PGA has been distinguished with several awards, based mostly on gathered customers' opinions and feedback:

Award	Related Years	Entity
Best European Regional Airline Award	2001, 2002, 2003, 2004, 2005	Skytrax
Medalha de Mérito Turístico - Grau Ouro	2004	Portuguese Ministry of Tourism
Best Portuguese Airline	2004	Take-Off Magazine
Second Best European Airline	2005	Skytrax
Best European Cabin Crew	2005, 2006	Skytrax
Skyliner Track Keeping Accuracy	2005	Manchester Airport

Table 3-2 - PGA awards

On June 2007 TAP Portugal, member of Star Alliance, acquired PGA, marking the beginning of a new era in the company. Though still flying with its own livery, PGA now operates in an ACMI lease. In an ACMI lease, the lessor (PGA) provides the aircraft, one ore more complete crews, including engineers, all maintenance and insurance for the aircraft; the lessor charges the lessee (TAP) for the Block Hour and the lessee is responsible for all ground handling, passenger and luggage insurance and it is the lessee that provides the flight code.

CHAPTER 4

4 Fuel Consumption Optimization

4.1 Why is it needed?

Facing such an appalling economic context most of the world's airliners are struggling to keep financial viability, and all of them know that when world economy recovers from its current recession the only survivors will be the ones that managed to achieve the best economical performance optimization possible.

In the particular case of a small airline operating a medium size fleet of Regional Jet (RJ) aircraft on short and medium-haul routes, like PGA - Portugália Airlines, some aggravating factors (mainly due to operational conditions), have to be considered.

Aircraft operations characteristics like airports served, stage lengths flown and flight altitudes, have a particularly significant impact on the *energy efficiency*[1] of RJs. They fly shorter stage lengths than large aircraft spending more time at airports, taxiing, idling, maneuvering to and from gates, in more technical words, RJ spend a greater fraction of their block hours (BH) in non-optimum, non-cruise stages of flight. It's possible to quantify this ground inefficiency with the difference between block hours (BH) and flight hours (FH), the bigger the difference the higher the inefficiency. This fact is due mostly to the fact that RJ flights' have been focusing on major urban airports sharing their facilities with major airliners, increasing airport congestion. Anyway, RJ require a similar runway length to large aircraft, setting aside some of the available secondary urban airports on which TP have no problem landing or taking-off.

Another RJ weakness is their high airborne inefficiency. RJ by definition fly shorter routes than larger aircraft, nonetheless they fly with the same type of engines and with similar systems technologies, having very similar altitude related performance charts they all fly preferably at the same altitudes. So if RJ have optimum flight levels as high as larger aircraft have, taking approximately the same climb distance but flying much shorter routes, they'll spend much of their flight time, not in cruise as it is intended, but in non-optimum conditions, being much more inefficient as stage length decreases.

Other important downside of RJ is their high ratio of cycles per flight hour, meaning that each flight takes very little time to complete. In other words, both the aircraft and the engines, complete much more cycles with less flight time. This increases maintenance costs as non-time related maintenance inspections must be carried out much more often. The figures regarding maintenance costs are clear, on large aircraft 11.6% of the direct operating costs are maintenance costs and in RJ this figures builds up to 20%.

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[1] Energy Efficiency – The efficiency of an aircraft measured by units of energy per ASK.

In spite of its disadvantages, RJs are still competitive as their load factors are generally 10 to 30% higher than their direct rivals the TPs. One very plausible reason for this is the passenger satisfaction upon flying on RJ. Smaller and more cosy and silent cabins, make the passenger feel more comfortable in his or her business or pleasure travel, while being provided a fast and more human way to fly.

In sum, due to a crushing economic scenario, to a more and more global conscience and broader perspective in what climate change is concerned, to operational difficulties and aggressive competition and in first hand, to the need to reduce direct operating costs, fuel consumption optimization is mandatory.

4.2 Optimization Tools and Solutions

Optimization is in itself a philosophy applicable in a transverse manner in an organization. In an airline company this is particularly important, both maintenance and operations departments are susceptible to and should be optimized.

It is important to keep in mind that optimization solutions are not miraculous actions that will unveil amazing new performance figures, but a series of well-thought ideas considering the very own nature of the company and in which way they are viable to achieve their goals as small parts of a global plan for the company, aiming to work altogether like a series of well oiled mechanisms with all its parts working in conjunction to achieve a common goal, optimization.

The most significant fuel consumption optimization solutions related to maintenance practices are stated below:

✈ **Controlling the Drag** – As an aircraft grows older there's an aerodynamic drag build-up since more and more imperfections occur. Maintenance crews should limit this aerodynamic efficiency deterioration by keeping all surfaces properly washed and cleaned, and by periodically inspecting and searching for unlevelled surfaces, especially between control surfaces and other aerodynamic elements, like flaps, slats, doors and seals, correcting any existing imperfection.

✈ **Controlling the Weight** – All aircraft usually suffer from a natural growth in weight. Whether by absorption of moisture, long term accumulation of dirt on inaccessible parts of the aircraft, refitting new equipment leaving old components, even if only electrical wiring, still installed due to hard and complex removal procedures or just by adding new cabin equipment or refurbishing the interior with heavier materials and parts, almost every aircraft grow in weight along their operational life, and it's up to maintenance crews to prevent and control these situations.

- **Controlling Engine Efficiency** – The fuel consumption of jet engines depends on the amount of thrust and on the flight conditions and is usually expressed as TSFC. The TSFC tends to increase with engine hours due to natural engine deterioration, being restored after periodic overhauls though destined never to have the same efficiency as it has had when new. Though possible, the full recovery of an engine's TSFC is often not economically worthy since very expensive hot section parts are to be removed. So, apart from running mandatory periodic inspections, it is important to keep track of the engines' performance data in order to early diagnose and correct problems arising from engine deterioration, proven by TSFC increase and loss in EGT margins (trend monitoring systems are discussed later). However there's a technically simple maintenance action that can be performed that can increase engine life while preventing TSFC degradation and EGT margin reduction which is, engine washing. Again a proper "fine-tuned" trend monitoring program is of the essence to assess whether engine washing is being cost-effective or not and if it is in fact cost-efficient, what is the best period between washes.

Fuel Consumption Optimization solutions concerning operational characteristics are listed below:

- **Pilot Techniques** – There are a series of flying techniques that can and should be monitored in order to correctly evaluate the right SOPs to be followed by the airline for each aircraft type. Some techniques may seem meaningless, although some of them can be very important and significant in the global context of an airline operation. Listing these techniques:

  – *APU* – The APU should be running only when necessary. Whenever possible, electrical power and hydraulic pressure should be provided by a GPU.

  – *Engine Start-Up* – The engine's start-up procedure should be done with a proper timing avoiding excessive fuel consumption still on ground. Engine start-up after pushback is a viable solution.

  – *Engine out taxi* – If it doesn't stand against company regulations or prohibited on the AFM, taxiing with one (or more, according to the aircraft) engine out is a solution to be considered.

  – *Proper trimming* – Whether by asymmetric fuel or payload distribution inside the aircraft, or by different engines' thrust outputs or even improper flight command, a small bank and correspondent side-slip, or vice-versa, is likely to occur. To reduce parasite drag, proper trimming should be set and if detected, the cause should be mitigated if possible.

– *Ice Protection* – De-icing systems aboard a commercial aircraft are of the utmost importance. However it is pointless to use it when it is not being needed since it is a high fuel consuming equipment. An automatic system that detects icing conditions and subsequently activates the de-icing equipment is highly recommended since it can save large amounts of fuel.

– *Autolanding* – The use of autoland requires an earlier interception with the localizer, increasing the distance and an earlier selection of the landing configuration, increasing drag, thus increasing fuel consumption. When possible and in accordance with the company's directives, autoland should be disregarded.

– *Flap setting on landing* – Usually, if more than one flap setting is available, the smallest setting is generally accepted as being the best for saving fuel and structural life of the flaps, even tough it leads to faster tyre and brake wear-out. The same principle may be applied to take-off as well.

- **Controlling Aircraft Weight** – Since aircraft weight has an unavoidable limiting effect on the payload capability, it is of the essence to reduce it as much as possible. An effective way to do this and by doing so also reducing fuel consumption is to reduce fuel reserves to strictly necessary values. This requires a thorough study to develop an optimized flight planning tool capable of establishing the necessary values of fuel reserves for each flight, since there is no flight exactly the same as another, whether the differences stand in route, payload or exterior conditions. This study may also mean that a different choice of an alternate is advised. Airlines may encounter a situation where an excessive fuel loading might be cost-worthy, when fuel prices at the destination airport is much higher than at the departure airport. This exclusively cost-worthy solution is called *tankering*.

- **Taxi Fuel** – Proper amount of taxi fuel should be loaded since it represents a considerable fraction of the total fuel weight on board the aircraft. Erroneous calculations regarding taxi fuel may render possible losses in income, since the more fuel is up-lifted, the less payload is carried, which is the actual product being sold by an airline. Even if no limitation is imposed on Payload, it will always cause an increase of fuel consumption due to the extra fuel weight carried.

4.2.1 FMS – The Navigator and the Flight Engineer all-in-one

A FMS is a tool designed primarily to compute a flight plan that not only satisfies all the operational constraints that might be imposed on it while being able to generate the least costly flight possible, in terms of the vertical profile, but it is also a means to enhance cockpit automation, reducing pilot workload. In a typical installation of an FMS, the total system consists of four units: two flight management computers and two Control-Display Units (CDU). Each pair is related to each pilot though having exactly the same valences they are operated also as a redundant system, for if one is rendered inoperative the other is still fully functional. On each CDU there is a keyboard specially designed for the purpose of entering navigation data and other dedicated information.

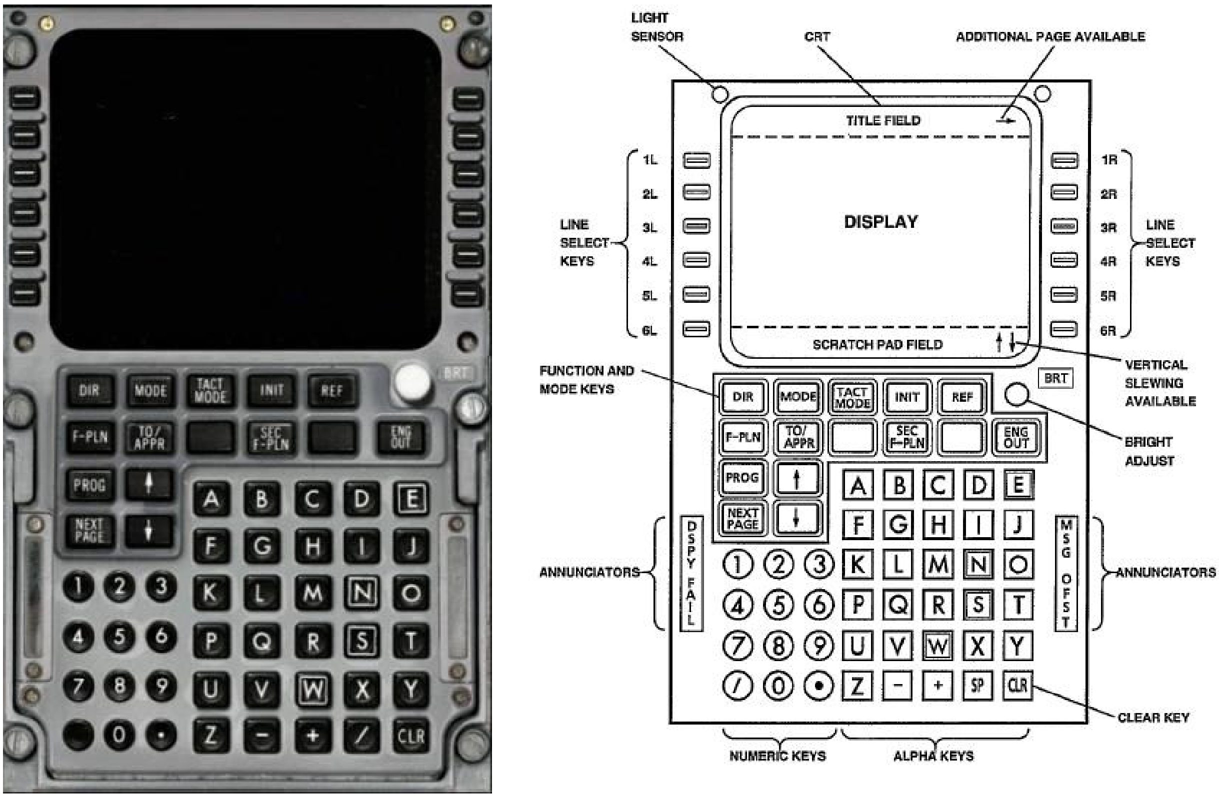

Figure 4-1 - Fokker 100 Honeywell FMS CDU
(source: www.voovirtual.com and AOM Fokker 100)

Figure 4-2 - Embraer ERJ145 Honeywell FMS CDU

The FMS allows the pilot to program an entire flight plan from start to finish including departures and arrival procedures (SIDs and STARs), having the aid of runway details and all the NAVAIDs along the designated route. The FMS is capable of calculating optimal speeds and altitudes for each stage of flight, predicting fuel consumption, ETA and ETE based on integrated performance models of the binomial aircraft/engines. The system allows a continued guidance along the flight plan combining a series of sensors aboard the aircraft. The information gathered by the INS with its gyros, the VOR and DME receivers and the GPS positioning system all work together continually monitoring the actual position and velocity of the aircraft, enabling the necessary navigation functionalities.

The FMS also provides both pilots with important information regarding flight performance, navigation and communications sensors' status and even allows pilots to make in-flight what-if questions to assess the viability of other flight-cost management strategies.

4.2.2 Cost Index – An Unexploited Wonder

Alongside the FMS there is usually a very important fuel consumption optimization tool, which to be more precise is one of the parameters that pilots can use to optimize each flight, by introducing it on the FMS, called the Cost Index or the CI.

Considering the total cost of a single flight as:

$$C = C_F \times \Delta F + C_T \times \Delta T + C_C$$

Equation 4-1 - Total cost of a single flight

Where: $C_F \times \Delta F + C_T \times \Delta T$ is the variable cost.

With: $C_F =$ Cost of fuel per kg

$\Delta F =$ Trip fuel

$C_T =$ Time-related cost per minute of flight

$\Delta T =$ Trip time

$C_C =$ Fixed costs independent of time

The CI is no more than the ratio between time-related non-fuel costs and the cost of fuel (assuming the fuel has a fixed value for a given sector and period):

$$CI = \frac{C_T}{C_F}$$

Equation 4-2 - CI ratio

Irrespective of the units used, the CI provides a convenient means of capturing the relationship between fuel and time-based costs. From the standpoint of CI, only direct costs which relate either to speed or time are relevant. Time-related costs contain the sum of several components:

- ✈ Hourly maintenance cost (excluding cyclic cost)
- ✈ Flight and cabin crew cost per flight hour

  Even for crews with fixed salaries, flight time has an influence on crew cost. On a yearly basis, reduced flight times can indeed lead to:

  - Normal flight crews, instead of reinforced ones
  - Lower crew rest times below a certain flight time (better crew availability on some sectors)
  - Better and more efficient use of crews

- ✈ Marginal depreciation or leasing costs (i.e. the cost of ownership or aircraft rental) for extra flying per hour, not necessarily a fixed calendar time cost, but possibly a variable fraction thereof.

In practice, these costs are commonly called marginal costs, for they are incurred by an extra minute or an extra hour of flight.

In addition to the above time-related costs, extra cost may arise from overtime, passenger dissatisfaction, hubbing or missed connections. These costs are airline-specific. If an airline can establish good cost estimates, it is possible to draw a cost vs. arrival time function and hence to derive a cost index. According to each company's management strategies, the cost of purchased carbon emission allowance can be included on the estimation of the cost index as a time-related cost, upon the introduction of the EU ETS (**2.3.1**).

With time-related costs, the faster the aircraft is flown, the more money is saved. This is because the faster the aircraft is flown, the more miles time-related components can be used and the more miles can be flown and produced between inspections when just considering maintenance cost. However, if the aircraft is flown faster to reduce time-related costs, fuel burn increases and money will be lost in turn. On the other hand, to avoid over-consumption of fuel, the aircraft should be flown more slowly. To solve this dilemma, the FMS uses both ingredients in the CI, and is therefore able to counterbalance these cost factors and to help select the best speed to fly for a given altitude, in order to reduce trip cost.

Two extreme values of CI can be identified, CI=0 and CI=MAX (value depends on hardware and software). CI=0 corresponds to a minimum fuel consumption mode allowing for maximum range. CI=MAX gives minimum flight time disregarding fuel economy. The cost index effectively provides a flexible tool to control fuel burn and trip time between these two extremes. Knowledge of the airline cost structure and operating priorities is essential when aiming to optimize cost by trading increased trip fuel for reduced trip time or vice-versa. The mere fact that fuel costs can significantly vary from one sector to another and throughout the year should prompt airlines to consider adopting different cost indices for their various routes, seasonally readjusted to account for recurring fluctuations.

Industry sources suggest that airlines are currently failing to exploit the full economic potential of FMSs, since there's no actual effort in obtaining accurate CI values. Much progress could be obtained by having airlines' financial departments assessing accurate time-related costs thoroughly across their entire operation net. Probably this doesn't happen because not everybody is fully aware of the importance of the Cost Index itself. Besides, realistic cost index calculations are not that easy to perform and require a transverse effort throughout the entire company.

When an airline decides to adopt genuine cost index flight management, there are two possibilities to choose from:

- Specific airline analyses can be performed, route and aircraft specific, tailored to the network and its operating and economic environment which the airline may know better than anyone else.
- Aggregate approximations can be performed, bundling routes in low/medium/high fuel- and time-related cost brackets, which the airline may decide to adopt as the most pragmatic approach.

Airlines should at least determine their average cost indices, possibly categorizing these in one way or another and periodically review these in order to alleviate trip cost penalties that could be incurred with inappropriate values. Periodic reviews should consider both fuel- and time-related costs.

Cost Index and Flight Performance

The flight profile of any given flight is composed of three flight phases: climb, cruise and descent. The objective is to minimize the cost of the whole flight and minimizing the cost of each phase separately does not work. Cruise cost would be minimized if the cruise segment was made as short as possible; however, the climb and descent segments would become very long and shallow, increasing overall costs. The climb cost would be minimized by minimizing cruise altitude and maximizing vertical speed, so that the cruise altitude would be reached as soon as possible, increasing in turn cruise costs. Though being preposterous the least-costly descent policy is to shut the engines off directly above the destination airport and then dive straight down (minimizing both fuel and time), but the cruise cost is then increased and passenger comfort seriously compromised to say the least. In conclusion, the least-costly flight may only be achieved considering the three phases altogether. The profile details are calculated with the use of an iterative process, in which the processing capacity of the FMS's computer is of the essence.

The influence of the CI on the climb profiles can be illustrated on the following figure (**Figure 4-3**):

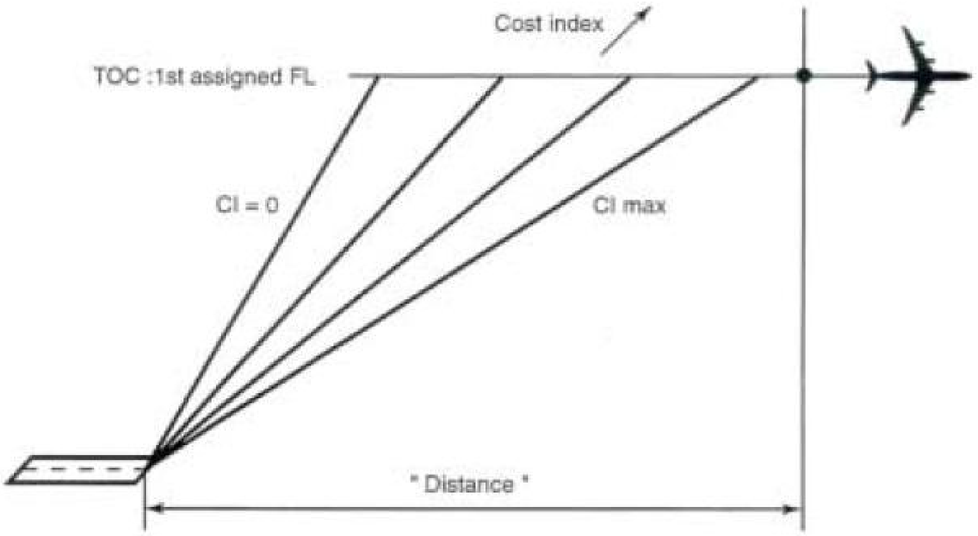

Figure 4-3 - Climb Profile vs. CI
(source: Airbus)

From which it is possible to infer that as CI increases:

- the shallower the climb path (the higher the speed)
- the longer the climb distance
- the farther the Top of Climb

In cruise, it can be generally said that, at a given CI:

- the higher the FL, the higher the optimum Mach
- the higher the aircraft gross weight, the higher the optimum Mach

Cruising at a given CI rather than at a given Mach number[1] provides the added advantage of always benefiting from the optimum Mach number as a function of aircraft gross weight, FL and head/tailwind component, which is to say, reducing fuel consumption without building-up considerable flight time.

Now looking for descent performance, **Figure 4-4** helps to illustrate its relation with CI:

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[1] In what the PGA fleet is concerned, only the Fokker 100 is equipped with an FMS that contemplates CI; the ERJ 145 operation is limited to a constant cruise Mach number strategy.

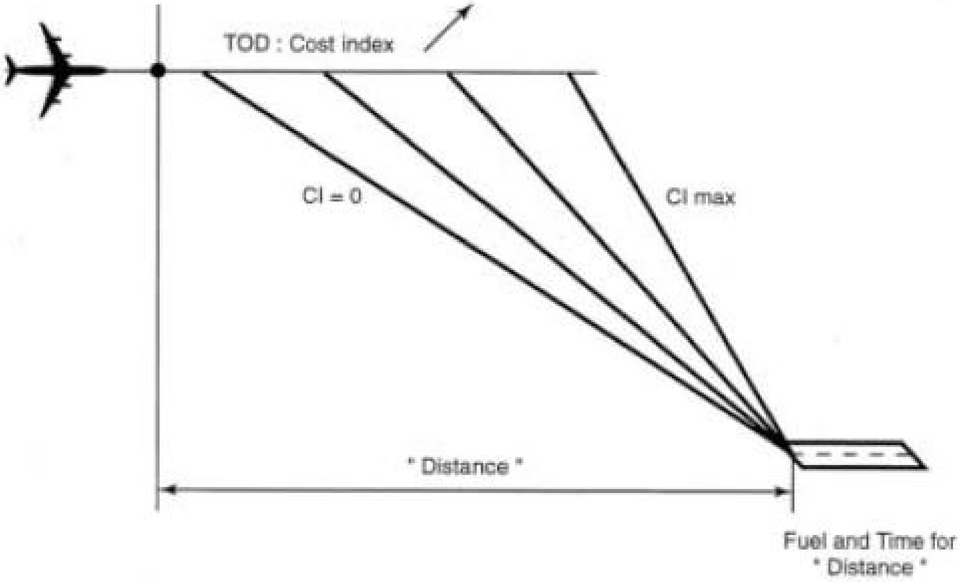

Figure 4-4 - Descent Profile vs. CI
(source: Airbus)

From mere observation, the higher the CI:

- the steeper the descent path (the higher the speed)
- the shorter the descent distance
- the later the Top of Descent

In sum, CI is a simple and effective tool when it is appropriately used by an airline. This means airlines should have a thorough knowledge of costs in order to optimize operating economics. This is the single and only purpose of the CI; its wrong utilization and/or wrong calculation leads inevitably to cost penalties. These penalties pertain to overall costs and not just to fuel costs; apparent excessive fuel consumption caused by the CI may sometimes be attributed to the need to save expensive flying time. It is important to bear in mind that the CI trades off both fuel and time provided they are properly assessed.

4.2.3 *Aircraft Performance Monitoring*

As well stressed on the above pages, aircraft's fuel consumption is a significant factor in aircraft operation, and low consumption has always been an important design objective for transport aircraft because of its impact on fuel costs and on payload capability on longer flights. Meaningful management of fuel saving programmes requires careful monitoring of the aircraft fuel consumption and of the effects of the measures taken.

Summarizing the main factors that have an effect on fuel consumption:

- Air Distance
- TOW
- FL
- Speed
- Drag
- Engine SFC

These and others are thoroughly monitored both by manufacturers and operators. During flight test phase, manufacturers pay much attention to accurate performance testing covering the whole flight envelope, in order to validate the mathematical model of the new design and to verify its estimated performance, to generate cruise control and flight planning data for the Operations Manual and for the performance database uploaded to the FMS. This enables to demonstrate compliance with fuel consumption and payload-range guarantees. Notwithstanding the precautions, the basic performance data produced by the manufacturers are sometimes not fully representative of the actual performance figures found in service, whether it is caused by airframe/engine degradation or by aircraft modifications.

Reasons for performance monitoring by operators include the following:

- Monitoring the fuel efficiency of the fleet
- Identifying high burners and ensuring that the company flight planning system and the FMS of the aircraft are using realistic data
- Verifying the effect of changes and modifications
- Diagnosing causes of performance deterioration
- Providing evidence in case of disagreement with manufacturers, on performance guarantees, on baselines used in manufacturers' cruise performance and flight planning data, and on performance deterioration of the fleet or of a specific aircraft, as well as on deterioration of engines.

Routine cruise performance monitoring by operators is performed in various ways and with different degrees of sophistication. This applies to the recording as well as to the processing of observations. Most manual recording is done by flight crew members using the basic flight log or a special cruise observation sheet. However the preferred way of recording flight data is to use a FDR. The primary goals which led to installing FDRs aboard most commercial aircraft were accident investigations and engine monitoring, since this equipment can record virtually every flight data parameter at a very high observation rate.

In fact, besides enabling to identify numerous parameters relating to the aircraft, the FDR is also capable of recording engine parameters allowing a much broader performance study. In most cases however, at least the ones related with the most modern engines equipped with a FADEC system, it is possible to perform a much quicker gathering of data and its analysis than with the "old", raw, unformatted data provided by the FDR. It is the case of the Embraer's engines, the RR AE3007A, versus, the Fokker's engines, the RR Tay 650-15.

One of the most practical examples of how an engine's proficient trend monitoring system can be of great help is to assess the possible benefits of a scheduled engine washing program. Maintaining a continuously updated database with engine performance data can assist in defining and fine-tuning the best time gaps, or flight cycles, between engine washes and even to assure that engines are kept under operating safety margins, despite a rigorous maintenance plan in place.

5 Operational Performance Study

This chapter is organized in three sections: **5.1 Routes**, **5.2 Fleets** and **5.3 Flying Techniques**, representing the main cornerstones of flight operations. Each section consists of its particular performance studies, using several metrics to analyze the available data, and to assess the performance status of the different areas of operation.

The entire set of studies carried out in this work is based on all the data gathered by the GSV, relative to the operational year of 2008. This data consists of operational values and other types of information regarding all flights operated by both fleets. All data was handled with the help of Microsoft® Excel 2003 software which allows the extended use of *pivot tables*[1], and it was organized as described in **APPENDIX C**. In order to validate the final results, some filters had to be set on the raw data. Entries relative to local flights (Arrival Airport being the same as the Departure Airport), without TOW, passenger figures or fuel values, single flights (only one sample) and flights with no information regarding the Captain were discarded, reducing the total number of entries to 27306 from the original 27664.

The series of metrics of different nature contemplated in this operational performance study aim to achieve a thorough understanding of the company's operation and its operational efficiency. It is also intended to show how a well-fitted data monitoring system which contemplates these different metrics, can be a powerful tool to identify certain performance trends and highlight casuistic efficiency flaws, that in other case would pass unnoticed.

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[1] Pivot table – Microsoft Office Excel tool that enables a parametric and changeable arrangement of large amounts of data.

5.1 Routes

All airlines around the globe count, in one way or another, with a flight planning system accountable for navigation, load information, performance data, etc. One can have more tools than the other, or it may allow a more flexible use of the company's resources than the other. Obviously it is up to each airline to choose the flight planning system that best suits its technical and commercial interests. However, the decision to fly a certain citypair is usually more of a commercial viability matter than a technical one. So, even though a company may have a state-of-the-art flight planning system, no miracle can turn an extremely short flight into a technically viable one (the shorter the flight, the less efficient it is). However, that flight might just be the very same flight with the biggest financial return.

This work does not focus on the financial analysis of the flight operations, though it reckons its major importance in the decision-making spheres. Instead, this work focuses more on a technical perspective of the flight operations.

The different metrics used in this section analyze the operational performance of the most flown citypairs[1] of each fleet, due to the huge number of citypairs flown by PGA by both fleets. This way there is a representation of the most relevant citypair activity and it is possible to evaluate where a small change in operational procedures, can have greater impact on the operational performance. Through the rest of the work, this will be somewhat of a constant feature; the two fleets are analyzed in parallel, if there's a graph studying a certain metric on one fleet, a correspondent graph for the other fleet is always present.

5.1.1 Ground Efficiency

All aircraft consume fuel on the ground at the airport while taxing, maneuvering to and from the gates, idling due to delays and by APU usage. All these situations represent unproductive fuel consumption, thus an inefficient use of fuel. To best quantify this inefficiency, a metric must be defined and one useful ground efficiency metric is the relation between block hours and actual time aloft (flight hours). Though some authors prefer to consider this metric as a ratio between flight hours and block hours, in this work however, this metric is considered to be the difference between these two values, in order to properly quantify ground operation time (GOT = BH – FH).

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[1] From this point forward citypairs will be referred to by their IATA codes, described on **APPENDIX D**.

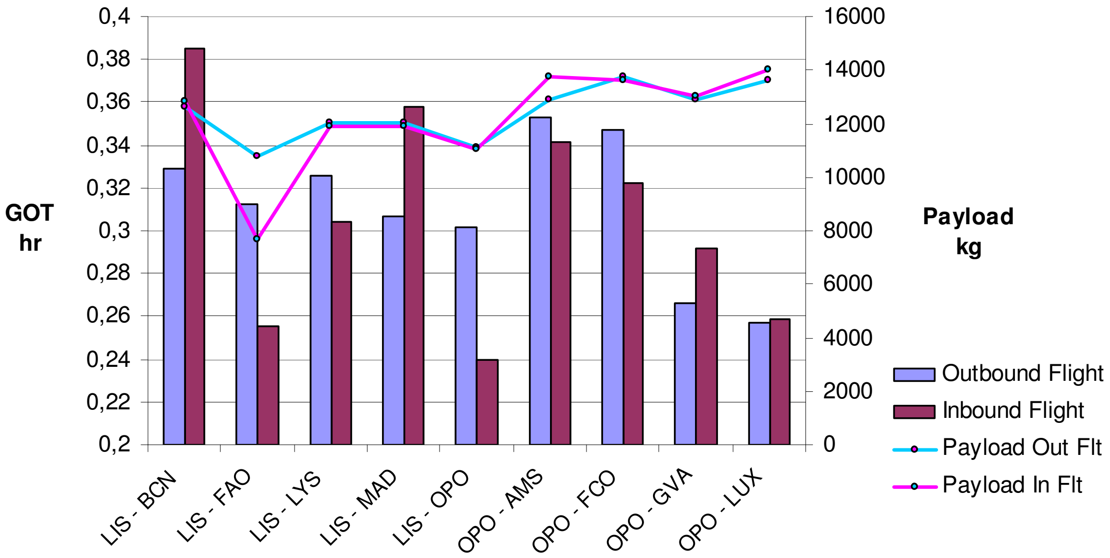

Figure 5-1 - Ground Operation Time (GOT = BH-FH) by Citypair – Fokker 100

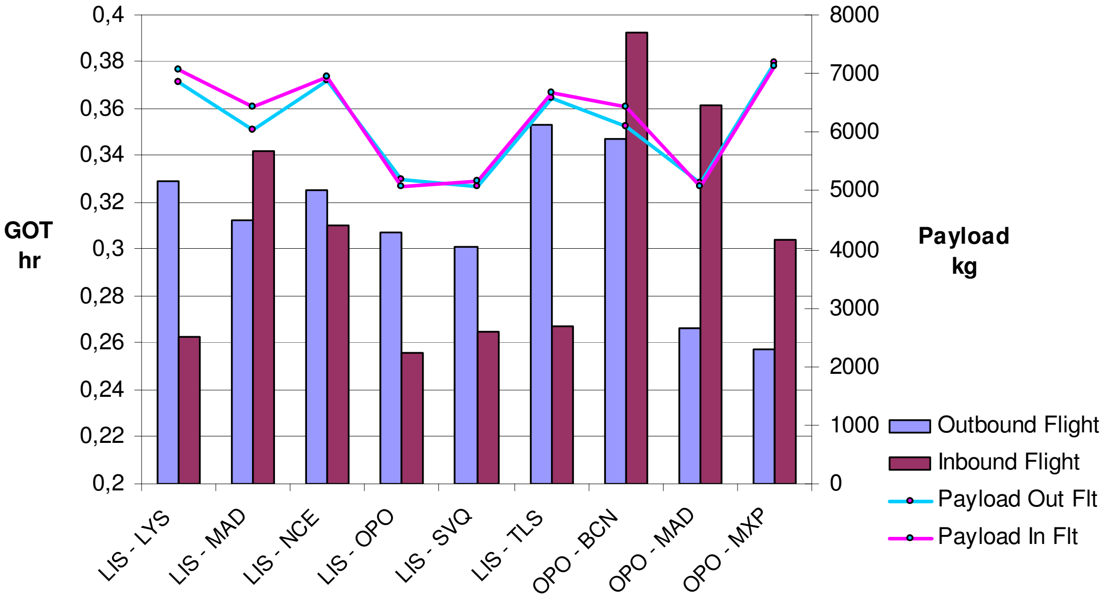

Figure 5-2 - Ground Operation Time (GOT = BH-FH) by Citypair - Embraer 145

Observing both **Figure 5-1** and **Figure 5-2** one can easily notice that all flights departing from LIS have systematically the same sort of value of ground efficiency, about 0.31hr on both fleets (the values are coherent even on both fleets). It is possible to infer from this fact that the ground operation at LIS is already well optimized and (/or at least) coherently executed both by flight dispatchers, ground handlers and by flight crews. These coherent values for LIS help us realise that the main contribution for ground (in)efficiency is the departure airport, since several airports that compose different citypairs with LIS, originate significantly different ground efficiency values. For instance, let’s consider the far most extremes: with the Fokker, BCN-LIS has a GE value of 0.385hr and OPO-LIS just 0.24hr; with the Embraer, MAD-LIS has a BH-FH of 0.342hr and again OPO-LIS only has 0.256hr; in all four situations the flight leg departing from LIS maintains a ground efficiency value of about 0.31hr.

Another conspicuous trend which cannot be left unnoticed is that the bigger and more congested the departure airport is, the higher the ground efficiency value is, i.e., the more inefficient it is. This obviously comes as no surprise, the bigger the airport, the greater the ground distance the aircraft has to travel, and the more congested the airport is, the longer the waits for clearances and more frequent the delays. The most notoriously GE aggravating airports are BCN (Barcelona – Spain), MAD (Barajas/Madrid - Spain) and AMS (Schiphol/Amsterdam – The Netherlands). The airport configuration and its traffic intensity are the dominant factors influencing ground efficiency.

Flights departing OPO do not show a distinct trend in ground efficiency values, neither is there a distinct difference between fleets, which was also something to be expected as this metric is of a single operational nature and not of a technological one.

In order to assess whether the weight of the aircraft affects the ground efficiency or not, the average payload is overlapped in both graphs (**Figure 5-1** and **Figure 5-2**). The payload was chosen instead of the TOW, in order to deliberately neglect the weight of the FOB; only this way it is fair to compare two citypairs with completely distinct direct ground distance, with very similar average payload values, i.e., the comparison is made based on the actual productive load.

It is easy to notice that the GE tends to follow the same trend as the Payload values and so this is in fact somehow affecting ground efficiency. Some exceptions occur though, and they are due to specific airport operational characteristics as explained before for the cases of BCN, MAD and AMS. Other exceptions are due to the exact opposite of the ones just mentioned, as they represent the smaller airports considered in the study, in **Figure 5-1** the route LUX-OPO shows a lower GE value in spite of having a higher average payload. The same happens in **Figure 5-2** with the routes LYS-LIS and TLS-LIS.

Another factor which can affect the ground efficiency is the geographal characteristics of the airports. The airports' altitude (AMSL) affects the air density and their locations affect them differently in terms of meteorology, meaning the operation at different ambient temperatures (OAT), these differences in operating conditions may influence ground efficiency values, including along the year with the seasons' succession.

Embedded in a data monitoring system this metric may provide useful data in order to more accurately estimate the needed taxi fuel in each airport PGA operates, based on the statistics of each airport associated with their specific climate behaviour throughout a year time.

5.1.2 Fuel On Board

This metric is useful to study how different factors make an impact on the necessary fuel to accomplish a certain flight.

The loading of fuel before departure is done by following the company's policy on this matter, as stated on "PGA Operations Manual", which also states that the captain may alter the amount of fuel as he seems fit (within certain limitations and subjected to scrutiny afterwards), to increase the amount of fuel in order to increase the safety margin of the flight.

It only seems logical that the company's fuel policy takes into account the length of the flight and the chosen alternate airport. Hence this metric is of an operational nature since it is of the flight operations' responsibility to establish proper flight plans, which already include the choice of the alternate airports.

As opposite to Figure 5-1 and Figure 5-2 the bars in the following graphs (**Figure 5-3** and **Figure 5-4**) do not represent the outbound and inbound flights, but instead the FOB Off Block and On Block. The FOB, both Off Block and On Block, are not shown for both legs separately, but actually the values shown are the total sums of both legs, outbound and inbound. This is explained by the fact that the FOB values relative to the outbound leg are not bound to be compared with the ones of the inbound leg, since from an operational point of view the two legs differ significantly from each other. In addition, each TMA/FIR has different ATC restraints which by limiting the admissible flight plans or by imposing in-flight flight plan changes can create huge discrepancies between air distance and direct ground distance, thus increasing the difference between the FOB Off Block on both legs. Also the broad varieties of European airports, which form several PGA's citypairs, in comparison with the Portuguese airports, have different impacts on fuel consumption (**5.1.1 Ground Efficiency**). Nevertheless the latter is a factor of much less relevance than the dominant winds.

The FOB values are overlapped by the line PL/TOW and by yellow distance markers, which show for each citypair the direct ground distance per leg in NM. The PL/TOW (or the payload vs. takeoff weight ratio) is a metric itself, and in a practical explanation, might be described as the productive fraction of the TOW, i.e., the actual product sold by the company in terms of a fraction of the TOW. This metric is useful to compare the influence of the payload on the FOB Off Block, between the two fleets, since it is dimensionless with the TOW, as well as between different citypairs, for which each one has a typical PL/TOW value. The PL/TOW values shown are the average between the outbound and inbound legs.

The distance markers are meant to show the obvious relation between the ground distance covered and the fuel loaded on the aircraft.

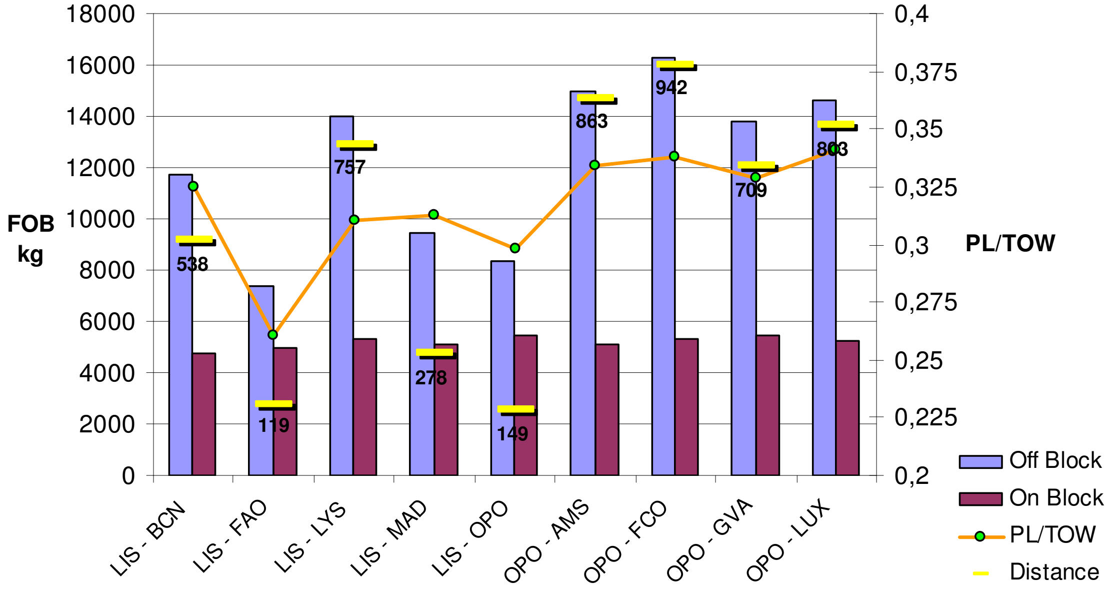

Figure 5-3 - FOB and PL/TOW by citypair - Fokker 100

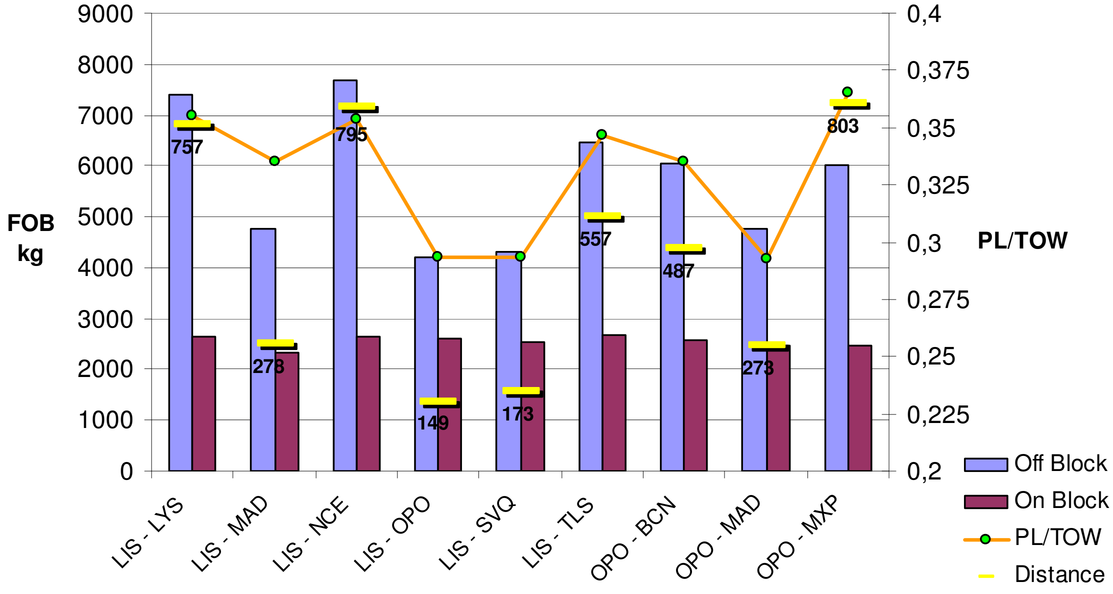

Figure 5-4 - FOB and PL/TOW by citypair - Embraer 145

On both graphs shown above, it is quite notorious how the FOB Off Block follows the exact same evolution as the distance yellow markers. This comes as no surprise, as distance is the key factor on all fuel policies, for the longer the flight, the higher the flight time and the higher the trip fuel needed. The PL/TOW values also follow the trend of the other two (FOB Off Block and Direct Ground Distance), fact explained by its very definition:

$$PL/TOW = \frac{PL}{TOW} = \frac{PL}{ZFW + FOB},$$

Equation 5-1 - PL/TOW

while FOB in its turn and as we have seen before, depends on the distance.

Studying these dependencies we know that if the Payload increases, more fuel is needed to lift the extra weight, so this is a double increase in the TOW; the actual added weight on Payload, which adds to the ZFW and the new FOB needed, both build-up the TOW, reducing PL/TOW. If the distance increases however, more fuel is again needed and so the FOB value is increased, decreasing the PL/TOW ratio, generally in a much more emphasized manner than the one that the increase of Payload produces, also because in this case there’s no increase in the numerator (Payload) to attenuate the decrease of this ratio. This is also explained by the different range of values of FOB and Payload. For the Fokker the FOB ranges from 7368Kg to 16309Kg while the Payload ranges from 22189Kg to 27637Kg (sum of both legs). For the Embraer the FOB ranges from 4193Kg to 7396Kg and the Payload from 10218Kg to 14214Kg (also the sum of both legs). These values’ differences are not very different, however if considered in terms of percentage they are quite very different. This to say that the FOB Off Block is slightly more dependent on the distance to be flown than the payload, however both metrics are extremely relevant for an accurate trip fuel calculation.

On both fleets it’s easy to observe the very consistent FOB On Block values. This is a direct result of putting into practice a studied fuel policy contemplating accurate reserve fuel calculations. The key element on these calculations is the choice of the alternate airports, whose distance to the intended destination varies casuistically. This fact explains the small fluctuations on the FOB On Block values from a citypair to another.

5.1.3 TFC and DFC – Flight Efficiency Metrics

The TFC or Time-Based Fuel Consumption is a metric intended to quantify the global fight efficiency, created by convenience to allow a direct comparison between two flights, whatever the flight time and the takeoff weight. It takes into account the total burned fuel in the whole flight and the total flight time (FH), and their ratio is corrected for the TOW.

$$TFC = \frac{\dfrac{Total\ Fuel\ (kg)}{FH\ (hr)}}{\dfrac{TOW\ (kg)}{MTOW\ (kg)}} = \frac{Total\ Fuel\ (kg)}{FH\ (hr)} \times \frac{MTOW\ (kg)}{TOW\ (kg)}$$

Equation 5-2 – TFC

For the Fokker, MTOW = 44450Kg, and for the Embraer 145, MTOW = 20990Kg; in accordance with **APPENDIX A – Fokker F28 Mk 100 Specifications** and **APPENDIX B – Embraer ERJ145 Specifications**, respectively. The dimensional analysis of this quantity renders ${}^{kg}\!/_{hr}$ as the final dimension.

By calculating the ratio with Total Fuel (from Off Blocks to On Blocks) and with FH (from takeoff to landing), this metric implicitly considers the ground efficiency for the given flight, since the taxi fuel is also considered when dividing by flight hours and not the block hours. The division by the dimensionless TOW allows the direct comparison between two flights of the same fleet no matter what the TOW values are.

Similarly to the TFC, the DFC or Distance-Based Fuel Consumption was also created to quantify the global fuel efficiency, but in its turn based on ground distance covered in each flight. DFC dimension is ${}^{kg}\!/_{NM}$.

$$DFC = \frac{\dfrac{Total\ Fuel\ (kg)}{Distance\ (NM)}}{\dfrac{TOW\ (kg)}{MTOW\ (kg)}} = \frac{Total\ Fuel\ (kg)}{Distance\ (NM)} \times \frac{MTOW\ (kg)}{TOW\ (kg)}$$

Equation 5-3 - DFC

However to compare the global flight efficiency, between the two, the TFC is considered to be the most suitable metric for the job since two different citypairs have totally different operational characteristics. More objectively, each airport has different typical ground operation times and approach procedures, i.e., a plane can cover a small ground distance while flying a considerable amount of time due to ATC requirements. Also variable winds can change runway in use, calling the need for en-route flight plan changes for the new approach procedures. In addition, since the DFC calculated is based on the direct ground distance, it lacks a great deal of accuracy; even if the simple ground distance was being considered, a very important factor would be neglected which is the winds aloft, but in fact with the direct ground distance not even the length of the actual flight plan is considered, rendering the DFC an inaccurate metric. This explains why the TFC was the chosen metric to evaluate the global flight efficiency.

Again, the most flown citypairs of each fleet were considered, and PL/TOW data is overlapped in the graphs to ease the analysis regarding its influence in flight efficiency. The direct ground distance covered in each citypair is also shown in yellow markers over the TFC bars.

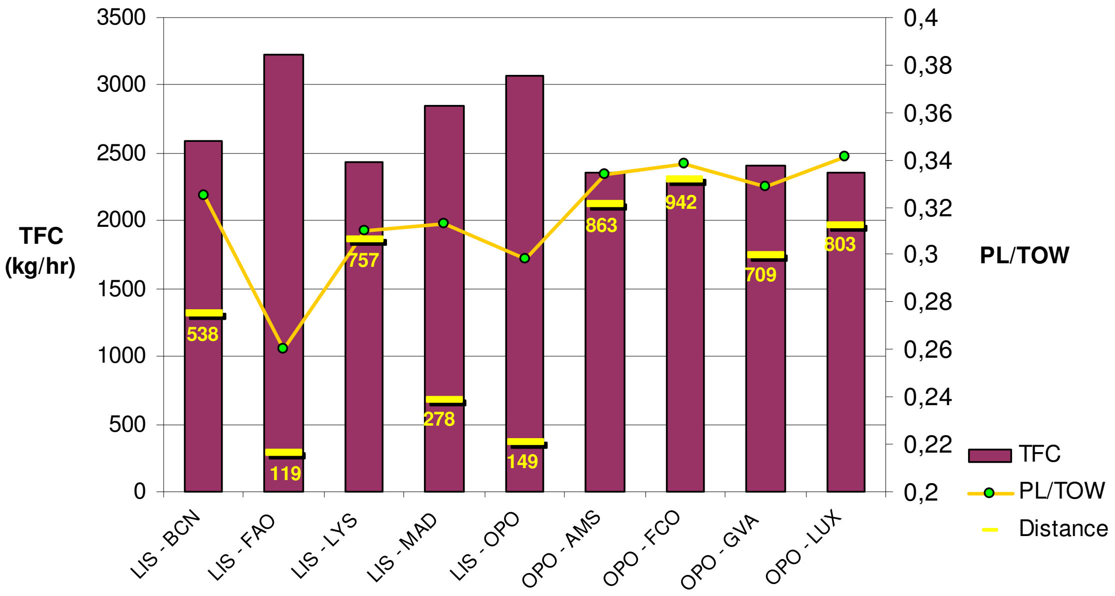

Figure 5-5 - TFC by Citypair – Fokker 100

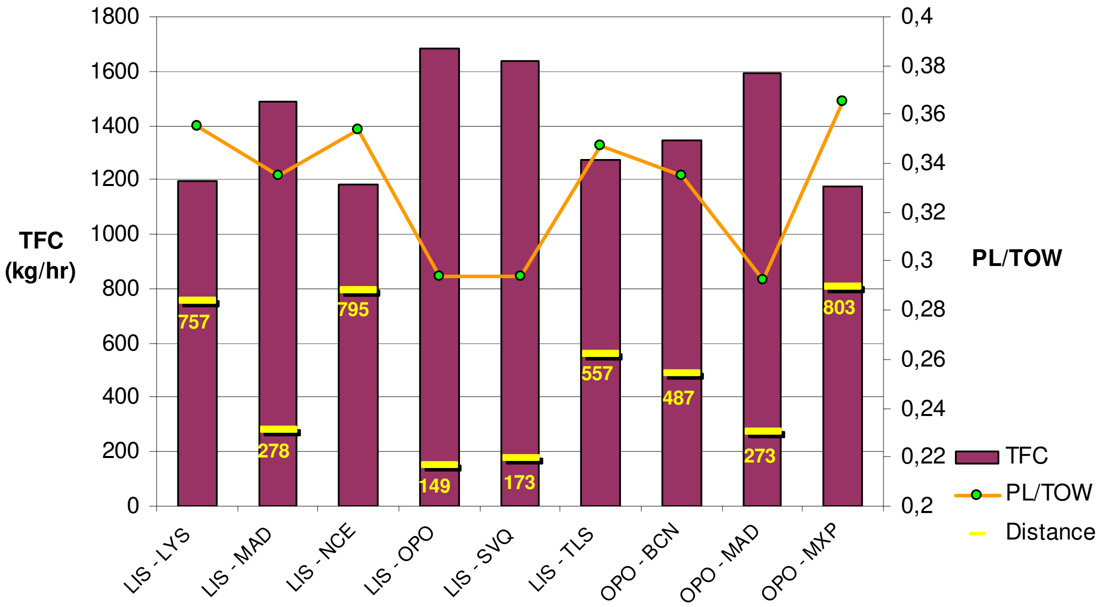

Figure 5-6 - TFC by Citypair - Embraer 145

If analysed altogether, the metrics shown on **Figure 5-5** and **Figure 5-6**, show a very coherent behaviour between the two fleets. The PL/TOW values have a matching evolution with the yellow distance markers, which in turn have the exact opposite trend of the TFC values. The shorter the flight the higher the TFC, in other words, the more inefficient the flight is. Citypairs LIS-FAO, LIS-OPO and LIS-SVQ are the most notorious examples of inefficient flights. The opposite is also true, longer flights are more efficient, like OPO-AMS, OPO-LUX and OPO-MXP.

However, two exceptions occur, in respect to the relation between PL/TOW and the direct ground distance, citypairs LIS-BCN and LIS-MAD (Fokker 100) have notoriously higher PL/TOW values than it was to be expected, judging by the other citypairs which serve as reference. But in fact, these flights have higher average passenger occupancy than the others, justifying the higher payloads on these shorter flights (lower FOB Off Block, hence less TOW).

5.2 Fleets

No machine is exactly like another, and aircraft, especially with their technological complexity, are no exception. This fact is even more relevant when one considers machines that have been operating for several years, and that may have been conditioned to different operational environments. The study of the performance of each aircraft is done by grouping the aircraft according to their respective fleet. Only this way it is possible to conduct any fair comparison between aircraft, and to identify the differences between the two fleets. For each fleet, all aircraft are compared in terms of Fuel Consumption per Flight Hour (FC/FH) and Time-Based Fuel Consumption (TFC).

The author chose to first introduce all the data and metric values of each fleet in dedicated sub-sections where all the aircraft are compared amongst themselves and with the fleet's average values, leaving the indispensable results' comments to the dedicated sub-section **5.2.3**. This way it is easier for the reader to identify the differences and similarities between the performance stats of the aircraft and/or fleets.

5.2.1 Fokker 100

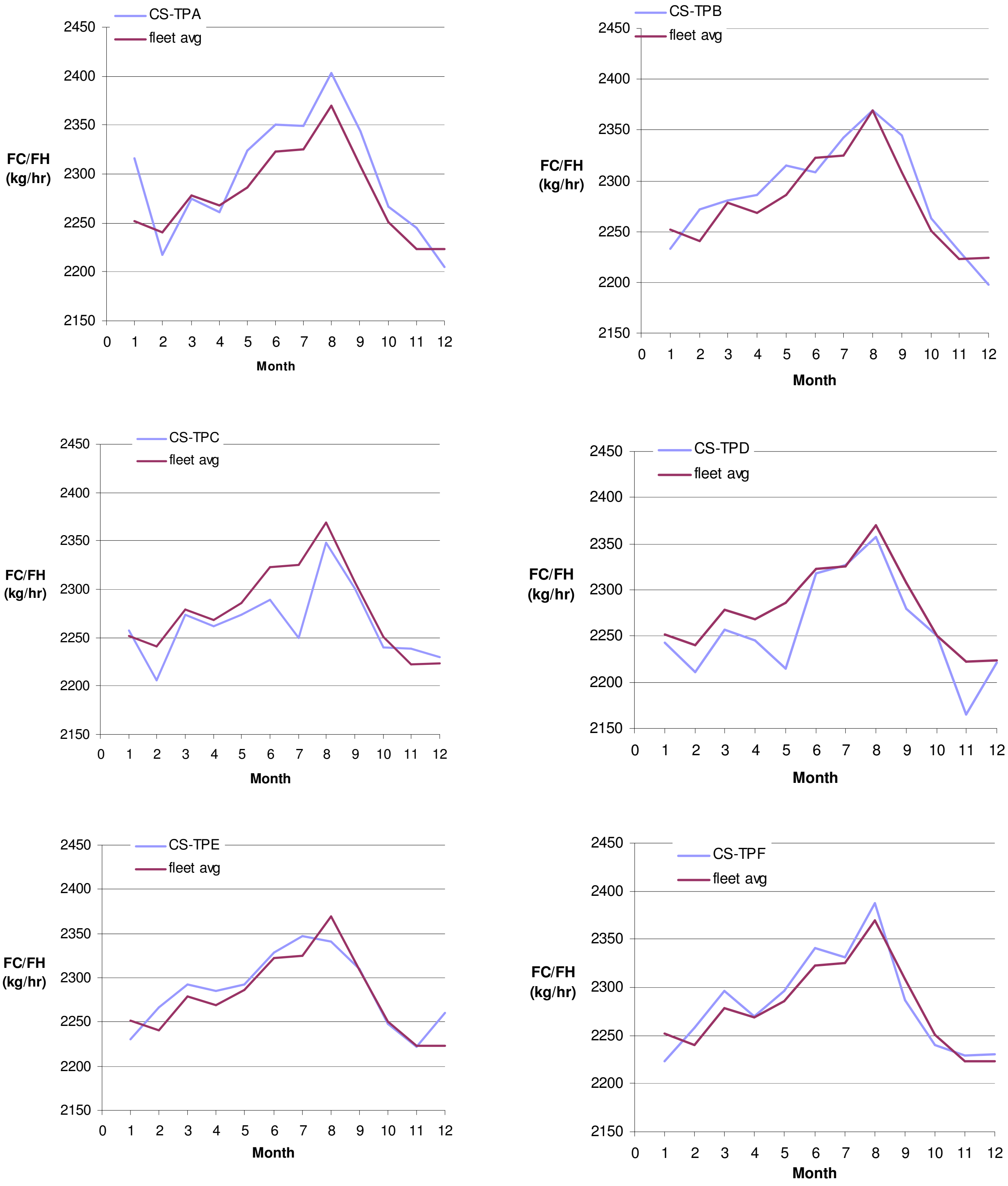

Figure 5-7 - Fokker 100 fleet's Monthly Fuel Consumption per Flight Hour

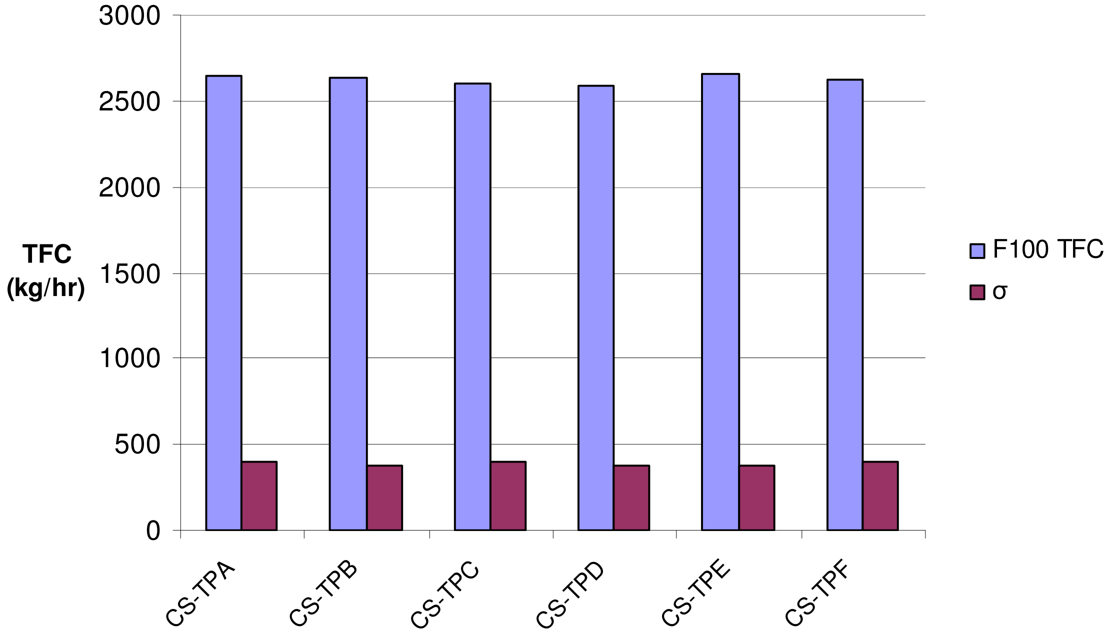

Figure 5-8 - TFC by Aircraft - Fokker 100

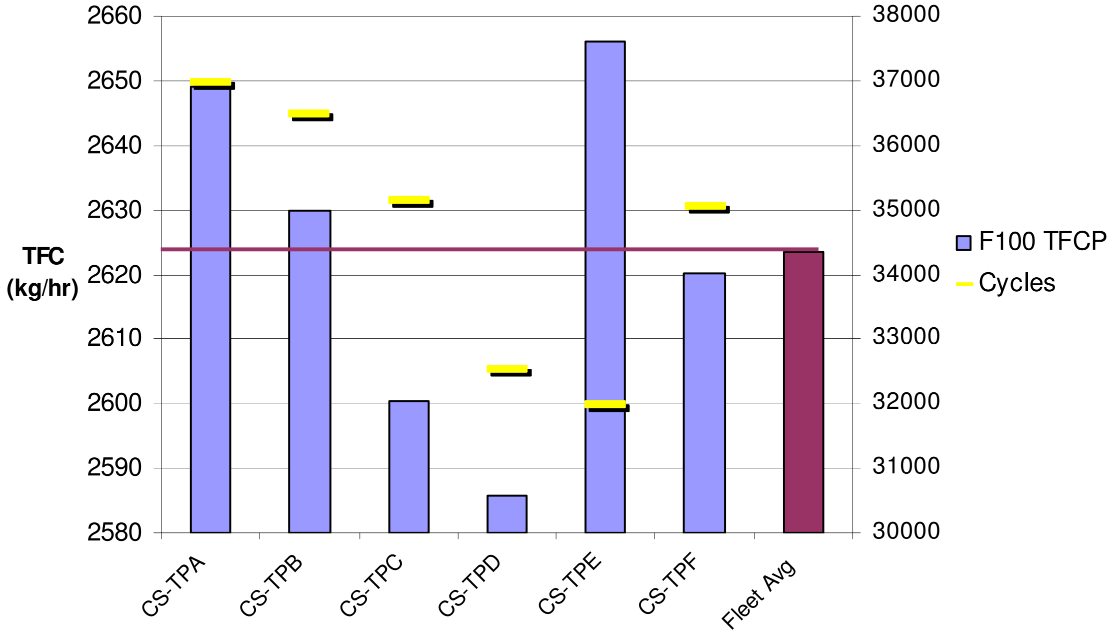

Figure 5-9 - Detailed TFC by Aircraft - Fokker 100

5.2.2 *Embraer 145*

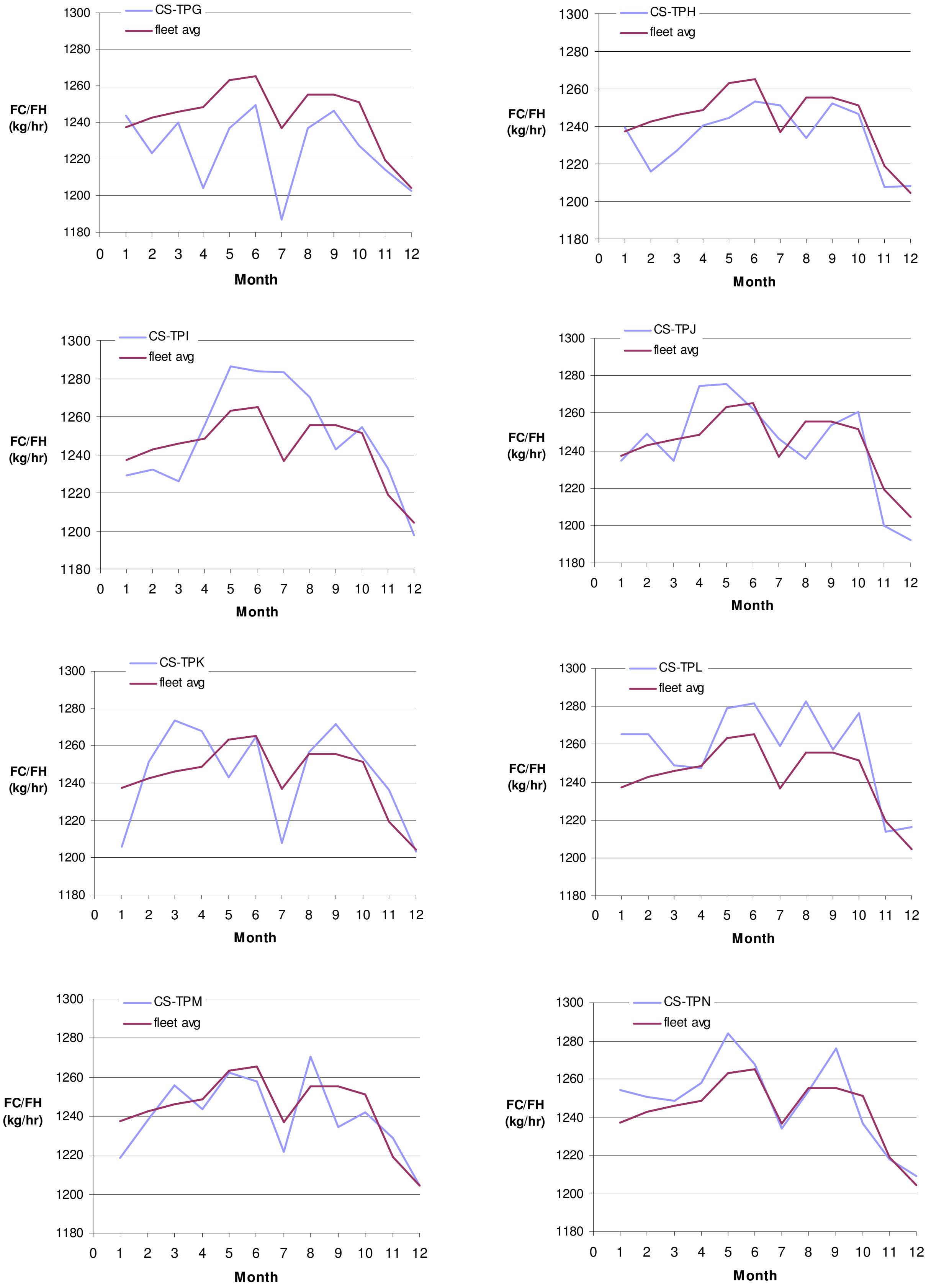

Figure 5-10 - Embraer 145 fleet's Monthly Fuel Consumption per Flight Hour

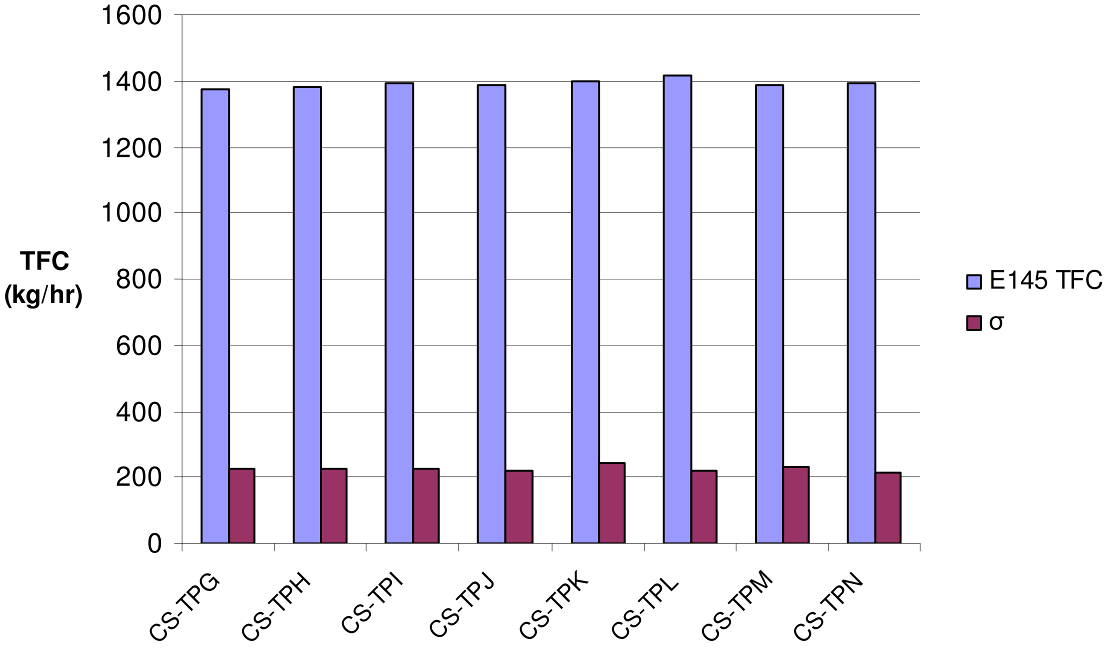

Figure 5-11 - TFC by Aircraft - Embraer 145

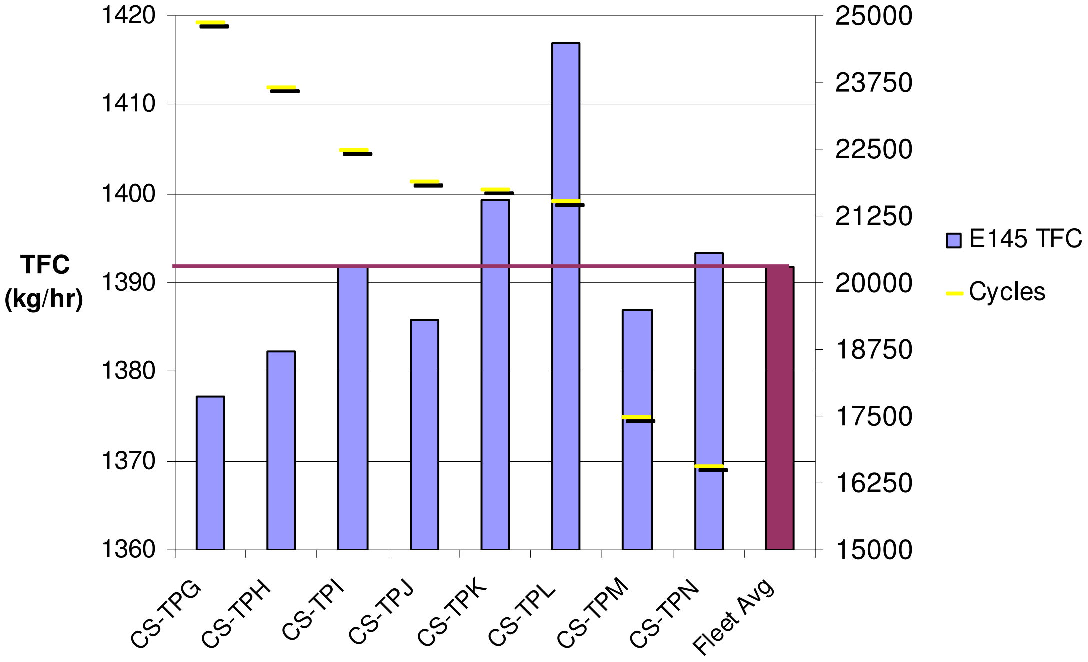

Figure 5-12 - Detailed TFC by Aircraft - Embraer 145

5.2.3 Comments and Analysis

Figure 5-7 and **Figure 5-10** show, respectively, the entire Fokker 100 and Embraer 145 fleets' Fuel Consumption per Flight Hour on a monthly basis. Each small graph represents a single aircraft, and contains the fleet's average FC/FH values throughout the year. The average FC/FH differences throughout 2008 are a result of different operational conditions and they affect the two fleets in different ways, as proven by the two FC/FH fleet averages each with its own trend.

For the Fokker 100 the summer months are clearly the most fuel-consuming ones being the more determining factors, the chosen FL as function of the winds aloft, the OAT and the TOW. The chosen FL during the summer is strongly influenced by the frequent occurrence of jet streams that can produce strong headwinds of about 120kt or more, forcing the choice of lower, hence less optimal, FLs. The notoriously higher temperatures during the summer season also increase the fuel consumption per flight hour. Also the flights during the summer carry more passengers, with an increase of the luggage weight per passenger, building up the TOW (by means of increasing payload), thus the FC/FH.

The Embraer monthly FC/FH fleet average has a more inconsistent evolution, mainly due to the very distinct performance values of the aircraft themselves. **Figure 5-10** reveals that each aircraft has its own FC/FH figures throughout the different seasons along the operational year. However, it is possible to observe the fleet's average and notice that the fuel consumption per flight hour is always, and similarly to the Fokker's figures, higher in the summer months, in spite of having a significant drop in July. On the search for a suitable motive for this distinctive behaviour, the very own nature of the flights along the year was studied by dividing the entire universe of PGA flights in clusters of distances with steps of 200NM and comparing their respective representation on a monthly basis (**Figure 5-13** and **Figure 5-14**).

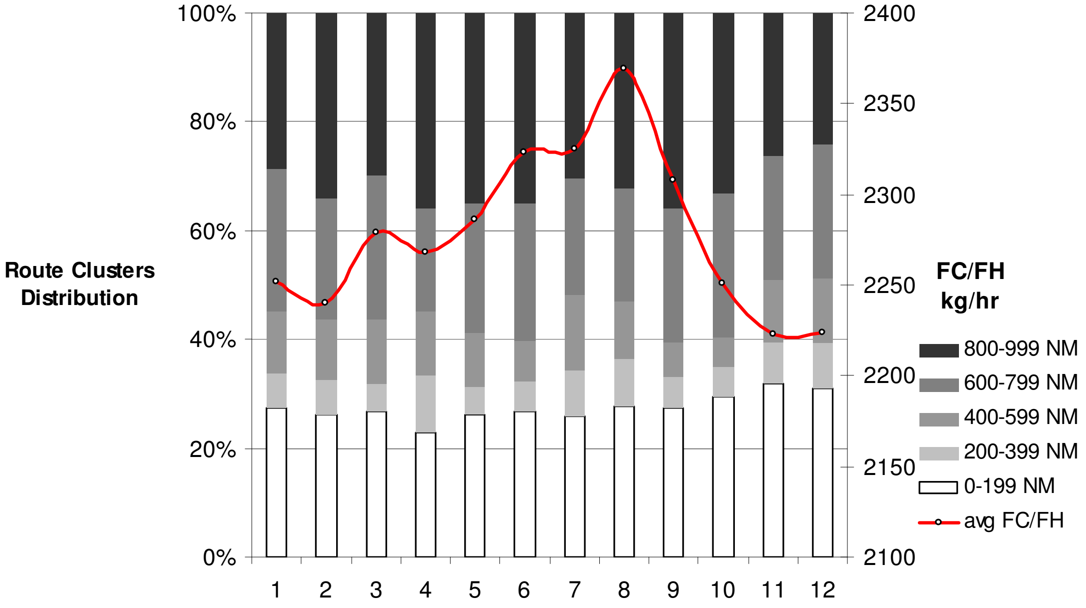

Figure 5-13 – Fokker 100's Route Clusters Distribution and FC/FH by month

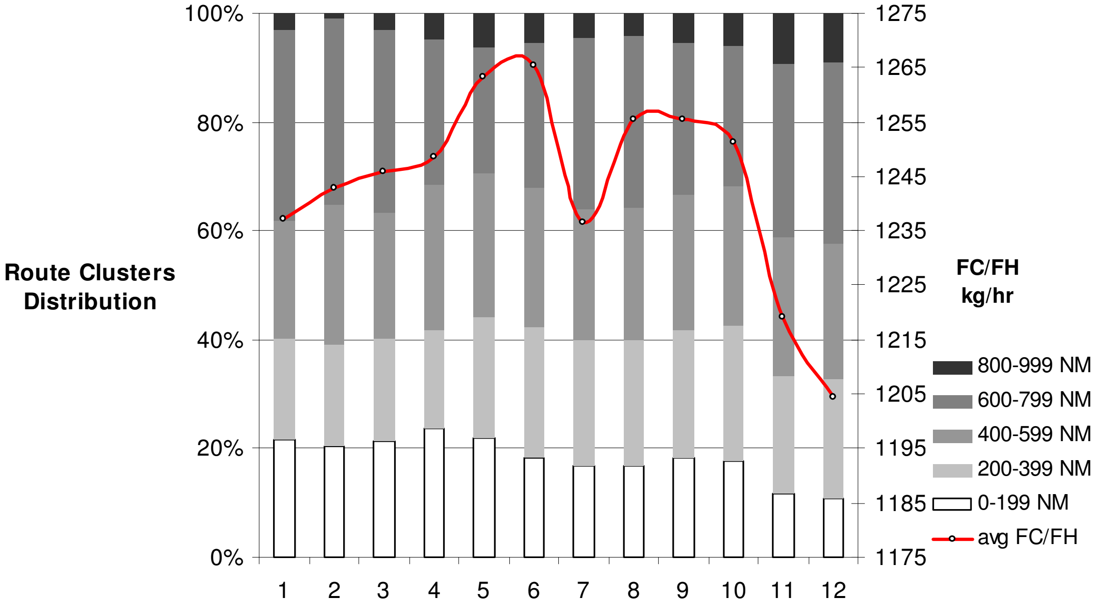

Figure 5-14 - Embraer 145's Route Clusters Distribution and FC/FH by month

These two graphs show a big difference between both fleets route distribution, the Fokker fleet has half of its flights in the 0-199NM and 800-999NM clusters (evenly distributed between the two), while the Embraer fleet has only 10 to 20% of its flights in the 0-199NM cluster and has an, almost, symbolical representation on the 800-999NM cluster (the longer flights). This fact indicates the different susceptibility to the nature of flights between the two fleets.

In order to assess whether the nature of flights is a determining factor on the hourly fuel consumption average figures, or not, the latter are overlapped in the graphs, however based on **Figure 5-13** and **Figure 5-14**) it's not perfectly clear if there's in fact a relation between the two metrics. To clarify this, an additional metric is created to properly relate the route clusters distribution with the hourly fuel consumption. The RDI, or Route Distribution Index, is the sum of the weighted percentages of the total flights in each cluster, by month.

$$RDI_{month} = 5 \times A_{month} + 4 \times B_{month} + 3 \times C_{month} + 2 \times D_{month} + E_{month}$$

Equation 5-4 – RDI, Route Distribution Index

being,

$$A = flights_{0-199NM}(\%)$$
$$B = flights_{200-399NM}(\%)$$
$$C = flights_{400-599NM}(\%)$$
$$D = flights_{600-799NM}(\%)$$
$$E = flights_{800-999NM}(\%)$$

The practical meaning of the RDI is a means of quantifying the global nature of the flights on a certain month, within a given fleet. The weighted percentages of flights on each distance cluster tends to represent how aggravating in hourly fuel consumption, the different distance clusters are. The shorter flights being more penalizing, A (cluster of flights in the 0-199NM distance interval) is multiplied by a factor of 5. This correction factor is successively decreased from one cluster to another by a unit, till the last cluster, multiplied by one, corresponding to the longer flights.

The values of this new metric are gathered and shown in the following graphs:

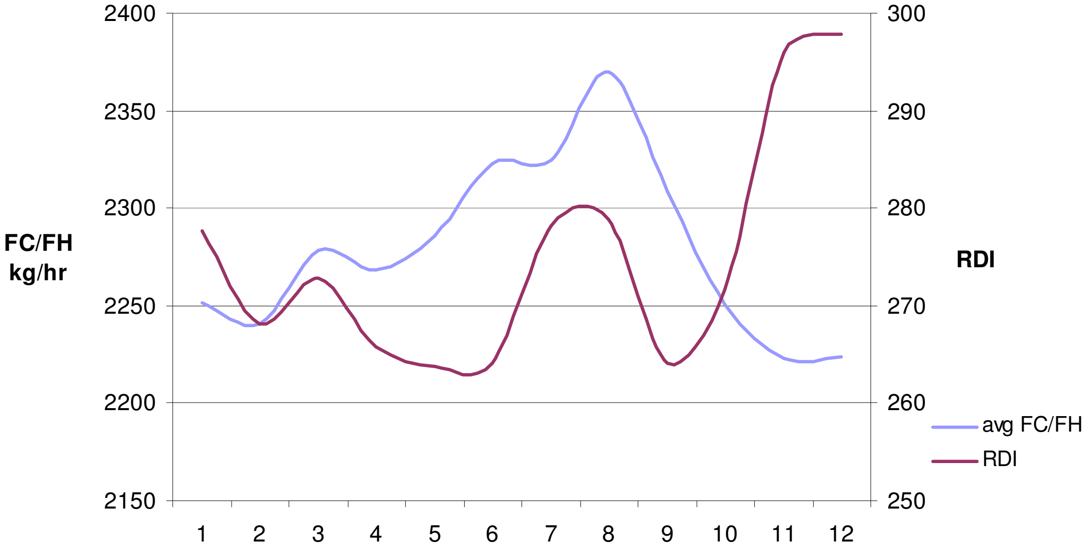

Figure 5-15 - Fokker 100's FC/FH and RDI on a monthly basis

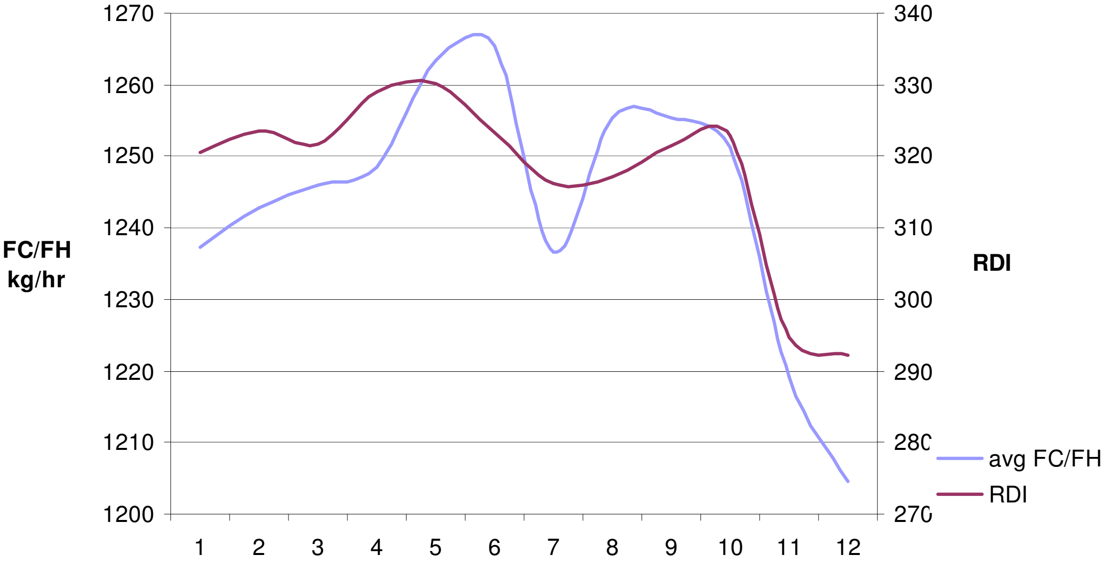

Figure 5-16 - Embraer 145's FC/FH and RDI on a monthly basis

In spite of not providing a true quantitative relation between the two metrics (FC/FH and RDI), the two graphs above, show qualitatively speaking, how well the RDI curves fit the FC/FH curves. So, making a qualitative analysis to these two metrics and their relation, it is possible to observe that Embraer's FC/FH and RDI curves are much more similar to each other than the Fokker's curves. This helps realising how one fleet is being more affected by the nature of the flights it is operating than the other. In this case, the Embraer fleet seems to be more affected than the Fokker fleet.

This helps understanding the sudden decrease in FC/FH in July. The route distribution index also decreases in July to quickly recover in the two following months, which is to say that the route distribution in July tends to favour more efficient (longer) flights rather than shorter flights.

The fleets' efficiency is analysed recurring one more time to the TFC. As explained in **5.1.3** the TFC is a flight efficiency metric.

Starting by the Fokker fleet (**5.2.1**), **Figure 5-8**, presents the TFC values of the six aircraft composing the Fokker fleet, as well as their respective standard deviation. All six aircraft show very similar standard deviation values. This coherency is a good validation for the values themselves. To properly evaluate the differences between the six aircraft **Figure 5-9** is a zoomed version of **Figure 5-8**, with the addition of a 7th bar indicating the fleet's average TFC value. Overlapping the graph are yellow markers representing the number of each aircraft's flight cycles, to assess the influence of this metric on the aircraft performance degradation. For the Embraer fleet of eight aircraft, the same methodology is followed, being the corresponding graphs, **Figure 5-11** and **Figure 5-12**.

These graphs show a consistent behaviour between the two metrics, FC/FH and TFC. The aircraft that consistently have an above average hourly fuel consumption throughout the year, also reveal an above average TFC. Fokker 100's fleet cases are CS-TPA, CS-TPB and CS-TPE and Embraer's fleet cases are CS-TPK, CS-TPL and CS-TPN. The inverse deduction is also true.

The yellow markers on **Figure 5-9** and **Figure 5-12**, intend to see if there's any relation between the aircraft's flight cycles and the performance degradation. At first, by looking at **Figure 5-9**, one can actually see that the yellow markers follow the TFC bars, with the exception of the CS-TPE, which could mean a possible situation of an aircraft expiring its airworthiness potential, requiring maintenance (whether it is time-related maintenance or not) in the nearby future. But considering **Figure 5-12** as well, this theory is shredded by the total opposite behaviour between the flight cycles and the TFC on the Embraers' figures.

This doesn't mean that there is no relation between the metrics; obviously there has to be some sort of degradation as an aircraft gets older (as it builds-up flight cycles). What it means is that the degradation suffered by an aircraft is not due to the airframe alone, but in fact it is related with the aging of all of the aircraft's elements; airframe, engines and systems. And so checking performance values against airframe flight cycles alone is worthless. An eventual future performance degradation study must include all the aircraft's elements data.

5.3 Flying Techniques

This section is dedicated to the study of the effects that one very important element of the aircraft has on its performance. It is an often forgotten element despite having a key role on an aircraft's operation, and that is the pilot. The pilot, more than a machine itself, is a human machine. And like all machines, has its own way of functioning, even though all pilots follow the same rules, respect the same policies and put into practice the results of similar training backgrounds and fly to achieve the same goals. A popular saying states: "practice makes perfect"; and this is undeniable when it comes to pilots, especially considering their human nature. So it makes sense that each pilot has its flying proficiency and techniques, resulting in different performance figures from one pilot to the next.

The goal is to make good use of a study like the one presented, to enhance the average performance of a fleet's pilot roster. This can be achieved by identifying the ones that prove to be more efficient, and making good notice of what particular techniques they have in order to, and once proven so, establish standard operating procedures applicable to all pilots based on those same performance-friendly techniques.

The following sub-sections show similar graphs to the ones presented in sections **5.2.1** and **5.2.2**. The metric used to evaluate the pilots' efficiency is once again the TFC though for this matter it is more useful to have a relative and qualitative demonstration of the pilots' performance figures to the average of the fleet's pilot roster, rather than an exact quantitative result of each pilot, as explained above. That is why the **Figure 5-17 b)** and **Figure 5-18 b)** are a zoomed version of **Figure 5-17 a)** and **Figure 5-18 a)**, respectively, with the addition of a reference line corresponding to the average fleet's roster, to better identify the different cases.

No reference to the pilots' names is made, whatsoever. Instead each pilot is randomly numbered, and only the pilots' numbers are shown in the graphs. It's important to realize that in this case, the main goal is not to identify spenders and savers, but to improve, optimize and enhance an entire fleet's operational results.

In **Figure 5-17 a)** and **Figure 5-18 a)**, the standard deviation values are shown, and they are considerably high and variable, enough at least, to question whether the differences in pilots' performance figures were mere random statistical results, or if in fact they have true statistical significance. That is why a statistical test is performed to assess how each pilot has a meaningful influence on the TFC values.

5.3.1 Fokker 100

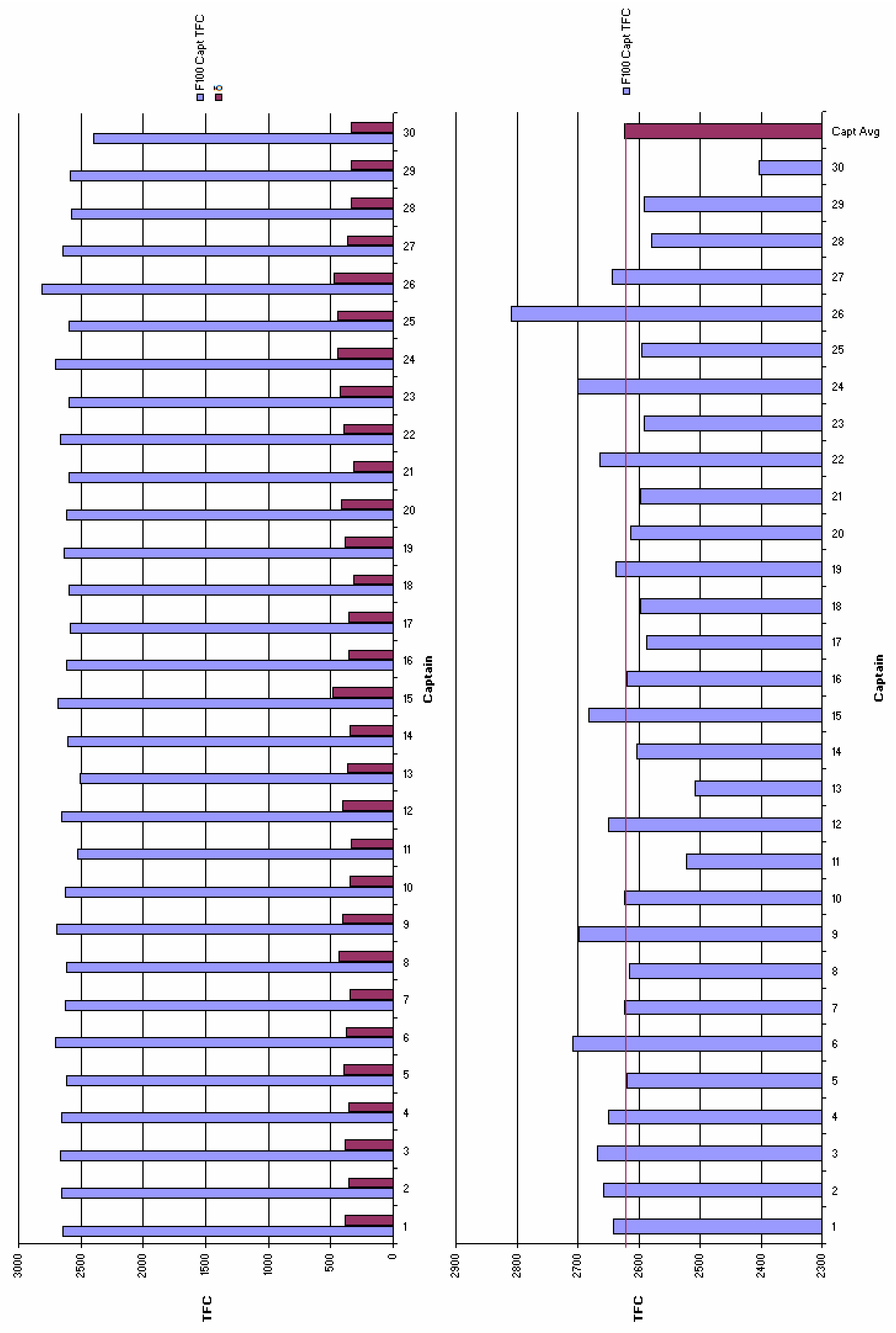

Figure 5-17 - a) TFC by Captain – Fokker 100

b) Detailed TFC by Captain – Fokker 100

5.3.2 Embraer 145

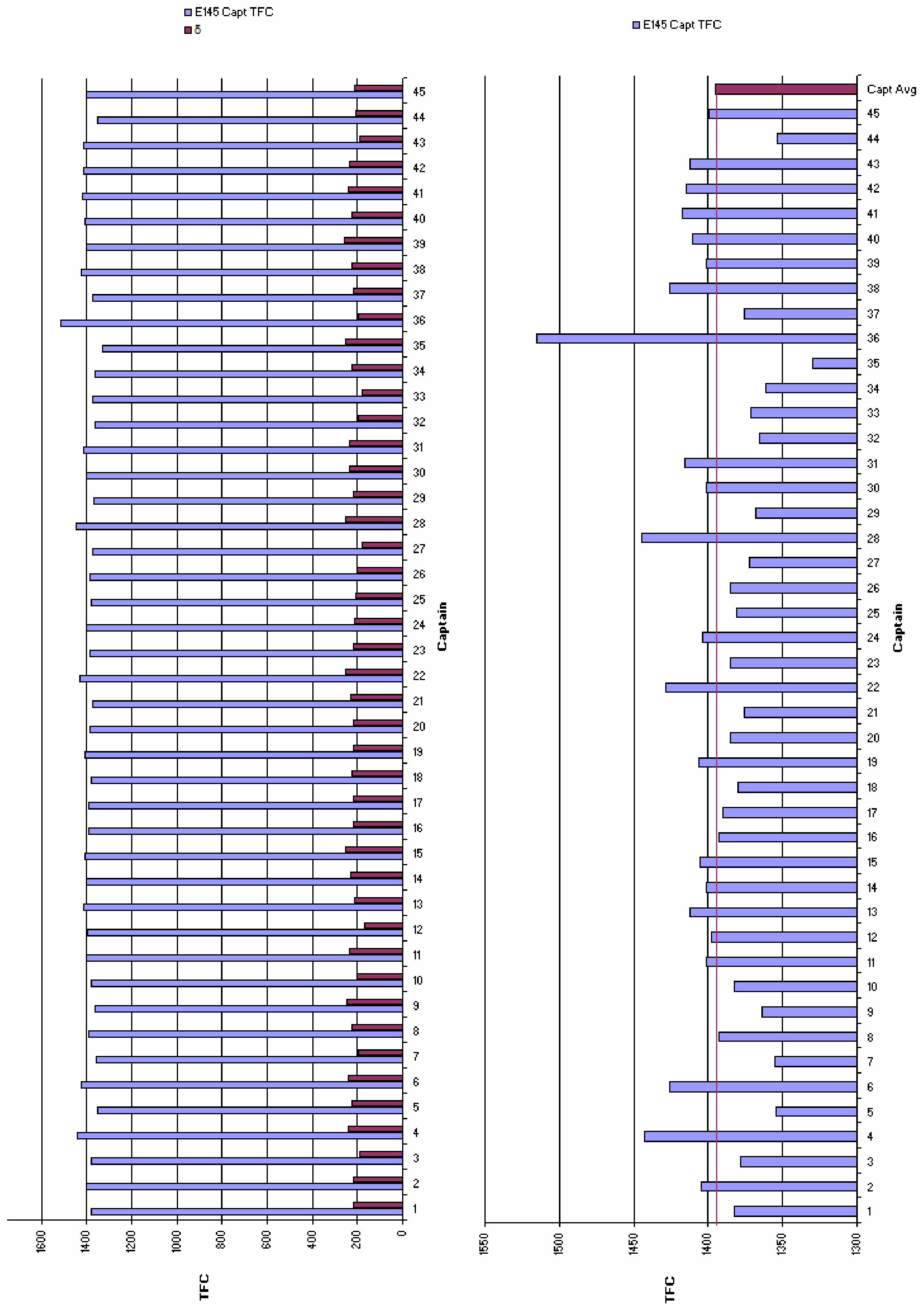

Figure 5-18 - a) TFC by Captain – Embraer 145

b) Detailed TFC by Captain – Fokker 100

5.3.3 *Statistical Analysis*

In **Figure 5-17 a)** and **Figure 5-18 a)**, the standard deviation values are shown, and they are considerably high, enough at least, to question whether the differences in pilots' performance figures were mere random statistical results, or if in fact they have true statistical significance.

The chosen test is called ANOVA, which stands for, Analysis of Variance. This test is particularly suited to compare data sets like the pilots' rosters and their respective TFC values. This test has the enormous advantage of being made almost automatically in Excel.

The ANOVA tests returns, among others, two values, F and F_{crit}, which are the ones that needed to accomplish our assessment. If F is greater than F_{crit}, there is statistically significant difference, if the opposite occurs and F is less than F_{crit}, the different TFC values are best explained by pure chance.

This test has the enormous advantage of being made almost automatically in Excel. However, since each captain flies hundreds of flights per year, it is not possible even in Excel to include all the flights, individually, in the calculation, so the figures presented below were calculated from the monthly TFC average of each pilot.

Fleet	F	F_{crit}	$F > F_{crit}$
ERJ 145	2.651502	1.40537	Yes
F100	7.240922	1.504681	Yes

Table 5-1 - ANOVA Tests Results

Observing **Table 5-1**, it is known that in both fleets all TFC values are not a mere statistical coincidence, but there is in fact a relation between the pilot and its own performance standing.

CHAPTER 6

6 Performance Statistics and Prediction

This chapter also focuses on the study of the operational performance of PGA. However, in **Chapter 6** this study is done with a different purpose thus with a different methodology. In the previous chapter, all the gathered data was treated and organized in a way that allows different perspectives of PGA's operation: **Routes**, **Fleets** and **Flying Techniques**. This chapter tries to make a more forward analysis of PGA's operation, perhaps a more objective and raw perspective of the performance figures, without specifying anything but the aircraft type. The performance metrics used are mainly the ones already explained in **Chapter 5**, FC, DFC and TFC and they all are studied as functions of the Direct Ground Distance, which is presented in a discrete form with 5 distance clusters of 200NM each.

This method intends to create a tool that, based on a statistical arrangement of the operational data, allows the prediction with an average level of precision of some of the performance metrics for any given flight in the scope of PGA's operations. Bearing that same purpose in mind, all graphs show trend lines, which can be 2^{nd} or 3^{rd} degree Polynomials, whose equations are presented right after the graph in question, and their respective R-squared values; a statistical parameter that quantifies how well-fitted the trend line is.

6.1 Flight Intensity

The graph below represents the cumulative sum of flights and the respective total fuel consumption. Each point refers to the cumulative sum of the referred values up to a certain distance cluster. For example, the fourth point (from left to right), refers to the cumulative sum of the values up to the 600-799NM distance cluster.

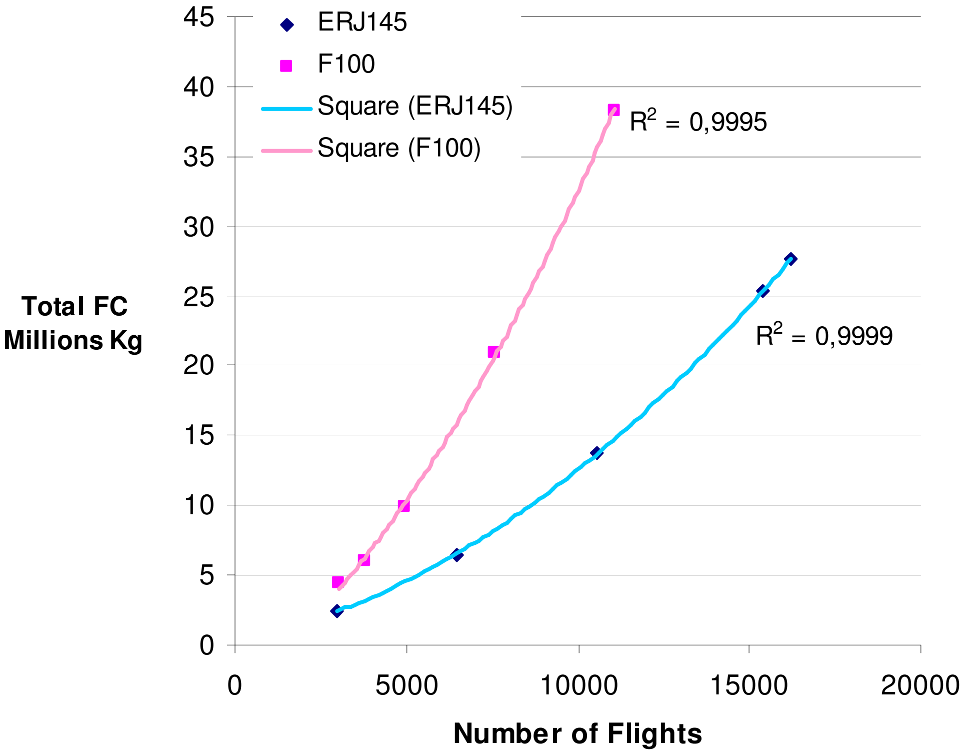

Figure 6-1 - Total FC vs. Flight Intensity

Fleet	Trend line	R^2
ERJ 145	$FC = 0.1768NF^2 + 1790.55NF - 3056259.72$	0.9995
F100	$FC = 0.0742NF^2 + 484NF + 318333$	0.9999

This graph has quite a straight-forward interpretation. The Embraer fleet flies more often and burns less fuel than the Fokker fleet. Of course, this is a very simplistic perspective, however it's a fact. Excluding the different nature of flights each fleet has, the different maximum payloads, and other technical and operational factors, Embraer flew more and burnt less. Again, this doesn't mean it is a more financially viable fleet, but it sure helps. Worth of notice is also the values of the R-squared of the two 2nd degree polynomials that form the trend lines, which are virtually 1, a perfect fit.

6.2 Fuel Consumption

This section presents several graphs where Fuel Consumption figures are shown according to different perspectives, i.e., FC per different metrics.

6.2.1 Fuel Consumption per Flight

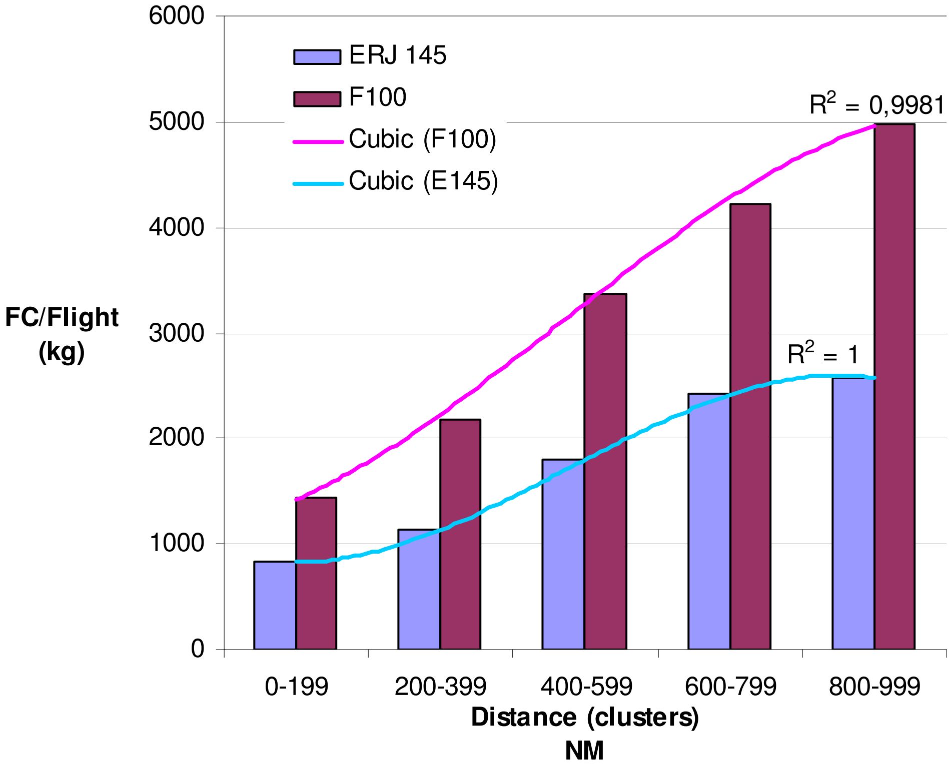

Figure 6-2 - Fuel Consumption per Flight

Fleet	Trend line	R^2
ERJ 145	$\frac{FC}{Flight} = -46.535D^3 + 397.24D^2 - 56.5D + 1127.6$	1
F100	$\frac{FC}{Flight} = -67.714D^3 + 585.76D^2 - 979.24D + 1290.4$	0.9981

Figure 6-2 shows Fuel Consumption per Flight of both fleets. However this comparison is somehow an unjust one since both aircraft types in question, have little to do with each other operationally speaking, since one has twice the passenger capacity of the other. With that thought in mind, it is nothing but reasonable to consider that very same aircraft specific characteristic and include it in the metric in question. So in the next sub-section the Fuel Consumption is shown per flight and per passenger capacity, or AS, available seats.

6.2.2 Fuel Consumption per Flight per Available Seat

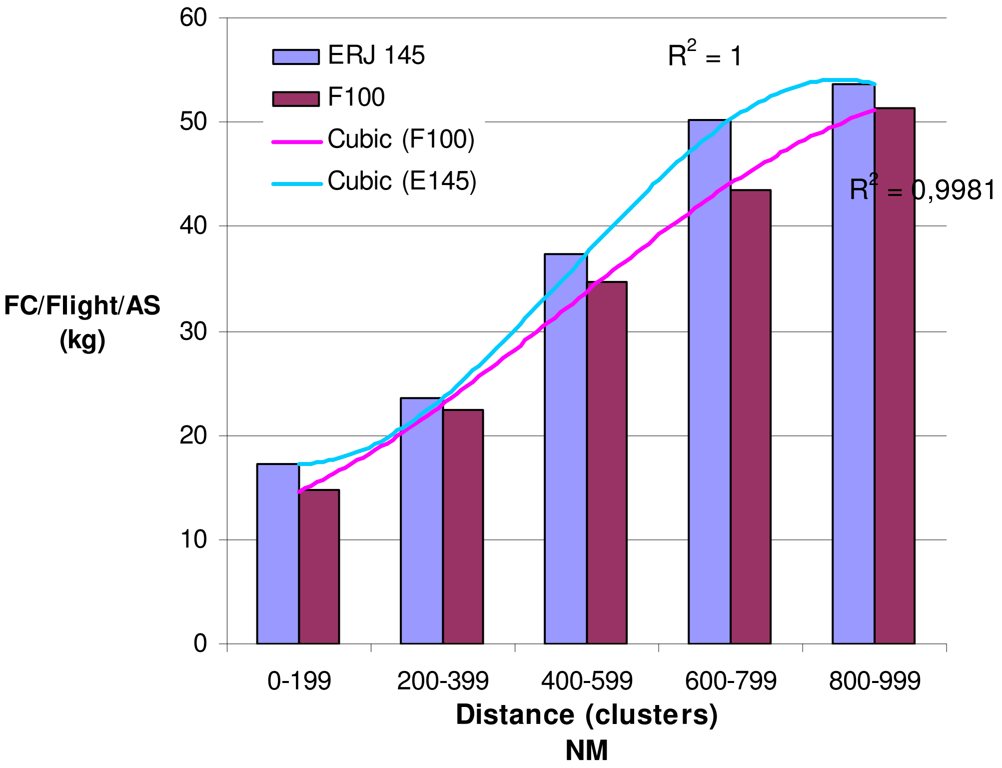

Figure 6-3 - Fuel Consumption per Flight per Available Seat

Fleet	Trend line	R^2
ERJ 145	$\frac{FC}{Flight \times AS} = -1.4107D^3 + 12.203D^2 - 20.401D + 26.884$	1
F100	$\frac{FC}{Flight \times AS} = -0.4797D^3 + 4.0953D^2 - 0.5825D + 11.624$	0.9981

And so **Figure 6-3** is drawn and when the Fokker appeared to be in a disadvantage, burning more fuel per flight, it is possible to consider that the Fokker has in fact the advantage of burning less fuel per flight per each available seat. This statement is obviously done by neglecting the average load factor on the flights of both fleets. Again, it must be remembered that this is a raw perspective of certain performance characteristics of the fleets without considering certain operational aspects.

6.2.3 Fuel Consumption per Nautical Mile per Flight

It might also be of interest to evaluate each fleet's performance based on the fuel consumption per nautical mile. This metric is somewhat similar to the TFC without the dimensionless TOW, however and as explained in the beginning of **Chapter 6**, the data in which these analyses were made follow a different methodology.

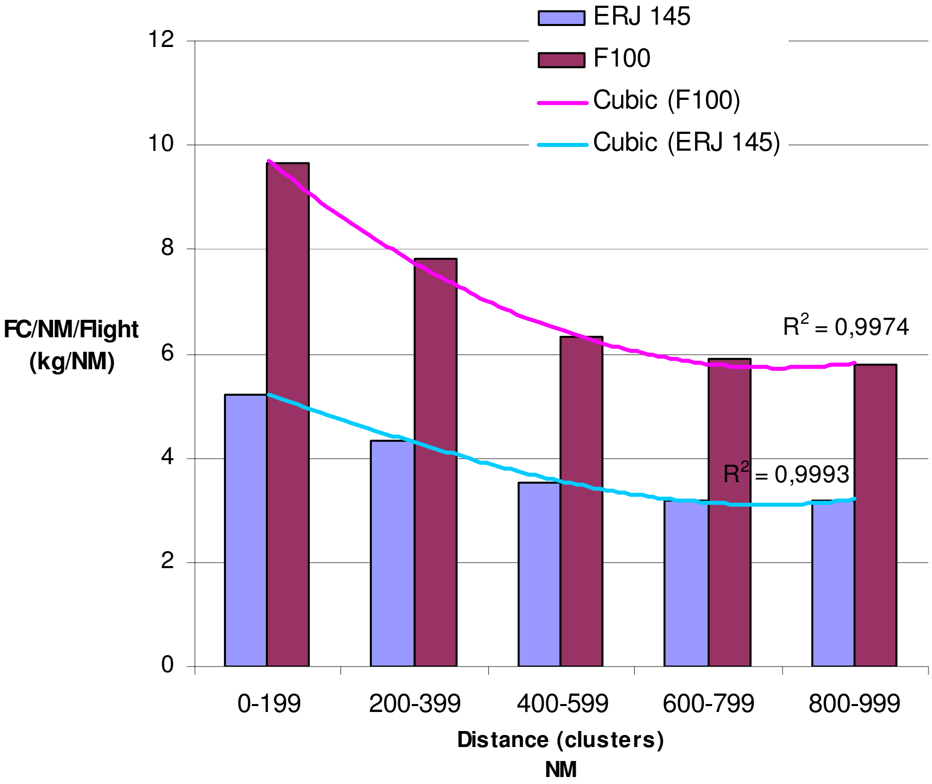

Figure 6-4 - Fuel Consumption per Nautical Mile per Flight

Fleet	Trend line	R^2
ERJ 145	$\frac{FC}{NM} = 0.023D^3 - 0.0399D^2 - 0.9789D + 6.2281$	0.9974
F100	$\frac{FC}{NM} = -0.001D^3 + 0.3383D^2 - 2.9688D + 12.332$	0.9993

6.2.4 Fuel Consumption per Flight Hour per Flight

In resemblance with the analysis presented in the previous sub-section, **Figure 6-5** presents the Fuel Consumption per Flight Hour per Flight

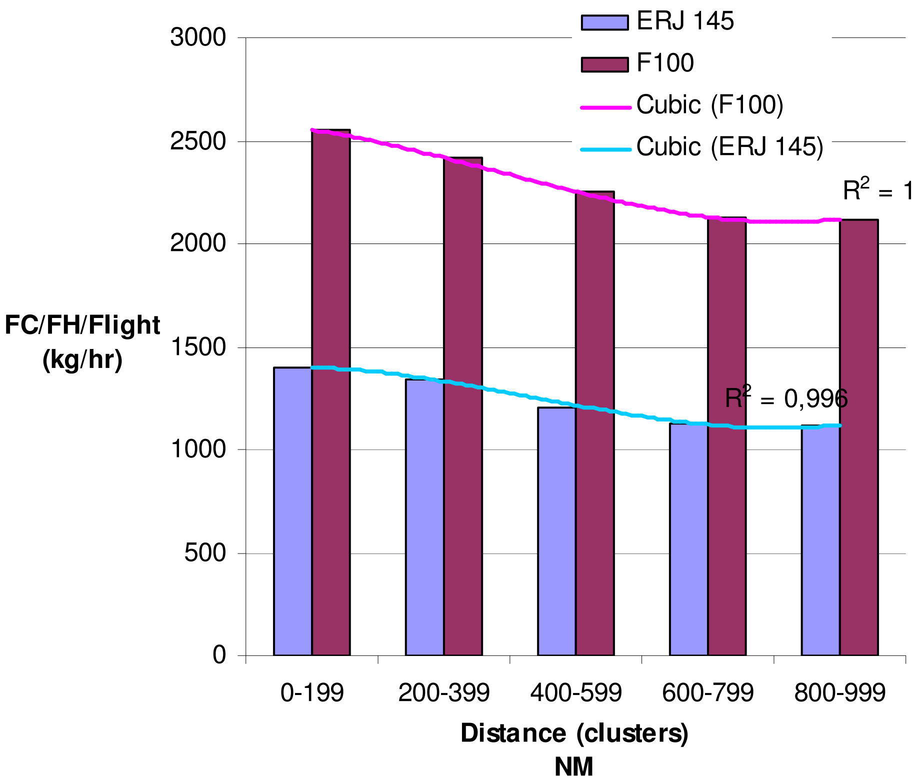

Figure 6-5 - Fuel Consumption per Flight Hour per Flight

Fleet	Trend line	R^2
ERJ 145	$\frac{FC}{hr} = 11.83D^3 - 95.737D^2 + 137.87D + 1344.3$	0.9996
F100	$\frac{FC}{hr} = 12.128D^3 - 88.295D^2 + 45.882D + 2581.9$	1

Both, **Figure 6-4** and **Figure 6-5**, represent similar analyses with similar metrics. Like in **6.2.2**, it is reasonable to also add include in the metric calculation de the available seats each aircraft type has. The results are expectable though; like in **Figure 6-3** the values would be scaled accordingly with the ratio between each aircraft's available seats number.

6.2.5 DFC

From the results previously shown of Fuel Consumption per Nautical Mile per Flight and Fuel Consumption per Flight Hour per Flight, and following the exposition of **5.1.3 - TFC and DFC – Flight Efficiency Metrics**, the same type of study was performed with DFC as the metric and TFC in the next sub-section.

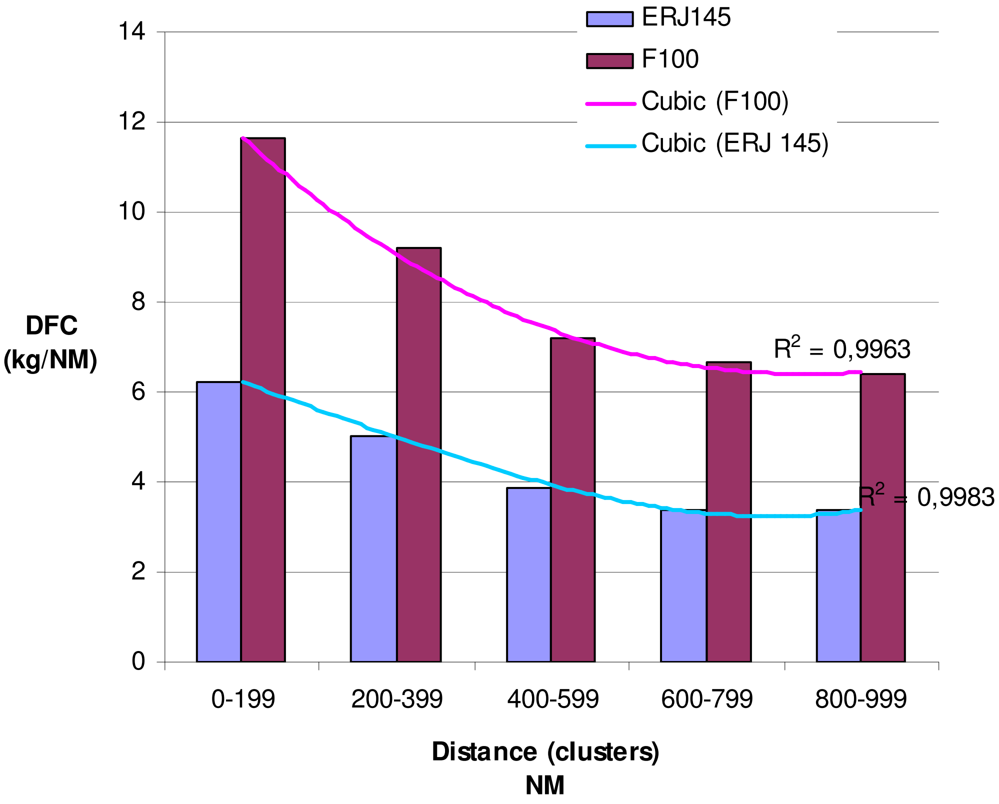

Figure 6-6 - DFC

Fleet	Trend line	R^2
ERJ 145	$DFC = 0.044D^3 - 0.179D^2 - 0.9996D + 7.3531$	0.9983
F100	$DFC = -0.018D^3 + 0.5801D^2 - 4.227D + 15.329$	0.9963

6.2.6 TFC

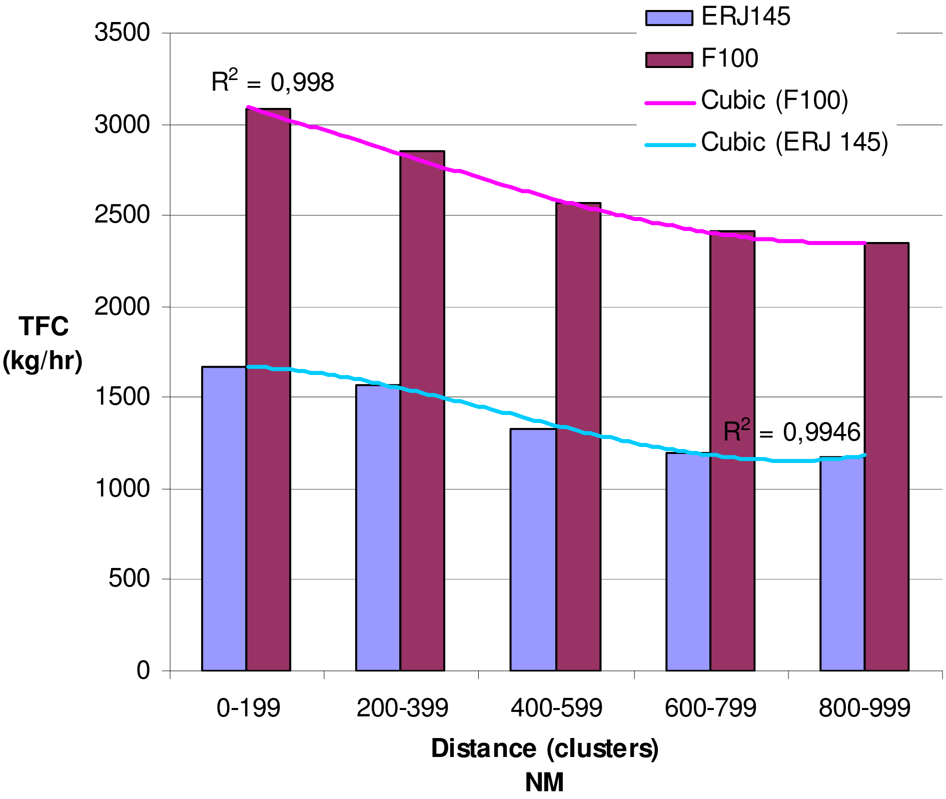

Figure 6-7 - TFC

Fleet	Trend line	R^2
ERJ 145	$TFC = 20.661D^3 - 166.28D^2 - 235.51D + 1579.4$	0.9946
F100	$TFC = 9.8199D^3 - 54.835D^2 - 160.43D + 3295.9$	0.998

Having both DFC and TFC defined as metrics, right after the exposition of FC/NM and FC/FH, that are in fact respectively only different from each other in the dimensionless takeoff weight, which is the key feature that defines DFC and TFC, it is possible to establish a comparison between them. It is clear that both DFC and TFC, maintain the same trend line, though increasing evenly in the entire range of values. This can be interpreted as the weight penalty being accounted for.

CHAPTER 7

7 Flight Economy – a savings analysis

This chapter is dedicated to the study of how certain flight-related metrics, influence flight economy. This study was performed in an entirely different approach than the previous presented in this work; it follows a more practical methodology trying to include more of a pilot's perspective. In fact all data used in this chapter was collected from the FMSs of the Embraer and the Fokker.

The main goal is to identify how two distinct flight strategies influence flight economy, specifically in terms of flight time and fuel consumption. The sample flights chosen for the study were the most frequent flights in each distance cluster for each fleet:

Distance Clusters	Embraer 145	Fokker 100
0 – 199 NM	LIS – OPO	LIS – OPO
200 – 399 NM	OPO – MAD	LIS – MAD
400 – 599 NM	OPO – BCN	LIS – BCN
600 – 799 NM	LIS – NCE	OPO – GVA
800 – 999 NM	OPO – MXP	OPO – AMS

Table 7-1 - Sampled citypairs for the savings analysis

In order to collect the desired data from the FMS, some information had to be given to the system. Only a proper aircraft configuration could allow trustworthy responses from the FMS. Average values of TOW and Off Block FOB of each flight were loaded to the FMS and typical flight plans, both in lateral and vertical profiles, were programmed.

Other parameters demanded by the FMS were left on default settings. ISA atmosphere was considered when calculating the TAS and CAS values with the program written in C[1], specially conceived for that purpose and transcribed in **APPENDIX E – velocidadescruzeiro.cpp**. TAS and CAS values are needed inputs in different steps of the FMS configuration.

With the FMS in a simulated ready-to-takeoff status, different scenarios were created changing the cruise Mach number (Embraer) or the CI (Fokker) and the configured TOW. Each scenario has its own flight time and fuel consumption figures, and it's those figures that are presented in the two sections below, one for each aircraft type.

---

[1] C – High-level programming language

7.1 Embraer 145

Since the FMS installed on the Embraer is a more simplistic piece of equipment than the one installed on the Fokker not contemplating cost index flight management, the different scenarios created for the Embraer study were based on different cruise Mach speeds. More specifically it is questioned what is the impact of reducing the typical cruise speed of the Embraer fleet from M=0.74 to M=0.72, and what is the result of flying with 200Kg less than the average TOW for each given flight. The results for the Embraer are shown on **Table 7-2.**

		LIS – OPO		OPO – MAD		OPO – BCN		LIS – NCE		OPO – MXP	
		FH	FC	FH	FC	FH	FC	FH	FC	FH	FC
TOW	M = 0.74	33’	1.4t	49’	1.7t	1h16’	2.4t	2h14’	3.2t	2h13’	3.2t
	M = 0.72	33’	1.4t	50’	1.7t	1h17’	2.4t	2h17’	3.2t	2h14’	3.1t
TOW - 200Kg	M = 0.74	33’	1.4t	49’	1.7t	1h16’	2.4t	2h14’	3.2t	2h13’	3.2t
	M = 0.72	33’	1.4t	50’	1.7t	1h17’	2.4t	2h17’	3.2t	2h14’	3.1t

Table 7-2 - Flight Time and Fuel Consumption FMS values - Embraer

It is clear after observing the table, that the only noticeable difference (highlighted in green) in Fuel Consumption occurs with the reduction of the cruise speed to M=0.72 on the longest flight (OPO – MXP). However the values are limited to the precision of the equipment which goes no further than the hundreds of kilograms and so it is possible to conclude that ranging from the shortest to the longest flight there’s a successive reduction on the Fuel Consumption values that refer to the cruise speed of M=0.72 when compared to typical M=0.74 speed, becoming noticeable only on the longest flight, by the time at which the difference is enough to change the hundreds case (<3150Kg). It is also worth of notice that there are no changes caused by the weight reduction. In spite of being obvious that there has to be some kind of difference in the amount of fuel burnt caused by the weight reduction, this means that it is far less significant its direct impact than the one caused by simply reducing the cruise speed by M=0.02. Also, the delays caused by the speed reduction are not anywhere near a substantial value, not exceeding one minute, which in operational results have little, if any, importance.

7.2 Fokker 100

The same methodology was used upon the Fokker analysis. Although and as explained before, the cost index flight management capability that the Fokker FMS (a powerful cockpit tool) contemplates was used, instead of the more simplistic approach of just selecting the cruise speed. Three different cost index values were chosen in a way that the typical range of CI values could be covered, and the weight reduction scenarios were replicated from the previous section.

		LIS – OPO		LIS – MAD		LIS – BCN		OPO – GVA		OPO – AMS	
		FH	FC	FH	FC	FH	FC	FH	FC	FH	FC
TOW	CI = 10	33’	1.1t	51’	1.7t	1h30’	2.8t	1h58’	3.7t	2h22’	4.3t
	CI = 15	32’	1.1t	51’	1.7t	1h29’	2.8t	1h56’	3.7t	2h20’	4.3t
	CI = 30	31’	1.2t	49’	1.8t	1h26’	2.9t	1h53’	3.7t	2h16’	4.4t
TOW - 200Kg	CI = 10	33’	1.1t	51’	1.7t	1h30’	2.8t	1h58’	3.6t	2h22’	4.3t
	CI = 15	32’	1.1t	51’	1.7t	1h29’	2.8t	1h56’	3.7t	2h20’	4.3t
	CI = 30	31’	1.2t	49’	1.8t	1h26’	2.9t	1h53’	3.7t	2h16’	4.4t

Table 7-3 - Flight Time and Fuel Consumption FMS values - Fokker

The same trends identified in the previous section are also observed in **Table 7-3**. The weight reduction does not have such a significant impact on fuel consumption reduction as the CI variation has. Again the FC FMS value has a limited precision to the hundreds of kilograms but already on the shortest flight it is noticeable a difference between the FC values corresponding to CI values of 15 and 30, fact maintained along all the sampled flights, as well as the fact that no difference is noticed between the FC values corresponding to CI=10 and CI=15. In the Fokker case the biggest Flight Time difference is eight minutes, which even though it is higher than the one noted for the Embraer it is still not that significant in an operational context with somewhat volatile flight schedules.

8 Conclusions

The dire economical situation the world has fallen to is unquestionable. Airlines worldwide are struggling for survival. To stay put is not an option. Challenges are ahead and everyone must face them or must dare the consequences.

Airline companies have to create financial viability and performance optimization is certainly a major mean to that end. Performance optimization provides the company with higher levels of efficiency, meaning less fuel consumption, less money spent, minor pollution trail, which is one of today's most serious concerns. Green policies are taking over all aspects of the industry, and there's nothing to be won by keeping one step behind in this matter. It is precisely the other way round. The EU ETS is mandatory and beginning to take shape, and operators who will not comply in time with their obligations, will be financially penalized.

The several fuel conservation strategies are very important elements of a performance optimization plan, and should not be disregarded. Their applicability and different implementation methodologies must be subjected to thorough investigation. That is also why a performance monitoring system is of the essence in such an organization. The several studies performed in this work, using all the different metrics, and by distinct approaches and methods, serve precisely, or wish to do so, to prove how useful a performance monitoring system can be, in identifying the different operational behaviours, trends, characteristics, of an airline. Knowing the operational nature of the company is the first step, to take any action, or undertake any plan or strategy towards performance optimization. This is common sense.

This work and any like it, in the author's humble opinion, is doomed to always leave something undone, some metric not studied, some perspective not considered, and why not, some opinions left unheard. So it is only fair to suggest some topics to serve as motto for future work:

The development of a standardised trend monitoring system for both PGA's fleets engines.

The viability study of the inclusion of engine compressor washes in maintenance programs, using a suitable trend monitoring system.

Calculation of route and flight-specific Cost Index values for the Fokker fleet.

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APPENDIX A – Fokker F28 Mk 100 Specifications

Tail Number	S/N	Engine	APU
CS-TPA	11257	2x RR TAY650-15	Honeywell GTCP-35
CS-TPB	11262	2x RR TAY650-15	Honeywell GTCP-35
CS-TPC	11287	2x RR TAY650-15	Honeywell GTCP-35
CS-TPD	11317	2x RR TAY650-15	Honeywell GTCP-35
CS-TPE	11342	2x RR TAY650-15	Honeywell GTCP-35
CS-TPF	11258	2x RR TAY650-15	Honeywell GTCP-35

Table A-1 - Fokker F28 Mk 100 fleet details

Cabin Configuration		**Minimum**	**Maximum**
		18C	97Y
Dimensions		**SI**	**Imperial**
	Length	32.5m	106.63ft
	Span	28.08m	92.14ft
	Height	8.5m	27.89ft
Weights		**SI**	**Imperial**
	MRW	44680Kg	98500lb
	MTOW	44450Kg	98000lb
	MLW	39915Kg	88000lb
	MZFW	37740Kg	81000lb
	OEW	24375Kg	53740lb
	Max. Payload	12635Kg	27260lb
	Max. Fuel	13040l	3445 US Gal
Engine			
	Type	Rolls-Royce TAY650-15	
	Design	Turbo-Fan type engine	
	By-pass Ratio	3.07	
	Compression Ratio	310	
	Thrust Reversers	Hydraulically actuated shell-type thrust reverser (Grumman Aerospace type 1159RDP41530)	
		SI	**Imperial**
	Inlet Massflow	189.6 - 193.23Kg/s	418 - 426lb/s
	Max. Thrust (SL/ISA)	6849.24Kgf	15100lbf
	Cruise Thrust (FL330;0.73M;ISA)	1451.50Kgf	3200lbf
	Weight	1595Kg	3516lb
Dimensions:			
	Fan Diameter	114.3cm	45in
	Max. Nozzle Diameter	89.91cm	35.4in
	Length	240.7cm	94.8in
Performance			
	Vmo	320kts	
	Mmo	0.77M	
	Maximum Altitude	FL350	
Noise			
	FAR part 36 stage 3	In compliance	
	Orange county (SNA)	In compliance	

Table A-2 - Fokker F28 Mk 100 specifications

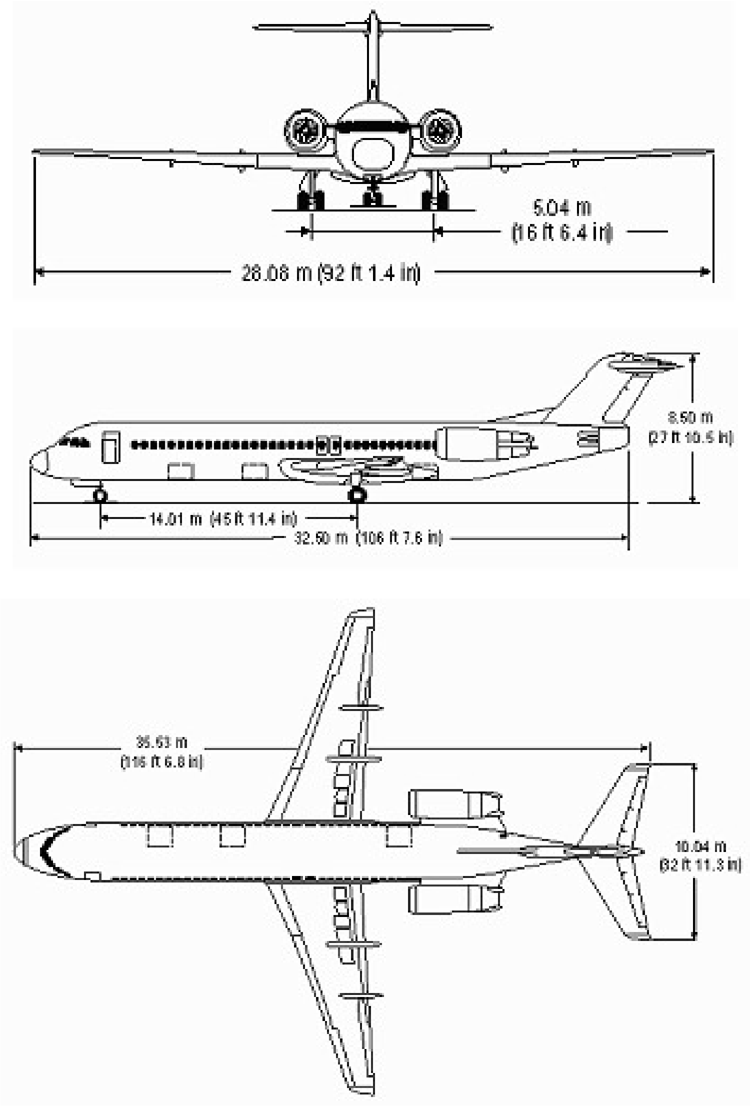

Figure A-1 - Fokker F28 Mk 100 Front, Side and Top Views (source: www.fokker.com)

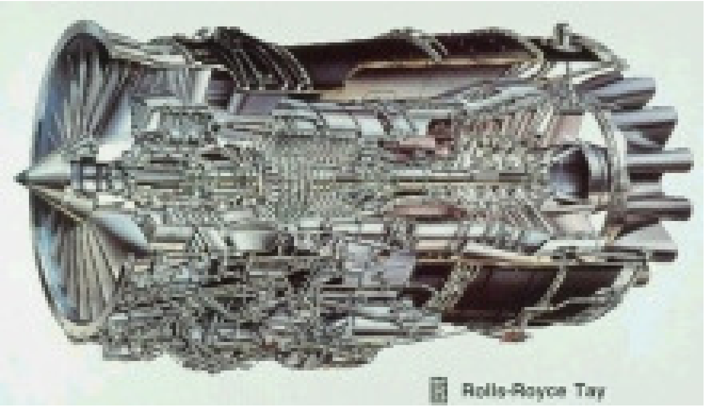

Figure A-2 - Rolls-Royce TAY650-15 cut-away drawing (source: www.fokker.com)

APPENDIX B – Embraer ERJ145 Specifications

Tail Number	S/N	Engine	APU
CS-TPG	145014	2x RR AE3007A	Sundstrand GTCP-35
CS-TPH	145017	2x RR AE3007A	Sundstrand GTCP-35
CS-TPI	145031	2x RR AE3007A	Sundstrand GTCP-35
CS-TPJ	145036	2x RR AE3007A	Sundstrand GTCP-35
CS-TPK	145041	2x RR AE3007A	Sundstrand GTCP-35
CS-TPL	145051	2x RR AE3007A	Sundstrand GTCP-35
CS-TPM	145095	2x RR AE3007A	Sundstrand GTCP-35
CS-TPN	145099	2x RR AE3007A	Sundstrand GTCP-35

Table B-1 – Embraer ERJ145 fleet details

Cabin Configuration		**Minimum**	**Maximum**
			50Y
Dimensions		**SI**	**Imperial**
	Length	29.87m	98ft
	Span	20.04m	65.75ft
	Height	6.76m	22.15ft
Weights		**SI**	**Imperial**
	MRW	21090Kg	46495.41lb
	MTOW	20990Kg	46275.03lb
	MLW	18700Kg	41226.44lb
	Max. Payload	5410Kg	11927lb
	Max. Fuel	5203l	1374.49 US Gal
Engine			
	Type	Rolls-Royce TAY650-15	
	Design	Turbo-Fan type engine	
	By-pass Ratio	4.8	
	Compression Ratio	310	
	Thrust Reversers	Hydraulically actuated shell-type thrust reverser	
		SI	**Imperial**
	Inlet Massflow	108.86 – 127.01- Kg/s	240 - 280lb/s
	Max. Thrust (SL/ISA)	3438.23Kgf	7580lbf
Dimensions:			
	Fan Diameter	98cm	38.5in
	Length	292.4cm	115.1in
Performance			
	Mmo	0.78M	
	Maximum Altitude	FL370	
Noise			
	FAR part 36 stage 3	In compliance	
	ICAO annex 16 chapter 3	In compliance	
	BCAR-N	In compliance	
	ISL	In compliance	

Table B-2 – Embraer ERJ145 specifications

Figure B-1 - Embraer ERJ 145 Front, Side and Top Views (source: www.embraer.com)

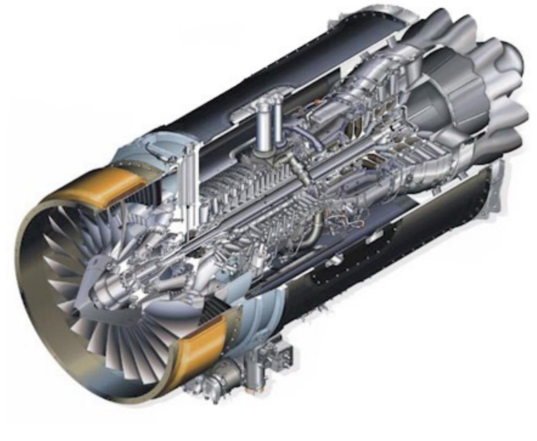

Figure B-2 - Rolls-Royce AE3007A (source: www.embraer.com)

APPENDIX C – Data as organized in Excel worksheets

Column	Column Name	Description
A	LEG_NO	Exclusive reference to each flight
B	Fleet	Aircraft Type
C	Aircraft Reg	Aircraft Register
D	DAY_OF_ORIGIN	Date of departure
E	DEP_AP_ACT	Departure Airport
F	ARR_AP_ACT	Arrival Airport
G	Route	Citypair
H	Dist Nm	Distance for the given citypair in NM
I	OFFBLOCK	Off blocks time
J	AIRBORNE	Airborne time
K	LANDING	Landing time
L	ONBLOCK	On blocks time
M	Trimestre	Trimester of occurrence
N	Mês	Month of occurence
O	FH	Flight Hours
P	BH-FH	Ground efficiency: Difference between Block and Flight Hours
Q	BH	Block Hours
R	DepDelay	Delay on departure
S	ArrDelay	Delay on arrival
T	CAPT	Captain
U	COP	Co-Pilot or First Officer
V	FuelOFFBLOCK	Fuel On Board Off blocks
W	FuelONBLOCK	Fuel On Board On blocks
X	TripAct	Actual fuel burned
Y	Cargo	Cargo loaded
Z	Payload	Payload
AA	TOW	Take-Off Weight
AB	PAX Total	Total PAX count
AC	PAXC	Business Class PAX count
AD	PAXY	Coach Class PAX count
AE	PAXMale	Male PAX count (88kg)
AF	PAXFemale	Female PAX count (70kg)
AG	PAXChild	Child PAX count (35kg)
AH	PAXInfant	Infant PAX count (0kg)
AI	PCD	DFC
AJ	PCT	TFC

APPENDIX D – List of IATA and ICAO airport codes

IATA code	ICAO code	City	Airport
AMS	EHAM	Amsterdam	Amsterdam Airport Schiphol
BCN	LEBL	Barcelona	Barcelona Airport
FAO	LPFR	Faro	Faro International Airport
FCO	LIFR	Rome	Leonardo da Vinci - Fiumicino Airport
GVA	LSGG	Geneva	Geneva Cointrin International Airport
LIS	LPPT	Lisboa	Lisbon Portela Airport
LUX	ELLX	Luxembourg	Findel Airport
LYS	LFLL	Lyon	Lyon - Saint Exupéry Airport
MAD	LEMD	Madrid	Madrid - Barajas Airport
MXP	LIMC	Milan	Milano Malpensa Airport
NCE	LFMN	Nice	Nice Côte d'Azur Airport
OPO	LPPR	Porto	Dr. Francisco Sá Carneiro – Porto International Airport
SVQ	LEZL	Sevilla	Seville - San Pablo Airport
TLS	LFBO	Toulouse	Toulouse Blagnac Airport

APPENDIX E – velocidadescruzeiro.cpp

```
#include <cstdlib>
#include <iostream>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

float FL=0;
float TAS=0;
float a=0;
float T=0;
double M74=0, M72=0, C74=0, C72=0;

void NivelCruzeiro(){

    printf("\nQual o Nivel de Cruzeiro?\t");
    scanf("%f",&FL);
    printf("FL%03.0f\n",FL);
}

void Temperatura(){

    T = (1-0.000006875*FL*100)*288;

}

void Velocidades(){

    M72 = 0.72*sqrt(1.4*287*T);
    M74 = 0.74*sqrt(1.4*287*T);

    C72 = sqrt( (pow( pow(1-0.000006875*FL*100 , 5.2561) * ( pow((0.72*0.72/5.)+1 , 3.5) -1) +
1 , 0.2857) - 1) / 0.0000004571);
    C74 = sqrt( (pow( pow(1-0.000006875*FL*100 , 5.2561) * ( pow((0.74*0.74/5.)+1 , 3.5) -1) +
1 , 0.2857) - 1) / 0.0000004571);
}

int main(/*int argc, char *argv[]*/){
```

```
        FL=0;
        TAS=0;
        a=0;
        T=0;
        M74=0;
        M72=0;

        char fim='s';

        NivelCruzeiro();
        Temperatura();
        Velocidades();

        printf("\n\tTAS(M0.72) = %.2fkts\n",M72*1.94384449);
        printf("\tTAS(M0.74) = %.2fkts\n\n",M74*1.94384449);

        printf("\tCAS(M0.72) = %.2fkts\n",C72/*1.94384449*/);
        printf("\tCAS(M0.74) = %.2fkts\n\n",C74/*1.94384449*/);

        printf("Correr novamente? (s ou n)\n");
        scanf("%c",&fim);
        while(fim != 's' && fim != 'S' && fim != 'n' && fim != 'N'){
                scanf("%c",&fim);
                if(fim != 's' && fim != 'S' && fim != 'n' && fim != 'N'){
                        printf("Correr novamente? (s ou n)\n");
                }
        }

        if (fim == 's' || fim == 'S'){
                main();
        }

        if (fim == 'n' || fim == 'N'){
                system("PAUSE");
                return EXIT_SUCCESS;
        }
}
```