Fuel Conservation Strategies
Through Flight Operation Optimization at PGA

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Abstract

Fuel conservation is an important topic for airlines, not only as a way of reducing operating and maintenance costs, but also emissions. Even with the current expansion of the airline industry and low fuel prices, it is estimated that a well implemented savings plan can help achieve 2% to 5% reduced fuel consumptions, which translates into higher profit margins. For this work, a Portuguese regional airline – PGA - was used as a case study, providing data on its new fleet of nine Embraer 190. A set of five operating measures suggested by the manufacturer (like Single Engine Taxi and Idle Descent) were studied and analyzed using data recordings from sixty flights, over three frequent and different length city pairs, with two flight legs each (outbound and inbound), in order for the sample to be representative. The goal of this work was to study and implement this set of operational measures in a software tool using MATLAB that was able to analyze the flights and estimate the potential savings if the measures had been fulfilled. The results of this work are very encouraging, and even though its full saving potential is unlikely to be achieved in a real-world scenario due to the nature and unpredictability of air traffic, it allows for PGA to understand and prioritize certain measures that provide greater return with a lower effort. The financial impact of these savings is also estimated, and can reach up to around 875k€ (3.62% of the fuel consumption) for PGA specific case.

Keywords: Fuel Conservation, Regional Airline, Operational Measures, Flight Data Analysis.

1. Introduction

The 2008 economical crisis shook the world, and for the aviation industry, this reflected in a lower demand and a rise in fuel prices, which resulted in an excessive offer and the growth of low-cost airlines. To remain competitive, airlines were forced to lower their fares, however, with this decrease in revenue, a corresponding reduction in expenses was also due. In this sense, it became of the utmost importance to develop sustainable policies for the airline operation, not only to provide a more efficient and optimized activity, but to also to make it more robust and less dependent on market fluctuations.

With this objective in mind, PGA - Portugália Airlines, a portuguese regional airline - started several years ago its first studies developing tools to identify cost reduction strategies. This work illustrates some of these efforts, applied to a recent fleet, and focuses on fuel conservation through the implementation of a set of operational measures. The fleet studied in this work consists of 9 Embraer E-190 aircraft that were bought and started flying on the 23rd May 2016.

1.1. Motivation

For a small airline like PGA, operating a fleet of regional jets on short and medium-haul routes, the operational conditions present different challenges when compared to larger airlines. This is due to shorter flight distances while still focusing on major urban airports, but also due to the inherently higher flight cycle to hour ratio, meaning higher maintenance costs, that can even reach about 20% of total direct operating costs.

When flying a particular airplane, airlines define a Cash Operating Cost (COC) relating to that operation, which for a determined route involves three main components: Fixed Costs, Time Related Costs and Fuel Related Costs. Since the year 2000, jet fuel has faced tremendous variations in price (Figure 1). On the one hand, political and economic factors, as well as wars, all influence the crude price, which can be highly unpredictable and volatile. On the other hand, Fuel Related Costs can reach up to 40% of the total COC of a flight, and are usually where the most flagrant saving opportunities are identified.

As a consequence, the implementation of fuel conservation optimization becomes one of the most important tools when it comes to cost reduction strategies. Even with jet fuel prices considerably lower compared to 2008, and the sector giving the first real signs of recovery since the beginning of the
crisis, it is still of the utmost importance for airlines to optimize their operation. Marginal profit margins imply not only small profits, but more importantly, the smallest variation in costs (e.g., jet fuel prices) can mean non-profitable operation and losses of millions in this industry.

Considering these facts, fuel conservation strategies are extremely important in the context of PGA. Even though there are complete fuel efficiency package tools available on the market (to be discussed in Section 2.1), they invariably come with a hefty price tag. This work is a preliminary way for PGA to evaluate the potential of implementing fuel conservation strategies on their new fleet, focusing on what were considered the most important and readily available operational procedures.

1.1.1 1% Fuel Conservation Estimations
One interesting value to calculate is the amount of savings, both in kg of jet fuel and in euros, that could be obtained for the company if it reduced its fuel consumption by 1%. To do this, a typical operational profile of the company is needed, and Embraer provides an estimate for a 600 NM trip, corresponding to a takeoff weight of 42 925kg, trip fuel of 3147kg and a total trip time of 90min.

Reducing trip fuel by 1% would result in 31kg of fuel saved per flight [2], which multiplied by the number of flights a fleet of 20 of these aircraft performs a year yields the surprising value of 1180 metric tons of potential fuel savings a year.

Considering the current jet fuel price in Europe of 446.6 $/metric ton provided by IATA [3], this means a total yearly saving estimate of approximately 237k$, equivalent to 212k€. Note that apparently small amounts of fuel economy translate to very significant financial differences, making this a very important topic when it comes to cost reduction.

1.2. Objectives
The main objective of this thesis is to evaluate the impact of fuel conservation strategies on a regional airline performance. For this work, the focus was set on operation optimization not because it has the highest saving potential, but because it is the most simple and direct way for an airline to start implementing fuel conservation. Therefore, the whole process was divided into three main objectives:

- Data collection from the aircraft recorder systems;
- Data selection, processing, and estimation of savings;
- Statistical data analysis, with the evaluation of each saving measure.

1.3. Structure
This work is divided into five different chapters. The second chapter discusses the state of the art in this industry, an overview of the current available solutions and the tools used during the execution of this work. The third chapter enumerates the methodology used for such analysis, the savings measures and the associated fuel economy metrics. The fourth chapter details the results of the analysis on the provided sample, discussing the various routes and measures. Finally, the fifth and last chapter presents the conclusions of this work, leaving suggestions for future work in the area.

2. State of the Art & Analysis Tools
2.1. Market offer
Nowadays, due to the growing fuel economy and environmental sustainability awareness, the number of companies offering complete software solutions to elevate airline efficiency has faced a great expansion. This includes Crew and Fleet optimization, as well as Maintenance and, most important for this work, Fuel Efficiency. Two of the most important suppliers of these services are Honeywell and OpenAirlines.

2.1.1 Honeywell - Aviaso
Aviaso was founded in 2003, in Switzerland, and bought by Honeywell in September 2015 [4]. Aviaso method to take on the Fuel Efficiency theme is divided into four main steps. First, it is important to collect the relevant data from the many airline departments and IT infrastructures, from flight planning, to operations, maintenance, etc. Then, the data must be checked for quality assurance. After having all the relevant data properly checked, fuel savings potential is calculated and the current fuel conservation program progress is monitored. Finally, it is imperative to convey this data to each of the responsible entities, customized for their necessities [5].

2.1.2 OpenAirlines - SkyBreathe
Founded in 2006, OpenAirlines is a company focusing on three main aspects of airline efficiency - Fuel, Crew and Fleet efficiency. By optimizing the resources across the various airline departments, OpenAirlines promises fuel savings in the region of 2% to 5% [6], corroborated by IATA estimates of 3% to 5% for a systematic airline optimization.
Much like the competition, Skybreathe also presents a few steps in its fuel conservation optimization analysis, five in this case. Both the data integration and quality control are similar, in terms of concept, with the difference that the analysis is separated into two different steps here - savings computation and data analysis. Finally, the data communication step to the different entities is given a great deal of importance, with fully customizable reports and dashboards for all types of users.

SkyBreathe dashboard allows for a comprehensive understanding of the airline efficiency. It allows for route analysis, flight phase analysis, best and worst practices (whether the saving potential is being fulfilled), individual aircraft savings and even pilot savings.

2.1.3 Embraer fuel conservation strategies
Like most aircraft manufacturers, Embraer provides manuals and technical sheets that focus on resource optimization either in terms of planning, operation or maintenance ([2], [4]). As stated earlier, this work focused on operation optimization and, therefore, Embraer recommended savings procedures constituted the foundation of this study. These procedures are presented and analyzed further in depth in Section 3.

2.2. Data capture and extraction
2.2.1 Quick Access Recorder
For fuel efficiency measures to be analyzed and implemented, it is necessary to have flight data regarding the flight planning and operations. In order to obtain the data from the various sensors and parameters computed by the airplane, the Quick Access Recorder (QAR) was used. It is used by airlines to improve flight safety and operational efficiency. Since usually a QAR is not a mandatory system on commercial flights, it is not designed to survive a crash, like the Flight Data Recorder (FDR). This also means that it is a more flexible system for airliners, as it can process data at much higher rates than the FDR, and frequently for longer periods of time.

The QAR unit used on PGA Embraer 190 fleet is manufactured by SAGEM, and its part number is ED35E109-04-00. This QAR dataframe is fully configurable - which parameters to be recorded and the sample rates are all programmable, as is the start and stop logic for the recording. For PGA aircraft, the QAR is set to record whenever the plane is energized, in order to keep a more comprehensive record for safety and fuel consumption analysis. The electrical energy for the plane systems can come from the engines, the APU or an external GPU.

2.2.2 Analysis Ground Station
To analyze, extract and produce reports with the QAR raw data, a special software tool is necessary, and for this work, the Analysis Ground Station (AGS) software by the QAR manufacturer SAGEM was used. Due to the complexity of the software, only a small part of its potential was used for this study. Essentially, it was used to filter the flights by routes and aircraft, then to produce reports based on the relevant variables, and finally to export this data, later to be read and processed by MATLAB.

3. Methodology
In order to evaluate the fuel saving potential for this airline, a group of significant measures that were simultaneously easy to evaluate and to put to practice were chosen and characterized. To do this, many articles by several aircraft producers and industry associates were analyzed and compared ([2], [4], [7]).

Then, to analyze the effect of each of the measures on the airline operations, a set of routes (city-pairs) was defined. This allowed for a rough statistical analysis of various flight scenarios and corresponding fuel savings, evaluating the financial viability of the previously defined measures.

3.1. Fuel Savings Measures
For this work, five main fuel saving measures were chosen for representing relatively simple day-to-day operational procedures that can help reduce fuel costs. These are: avoiding the use of the Auxiliary Power Unit and Thrust Reverser systems, and shutting them down as soon as possible; Single Engine Taxi In and Out; and using the Idle Descent, consisting of setting the engines to idle thrust during descent.

It should be stressed that all the savings estimated in this work are calculated for optimal conditions and thus, their full saving potential can be very hard to achieve under real-life operation. Be it because of ATC, flight delays, meteorological aspects, mechanical condition of the aircraft or many other reasons, the important result is to recognize how much fuel could be saved by simply accomplishing these measures, if all the unpredictable aspects of flying went according to plan.

3.1.1 Auxiliary Power Unit
The APU, or Auxiliary Power Unit, is a device designed to generate pneumatic and electrical AC power for the various systems of the aircraft. It consists of a gas turbine engine, located in the airplane tailcone, that runs on regular jet fuel and can provide bleed air for starting the engines and for the air conditioning packs, coupled with an electrical AC generator that supplies 115V 40kVA to the electrical system.

Considering jet fuel prices, using the APU on ground is much more expensive than running a GPU as an electrical power source. Similarly, external air carts can be used to power the air conditioning packs, saving valuable fuel on ground.
Companies are invited to evaluate if continuous use of APU at the gate instead of GPU is the best option, considering that main APU components fail by cycle, and therefore, for really short turnarounds, the marginal fuel saving might not justify the extra APU maintenance costs; GPU power, like external air carts, is most of the time leased from ground handling companies and can be excessively priced in some situations, or charged by the hour, turning it into a pricier option.

For when APU continuous use on the ground is actually the most cost effective measure, it is recommended its usage time be minimized. This means only turning the APU on after landing and turning it off immediately after starting up the engines.

**Conditions** Unfortunately, evaluating the savings potential on turnarounds would require a constantly up-to-date database of fuel prices, GPU and external air leasing prices in every airport and all the conditions associated with the lease.

Therefore, the only condition set for the savings analysis of the APU, is that it should be turned off whenever there is at least one engine running. This means turning off the APU as soon as the first engine is started and turning it on only immediately before shutting the last engine down. A buffer time of 60s is granted in both of these situations, for the crew start-up/shutdown checklist time.

**Savings estimates** Whenever the above condition is not met, and the APU is running simultaneously with the engines, a fuel saving can be estimated. This is done by converting the APU Fuel Flow from PPH to kg/s and integrating it over that time interval. The result is the amount of kg of fuel that could have been saved, had the APU been used efficiently.

### 3.1.2 Single Engine Taxi

In order to improve fuel savings, a single engine taxi can be used, delaying the start of the second engine prior to takeoff and shutting one engine just after landing when taxiing in. A set of conditions influence this maneuver, including: ramp weight; ramp gradient; engine warm up and cooling down period; contaminated taxiways; and the higher pilot workload associated.

These aircraft are relatively light and thus require less power to taxi, however, the engine warm up and cooling down periods must be met to allow for engine thermal stabilization - the second engine must be kept running for at least 2 minutes at idle before selecting high thrust settings or shutdown. It is also advised that, when taxiing out, the second engine should be started with the airplane static to avoid pilot heads down condition during taxi.

During single engine taxi, the fuel flow is approximately 5 kg/min or 300 kg/h, due to an increment in thrust compared to normal taxi thrust per engine [2].

**Conditions** For SETO (Single Engine Taxi Out), the only limitation is the second engine warm up time, and therefore, the only condition is to start the second engine 2 minutes before takeoff [2]. Similarly, for SETI (Single Engine Taxi In), the only condition is to shutdown the second engine 2 minutes after landing, in other words, 2 minutes after taxi out starts.

**Savings estimates** Whenever the above conditions are not met (i.e. the second engine is running more than 2 minutes before takeoff or after landing) a fuel saving can be estimated. This is done by calculating the difference between the actual aircraft fuel flows (FF1 + FF2) and the average SET fuel flow (300 kg/h) and integrating it.

#### 3.1.3 Thrust Reversal

Reverse thrust can be used to stop the aircraft in a shorter runway length. This is essentially accomplished by redirecting the engine exhaust forward, rather than backward, providing deceleration. Even though this system can help reduce wear on the brakes, it also usually means higher fuel consumptions and engine wear, depending on the amount of reverse thrust selected by the pilot. With full reverse thrust, fuel flow can reach 3200 kg/h, a value similar to takeoff thrust configuration.

The higher the aircraft speed, the more efficient reverse thrust is, since it uses more air mass and therefore produces bigger brake forces. However, applying high reverse thrust at lower speeds can induce an inlet vortex, exhaust gas and FOD ingestion, especially in contaminated runways, and should therefore be avoided. On snow or ice covered runways, it can even lead to low forward visibility due to a “whiteout” (snow being propelled forward by the engines).

**Conditions** One should note that, considering fuel efficiency, the thrust reversers should only be engaged when absolutely necessary, due to runway length or other limiting factors like inoperative brakes. According to the GP1999 by Embraer [2], FOD ingestion can occur below 80 KIAS, so it is advised to turn off maximum reverse thrust below that speed. As the airspeed reduces, so does the thrust reversers efficiency, and so it is stated that at 60 KIAS reverse should be canceled altogether in such way that it will be completely stowed when reaching normal taxi speed.

**Savings estimates** "Keeping full reverse thrust actuated until airplane stops completely will increase approach and landing fuel by 10 kg [2]." Therefore, it is expected that the savings calculated with this method fall below that number. Whenever reverse thrust usage does not comply with
above stated conditions, a saving is calculated by subtracting to the actual engines fuel flow, the average idle fuel flow, and integrating it over that period of time.

3.1.4 Idle Descent
The descent phase usually represents a lower fuel consumption than the climb or cruise phases, with a trip time percentage that should be around 10% for short and medium range flights, and fuel flows many times smaller. From a fuel consumption point of view, the descent should be done as fast as possible, using high speeds. However, this can cause passenger discomfort, due to the cabin pressure rate of change, and for really high speeds, can cause the trip fuel to actually increase due to the extended cruise period and high fuel flows during descent.

To maximize fuel savings, idle thrust coupled with a constant flight path angle is recommended by Embraer and enforced by PGA in their SOP [7], due to the lower fuel flows, effectively decreasing descent fuel. This procedure is called Idle Descent.

Currently, many worldwide operational safety regulations require a speed limit of 250 KIAS below 10000 ft. The manufacturer stresses that the Embraer 190 was designed and flight tested for bird impacts up to speeds of 300 KIAS, and can therefore fly those speeds below 10000 ft safely. It is estimated that the elimination of these speed limits both in the descent and climb phase would result in savings between 14 and 25 kg of fuel per flight, while contributing to reducing the flight time (and therefore time costs).

Conditions For the savings analysis, the engines thrust setting was taken into consideration. As such, whenever the Thrust Lever was not set to idle in any of the engines during the descent phase, a fuel saving opportunity was identified.

Savings estimates Whenever at least one engine has its thrust setting different from idle during descent, the potential fuel saving is calculated taking into account an average idle fuel flow per engine. However, idle fuel flow depends linearly with the operation altitude [8], and therefore must be estimated every second. This estimation was made based on a flight in our database with a nearly perfect idle descent, that resulted in the following linear fit:

\[ FF (kg/h) = -0.016 \times h (m) + 377.013 \] (1)

This means calculating the extra fuel burned by adding both engines fuel flow, subtracting the average estimated idle fuel flow for that altitude, and integrating it over the period in which the conditions were not met.

3.2. Route choice
Having the savings measures correctly implemented, it became imperative to define a sample that could represent this regional airline operation.

Figure 2: Idle Fuel Flow variation with Altitude

In that sense, the flight data was analyzed and the various flown city-pairs were listed both by distance and number of flights, as of 30th June 2016. In order to obtain more homogeneous results, three city-pairs were chosen, one short, one medium and one long-haul, taking into account the number of flights in each category. Additionally, each city-pair represented and outbound and inbound flights, which meant the sample was comprised of 6 routes:

- LIS-OPO & OPO-LIS (flights between Lisbon and Oporto);
- LIS-BCN & BCN-LIS (flights between Lisbon and Barcelona);
- LIS-NCE & NCE-LIS (flights between Lisbon and Nice);

Then, for each of these routes, 10 flights were selected and run through the simulation, in order to have a significant sample to analyze statistically.

4. Results
4.1. Route Analysis
4.1.1 LIS-OPO & OPO-LIS
Being the shortest route analyzed, it is to be expected that a flight between Lisbon and Oporto has a fairly low efficiency, as less time is spent cruising and more time in non-optimal phases of flight like taxiing, taking off and climbing. However, this does not necessarily mean higher saving potentials, but a careful study of an average flight can help identify and justify the best savings to be implemented.

Figure 3: LIS-OPO phase time and fuel consumption

In this short route, taxi times are very prominent (Figure 3). We can see Taxi Out is actually the longest flight phase for this route, reaching above
25% of the total trip time and Taxi In times just under 10%. Still, the phase with the most fuel consumed is clearly Climb, with about 40% of the fuel consumed, but only under 15% of the total time, which is a very similar duration to Cruise.

For the returning flights, taxi times are very relevant, but here the longest flight phase is actually Descent, which is a consequence of the very short distance of the flight. Also like before, the phase with the most fuel consumption is Climb, which is explained by its rather high relative duration combined with very high fuel flows. It is also relevant noticing Taxi Out times with a much shorter duration, nearly halved from 25.5% to 12.5%, as well as Taxi In times with a fairly higher duration, reaching 11.9%, compared to the previous 8.7%. Both these differences come from the fact that Lisbon International Airport is much more congested and with more complex and longer taxiways, therefore taxi times are usually much higher than in Oporto.

From Table 1 it is possible to see that SETO is the highest potential saving measure for the LIS-OPO route, with nearly 2% total trip fuel that can be saved from correct implementation of this measure. In fact, the difference is pretty dramatic, with APU and SETO savings practically halved for the reverse route (OPO-LIS), while Idle Descent reaches more than 3.5%.

Idle Descent savings potential also relates to the higher traffic found in Lisbon International Airport, because many times pilots are encouraged by ATC to accelerate or to keep a certain speed depending on other departing and/or arriving aircraft. It is always preferable to adapt the descent phase than to be forced to enter a holding pattern, thus Idle Descent savings potential more than doubles when landing in Lisbon compared to Oporto.

Finally, regarding the comparison between each measures relative percentage in terms of the total saving SETO is, as expected, the main focus for fuel conservation in the LIS-OPO route (45%), followed by Idle Descent (33%). For the inbound flight, the preponderance goes to Idle Descent measures, at 72%, with SETO down to a more reasonable 17%. For both flights, Thrust Reverser operation and SETI have minimal relative percentages, the first because it is not used very often, and the second because the procedure is nearly optimized.

4.1.2 LIS-BCN & BCN-LIS

On a medium-haul route like the connection between Lisbon and Barcelona, the efficiency is expected to be greater than that seen on the previous shorter routes. Due to the longer flight distances, a bigger percentage of the time is spent cruising, with an expected percentage-wise reduction of taxi times.

![Figure 4: LIS-BCN phase time and fuel consumption](image)

In fact it is possible to identify in Figure 4 the three main flight phases - Climb, Cruise and Descent - as the longest, which is to be expected for medium-haul flights. This is also valid for fuel consumption, as these three phases represent around 90% of the total fuel consumed for the flight. Despite this, Taxi Out times are still significant, with over 10% of the time spent on this phase, which only proves that the Lisbon Airport has a low efficiency when it comes to taxiing, much due to the high amount of traffic exceeding the airport capacity. The main difference for the inbound flight in this route is the slight reduction in Taxi Out and Descent relative times, with the corresponding increase in the percentage of time spent cruising, which usually means a more efficient flight. Even though Barcelona airport is much bigger, complex and carries more traffic, Taxi Out times still average around 50 seconds less than in Lisbon, which only proves the latter’s lack of capacity for the current traffic it deals with.

For these routes, both departing from Lisbon and Barcelona (Table 2), Idle Descent is clearly the fuel landing in Lisbon.

<table>
<thead>
<tr>
<th>Route</th>
<th>Unit</th>
<th>Thrust Rev</th>
<th>APU</th>
<th>SETO</th>
<th>SETI</th>
<th>Idle Descent</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIS-OPO</td>
<td>kg</td>
<td>0.49</td>
<td>10.36</td>
<td>26.57</td>
<td>1.92</td>
<td>19.35</td>
<td>59.09</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.03</td>
<td>0.74</td>
<td>1.47</td>
<td>0.14</td>
<td>1.38</td>
<td>4.16</td>
</tr>
<tr>
<td></td>
<td>Relative %</td>
<td>0.83</td>
<td>17.87</td>
<td>44.96</td>
<td>3.24</td>
<td>39.09</td>
<td>100.00</td>
</tr>
<tr>
<td>OPO-LIS</td>
<td>kg</td>
<td>0.94</td>
<td>5.96</td>
<td>12.76</td>
<td>1.55</td>
<td>30.65</td>
<td>75.00</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.04</td>
<td>0.38</td>
<td>0.85</td>
<td>0.16</td>
<td>3.65</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>Relative %</td>
<td>0.72</td>
<td>7.46</td>
<td>10.83</td>
<td>1.38</td>
<td>37.92</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 1: LIS-OPO and OPO-LIS average savings estimates

As flight distances and durations are fairly similar for the inbound and outbound flights of the same city-pair, comparing savings estimates in % between them is viable, however, it is always preferable to analyze the results in absolute values. This also allows for comparison across different flight distances, presented further ahead. Here, for example, it is possible to see that the inbound flight has a saving potential more than 15kg higher, despite 26.57kg of fuel wasted in the Taxi Out phase for the outbound one, largely outweighed by the fact that Idle Descent has a saving potential 35kg higher when
conservation strategy with the highest saving potential. It is to be expected that savings measures for the three main phases of flight become more significant as the flight distance increases, considering the amount of time spent on these phases is higher, percentage-wise. The fact that Idle Descent represents savings of 5.35% (169.97 kg) per outbound flight and only 2.94% (101.54 kg) for inbound ones has to do with a multitude of factors, including the approach procedure for each airport, the bigger experience with the maneuver in Lisbon airport, but more importantly, because of ATC imposed limitations. Barcelona airspace is very crowded, and because of that some of its regulations are stricter. Pilots are often encouraged to accelerate the aircraft engines in order to keep a certain speed, descend faster or above all, avoid holding. Of course, this means longer periods of time not complying with the idle thrust policy, therefore a fuel saving can be calculated by the program for a longer period of time, resulting in higher fuel conservation estimates.

<table>
<thead>
<tr>
<th>Route</th>
<th>Unit</th>
<th>Thrust Rev</th>
<th>APU</th>
<th>SETO</th>
<th>SETI</th>
<th>Idle Des.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIS-BCN</td>
<td>kg</td>
<td>0.23</td>
<td>8.84</td>
<td>25.64</td>
<td>4.14</td>
<td>169.97</td>
<td>208.83</td>
</tr>
<tr>
<td>Relative %</td>
<td></td>
<td>0.01</td>
<td>0.26</td>
<td>0.75</td>
<td>0.12</td>
<td>0.00</td>
<td>6.14</td>
</tr>
<tr>
<td>BCN-LIS</td>
<td>kg</td>
<td>0.51</td>
<td>9.15</td>
<td>14.64</td>
<td>1.78</td>
<td>101.54</td>
<td>127.60</td>
</tr>
<tr>
<td>Relative %</td>
<td></td>
<td>0.01</td>
<td>0.23</td>
<td>0.37</td>
<td>0.04</td>
<td>2.58</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Table 2: LIS-BCN and BCN-LIS average savings estimates

It is hard to "blame" any specific measure for the big difference of almost double the total savings percentage between the outbound and inbound flight legs. In fact, almost every fuel conservation strategy potential is halved for flights arriving in Lisbon, which leads to think that the whole LIS-BCN route has a lower efficiency when compared to BCN-LIS. Despite the difference in absolute savings, the savings relative distribution between both flight legs is relatively similar with around 80% coming from the Idle Descent procedure and 12% from the SETO maneuver.

4.1.3 LIS-NCE & NCE-LIS

A flight connecting Lisbon and Nice is already considered a long-haul flight for many regional airlines, even though the Embraer E190 has a range of nearly triple that distance. This makes for a potentially more efficient flight, since the aircraft spends more time in the conditions it was designed to operate - cruising - instead of maneuvering, accelerating or taxiing on the ground.

For this route, Cruise really stands out as the longest and most fuel consuming phase of the flight for both legs (Figure 3), which is to be expected. Fuel consumption in the three main phases reaches above 90% of total values, and therefore, the longer the flight, the more important it is to optimize operations and planning for these flight phases. For the inbound flight, like before, Taxi Out times are reduced by almost 200s, and Taxi In times are close to 40s longer on average, strengthening the hypothesis that Lisbon airport is over encumbered, and thus ground operations suffer from it.
with a significant increase in APU contribution, as well as a small increment for SETO.

4.2. Total Sample Analysis
After studying all the routes one by one, a sample with all the 60 flights was constructed, and the same type of analysis was put into practice to develop a baseline fuel conservation performance analysis for the company as a whole, based on the five strategies applied in this work.

Figure 6: Total average phase time and fuel consumption

Analyzing all the flights, it is clear that Cruise is the longest and especially most fuel consuming phase overall, followed by Climb and Descent (Figure 6). One special note regarding taxi times, which reach a total of almost 16% of the total flight time - still a very significant value. Comparing the total and individual routes results, the similarity between the total results and the LIS-BCN route strikes immediately. Being the intermediate-length flight, it makes sense for the results of the three different routes average to fall somewhere in the middle, which explains the similar flight phase durations and fuel consumption.

Figure 7: Total average savings

Idle Descent, with a little above 2.5% fuel to be saved (Figure 7), is clearly the most significant saving measure, followed by SETO marginally above 0.5% and APU with about 0.25%. It is interesting to note that the more a given measure is dependent on ATC coordination, the higher its saving potential, as illustrated by the dominance of Idle Descent and SETO. This, however, is not a coincidence, and is actually the main reason state of the art software and companies (Section 2.1) are trying to attract the ATC authorities for a transversal effort in the industry towards optimizing fuel conservation.

Table 4: Total average savings estimates

<table>
<thead>
<tr>
<th>Route</th>
<th>Unit</th>
<th>Thrust Rev.</th>
<th>APU</th>
<th>SETO</th>
<th>SETI</th>
<th>Idle Desc.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>0.41</td>
<td>9.19</td>
<td>10.96</td>
<td>2.63</td>
<td>53.22</td>
<td>125.31</td>
</tr>
<tr>
<td>Relative %</td>
<td></td>
<td>0.01</td>
<td>0.27</td>
<td>0.57</td>
<td>0.08</td>
<td>2.70</td>
<td>3.62</td>
</tr>
</tbody>
</table>

Figure 8: Average saving per route in %

The fact that most of the implemented operational procedures, with the exception of Idle Descent, are related to ground operations, allows to predict that the savings potential should decrease, in percentage, with the increase of flight distance - as the relative time spent in the non-airborne stages of flight should also decrease. Indeed, this tendency is confirmed by Figure 8, where the shortest city-pair links present higher values of relative saving than that of the LIS-NCE route overall. However, the LIS-BCN flight presents the highest saving potential, on average, and this has to do with the substantial savings for the Idle Descent measure on all outbound flights, but especially on this route. One
can notice the absolute savings from the remaining measures, in kg, are relatively constant, while the Idle Descent implementation tends to vary significantly from one city-pair to another, and even between inbound and outbound flight legs for the same city-pair. This difference is what explains the dominance of the LIS-BCN route, in terms of relative savings, as this route has more kg of fuel to be saved in Idle Descent than any other.

![Figure 9: Average saving per route in kg](image)

**Figure 9: Average saving per route in kg**

In terms of absolute savings, it is expected that the longer the flight distance is, the bigger its saving potential, however this is not quite the case, as depicted in Figure 9. While the LIS-OPO route presents the lowest saving potential in kg, as expected, flights departing to and from Barcelona outweigh those that fly to Nice. Savings potentials for outbound and inbound flights seem in line with each other, with the exception of Idle Descent, which proves this maneuver has a big margin for improvement when it comes to the Barcelona flights, and while it is fairly straightforward to explain why the OPO-LIS has a smaller saving potential for Idle Descent than the other two inbound flights (due to lower cruising altitudes and therefore shorter descents), it is not quite clear why flights landing in Lisbon coming from Barcelona and Nice have so distinct values, as both flights cruise altitudes and even approach procedures are fairly similar.

Analyzing all of the relative savings results in groups of outbound (blue) and inbound (yellow) flights, it is even more apparent the under-optimization of all flights leaving Lisbon International Airport, and this is mainly due to two reasons: higher SETO average savings potential for all outbound flights, compared to inbound flights for the same route, which proves Lisbon Airport difficulty to deal with the increasing amounts of air traffic it receives, and therefore its lower ground efficiency; and higher Idle Descent average savings potential, especially in Barcelona and Nice, much due to higher air and ground traffic, therefore stricter ATC requirements and regulations, as well as less fuel efficient approach procedures, with the growing number of paths designed for noise abatement in large cities.

### 4.3. Savings Estimation

Perhaps as important as calculating how many kg of fuel could be saved via the implementation of the measures described in this work, is estimating how that translates into yearly savings, in financial terms.

<table>
<thead>
<tr>
<th></th>
<th>Distance (NM)</th>
<th>Duration (s)</th>
<th>Fuel Burned (kg)</th>
<th>Saving Potential (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>32 845</td>
<td>366 606</td>
<td>207 479</td>
<td>7518</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>547</td>
<td>6110</td>
<td>3458</td>
<td>125</td>
</tr>
<tr>
<td><strong>Saving Potential (%)</strong></td>
<td>3.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Final savings estimates results

Comparing Table 5 with the typical operational profile described by Embraer and presented in Section 1.1.1, it is possible to see that in fact the estimates are not too far from reality, regarding average Distance (547 NM vs. 600 NM), Duration (6110s vs. 5400s) and Fuel Burnt (3458kg vs. 3147kg).

Of course these estimates would represent the company operation better the more flights and routes would be analyzed, and possibly come even closer to Embraer estimates since the LIS-OPO route, for example, is less flown than the others and represents a much higher fuel to distance ratio. For a 1% savings estimation, according to the results obtained from the sample, there would be $0.01 \times 3458 = 34.5$ kg of fuel saved per flight, which using Embraer estimates for a 600 NM flight would result in approximately 591 metric tons of fuel saved per year for PGA fleet. In turn, this represents around $591 \times 446.6 = 263\,941$, nearly $235k$, in yearly savings, which is fairly close to Embraer estimate of $212k$.

However, for PGA case, applying just these five simple operational procedures an average total saving of 3.62% was obtained. This means an average saving of 125kg of fuel per flight, which for a typical operational profile of 600 NM, according to Embraer, results in about 2141 metric tons yearly savings in fuel. Considering the average current price of jet fuel in Europe of 446.6 $/mt, this means savings of 956k$, or 850k€ per year.

Nearly one million euros in savings if the full potential of these five savings measures was attained through its correct implementation is a very notable result, and certainly very significant for any airliner. It is important to remind that this result is proportional to fleet size.
4.3.1 Additional Savings

If the full potential of these measures could be achieved under all operating conditions, then PGA would be transporting 3.65% of unused extra fuel on each flight, equivalent to 125kg. In turn, this would increase takeoff and landing weight, leading to trip fuel increase and even premature wear of the landing gear, brakes and tires, increasing maintenance costs as well. This means that if these measures could be reflected in flight planning, reducing the amount of fuel that is uplifted to the aircraft without compromising safety, an additional fuel saving could be attained.

![Figure 10: Expected fuel burn increase adding 200kg of extra fuel](image)

According to Embraer, for each 200kg of extra fuel uplifted to the aircraft, the trip fuel increase changes depending on the trip distance as shown in Figure 10. Even though PGA E-190 is the least influenced by extra weight when compared to the rest of the E-Jets family, it still presents some important potential. According to the estimations on this work, the average distance a PGA flight covers is 547NM, and we can see according to the graph that would translate into approximately 0.25% of additional fuel saved, if 200kg of extra fuel was not uplifted. However, the average fuel saving calculated is 125kg per flight, so the only conclusion possible is that the real saving value would be somewhere below this number, as there is no information about its variation with the weight.

If we assume, for the sake of this estimation, that the saving increases with the weight somewhat linearly, then we can project an additional saving of about half that presented in the graph, as the weight is reduced from 200kg to 125kg. This would result in a saving estimation of about 0.125%, or 4kg per flight, which translates into 68 metric tons yearly, equivalent to an additional 27k€ saved.

5. Conclusions

This project studied the impact of the implementation of fuel efficient operating measures on PGA new Embraer 190 fleet.

5.1. Achievements

The results obtained in this work are very encouraging, as they show that even with simple day-to-day measures, big airlines can save a significant amount of fuel, and therefore, money. However, the full savings potential obtained for this work is not attainable without the cooperation and consequent optimization of local ATC itself. These results are important for airlines to show the local ATC the impact their regulations can have, as away to sensitize them to this issue and count on their support.

5.2. Future Work

The next step in terms of airline optimization is applying the same philosophy to both flight planning and maintenance procedures optimization. Also important would be to gather the pilots’ feedback regarding the measures described in this study, in order to assess its feasibility, ease of application and eventual limitations. This would also sensitize the pilots to the potential savings that can come from their direct actions, and thus help with the transverse effort that is required within the company to achieve such goals. Unfortunately, such feedback was not possible to gather during this work duration, much due to the constant training and flying the pilots were attending because of the new fleet.

References