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A Method for High Level Assessment of the Aeronautical Infrastructure Efficiency

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Abstract

Purpose: The aim of this article is to analyze the evolution of fuel consumption efficiency of the domestic flights in Brazil along the period 2000-2015 in order understand the overall efficiency of the aeronautical infrastructure in this country.

Design/methodology: This article proposes a method for high level assessments of the aeronautical infrastructure efficiency (either on ground or airspace) in a fast and easy to grasp manner, using the key performance indicator of useful distance per flight hour. The method estimates the average flight time spent by the national carriers to accomplish the average stage lengths in each year of the period 2000-2015 and compare these results with the flight time baseline included in the flight planning data of the aircrafts composing the Brazilian commercial aircraft fleet.

Findings: This approach leads to huge differences between the referred results and the fuel consumption shown by flight operations manuals and were attributed to the inefficiencies existing in the acknowledged overloaded aeronautical infrastructure (either in the air or on ground) in Brazil. With that it is concluded that there is a potential reduction opportunity of almost 30% in aircraft fuel consumption in domestic flights in Brazil, which has been until the moment almost unconsidered. Thus, government policy-makers and all stakeholders will be able to quantify the impacts and recommend investments in infrastructure in a well-founded way. Furthermore, the return on investments of public funds, which are especially scarce in the developing countries, will be assessed in a simple manner. Under this scope investments and research on Air Traffic Management (ATM) new technologies and flow management techniques are strongly suggested in order to improve airspace operational efficiency

Originality/value: A new and innovative method for high level assessment of the aeronautical infrastructure efficiency.

Keywords: aeronautical infrastructure, fuel consumption, flight time, inefficiencies and air traffic management

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1. Introduction

In the last years in Brazil it has been found significant differences between the actual fuel consumption per distance flown and the estimations made by the aircraft manufacturers. Very often these estimations have been considered as being an understandable optimism from the latter ones. These differences have a huge impact on the economic performance of the commercial aircrafts because the fuel costs is by far the most important operating cost of the airlines especially in domestic flights Brazil. Actually, fuel costs have grown worldwide very much in the 2000's as a consequence of the persistent and sharp growth trend of the oil barrel international prices. However, in Brazil the magnitude of fuel prices is even higher than the vast majority of the countries in the world as the Figure 1 shows.

As shown in Figure 2, the prices vary greatly if the aviation fuel is used in domestic or international flights. The reason for these differences is related to the huge tax burden on aviation fuel for domestic flights, which, in average, is around 26% of its price. In parallel, the participation of the fuel cost on the airlines total operating costs has grown much along the time, achieving more than 41% in 2012 (ABEAR, 2014). Currently the air transport industry has devoted many initiatives seeking to persuade government officials to reduce the tax burden on aviation fuel. Particularly in Brazil, it has been extremely difficult to reduce fuel state VAT (so called ICMS) due to local government resistance, turning the fuel price in country´s airports the most expensive in the world (as shown in Figure 1 – red labeled airports). In a recent study, Turolla, Lima & Ohira (2011) point this difficulty one of the major challenges tackled by airlines to reduce operational costs in the country.

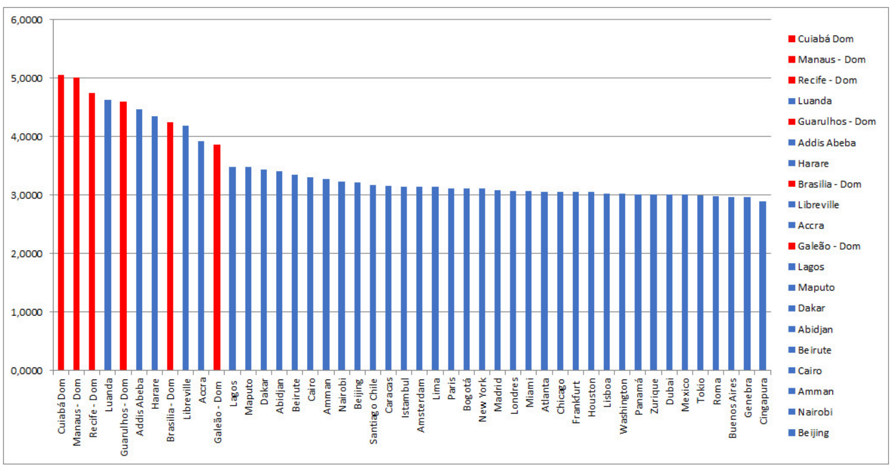

Figure 1. Jet Fuel Costs (USD/gal) in Several Cities by June 2014 (ABEAR, 2014)

Nevertheless, the reduction of operating costs related to the jet fuel has been faced with several efforts towards the reduction of physical consumption exploring aircraft performance and operations techniques. In fact, the wide implementation of Fuel Conservation Programs by airlines, considering specific flight operations and maintenance procedures, may bring potential extra improvements on fuel burn in a range of 1% to 5%, with relatively small amounts of investments. Although this might be seen as a small contribution on operational costs, the impact of fleet savings in the whole network throughout a year is significant. For example, considering a fleet of 120 narrow body aircraft in a low-cost airline, 1% of fuel burn reduction potentially brings 5.7 Million USD annual savings, considering the world average fuel price of 1.00 USD/kg (Mattos, Fregnani, & Magalhães, 2018).

In addition, because of airspace congestion, tactical crew requests to more direct routes are not always allowed by ATC and results in the airplanes taking suboptimal longer routes. This burns more fuel than necessary, takes longer flight times on the associated flight sectors and consequently increases network delays. A study from IATA (2015) suggests that Air Traffic Management initiatives related to airspace capacity improvement and optimization, directly affecting flight delays, have potential to improve fuel efficiencies up to 12%, more than double of the flight operations potential.

Historically, the evolution of aircraft design has always been driven by fuel efficiency. Figure 3 shows that over the last 50 years since the operations of the first generation of jet transport aircrafts, the fuel burn per passenger kilometer (fuel efficiency) has been reduced by over 80%. Worth to mention that today's 4th generation of jet engines and carbon fiber airframe technology are offering 20% improvement in fuel efficiency over 1990`s levels.

Aircraft and the engine manufacturers have been investing heavily to produce the airplanes as fuel efficient as possible. The main areas have direct impact on fuel efficiency are envisioned to be airframe (aerodynamics, structures, equipment systems and new configurations) and engines technologies. It can be easily observed that each subsequent generation of airplane has better weight-to-drag ratios, improved wing performance, and the engines that use less fuel. These efficiencies can be measured and are part of the proposition airlines evaluate when deciding to acquire or lease new airplanes.

Therefore, fuel is the most important single cost element for airlines and, the highly volatile oil prices of the last years have even more increased their need for more fuel-efficient aircraft. Fuel efficiency of civil aviation may be improved by a variety of means, besides new technologies, including the incorporation operations techniques and air traffic management strategies.

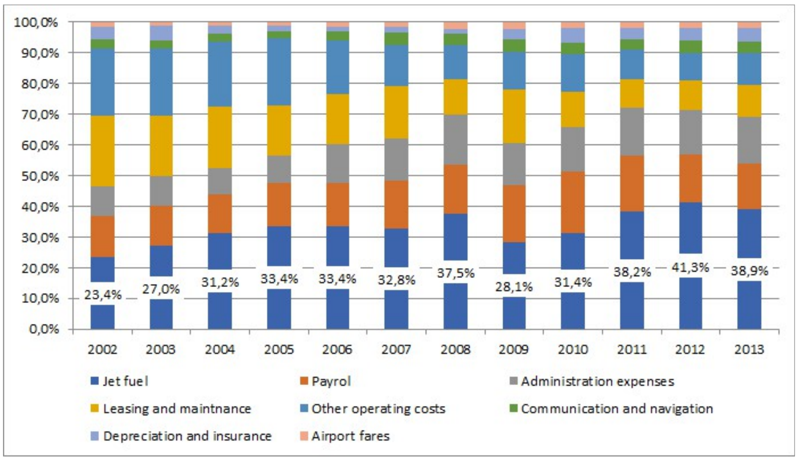

Figure 2. Airlines Domestic Costs Composition in Brazil (ABEAR, 2014)

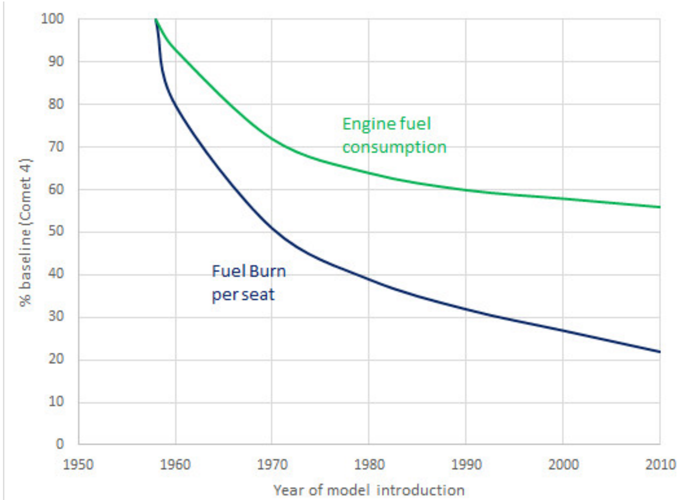

Figure 3. Fuel efficiency gain since the early jet age (ATAG, 2014)

2. Literature Review

The research on aeronautical infrastructure efficiency determination have been widely explored by the academia since early days of air transport. Very sophisticated models have been developed to aim the reduction of enroute and gate delays, greater predictability in flight planning and reduction terminal inefficiencies. Factors that have an important role to play in reducing aviation fuel consumption, such as route shortcuts or minimum ground times, have been frequently introduced in these models.

Under this scope, metrics to evaluate airspace and ground infrastructure efficiency are frequently provided to drive decision makers on infrastructure investments and improvements of the system. Historically, the performance of the aeronautical infrastructure and its impacts on the operating efficiency of its users have been measured primarily by delay metrics. In fact, few advances on this field have been developed so far, once this is a metric very convenient to ATC optimization. Some variations were introduced in order to provide more realistic operational variables. For example, Bolczak, Hoffman, Jensen & Trigeiro (1997) propose a set of key performance indicators for airspace efficiency using average distances/separations and delays statistics for both ground and flight segments.

In the airlines side, efficiency models and metrics always involve fuel efficiency, despite of airspace delays measurements. Significant studies have been recently conducted using airline's data, pointing that operational improvements could impact significantly on the airspace efficiency.

For example, Gwiggner & Nagaoka (2010) analyze the impact of trajectory prediction errors on the fuel efficiency of speed control techniques. A stochastic model of delay propagation is built and conclude that in high traffic densities, a balance between delay absorption on low and high altitudes is reasonable, even when the objective is to minimize fuel consumption.

Ryerson, Hansen & Bonn (2014) analyze actual flight-level fuel consumption data reported by a major U.S. airline, studding possible fuel savings provided by ATM improvements, allowing flights to better adhere to their planned trajectories both enroute and terminal areas. In this study a model is developed to isolate the contribution of airborne delay, departure delay, excess planned flight time, and terminal area inefficiencies on fuel consumption using complex econometric techniques. The results show that, for two common aircraft narrowbody types, the system-wide averages of flight fuel consumption attributed to ATM delay and terminal inefficiencies are 1.0–1.5% and 1.5–4.5%.

Zou, Elke, Hansen & Kafle (2014) propose a ratio-based, deterministic, and stochastic frontier approach to investigate fuel efficiency among 15 large jet operators (mainline airlines) in the US, considering not only fuel efficiency of individual mainline airlines, but also the joint efficiency of each mainline and its regional subsidiaries, as well as efficiency in transporting passengers from their origins to destinations. The study concludes that average airline fuel efficiency for the year 2010 is 9–20% less than that of the most efficient carrier, while the least efficient carriers are 25–42% less efficient than the industry leaders.

Other studies are conducted through a more general approach in the airlines context. For example, Reynolds (2014) study potential causes of flight inefficiencies, developing specific system performance metrics, based on track extensions and operational data related to fuel consumption. Mallikarjun (2015) applies the unoriented DEA network method to measure US airlines' performance compared to that of peer airlines and identifies the sources of its inefficiency. In the same line of research, Cook, Belkoura & Zanin (2017) investigate airspace performance using longitudinal and cross-sectional metric metrics across Europe, the US and China regions.

In the airport side, Liu (2016) evaluates the overall efficiency and the operational efficiencies of aeronautical service sub-process and commercial service sub-process for 10 East Asia airport companies from 2009 to 2013 using Network Data Envelopment Analysis (NDEA).

2.1. Objective

This article proposes a method for high level assessments of the aeronautical infrastructure efficiency (either on ground or airspace) in a fast and easy to grasp manner, using the key performance indicator of useful distance per flight hour, to be explained in the following sessions. It aims to demonstrate that there is a potential reduction opportunity in aircraft fuel consumption in domestic flights in Brazil, which has been until the moment almost unconsidered.

3. Methodology

In order to evaluate the aeronautical infrastructure efficiency, we propose to use as proxy parameter the evolution of fuel consumption efficiency of the domestic flights in Brazil along the period 2000-2015. The main idea is to estimate the average flight time spent by the national carriers to accomplish the average stage lengths in each year of the period and compare these results with the flight time baseline included in the flight planning data of the aircrafts composing the Brazilian commercial aircraft fleet.

For that it is necessary first to define some metrics for distances flown and flight times. In this study distances flown correspond to the total of the spherical distances traveled by aircraft during flights, i.e., correspond to the shorter distances counted between the departure and the arrival points assuming that the Earth's is a perfect sphere with average radius of 6,371km according to the Brazilian Civil Aviation Authority (ANAC, 2011) recommended method for distance reporting. It is worth mentioning that according to the pertinent literature (UK Admiralty Manual of Navigation,1987) (Vincenty, 1975), the difference between the distances calculated by the spherical method and the ones calculated by the WGS84 ellipsoid great circle solution may reach 0,5%, considered irrelevant in this study. Obviously, the distances flown as defined above are smaller than the actual distances effectively travelled by the aircraft. There are three main reasons for the existence of this divergence: 1) the airways in which the aircraft fly, by design, add path lengths to the spherical distances. 2) Due to the congestion of the aeronautical infrastructure or due to adverse weather conditions, often the aircraft are placed on holding awaiting authorization for approach and 3) landing or deviated from planned routes in order to maintain proper in-flight separations by ATC. When this occurs, distances should be computed in addition to the spherical distances. In this study we consider that these additional distances covered are not useful and therefore this difference will be embedded by the additional flight time associated to them. Thus, the spherical distances travelled by the aircraft, will be called herein as **useful flight distances**.

Flight times are herein understood as being the total of the time computed between liftoffs and touchdowns, not considering, therefore, taxi in and out times. Once the total useful flight distances in the domestic sectors are officially reported by the Brazilian official statistics as well as the corresponding flight times, the respective average speed quotient was calculated for each year in the period 2000-2015, herein named useful average distance per flight hour. Furthermore, by dividing the total useful distances flown by the corresponding quantities of landings carried out each year (also available in Brazilian official statistics) the average stage length flown may be calculated on each year.

The **average distance per flight hour** (basekline) were calculated as the weighted average of the economic flight speeds of the aircraft (extracted manufacturers' flight operations manuals) in operation in each year by the respective utilizations of these aircraft. The utilizations of the aircraft were calculated from a database provided by the International Civil Aviation Organization (ICAO) covering 81% of the total flights. The average flight stage lengths as well as the load factors of each aircraft in operation were assumed to be uniform and equal to the industry average. The ratio between the average distance per flight hour and the useful average distance per hour corresponds to a measure of the operational inefficiency of the system in each year.

Similarly, the average minimum fuel consumption per flight hour was calculated by the weighted average of the economic fuel consumption of the aircraft in operation in each year. By multiplying the average minimum consumption per flight hour by the total hours flown in each year it was possible to estimate the minimum fuel burn total in each year. Additionally, by multiplying the minimum fuel burn total by the ratio of the optimal operating speed and the actual useful average distance per hour in the same year one shall have a rough calculation of the annual additional jet fuel expenditure in each year. The additional fuel consumption was multiplied by the corresponding current average price in each year resulting in the financial measure of the additional fuel consumption.

Based on the description above, the following calculation steps are proposed to estimate the overhaul aeronautical infrastructure efficiency:

a. From ANAC's Annual Statistical report for every year (period 2000-2015), calculate the Actual Average Distance Per Flight Hour (Vua) and Average Stage Length (ASL) from as follows:

$$Vua = \frac{TDF}{TFH} \qquad \text{(Equation 1)}$$

$$ASL = \frac{TDF}{TNS} \qquad \text{(Equation 2)}$$

Where: TDF = Total distance flown reported (km), TFH = Total block time reported (h), TNS = Total number of sectors reported.

Distances reported by operators correspond to the total of the spherical distances traveled by aircraft during flights, i.e. the shortest distances counted between the departure and the arrival points assuming that the Earth's is a perfect sphere with average radius of 6,371km according to the Brazilian Civil Aviation Authority (ANAC, 2011) recommended method for distance reporting.

b. From ANAC's Annual Statistical report, based on the reported average stage length for each aircraft type i (Di), Average Calculated Trip Time (ACTTi) is determined according from Operations Manuals Tables/Graphs in the "Short Trip Fuel and Time" sections. In addition, the following assumptions are used to calculate the mission profile for each aircraft types:

- Climb/Descent Speed: standard adopted in the Operations Manuals;
- Cruise Speed: Long Range Cruise (LRC);
- Typical Operational Empty Weight (OEW);
- Payload-range envelope limitations respected;
- Optimum Cruise Altitude (best specific range);
- Most common engine type;
- Standard Domestic Fuel Reserves (RBAC121 domestic);
- Alternate airport distance: 100nm.

Takeoff weight is calculated considering the average payload for the refereed aircraft type in the period and the adequate fuel reserves according to the mission profile. The aircraft types considered in the analysis correspond to 81% of total domestic traffic in the reported years (2000-2015). They were: Boeing 737-300, Boeing 737-300, Boeing 737-500, Boeing 737-700, Boeing 737-800, Airbus 318, Airbus 319, Airbus 318, Airbus 320, Airbus 321, Fokker F28-100, Embraer 135LR, Embraer 145LR, Embraer 170 and Embraer 175.

c. F or each year calculate the Calculated Useful Average Distance per Flight Hour (Vuc) as follows:

$$Vuc = \frac{1}{NF} \frac{\sum_{i=1}^{NF} NF_i \cdot D_i}{ACTT_i} \qquad \text{(Equation 3)}$$

$$NF = \sum_{i=1}^{NF} NF_i \qquad \text{(Equation 4)}$$

Where: NF_i=Number of flights for each aircraft type i, D_i=Reported Average Stage Length for each aircraft type i, $ACTT_i$=Average Calculated Trip Time for each aircraft type i, NF=Total number of flight for the aircraft types considered.

d. For each year calculate the Operational Efficiency Delta (OED) as follows:

$$OED = \frac{Vuc - Vua}{Vua} x\, 100 \qquad \text{(Equation 5)}$$

4. Results and Analysis

Proceeding as the discussed above Table I shows the differences between the useful and average distances per flight hours. It may be noticed that the referred speed differences up to 2006 are in the range between -4% and 3%. Interestingly, the gaps present a significant increase between 2006 and 2007 (3% to 7%) and between 2007 and 2008 (7% and 12%), remaining stable around 11% until 2014 and returning to 2007 levels in 2015. The increase in the difference of average speeds brings evidence that flights were flying, in average, at slower speeds than the predicted in the flight operations manuals, mainly caused by the extension on average flight times.

The authors of this paper have not identified any cause for these abrupt changes between 2007 and 2009, except the increasing load of the system. It is worth mentioning that even the World Cup event in 2014 such index remained stable around 11%, according to the results in Table 1. In fact, the drop to 7% in 2015 suggests that lessons learned in such event (in terms of implementation of new procedures on airspace and slot management) might have improved in the aeronautical infrastructure and therefore bringing fuel efficiency benefits of the airlines when compared with previous years.

It is worth mentioning that in these two periods (2006-2007 and 2008-2009) there was reported a significant increase in the number of take-offs, which came to levels never reached before. In fact, according to ANAC, the air traffic overcame the mark of 700 thousand takeoffs per year in 2009.

It is therefore reasonable to assume that the Brazilian aeronautical infrastructure ceased to be capable to absorb the new levels of use and entered into permanently congestion after that. In discussions the authors had with pilots, system managers and other players in the process, the above conclusion seemed reasonable and adherent to their individual perceptions. However, what is new for all is the magnitude of the impact of the new reality in terms of system efficiency. In addition, in the aeronautical environment there was no awareness of the economic impact of the inefficiencies of the air transport system that came to happen thereafter the biennium 2007-2009.

Although the magnitude of the gap between the average useful distances per flight hour and the reference values in domestic flights in Brazil seems to be large by itself, at this point remains the doubt if this phenomenon is expectable for a complex and intense air traffic as the one prevalent in Brazil.

For the sake of comparison, the same methodology was applied to United States case considering the statistics from 2000 to 2015 as reported by International Civil Organization, as shown in Table 2. It is noticeable that the gap found for this country was significantly smaller than the gap found in Brazil in the recent years. In other words, the numbers suggest that the air traffic in United States is more efficiently managed with the available infrastructure than in Brazil, even being its volume more than sixteen times larger than in the latter country.

Finally, Table 3 presents the economic impact restricting only to costs related to the additional expense of jet fuel up to 2015, derived from Table 1. Therefore, it is estimated that the cost of infrastructure inefficiencies in the last fifteen years may have impacted on US$ 3.6 Billion to the airlines in terms of extra fuel burn, equivalent to acquiring a fleet of 60 brand new narrow body aircraft.

Year	Departures	Kilometers flown	Hours flown	Average Stage Length (km)	Effective Average Distance per Flight Hour Fight Time (km/h) – Reference (a)	Average Distance per Flight Hour Flight Time (km/h) – Baseline (b)*	Difference (b) – (a) (km/h)	Difference (b-a) / (a)
2000	687,346	419,097,826	867,068	610	483	462	-21	-4%
2001	702,159	428,957,136	883,994	611	485	465	-20	-4%
2002	660,287	412,918,907	816,199	625	506	479	-27	-5%
2003	525,960	350,145,816	668,461	666	524	516	-8	-1%
2004	501,203	345,207,195	658,359	689	524	521	-3	-1%
2005	534,609	369,053,258	732,767	690	504	518	14	3%
2006	561,499	403,643,092	788,861	719	512	528	16	3%
2007	605,519	452,604,173	896,752	747	505	540	35	7%
2008	639,416	486,573,964	986,214	761	493	550	57	11%
2009	715,520	563,448,745	1,102,861	787	511	560	49	10%
2010	829,232	673,082,692	1,309,337	812	514	566	52	10%
2011	940,296	771,367,324	1,503,710	820	513	571	58	11%
2012	974,035	796,515,234	1,547,839	818	515	573	58	11%
2013	930,375	767,478,427	1,487,729	825	516	573	57	11%
2014	925,550	772,297,197	1,496,898	834	516	574	58	11%
2015	867,271	755,345,640	1,423,583	871	531	570	39	7%

Table 1. Annual Operating Statistics of the Domestic Passenger Air Transportation in Brazil, Useful Average Distances Flown per Flight Hour and Baseline Values. Note: The average useful distance per hour of reference corresponds to the weighted average of the flight speeds of the aircraft (as per the manufacturers' flight operations manuals recommended economic speed regimes in climb, cruise and descent phases) in operation for each year by the respective utilizations of these aircraft

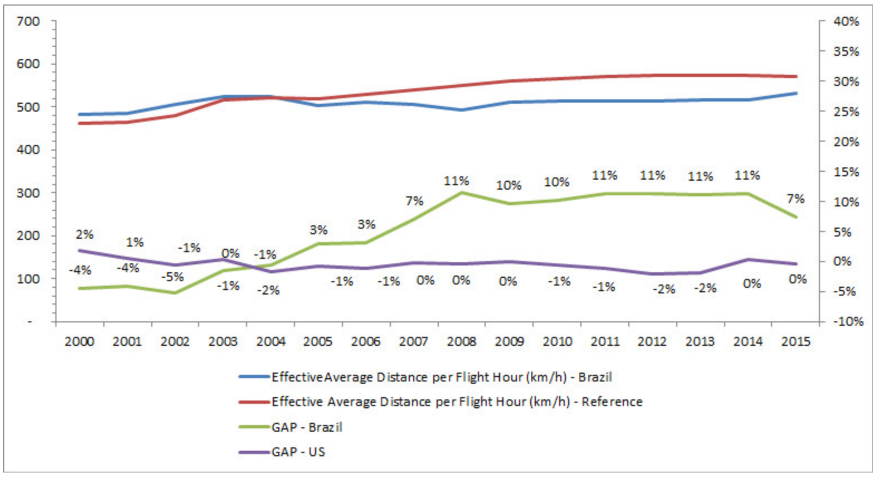

Figure 4. Average Useful Distances per Flight Hour and Reference Values For Domestic Flights in Brazil

Year	Departures	Kilometers flown	Hours flown	Average Stage Length (km)	Effective Average Distance per Flight Hour Fight Time (km/h) – Reference (a)	Average Distance per Flight Hour Flight Time (km/h) – Baseline (b)*	Difference (b) – (a) (km/h)	Difference (b-a) / (a)
2000	8,357,668	8,699,820,000	13,256,402	1,041	656	668	12	2%
2001	7,979,925	8,479,370,000	12,762,108	1,063	664	668	4	1%
2002	7,611,496	8,304,817,000	12,355,131	1,091	672	668	-4	-1%
2003	8,042,069	8,670,046,000	12,877,589	1,078	673	675	2	0%
2004	8,799,530	9,576,562,000	14,243,046	1,088	672	661	-11	-2%
2005	9,140,922	9,954,856,000	14,837,086	1,089	671	666	-5	-1%
2006	8,677,704	9,687,290,000	14,400,067	1,116	673	665	-8	-1%
2007	8,695,565	9,768,379,000	14,519,867	1,123	673	671	-2	0%
2008	8,194,333	9,253,115,000	13,800,556	1,129	670	668	-2	0%
2009	7,952,265	8,763,433,000	13,062,920	1,102	671	671	0	0%
2010	8,002,540	8,981,586,000	13,329,580	1,122	674	670	-4	-1%
2011	7,943,880	9,065,131,000	13,411,842	1,141	676	668	-8	-1%
2012	7,762,498	9,002,892,000	13,208,188	1,160	682	668	-14	-2%
2013	7,782,839	9,092,930,000	13,352,525	1,168	681	668	-13	-2%
2014	8,215,093	8,811,038,000	13,232,244	1,073	666	668	2	0%
2015	8,154,169	8,972,615,000	13,384,711	1,100	670	668	-2	0%

Table 2. Annual Operating Statistics of the Domestic Passenger Air Transportation in United States, Useful Average Distances Flown per Flight Hour and Reference Values. Note: The average useful distance per hour of reference corresponds to the weighted average of the flight speeds of the aircraft (as per the manufacturers' flight operations manuals recommended economic speed regimes in climb, cruise and descent phases) in operation for each year by the respective utilizations of these aircraft (ANAC)

Year	Estimated minimum fuel burn (l)	Approximate additional expense (%)	Approximate annual expense (%)	Average unit price(USD/l)	Additional expense (USD million)	Additional emissions (CO_2 tonnes)
2000	1,771,780,717	-4,5%	-79,730,132	0,68	53,0	205,704
2001	1,867,268,905	-4,2%	-78,425,294	0,57	45,0	202,337
2002	1,890,738,555	-5,2%	-98,318,405	0,71	69,8	253,661
2003	1,632,557,078	-1,49%	-24,325,100	0,71	17,2	62,759
2004	1,734,680,824	-0,7%	-12,142,766	0,85	10,3	31,328
2005	1,890,583,462	2,81%	53,125,395	1,11	58,9	137,064
2006	2,121,558,592	3,15%	66,829,096	1,19	79,7	172,419
2007	2,377,314,314	6,95%	165,223,345	1,21	199,6	426,276
2008	2,660,035,848	11,5%	305,904,123	1,47	450,2	789,233
2009	3,315,379,624	9,55%	316,618,754	0,93	293,3	816,876
2010	4,308,896,023	10,1%	435,198,498	1,12	488,5	1,122,812
2011	4,933,636,822	11,375%	561,201,189	1,37	769,0	1,447,899
2012	5,196,724,508	11,263%	585,307,081	1,30	758,8	1,510,092

2013	5,101,432,019	10,988%	560,545,350	1,29	723,2	1,446,207
2014	5,133,462,401	11,235%	576,744,501	1,30	749,7	1,488,001
2015	5,020,785,338	7,365%	369,780,840	1,32	488,1	954,035
Total	50,956,835,030	7%	3,703,536,474	1,31	4,864	9,555,124

Table 3. Annual Additional Expenses for Fuel and Carbon Emission in the Domestic Passenger Air Transport in Brazil. Note: At unit prices as of January/14 (IPCA – Índice de Preços ao Consumidor Amplo, published by Instituto Brasileiro de Geografia e Estatística) converted to current USD. The ratio of 2.58kg of CO_2 per liter of aviation kerosene consumed was considered

5. Conclusions

As it was demonstrated the air transport infrastructure in Brazil was able to accommodate the significant growth in the recent years (2000-2015) but started to show reduction in efficiency after ramping up in 2007 to 2009, being accentuated when air traffic overcame the mark of 700 thousand takeoffs per year. Although investments in infrastructure have been made by the Brazilian Aeronautical Authorities, with technical excellence, this effort has not been enough to reverse the inefficiencies due to air traffic congestion. Although the Brazilian system has been capable to accommodate traffic growth, the impact of the aeronautical infrastructure inefficiencies has not been negligible in economic and in environmental terms as demonstrated above. Apart from that, it was demonstrated that Brazil had been able to operate a relatively efficient air transport system until 2007, with extra fuel consumptions in a range of 3% to 5%. In parallel, by comparing the efficiency of air transport in Brazil with the one existing in United States, vis-à-vis the disparity of the air traffic volume between these two countries, it may be concluded that inefficiency (adopting the proposed methodology) is not intrinsically related to high air traffic volume.

Figure 4 and Table 3 provide the basis for computing good average numbers for potential improvement in efficiency in the Brazilian airspace. It is observed that since 2008 an average extra fuel burn of 10% has been calculated (adopting the proposed methodology), representing a clear opportunity for improvement of fuel efficiency. Further studies in this field in Brazil should concentrate in determining where are the sources of air traffic congestions are this country -either in the air or on the ground- given the magnitude of the economic resources and the damage to the environment involved, as shown in Table 3.

According to ICAO (2003), Air Traffic Management initiatives have potential to improve fuel efficiencies up to 12%, which is more than the potentials provided by operational procedures and fuel conservation policies adopted by airlines. This area may be considered as the ultimate enhancement of flight operations initiatives once technology developments on this area have direct impact on the operations of aircraft with potential to mitigate the inefficiencies shown in this paper. In addition, more and more the integration of onboard and ground systems (related to new CNS/ATM technologies) have been driven the efficiency of the airspace as a whole, considering all stakeholders (airlines, airports and air navigation service providers). Under this scope, investments and research on Air Traffic Management (ATM) new technologies, especially related to flow management techniques, are suggested in order to improve airspace operational efficiency in the Brazilian Airspace.

Finally, it is worth mentioning that on-going Brazilian industry developments, mostly concentrating on short term actions (as per the nature of the work and activity of the authorities and airlines) are already in place under collaborative decision-making models. OEMs, providers of air space technologies and services are also industry stakeholders that could actively contribute in such initiatives, helping to address strategic actions that will result in harmonizing the future fuel efficiency opportunities and prioritizing actions with higher potential gains.

Declaration of Conflicting Interests

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