AN OVERALL ASSESSMENT OF THE FUEL CONSUMPTION EFFICIENCY OF THE DOMESTIC FLIGHTS IN BRAZIL (PERIOD 2000-2015)

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ABSTRACT

The purpose 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. The methodology used was to estimate 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. This approach indicates huge differences between the referred results and the fuel consumption indicated 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. 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. 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

Keywords: aeronautical infrastructure, fuel consumption, flight time, inefficiencies.

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.

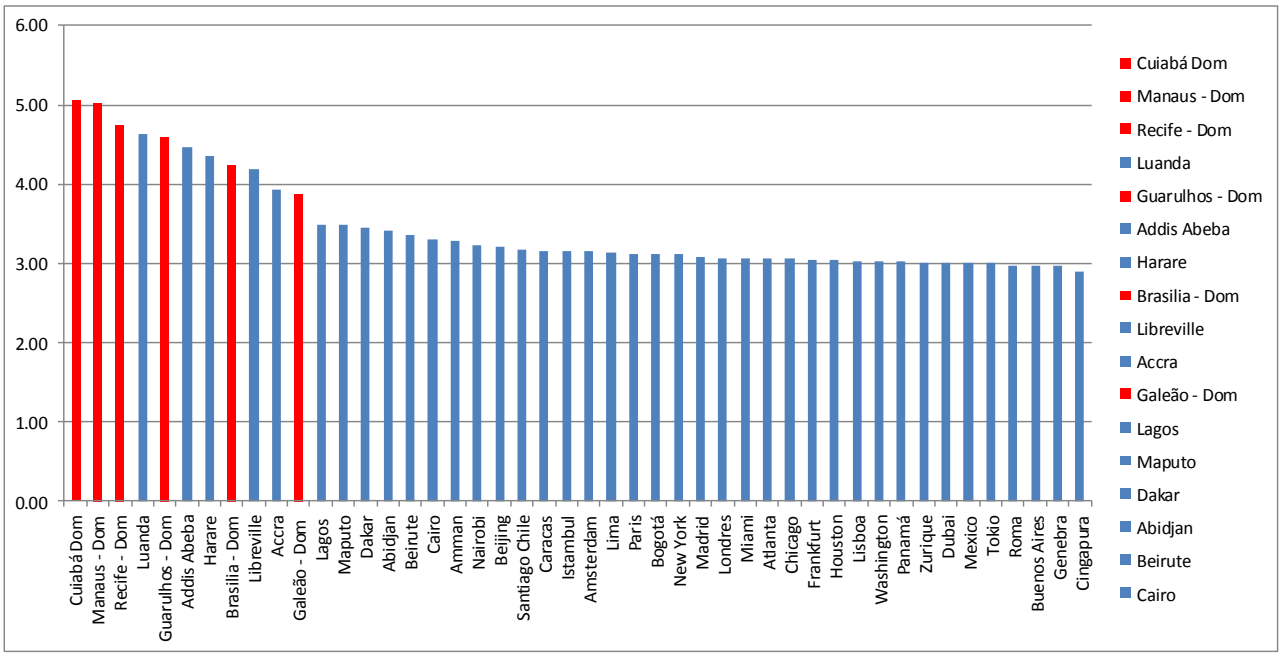


Figure 1: Jet Fuel Costs (USD/gal) in Several Cities (ABEAR, 2013)

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,2013). The air transport industry has devoted much effort seeking to persuade government officials to reduce the tax burden on aviation fuel. However, it is known to be extremely difficult to reduce taxes since the government resistance to this kind of initiative is very large. Nevertheless, the reduction of operating costs related to the jet fuel has not been faced with the effort that might be expected from the side of the reduction of physical consumption. In fact, the efforts of airlines in this direction have been timid, limited to aspects related to improving the

performance of the aircrafts. This article will demonstrate 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.

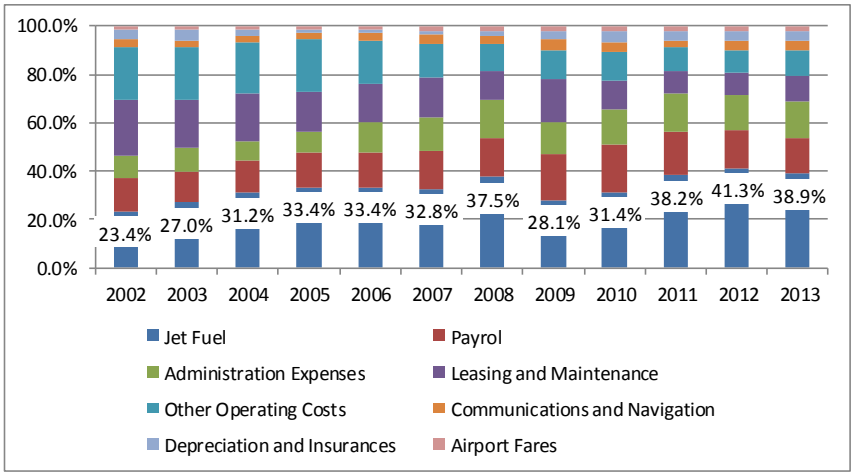


Figure 2: Airlines Domestic Costs Composition in Brazil (ABEAR, 2013)

Fuel Efficiency

Historically, the development of aviation has always been driven by fuel. **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.

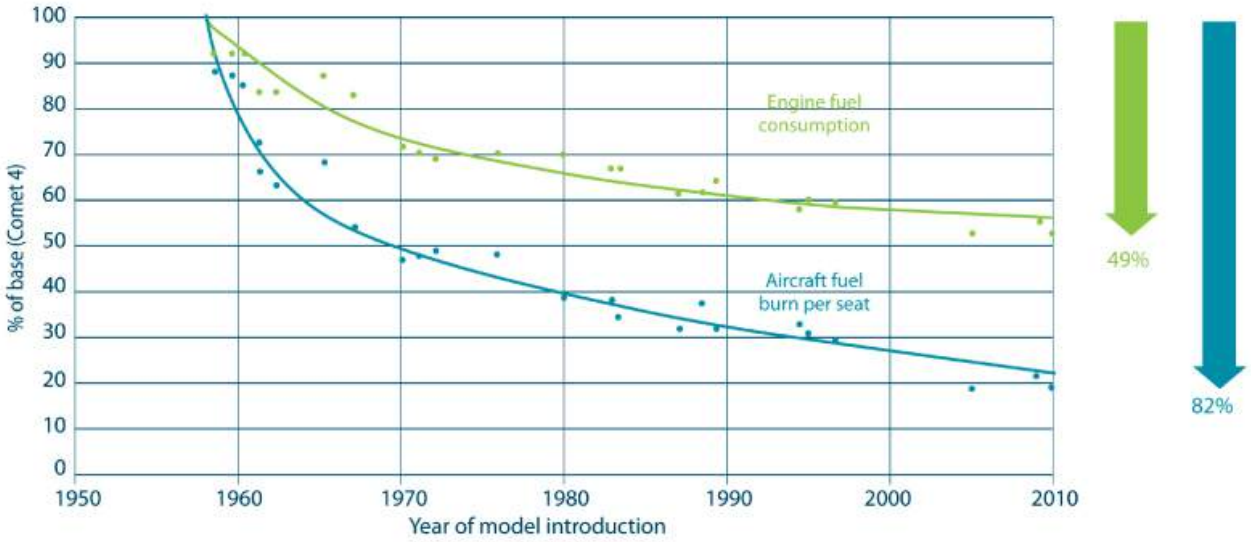


Figure 3: Fuel efficiency gain since the early jet age (ATAG, 2014)

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.

Fuel is actually 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 can be improved by a variety of means, besides new technologies, including the incorporation operations techniques and air traffic management strategies. Fuel conservation programs are widely adopted by airlines and present potential extra improvements on fuel efficiency on the range of 5% to 10%, with relatively small amounts of investments from airlines. Finally although all technological and operational options, airspace congestion may not permit airplanes to be flown the most costly efficient routes and therefore may represent a bottleneck towards the optimum operations. Because of congestion, tactical crew requests are not always allowed and results in the airplane taking a suboptimal routing, burning more fuel than necessary and taking longer to transit the associated flight sector.

2. METHODOLOGY

For the development of this article it is necessary first define some metrics used herein such as distances flown and flight times. In this text, 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 reporting1 . It is worth to mention 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%, which was considered irrelevant for the purpose of this paper.

Flight times are herein understood as being the total of the times computed between liftoffs and touchdowns, not considering, therefore, taxi times.

Actually, the distances flown as defined above are smaller than the distances effectively travelled by the aircraft. There are two main reasons for the existence of this divergence. Firstly, the airways in which the aircraft actually fly, by design, add path lengths to the spherical distances. Secondly, 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 landing. When this occurs, distances are travelled and that should be computed in addition to the spherical distances. In both cases the additional distances covered are not useful and in this article will be measured by the additional flight time needed to cover the corresponding spherical distances. Thus, the spherical distances travelled by the aircraft will be called herein useful flight distances. Once the total useful flight distances in the domestic sector are provided by the Brazilian official statistics as well as the corresponding flight hours, the respective quotient was calculated for each year in the period 2000-2015, which was named useful average distance per flight hour. Furthermore, by dividing the total spherical distances flown by the corresponding quantities of landings carried out each year (also available in Brazilian official statistics) it was calculated the average stage length flown each year. As in the first minutes of flight the speed of the aircraft are smaller (climb to cruise altitude) it would be expected that to the growth of flight averages stage length correspond to the increase in useful average distance per hour. However, this did not occur as it will be discussed below.

On the other hand, it was built a reference curve based on the weighted average of the economic flight speeds of the aircraft (as indicated by the 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. As can be seen, the speed given in each year by the reference curve corresponds to the optimum operating speed which provides the minimum fuel consumption. The proportion between the ideal operating speed 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.

3. FINDINGS

Proceeding as the discussed above and based on the annual statistics reported by the International Civil Aviation Organization (ICAO) for the domestic air transport of passengers in Brazil and United States, the take-offs made and the distances and hours flown in each year between 2000 and 2015 have been computed. The average stage lengths and the actual useful average distances per hour were calculated by simple arithmetic calculation. Besides, the reference average useful distance per hour was calculated as described above, i.e., based on the flight operations manuals of the aircrafts composing the fleet operating each year. As can be seen, at the beginning of the period of analysis the differences between the actual and the reference useful distances per hour are not relevant and attributable to acceptable differences between the straight distances between the origin and the destination points and those imposed by the airways in which aircraft actually fly. Thus, the referred differences in the beginning of the period are situated around 5% and increase to 34%. Interestingly, the gaps grow much between 2008 and 2009 and between 2009 and 2010 and remain so until the end of the period. **Tables 1** illustrates the above comments.

Table 1: Annual Operating Statistics of the Domestic Passenger Air Transportation in Brazil, Useful Average Distances Flown per Flight Hour and Reference Values (*).

Year	Takeoffs	Km flown	Flight Hours	Average stage length (km)	Useful average distance per hour (km/h) – Actual (a)	Average useful distance per hour (km/h) – Reference (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	- 21	-4%
2002	660,287	412,918,907	816,199	625	506	479	- 26	-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	- 4	-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	12%
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%

(*)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.

The authors of this paper have not identified any cause for these abrupt changes except the increasing load of the system. Thus, in those two years (between 2008 and 2009 and between 2009 and 2010) there was a significant increase in the number of take-offs, which came to levels never reached before. 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. 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 mean there was not awareness of the economic impact of the inefficiencies of the air transport system that came to happen thereafter the biennium 2008-2010. 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.

Table 2: Annual Operating Statistics of the Domestic Passenger Air Transportation in United States, Useful Average Distances Flown per Flight Hour and Reference Values (**).

Year	Takeoffs	Km flown	Flight Hours	Average stage length (km)	Useful average distance per hour (km/h) – Actual (a)	Average useful distance per hour (km/h) – Reference (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	- 13	-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	- 10	-1%

(**)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. Sources: ANAC

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.

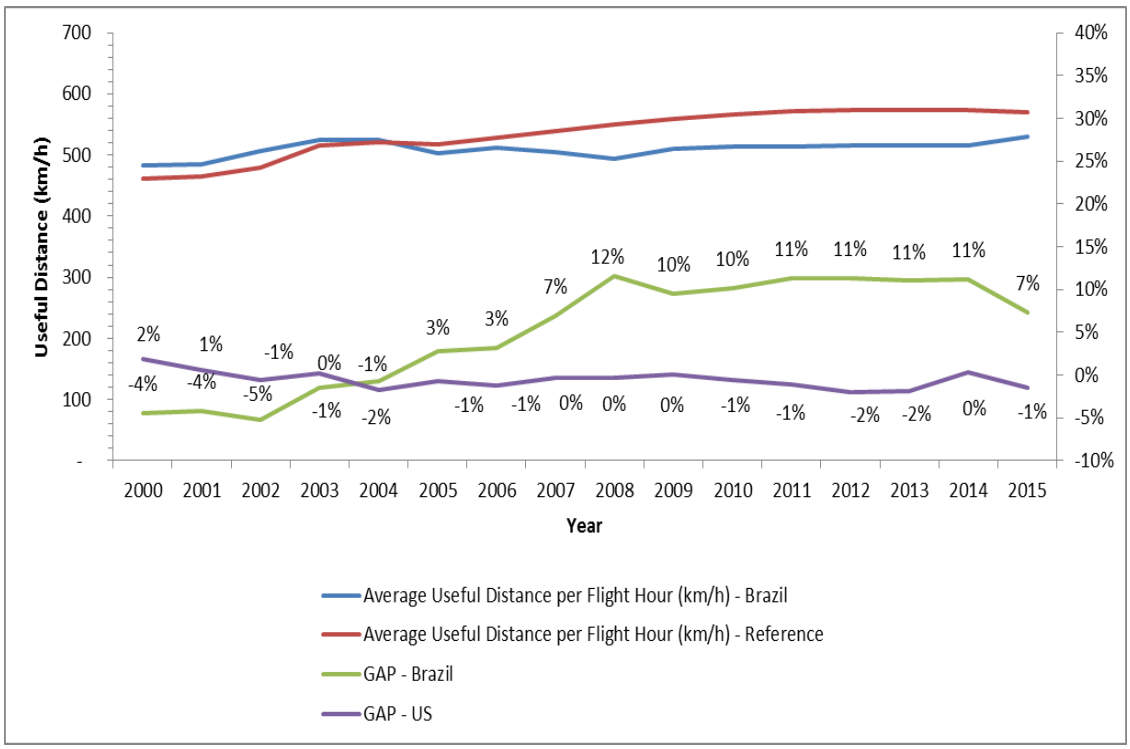


Figure 4: Average Useful Distances per Flight Hour and Reference Values For Domestic Flights in Brazil

Table 3 – Annual Additional Expenses for Fuel and Carbon Emission in the Domestic Passenger Air Transport in Brazil (*)

Year	Estimated minimum fuel burn (l)	Approximate additional expense (%)	Approximate annual expense (l)	Average unit price (USD/l)	Additional expense (USD million)	Additional emission (CO2 ton)
2000	1,771,780,717	-4%	- 78,547,429	0.68	- 53.0	- 202,652
2001	1,867,268,905	-4%	- 79,427,970	0.57	- 45.0	- 204,924
2002	1,890,738,555	-5%	- 98,928,124	0.71	- 69.8	- 255,235
2003	1,632,557,078	-1%	- 24,280,542	0.71	- 17.2	- 62,644
2004	1,734,680,824	-1%	- 12,149,105	0.85	- 10.3	- 31,345
2005	1,890,583,462	3%	53,200,469	1.11	58.9	137,257
2006	2,121,558,592	3%	66,973,542	1.19	79.7	172,792
2007	2,377,314,314	7%	165,237,829	1.21	199.6	426,314
2008	2,660,035,848	12%	306,727,073	1.47	450.2	791,356
2009	3,315,379,624	10%	316,510,882	0.93	293.4	816,598
2010	4,308,896,023	10%	435,739,942	1.12	488.6	1,124,209
2011	4,933,636,822	11%	561,142,167	1.37	769.0	1,447,747
2012	5,196,724,508	11%	585,298,212	1.30	758.8	1,510,069
2013	5,101,432,019	11%	560,544,187	1.29	723.2	1,446,204
2014	5,133,462,401	11%	576,679,182	1.30	749.7	1,487,832
2015	5,020,785,338	7%	369,774,674	1.32	488.1	954,019
Total	50,956,835,030	7%	3,704,494,987	0.98	3,626.0	9,557,597

(*) 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 CO2 per liter of aviation kerosene consumed was considered.

4. 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 this 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 to mention 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.

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