Innovative Aircraft in Air Transport Industry – a Comparative Analysis of Airbus and Boeing

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The purpose of the paper is to examine product innovation which enables achieving higher fuel efficiency by its lower usage per unit, introduced by two leading competitors on the market of narrow- and wide-body aircraft, which are Airbus and Boeing. Technological, economical and environmental impact of product innovations are discussed. The method includes a mathematical formula to calculate fuel usage per Available Seat Kilometre (ASK). The average fuel consumption for chosen models of Airbus and Boeing as closest competitors is presented. The result of the study is to indicate the most competitive aircraft of Airbus and Boeing accordingly, which are more fuel efficient in average estimates and contribute to lower emissions, as externalities to natural environment. Indicated aircraft types can be recommended for airlines in context of economical efficiency in viewpoint of lower exploitation cost and effective fleet management.

Keywords: air transport industry, aircraft fuel efficiency, innovations, Airbus, Boeing.

1. INTRODUCTION

Instability of fuel prices and their high share in exploitation cost of an aircraft, determines innovative approach in search for better efficiency. Aircraft producers, following demand of airlines to purchase and maintain in their fleet the most cost efficient planes, design and launch jets which use less fuel. The paper presents innovative solutions, implemented in aircraft production, containing: usage of composite materials, new generations of engines, more aerodynamic shape of construction elements i.e. winglets and its impact on fuel efficiency. The selected narrow-body as well as wide-body aircrafts of Airbus and Boeing are compared, which can be interchangeably operated and maintained by airlines to serve passengers, according to their number of seats and route length.

The results are important, because they allow an easy appraisal of how changes in an airline's fleet and operating characteristics, and in the fuel price it faces, affect fuel consumption and level of carbon emissions, respectively. Moreover, the outcome has a practical significance, comparing aircrafts offered on the market and model designed to be introduced in the foreseeable future.

2. DETERMINANTS OF INNOVATIVE CIVIL AIRCRAFT

Airlines operating in changing environment are exposed to the risk of external factors, affecting demand on the market, such as economic crises, terrorist attacks, wars, epidemic, volcano eruption, weather conditions, etc., exerting impact on number of passengers carried, and in consequence financial result. Moreover, there are components of operating costs, directly influencing profitability, relatively to its share in the expenditures in comparison to the effects. Undoubtedly, fuel is one of the highest operating costs, regarding economy of scale, in aircraft exploitation.

According to IATA estimation, based on data of member airlines, fuel and oil expenditures constitute about 25 per cent of overall operating cost. Moreover, flight equipment maintenance represents even 12 per cent of operating cost. Admittedly, fixed costs related to aircrafts are relatively high. In air transport one can identify significant scale effect [Button, 2010]. Therefore, it is essential to reduce fuel consumption to gain lower unit cost of airlines business. It can be achieved, inter alia, by introducing innovative, more fuel-efficient aircrafts.

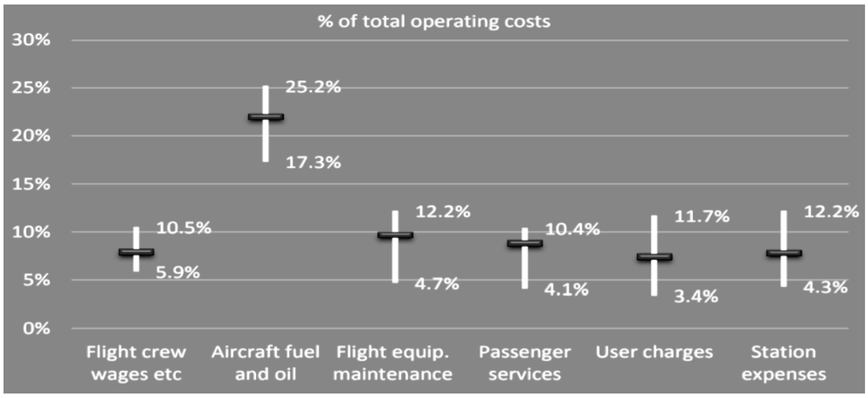

Fig. 1. The structure of main airline's operating costs in year 2016 (in %). Source: own elaboration based on IATA Economics.

1Furthermore, one can observe several oil crises in economic history, which affected approach to search for more fuel efficient solutions in many sectors, as well as aircraft production [Epstein, 2017]. In the past decades and at present, one can observe changeable jet fuel prices, with strong correlation to oil cost. Several years of extremely high fuel prices have been noted, with great impact on airlines economics and profitability.

Within the last decade 2006-2016 oil price was relatively high and unstable. At the beginning of the 21st century, the price on the world market fell and a barrel cost approximately 24 USD. The breakthrough was in 2003, due to the Iraq war and the OPEC policy to reduce oil supply. In consequence a several-year upward trend lasted to 2008, when oil barrel reached an average annual value of more than 99 USD. Compared to 2003, when about 29 USD was paid, there was a price increase of over 240 per cent within five years. The historic level of almost 128 USD per barrel arose during the global financial crisis, lasted in years 2008-2009. It made the situation of airlines additionally difficult. Firstly, there was a decrease in demand and number of passengers carried, resulting in falling revenues. Secondly, high prices of fuel increased operating cost of airlines. Economic and fuel crises affected the profitability significantly.

The recovery was achieved in the following years, through oil price drop and relatively higher demand for air travel. Unfortunately, after the tide of declines, the next several years of intense oil price growth took place, up to more than 110 USD per barrel in 2012. Afterwards, one could observe a decreasing tendency. Record-breaking in this respect was 2014, when prices fell by 46 per cent and 2015, with the drop of 30 per cent and end-of-year prices of around 37 USD per barrel. The favourable downward trend was due to the fact that OPEC did not limit its supply, as well as a result of resumption of extraction by the US and entering the market of additional supply from Iran. At the beginning of 2016, oil continued to fall below 30 USD, which means a return to the price from the beginning of the 21st century. In the middle of the year 2017 a barrel price was approximately 47 USD and a few analysts forecasted possible further increase. Oil prices are subject to significant fluctuations and they have an impact on airlines operating cost and profitability.

Table 1. Fuel cost for the world airline industry in years 2003-2016.

Year	Fuel share in total operating cost (%)	Average oil price per barrel (USD)	Break-even oil price per barrel[1] (USD)	Fuel cost for airline industry (billions USD)
2003	14	28.8	23.7	44
2004	17	38.3	34.7	65
2005	22	54.5	52	91
2006	28	65.1	68.1	127
2007	30	73	81.7	146
2008	36	99	83.4	204
2009	28	62	59.1	134
2010	28	79.4	89.8	152
2011	31	111.2	116.1	191
2012	33	111.8	117.1	228
2013	33	108.8	114.8	230
2014	32	99.9	109.3	226
2015	27	55	72.2	180
2016	21	51	69	135

Source: own calculations based on IATA Economics.

[1] *Break-even price* – fuel price, which does not cause losses or profits for aviation sector.

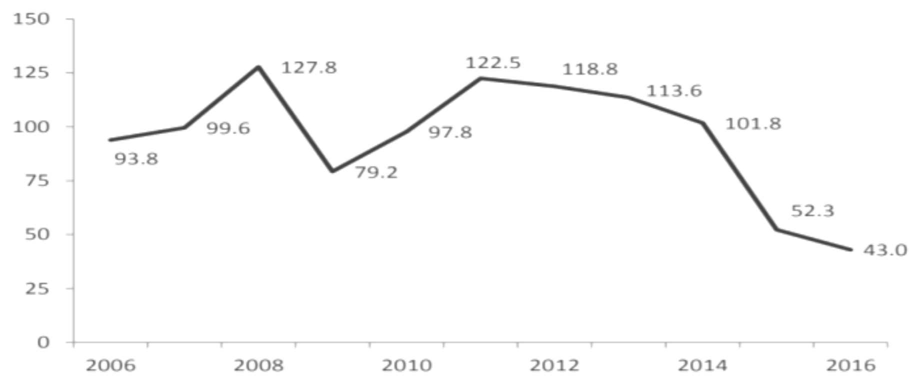

Fig. 2. Average real oil prices per barrel in years 2006-2016 (in USD). Source: own elaboration on the basis of IMF and IATA data.

As it is proved, oil price has a significant impact on fuel share in operating cost of airlines. Within the years of relatively lower oil prices it was below 20 per cent. Whereas in period of oil crises, fuel share reached level up to 36 per cent (in 2008). Despite the increase in fuel price in years 2011-2014, the share in overall operating cost was relatively low. One can formulate a hypothesis that it was an effect of introducing innovative aircraft into airlines' fleet. In subsequent years 2015-2017, decreasing fuel prices contributed to lower fuel cost for airline industry, which was reinforced by operating innovative, more fuel efficient aircrafts, with better perspectives for financial results and competitive advantage.

3. RELATED LITERATURE

Aircraft producers are obliged to follow demand and requirements of airlines, facing the challenge of achieving effectiveness, in pursuit of revenue and profit maximization. From the viewpoint of transport economics [Spurling, 2010], one can observe relatively high fix costs in airline industry. It is essential, to rationalize fleet utilization, to achieve the highest possible load factor, by serving more passengers. Airlines benefit from the economy of scale [Button, 2010], and capacity utilization [Jara-Diaz, Cortez & Moralez, 2013]. Therefore, it is crucial to purchase and maintain in their fleet innovative aircrafts, which provide relatively lower fuel consumption and operational savings, accordingly. Moreover, aircraft offering, through innovative seats location, more capacity to carry relatively higher number of passengers, enables economic efficiency.

Additionally, lower fuel consumption of aircrafts results in limitation of carbon emissions, which is a concern of airlines and the entire industry [Brueckner, Zhang, 2010]. Recognizing the importance of climate change and environmental impact of airlines, the European Union formulated in 2012 a plan which demands from all airlines operating on the EU market to acquire allowances under their emission trading system (ETS). Finally, the charges concept was limited to EU member states airlines [Brueckner, Abreu, 2017; Albers, Buehne and Peters, 2009]. Following the EU's efforts, the UN's International Civil Aviation Organization (ICAO) in 2016 proposed two emission-reduction programs with an international scope [Brueckner, Abreu, 2017]. There are two main drivers of innovations in aviation: economic efficiency and pursuit to achieve a competitive advantage, as well as environmental impact and aim to reduce carbon emissions.

In the discussed literature there are sources and types of innovations in carrier aviation and spread of the technology changes [Hone, Friedman, 2011]. The introduction of advanced-technology airplanes, in a combination with new business models of airlines in conditions of open skies agreements and market liberalization, is considered as a milestone in aviation [Taneja, 2010, pp. 246-250]. On the global market of jet civil aviation aircrafts, one can observe duopoly, with a dominant position of two manufacturers: Airbus and Boeing [Vasigh, Fleming, Tacker, 2016, p. 229], introducing innovations with impact on long-haul and medium-haul routes operations.

V. Singh and S. K. Sharma present a literature review concerning fuel consumption optimization in air transport [Singh, Sharma, 2015]. In particular the air transport efficiency and its measures are discussed. Several authors describe methodology to calculate fuel efficiency of aircrafts. Fuel burning rates of commercial passenger aircrafts are presented, depending on seats configurations, taking into consideration new models of airplanes.

Emphasis is given to correlation between fuel consumption and emissions and widely spoken externalities [Park, O'Kelly, 2014].

B. Zou, M. Elke, M. Hansen distinguish *fuel efficiency* as well as *fuel inefficiency* of aircrafts. As fuel efficient considered are market leaders. As inefficient recognized are types of aircrafts with relatively higher fuel consumption in comparison to fuel efficient benchmarks. Methodology to calculate fuel efficiency is based on input-output analysis. Ratio-based metrics measure the amount of fuel to produce a unit output, or the amount of output produced with the consumption of one unit of fuel. Output measure can be aircraft capacity expressed by Available Seat Miles (ASM) or Available Seat Kilometres (ASK), depending on the unit accepted. It can also be assumed to use indicator of Revenue Seat Miles (RSM) or Revenue Seat Kilometres (RSK) accordingly [Zou, Elke, Hansen, 2012, pp. 8-9].

Aircrafts productivity, except of their technical characteristics, depends on their utilization by airlines and factors such as: number of flight departures per day with the existing aircraft fleet, the average stage length and number of seats [Belobaba, Odoni, Barnhart, 2009, p.147]. Larger aircrafts are confirmed as relatively more efficient, in terms of marginal operating cost [Givoni, Rietveld, 2009; Swan, Adler, 2006].

Production strategies of Airbus and Boeing are different and contrasting. Boeing is focused to offer medium sized aircrafts enabling long-haul flights. Airbus follows opposite strategy, to provide large size types, such as A380 [King, 2007]. Airbus is a market leader from the viewpoint of the largest aircraft construction, whereas to Boeing belongs a record of the longest flight range. Specific approach of the duopoly companies to the aircraft production and implemented innovations are a subjects to examine. The paper evaluates the differences between a wide range of aircrafts and specific models as direct competitors to prove and examine a range of innovations and fuel efficiency.

4. THE ROLE AND TYPES OF INNOVATIONS IN AIRCRAFT PRODUCTION FOR LOWER FUEL CONSUMPTION

Since aircrafts launch into the market, engineers have been constantly striving to improve them and make the construction more efficient. In aviation, fuel efficiency correlates directly to the distance an aircraft can fly, the amount of payload it can carry and importantly, better environmental performance [ATAG, 2017]. There is a wide range of innovations concerning new and more modern models of aircrafts. Among many changes in design and production of aircrafts, in pursuit of achieving better fuel efficiency, one can distinguish the following [Wald, Fay, Gleich, 2010]:

- growing usage of light composite materials,
- new generation of engines,
- more aerodynamic types of winglets,
- additional seats through space reorganization,
- construction modifications.

Aircraft producers understood the principles of aerodynamics, although the advantage of heavier-than-air machines depended upon the availability of lightweight and efficient engines. In the last 40 years airline industry has focused on growth in efficiency. Faced with the challenge of delivering more powerful aircraft at lower noise levels, engine designers developed the extraordinary 'high-bypass ratio' engine which, since the 1970s, has delivered a quantum increase in power and a significant decline in noise. Owing to the continued evolution of the high-bypass turbofan, aircrafts are nowadays 50% quieter on average than they were 10 years earlier [ATAG, 2017; Epstein, 2017].

We can also observe a perceivable growth in the usage of composite materials in aircraft construction throughout the years. Less heavy constructions require lower fuel consumption. In the recent decades, as an aftermath of oil crises and precaution to further high fuel prices, aircraft producers followed a strategy to design lighter constructions, made of composite materials and their use increases successively in new models of aircrafts.

Comparing Airbus A 320 Family, launched in 1987 into the market, with its counterpart and main competitor – Boeing B 737 (produced since 1968), one can assume that aircrafts A320 were the first machines that are so much built with the use of composite materials. Moreover, airplanes of this family are the first civilian machines equipped with a *fly-by-wire* control system, in which there are no direct mechanical or hydraulic connections between the steering surfaces and the cockpit [Tooley, Wyatt, 2007].

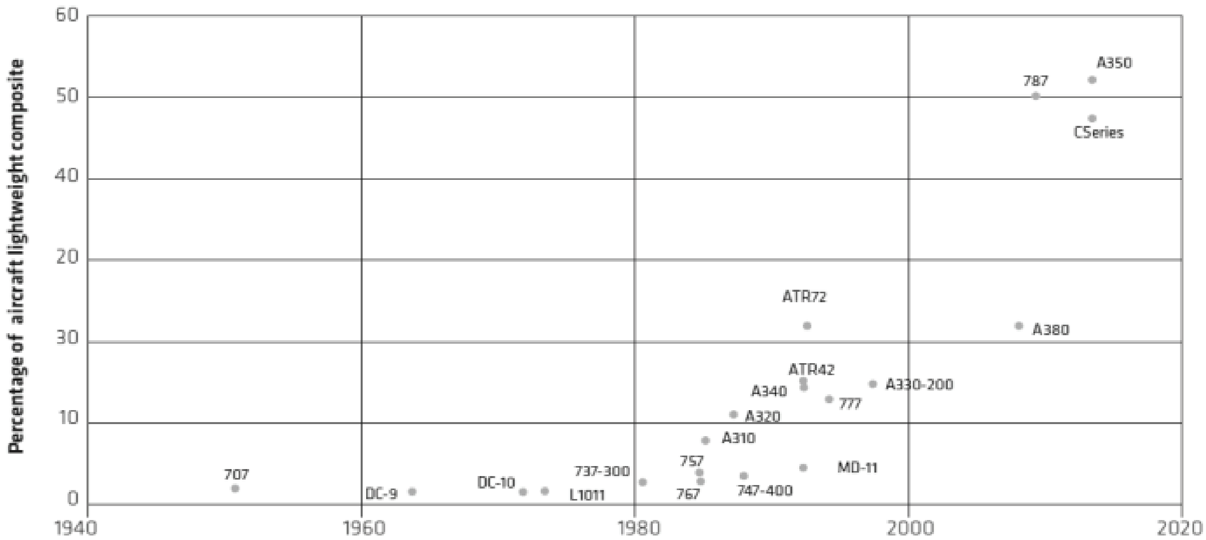

Fig. 3. Use of composites in aircraft construction in years 1950-2017 (in %). Source: own elaboration based on ATAG.

Taking into consideration the leading wide-body aircraft: supreme Airbus A 380 (introduced in 2007 as the largest in the market) and Boeing B 787 Dreamliner (in service since 2011), there is a noticeable advantage of the American construction, that is 20 per cent more fuel efficient than its antecedent Boeing 767, which was intended to replace it. However, Airbus A 350 introduced in 2015 is characterized by the highest contribution of composites, up to 60 per cent [Palmer, 2017].

of fuel consumption per 100 passenger kilometres. Moreover, wide-body A380s and B787s consume up to 3 litres of fuel per 100 passenger kilometres [Williams, O'Connell, 2011, p. 88].

There are four pillars of technology with the impact on increase in aircraft fuel efficiency. The progress in fuel efficiency in the aviation industry is significant. New aircrafts are 70% more fuel efficient than 40 years earlier and 20% better than a decade ago. Modern jets have achieved 3.5 litres

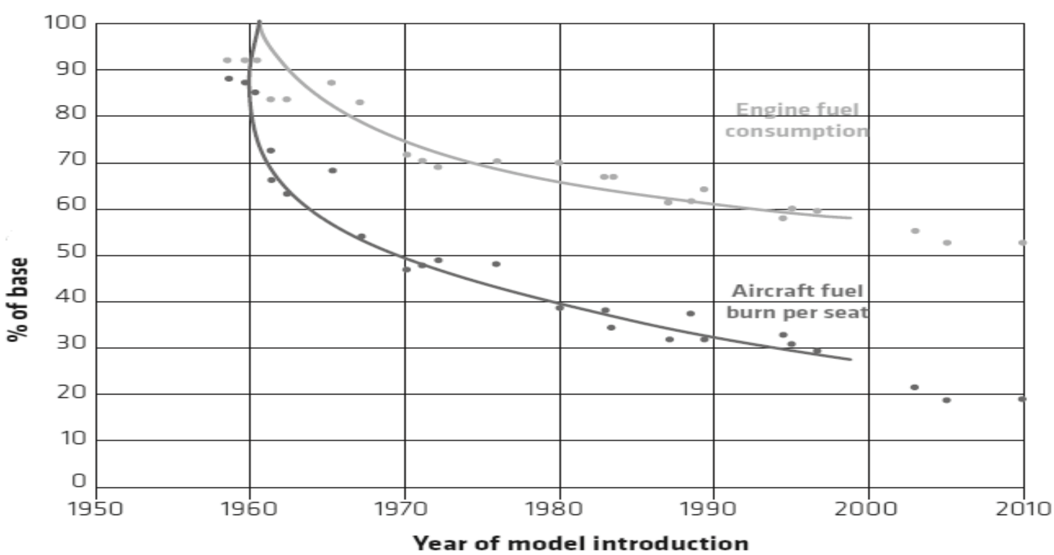

Fig. 4. Fuel efficiency according to year of aircraft introduction (in %). Source: own elaboration based on ATAG, IPCC.

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Table 2. Technology impact on improvements in aircraft fuel efficiency.

Retrofits	Production improvements	Aircraft design before 2020	Aircraft design after 2020
- Engine components - Cabin retrofits - Winglets	- Airframe made of lightweight composites - Advanced engines	- Geared turbofan engines - Open rotor - Laminar flow	- Blended wing body - Revolutionary engine architecture - Fuel cell system for on-board energy
Total impact: 7 – 13 %	Total impact: 7 – 18 %	Total impact: 25 – 35 %	Total impact: 25 – 50 %

Source: own elaboration based on IATA data and estimations.

5. METHODOLOGY REVIEW

The study outlines the progress, being made in innovative solutions and fuel efficiency of aircrafts. Considering aircraft capacity, fuel consumption per Available Seat Kilometre (ASK), depends on five factors, such as [Brueckner, Abreu, 2017, p. 3]:

- *e* – a measure of aircraft fuel efficiency,
- *s* – seats per aircraft,
- *d* – stage length,
- *l* – load factor,
- *v* – fuel-conservation effort.

Emphasis in this study is given to aircraft innovation. Therefore, examined will be primarily factors directly related to characteristics of an aircraft, such as: a measure of fuel efficiency (*e*) and number of seats (*s*). Intentionally excluded from the analysis were parameters related to specificity of a particular flight, because of its variability. Due to the limitation of the study and availability of data, average estimates of fuel consumption and efficiency are applied, as well as number of seats per aircraft, according to aircraft producers' specifications.

Taken into consideration are selected wide- and narrow-body aircrafts of Airbus and Boeing, as closest competitors and relatively popular models in airlines fleets all over the world. Moreover, examined are jets in operation, as well as those designed and planed to be launched into the market. The brand new models anticipate changes in technological environment, and further expectations of airlines as final customers.

6. COMPARISON OF SELECTED AIRBUS AND BOEING PLANES

Marketing oriented aircraft producers create innovative design solutions to provide less fuel consumption. The below table illustrates the technological progress of several selected models of the world's most used airplanes in their subsequent more fuel-efficient versions.

The first category of medium-range, narrow-body single aisle jets is represented by competitive A 320 and B 737, used by both low cost and flag airlines. The second division of wide-body, long-haul aircraft constitutes: A 330, A 350 and A 380, as well as B 746, B 767 and B 787 Dreamliner, in operation of flag, national carriers.

Table 3. Fuel efficiency evolution of selected Airbus and Boeing aircrafts.

Aircraft model	First flight year	Number of seats	Fuel use (kg/km)	Fuel efficiency (l/seat/100 km)
Airbus A 320	1987	150	3.18	2.61
Airbus A 320 neo	2015	154	2.82	2.25
Boeing 737-300	*1984*	*126*	*3.55*	*3.46*
Boeing 737-MAX 7	*2017*	*140*	*2.55*	*2.04*
Airbus A380	2005	525-853	10.16	2.9 – 3.27
Boeing 767-400ER	*1999*	*304*	*5.93*	*2.42*
Boeing 787-9 (Dreamliner)	*2013*	*304*	*5.7*	*2.31*
Airbus A330 neo-900	*2017*	*300*	*5.94*	*2.48*
Airbus A 350-900	*2013*	*315*	*6.03*	*2.39*

Source: own elaboration based on Airbus and Boeing data estimates

The exemplification of the technological advancement of A 320 aircraft model is its successor A 320 neo (first flight was held in 2015). The abbreviation neo means *New Engine Option* as opposed to the previous generation A 320, which gained a nickname *Current Engine Option*. New engine type's demand for fuel is lower by approximately 12-16%. It provides on board more seats for passengers due to space reorganization. The solution known as *Airbus Space-Flex* aims at bringing measurable benefits to change in the arrangement of elements in the passenger compartment, including: the removal of two tables and kitchen cabinets, the relocation of toilets to the rear and their combination, so that the disabled can use more space. Saved space was allocated to the row of several seats.

Winglets as wing tips have been replaced with *Sharklet* blended winglet, resembling shark fin shapes, that offers a 3.5% fuel burn reduction on flights over 2,800 km, providing better takeoff performance and rate-of-climb, higher optimum altitude, higher residual aircraft value and greater safety margins in case of engine failure. This innovation ensures that airlines can afford to compete with the lowest airfares in an increasingly competitive market. The new-generation engine and innovations involving other wing tips contributed to a 20 per cent reduction in fuel consumption compared to previous generations. External effects, such as carbon dioxide and nitrogen emissions, have decreased by 10 per cent and noise emissions by 50 per cent [Airbus, 2017].

Considering Boeing 737, as the most popular aircraft globally, with its advanced engines and innovative wing tips, it is 20 per cent more fuel efficient than first *Next Generation* planes, increasing its range without refueling to 6.4 thousand km, which means progressing by 1,000 km. The latest B737-MAX according to estimation tends to burn by 8 per cent less fuel than competitive A 320 neo. Moreover, there is also a noise reduction of around 40 per cent [Boeing, 2017].

Boeing introduced a new model, B 787, which replaced B 767. Dreamliner was the first major commercial airplane to have a composite: fuselage, wings, and most other airframe components. Composites account for half of the overall weight and as much as 80% of volume, resulting in a lighter airplane design. B 787 achieved the highest efficiency in terms of the demand for aviation fuel from all long-haul aircraft, consuming only 2.3 l per passenger per 100 km. B 787-9, introduced in 2013, two years later than the first B 787-8, has a range of 16,300 km, the longest in this model of aircraft [Boeing, 2017]. Supreme A 380, providing higher quality and more in-board entertainment space for passengers, is less efficient. New generation of A 330 neo and A350 XWB (*Xtra Wide Body*), is an example of a construction, up to 70 per cent of light materials, even 56 per cent of composites and about 90 per cent of it can be recycled. To sum up, Boeing has adopted the strategy of producing relatively smaller aircrafts with the widest range of flight without refueling, as opposed to Airbus, which produces the largest passenger aircrafts, with emphasis given to comfort of passengers [Eden, 2015].

7. CONCLUSION

Aircraft manufacturers and airlines, operating on a growing and competitive market, remain in constant search for competitive advantage, facing a challenge of economic fuel efficiency. Operation of larger aircraft is beneficial, reducing fuel usage and carbon emissions, holding an airline's overall capacity fixed [Brueckner, Abreu, 2017]. According to the results of the study, the highest fuel efficiency is achieved by the next-generation Boeing 737-MAX as single jet, narrow-body aircraft and 787 Dreamliner in long haul, wide-body segment.

Aircraft innovations have an impact on environment and better economic efficiency of airlines, which is of great significance in the era of fuel cost variability and threat of emission charges. The ongoing process to search for new solutions in aircraft design and exploitation will be determined by technological opportunities and pressure of external factors, including airlines expectations and legacy regulations. Another issue, as a subject of further research, can be organizational innovations, introduced by airlines, to accomplish lower fuel consumption per flight. Through air traffic management systems one can pursuit to reduce congestion in the air, causing delays and additional fuel consumption.

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