Future directions of fuel efficiency in aviation industry

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Abstract: *A major goal for the aviation community is reducing fuel consumption. Nowadays we can see so much effort to design a modern aircrafts that offer weight and low fuel burn savings. This study could help to understand the long way during the production of the efficient engine such as PurePower and it shows us many advantages in fuel economy. In the second part of this study the author describes technological enhancements and inevitable measures for the improvement of fuel economy. Current fuel efficient engines and future innovations in aircraft designs are introduced in the third part of the thesis. It also shows a great vision in improving aircraft performance and reducing fuel consumption. Anyway, it is too early to say which of many researching ways will lead to viable solutions, but the air transport industry is committed to support advanced technological innovations. Also, technologies are constantly being deployed and researched by the aviation industry to continuously increase performance. But we cannot forget that our effort to achieve an increased efficiency in terms of fuel consumption is still pushing the industry further.*

Key words: *advanced technology, fuel efficiency, aircraft engines, fuel consumption, and electrical aircraft.*

1. INTRODUCTION

In aviation, fuel efficiency correlates directly to the distance an aircraft can fly, the amount of payload it can carry and, more importantly, to better environmental performance. This paper explores the challenge of pushing efficiency in the aviation sector and some of the ways in which today's industry is meeting that challenge, while ensuring it remains the safest form of transport.

Reducing fuel consumption is a major goal for the aviation industry. The rise of fuel prices has increased its proportional contribution to airline costs. Fuel costs used to represent the second largest part of airlines' operating cost after the personnel costs. Aircraft operations are already over 20 % more efficient than 10 years ago, but the industry is aware that much more needs to be done. Even so, our effort to achieve an increased efficiency in terms of fuel consumption is pushing the industry further still.

2. MEASURES TO IMPROVE FUEL EFFICIENCY

Fuel is one of the highest cost items of an airline operation and oil prices are changeable. Therefore, when an airline decides to buy new equipment, fuel consumption is one of the first things it looks at. Being able to operate efficiently is critical to the future of the aviation

industry, not just for environmental reasons but also for financial ones, especially since fuel is one of the industry's most costly expenses.

Aircraft operations are already over 20% more efficient than 10 years ago, but the industry is aware that much more needs to be done.

Consequently, the quest for further efficiency continues on a number of fronts, as it is shown in Figure 1. [1]

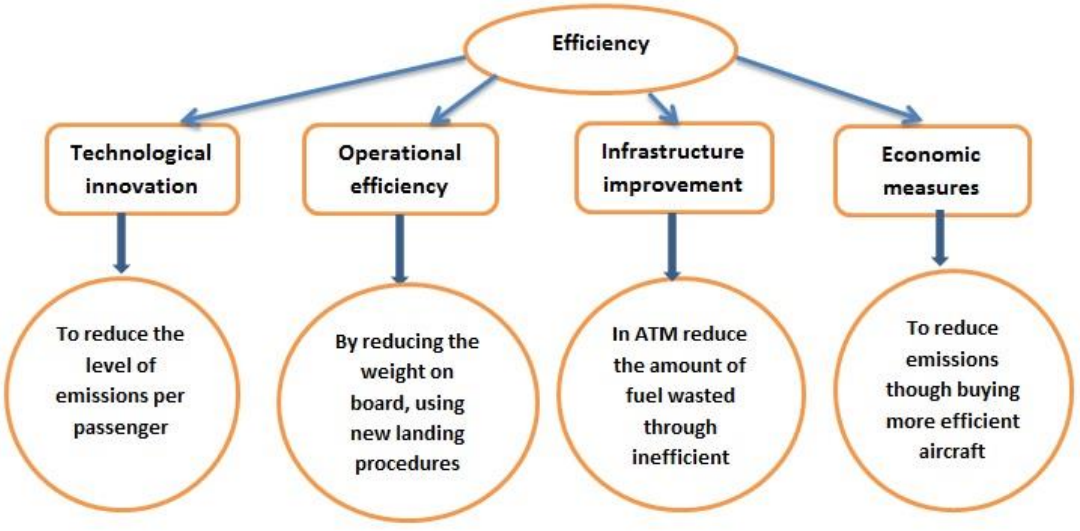

Fig. 1 Efficiency diagram (Source: Processed by author)

Today airlines face a dramatically changing business landscape, largely because of volatile jet fuel prices, that's why it is necessary to invest in fuel improvements. Fortunately, a number of relatively easy-to-implement technologies involving engine efficiency and reduced aircraft weight and drag could yield large fuel savings, and some of those technologies are already being widely adopted. For instance, Pratt&Whitney has developed the PurePower PW1000G engine that improves fuel burn by 16 % as compared to today's best engines.

2.1 Technological enhancement – main driver for greater fuel efficiency

The aviation industry has developed many operational measures to minimize fuel usage. Moreover, operational improvements could provide a 6 % overall fuel saving. One step ahead is to reduce fuel consumption and CO2 emissions (per revenue tonne kilometre) by at least 25 % by 2020, compared to 2005 levels.

Aircraft engine emissions are directly related to fuel burn. Each kilogram of fuel saved reduces carbon dioxide emissions by 3, 16 kg.

So the key for airlines to minimize their environmental impact is to use fuel more efficiently. [2][3]

On the other hand, IATA has proposed "*Technology roadmap*" that includes technological opportunities for future aircraft.

It is necessary to make technological changes including new engine architectures, natural and hybrid laminar flow, winglets and reduced-weight components and also CNS and ATM technologies.

Table 1 shows the examples of technologies expected in future aircrafts.

Table 1 Possible timeframes for availability of technologies (Source: IATA website)

Timelines of technologies	Examples of technologies	Total impact
Nowadays	*Retrofits (winglets, lightweight cabin furnishing) for aircraft without the respective technology*	5 – 12%
Nowadays	*Serial Upgrades (active load alleviation)*	9 – 20%
Before 2020	New Aircraft designs (geared / advanced turbofan)	10 – 21%
After 2020 or later	New aircraft designs (laminar flow, open rotor)	25 – 40%
Beyond 2030	Radical technologies (blended wing body, electrical aircraft)	Up to 50%

Moreover, technologies that will allow the fuel utilisation with modern aircraft´s precision navigation capabilities will enable the implementation of fuel-saving and noise mitigating operations, especially during the take-off and landing manoeuvres of the aircraft. [4]

NASA has set aggressive fuel burn, noise, and emission reduction goals for a new generation (N+3) of aircraft targeting concept that could be viable in the 2035 timeframe. We have to realize that the propulsion system is a key element to achieving these goals due to its major role with reducing emissions, fuel burn and noise.

Thus, projected benefits once technologies are matured and implemented by industry.

Benefits vary by vehicle size and mission. N+1, N+2 values are referenced to a 777-200 with GE90 engines and N+3 values are references to a 737-800 with CFM56-7B engines.

In addition, goal-driven advanced vehicle concept studies (N+3) stimulate thinking to determine potential aircraft solutions to address significant performance and operations issues of the future.

Table 2 shows technology benefits according to technology generations.

Table 2 Technology benefits according to generations (Source: NASA website)

Technology benefits	Technology generations		
	N+1 (2015)	N+2 (2020)	N+3 (2025)
Noise	-32 dB	-42 dB	-71dB
LTO NOx Emissions	-60%	-75 %	-80 %
Cruise NOx Emissions	-55%	-70 %	-80 %
Aircraft Fuel/Energy Consumption	-33%	-50 %	-60%

No doubt, advanced vehicle concept studies by NASA drive future possibilities ahead and also stimulate thinking to determine potential aircraft solutions to address significant performance and environmental issues of the future.

For instance, let’s take a look at *Core/Combustor Technology*, because propulsion system improvements require advances in this technology.

It is clear that low NOx combustor concepts can increase thermal efficiency without increasing the NOx emissions (as can be seen in Figure 2).

Moreover, improved fuel-air mixing can minimize hot spots that create additional NOx.

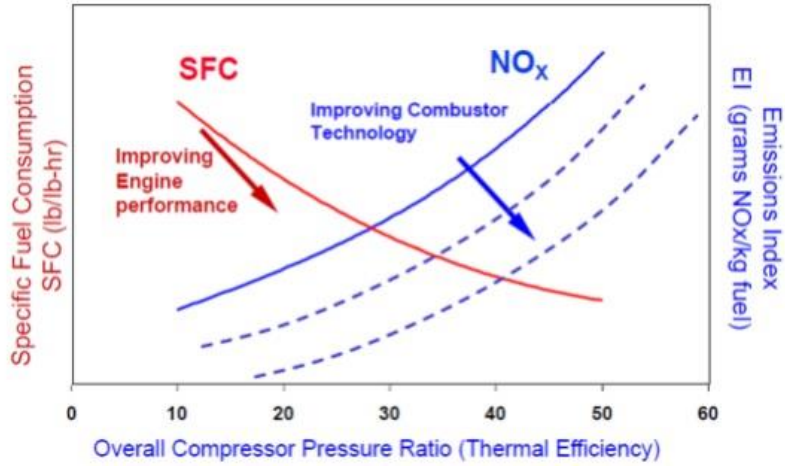

Fig. 2 Illustration of low NOx combustor concept

On the other hand, we can focus on electric propulsion. Turboelectric engine cycle has got many advantages, such as decoupling of the propulsive device (fans) from the power-producing device (engine core) that ensure high performance and design flexibility of the aircraft. Another important thing is high effective bypass ratio and it means high fuel efficiency due to improved propulsive efficiency and maximum energy extraction from the core. (NOTE: Further information about future electrical aircraft can be found in the next chapter). [6]

2.2 Fuel consumption and operational performance on selected en-routes

Reducing fuel consumption is a major goal for the aviation community due to environmental concern and fuel price uncertainty. It is clear that reducing the fuel consumption is a way to manage the risk related to fuel price fluctuations and uncertainty surrounding a future environmental policy. Anyway, operational performance plays key role in this case, too. In this paper, the author will generate scenarios of operational performance and predict fuel consumption due padding, departure delay, and airborne delay, along with a baseline fuel consumption assuming zero delays. For better illustration, the author evaluates a medium-haul and a long-haul airport origin-destination pair for Boeing 757-200 and B737-800.

2.2.1 Numerical illustrating of Boeing 757-200 fuel consumption

Firstly, let´s take a look at Boeing 757-200: the 1345 mile route of Los Angeles International Airport (LAX) to Minneapolis Saint Paul International Airport (MSP) and 2300 mile route of John F. Kennedy International Airport (JFK) to San Francisco International Airport (SFO). No doubt, LAX and JFK are interesting airports because they are certainly congested with a very diverse fleet mix yet neither is dominated by a single carrier. This is reflected in the airport fixed effects: as an origin the fixed effects are negative and statistically significant, yet as a destination the fixed effects are statistically insignificant meaning that the impact of the terminal area is not statistically different from that of congested Atlanta Airport. While MSP and SFO are both hubs for a major US carrier like ATL, they have fewer operations and may be less prone to the peaks present at ATL; this is reflected in the origin and destination fixed effects for both airports, which are both negative and statistically significant at the 1% level. Additionally, both routes experienced large peaks in departure delay and padding, and as such present a strong opportunity to evaluate the impact of these 2

operational performance variables. Table 1 presents values for the three operational performance variables for the maximum overall, maximum and average flight. [5]

Table 3 Illustration of the departure delays to selected flights – B757 (Source: ATM Seminar)

Variable name	Flight scenario					
	Maximum overall flight		*Maximum flight*		*Average flight*	
	JFK-SFO	*LAX-MSP*	*JFK-SFO*	*LAX-MSP*	*JFK-SFO*	*LAX-MSP*
Departure delay	**79**	**14**	**79**	**147**	**3.7**	**10.1**
Airborne delay	**23**	**18**	**43**	**29**	**7.5**	**4.2**
Padding	**24.6**	**24**	**51.6**	**37**	**17.7**	**10.5**

Figure 3 shows the results for LAX-MSP and Figure 4 gives the results for JFK-SFO (note that the x-axis begins with 85 % for the purposes of zooming in on the operational performance variables).

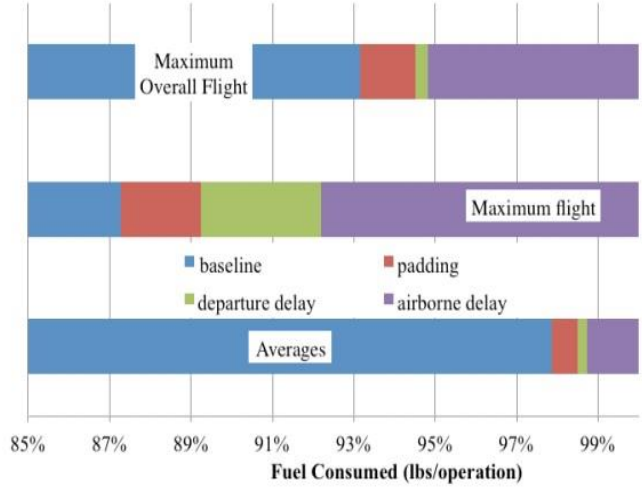

Fig. 3 Fuel consumption on a 757-200, LAX-MSP (Source: ATM Research and Development Seminar)

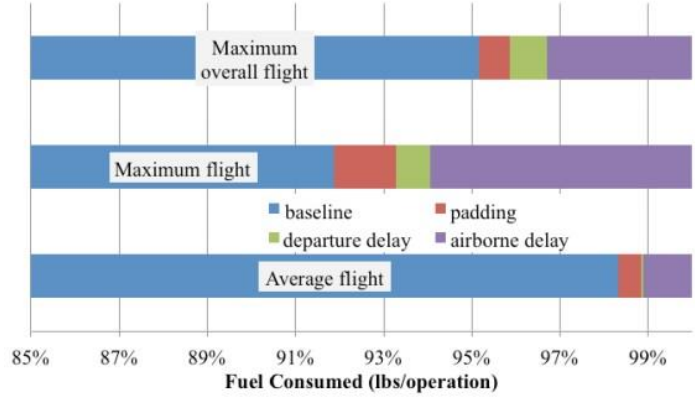

Fig. 4 Fuel consumption on a 757-200, JFK-SFO (Source: ATM Research and Development Seminar)

We can see that for the long-haul route the overwhelming percent (95% or higher) of fuel consumed during the flight is not related to operational performance.

The medium route is more significantly impacted by operational performance metrics; as it is a shorter flight the operational performance variables account for a larger percentage of the fuel consumed.

Table 3 shows that the departure delay incurred on the maximum flight for both routes is significantly higher than the airborne delay, however the percentage of fuel attributed to departure delay is minimal compared with airborne delay.

Both flights experience larger levels of padding for all scenarios, yet Figure 3 and 4 show that the magnitude of the fuel consumed in airborne is significantly greater than that consumed in padding.

2.2.2 Numerical illustrating of Boeing 737-800 fuel consumption

Let's take a look at a short-haul and a medium-haul airport origin-destination pair for the B738: the 569 mile route of BOS to Detroit Metro Airport (DTW) and 1700 mile route of ATL to John Wayne Airport (SNA).

Also, these airports are not statistically different from ATL; as such the fixed fuel consumption may play a larger role in the overall fuel consumption.

Table 4 presents values for the three operational performance variables for the maximum overall, maximum and average flight like in previous example mentioned above.

Table 4 Illustration of the departure delays to selected flights – B737 (Source: ATM Seminar)

Variable name	**Flight scenario**					
	Maximum overall flight		***Maximum flight***		***Average flight***	
	ATL-SNA	***BOS-DTW***	***ATL-SNA***	***BOS-DTW***	***ATL-SNA***	***BOS-DTW***
Departure delay	**28**	**0**	**28**	**21**	**1.4**	**1.3**
Airborne delay	**2**	**23**	**21**	**29**	**2.0**	**8.4**
Padding	**22**	**6.6**	**35**	**14.6**	**9.7**	**3.2**

As can be seen in Figure 5 and Figure 6 below, BOS-DTW reduced operational performance greatly impacts the overall fuel consumption of a flight.

For this route, we see that for the maximum overall flight, 10 % of the fuel consumption is attributed to operational performance variables.

If the maximum observable padding, departure delay, and airborne delay are experienced on the same flight, about 13 % of the fuel consumed is attributed to operational performance.

On the other hand, we can see that a flight with high airborne delay (BOS-DTW, Maximum overall flight) attributes a much higher percentage of the overall fuel consumption to operational performance variables compared with a flight with high padding and departure delay (ATL-SNA, Maximum overall flight). [5]

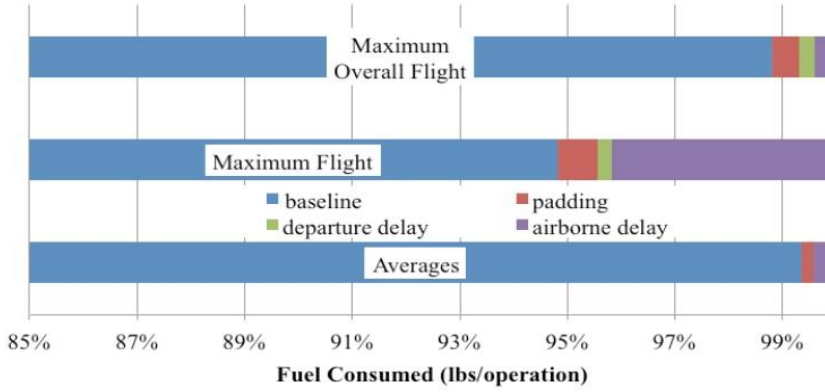

Fig. 5 Fuel consumption on a 737-800, ATL-SNA

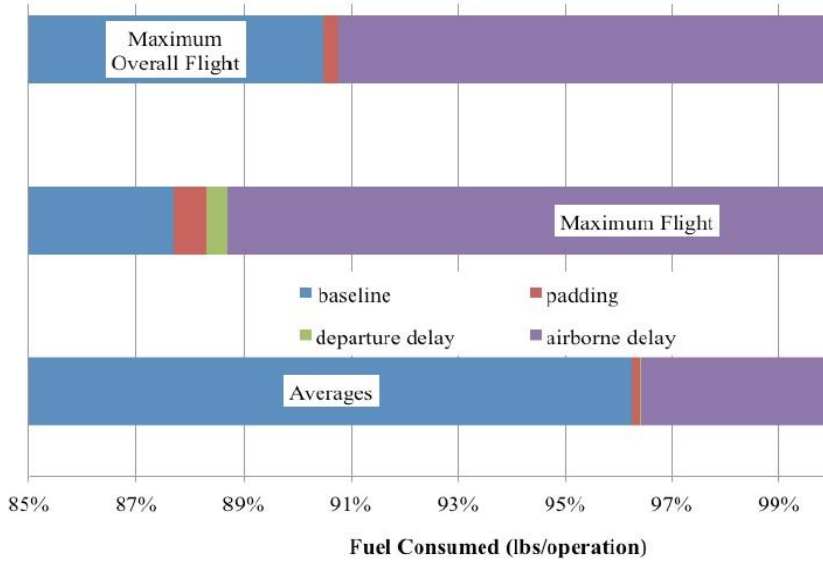

Fig. 6 Fuel consumption on a 737-800, BOS-DTW

Results:

It is clear that a minute of airborne delay leads to about 60 lbs. of fuel consumption for the B752 and 50 lbs. for the B738. These values are about 50% of the median fuel per minute for both aircraft types.

A minute of schedule padding added to the schedule leads to 11.9 lbs. of fuel consumed for the B757-200 and 4.5 lbs. for the B738. The contribution of a minute of schedule padding is significantly less than a minute of airborne delay, leading to an interesting trade-off between planned and un-planned delays.

A minute of padding adding to the schedule is incurred regardless of airspace conditions – said another way, if an airline adds 10 minutes of padding to the schedule, they are increasing their per-trip fuel consumption by 119 lbs. of fuel on a B757-200.

If the actual trip time is less than the scheduled, this fuel is expended in vain; it was unnecessary because the planned-for delays did not materialize. However, if the 10 minutes of padding were not added and 10 minutes of delay were incurred, the fuel consumed in airborne delay would be 601 lbs. instead of 119.

PARTIAL CONCLUSION

By gradually incorporating advanced technology, airlines have made impressive fuel efficiency improvements on their fleets. Each new aircraft generation brings a step change in technology.

New-generation aircraft planned by 2020 are expected to reduce fuel burn and carbon emissions by 25 – to 35 % compared to the aircraft they will replace just by using new technologies.

On the other hand, we have to realize that operational performance is responsible for up to 10% of airborne fuel consumption. Also, planning for operational performance degradation incurs a fuel cost; however, this fuel cost is significantly less than the fuel consumed if the delay were not anticipated. Mentioned example in this chapter may help to understand the relationship between schedule padding and airborne delay from a fuel consumption perspective.

Anyway, the selected technologies must demonstrate environmental benefits under operational conditions.

It is necessary that manufacturers and airliners work together on technologies to achieve this goal. The volatile price of fuel is a key driver to reduce fuel burn, reduce emissions and reduce costs.

While optimising future efficiencies, safety must always have first priority. Hence, all new technologies must be rigorously evaluated for their safety implications.

3. SELECTED INNOVATIONS KEEPING FUEL CONSUMPTION DOWN

For commercial jetliners, the most important factors are aerodynamics and engine performance. Engine specific fuel consumption has improved by 30 % since 2010. High performance ceramics and improved flow designs are in wide usage, including the high-efficiency, small core components that are implied by the large increased in fan bypass ratio and the major decreases in aircraft drag.

In addition, the pace of efficiency improvements has resulted in many more operators renewing their fleets more regularly to ensure that they are always using the latest, most efficient technology.

3.1 Selected types of current engines for illustrating fuel efficiency

The aviation industry has successfully reduced the specific fuel consumption of engines and aircraft in recent decades.

Since the introduction of jet aircraft about 50 years ago fuel consumption per 100 km has been reduced by 70%. Around 2/3 of the reduction I fuel consumption is attributable to greater engines efficiency during the cruise phase.

No doubt, in the short term, the present worldwide fleet will set the standard for total fuel consumption. For example, aircraft types A380, B787 and A350 with modern TRENT 900, GP7000, GEnx and TRENT XWB engines will define the current technological standard. In the medium term, from about 2017 or 2018, new and more efficient aircraft are expected as successors to the A320 and the B737.

In the short and medium term, however, these new aircraft have influence on total fuel consumption.

The next stage of this chapter takes a look at selected engines that significantly cut fuel consumption down.

3.1.1 PW1100G Pure Power Engine by Pratt&Whitney

The next generation engine deserves next-generations service. It is the right match for fuel efficiency and ease of maintenance. This Geared Turbofan engines are giving you predictable costs and peace of mind. And in my point of view, saving costs add up to a competitive advantage for airliners – simply – the lowest cost and the most flexibility.

For instance, the **A320neo** offers a 15% fuel burn saving as compared to current single-aisle aircraft operations, with 12.5% provided by its new engine options (CFM International's LEAP and the PW1100G PurePower from Pratt & Whitney) and 2.5% from the use of Airbus' Sharklet wingtip devices.

The PurePower PW1000G engine improves fuel burn – gate to gate – by 16% versus today's best engines. With its benefits of a new, advanced airplane the fuel burn benefit can be even greater – over 20% versus today's best aircraft.

The secret of the PW1100G engine is not the Fan Drive Gear System. It is the game-changing geared turbofan architecture enabled by the FDGS and supported by a family of engines at the highest level of technology readiness. [7]

High Tech to a Higher Power – saying which Pratt & Whitney adores, is shown in Fig. 7 below.

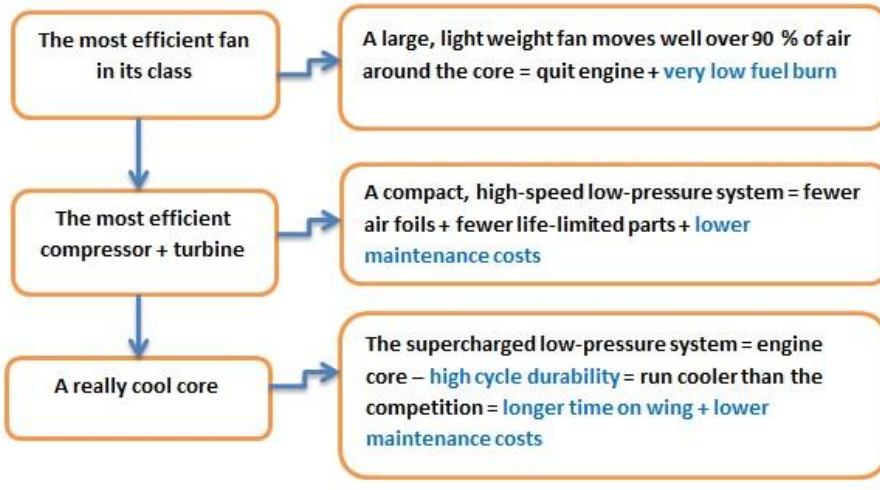

Fig. 7 PurePower Engine and its facilities (Source: P&W website)

3.1.2 Rolls-Royce Trent XWB engines

Airbus A350 XWB is a step ahead of new generation competitors and a generation beyond in-service aircraft, offering 25 % lower seat-mile costs. It is also designed to maximise fuel efficiency and to reduce maintenance costs.

Simply put, every tonne of fuel saved means more than 3 tonnes of CO2 avoided, and the A350 XWB´s operations ensures margins for both current and future international environmental protection regulations. [8]

At least, the Trend XWB is the world's most efficient aero engine flying today, although it has been designed specifically for the Airbus A 350 XWB. It uses the successful three-shaft architecture of Rolls-Royce engines and it also incorporates the latest technology from research and demonstrator programmes giving a low risk solution with the best combination of performance, reliability and operating costs. [9]

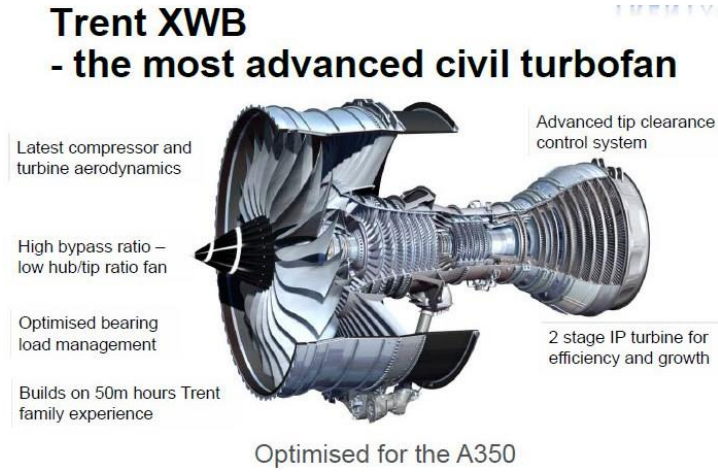

Fig. 8 Trent XWB Engine and its facilities (Source: Rolls-Royce website)

We have to realize that the fuel reduction achieved by one A350XWB jetliner equates to 10.5 million litres of fuel savings per year, or the fuel consumption of around 7.500 mid-size cars. In this case, the development of fuel efficient aircrafts is the major goal for greener aviation environment. [10]

Anyway, let's get looking at advanced technology introduced by Trend XWB engines in Fig. 9 shown below.

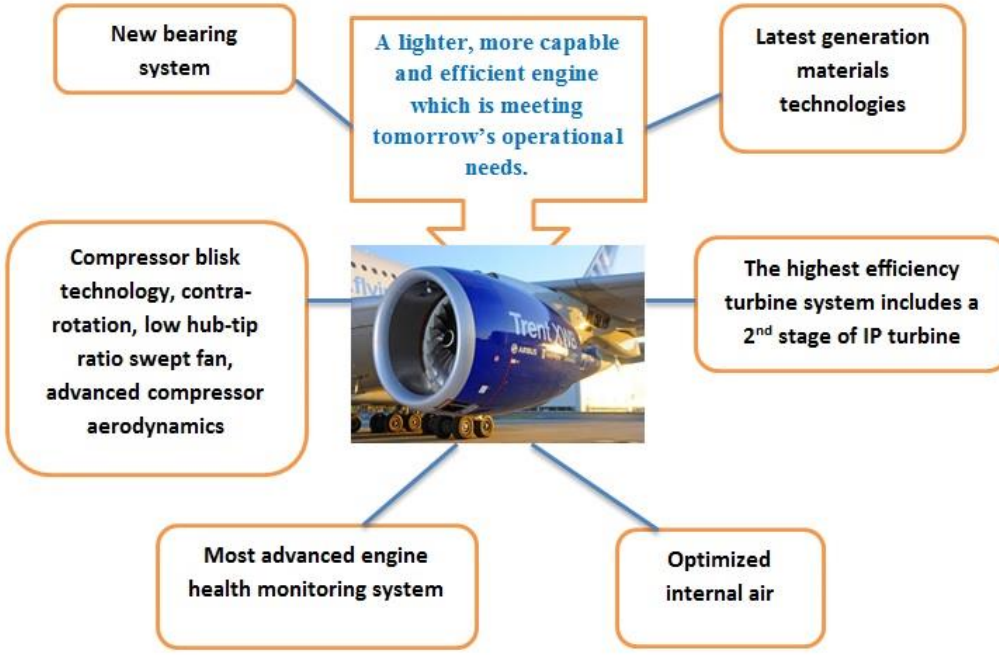

Fig. 9 Diagram of the engine advanced technology (Source: processed by author)

As a matter of fact, with the efficient aircrafts like Airbus, the manufacturers have demonstrated that creating an eco-efficient aircraft means thinking about more than the aircraft itself. So, the next steps ahead should be realized with the future in mind.

3.1.3. The engine of future"GE9X"

GE Aviation is a world-leading provider of commercial and military jet engines and components as well as avionics, electric power and mechanical systems for aircraft with an extensive global service network to support these products.

The GE9X will be the most fuel-efficient engine GE has ever produced on a per-pounds-of-thrust basic, designed to achieve a 10 % improved aircraft fuel burn versus the GE90-115B-powered 777-300ER and a 5 % improved specific fuel consumption versus any twin-aisle engine at service entry. [11]

GE is conducting extensive testing on the GE9X, including its advanced materials, coatings and aerodynamics. Over the next years, many milestones will take place, each providing further proof of the maturity and dependability of the GE9X.

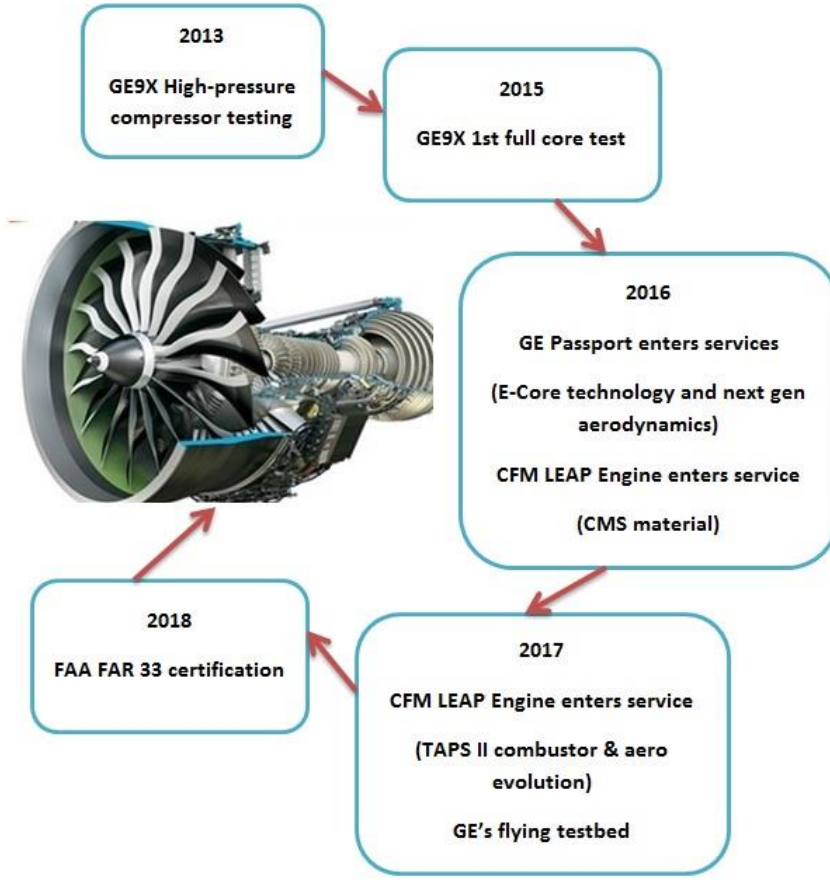

Fig. 10 Milestones diagram of GE9X engine (Source: GE website)

Anyway, Boeing's confirmation in March that GE Aviation will provide the new GE9X engine to power its proposed 777X aircraft is such good news and mainly it promises a 10 % reduction in fuel burn compared with the GE90-115B engines on the existing 777-300ER. Also promised is a 5 % improvement in specific fuel consumption over rival wide body engines by 2020. [12]

Additionally, new technology must be built on a strong business case, so no doubts; GE has made a big step in engine improvement.

3.2 Future innovations in aircraft designs and fuel consumption

The most noticeable/obvious technological differences are in *aircraft configuration*. While the tube and wing and wing configuration had been dominant in civil aviation from the inception of the jet age, more advanced technologies are under development.

For instance, we can expect propulsive efficiency - engine architectures are evolving (advanced turbofan), some different concepts are emerging (advanced turbo-fans, open-rotors, hybrids); each with their own multi-generation product development plans, as can be seen in Figure 11.

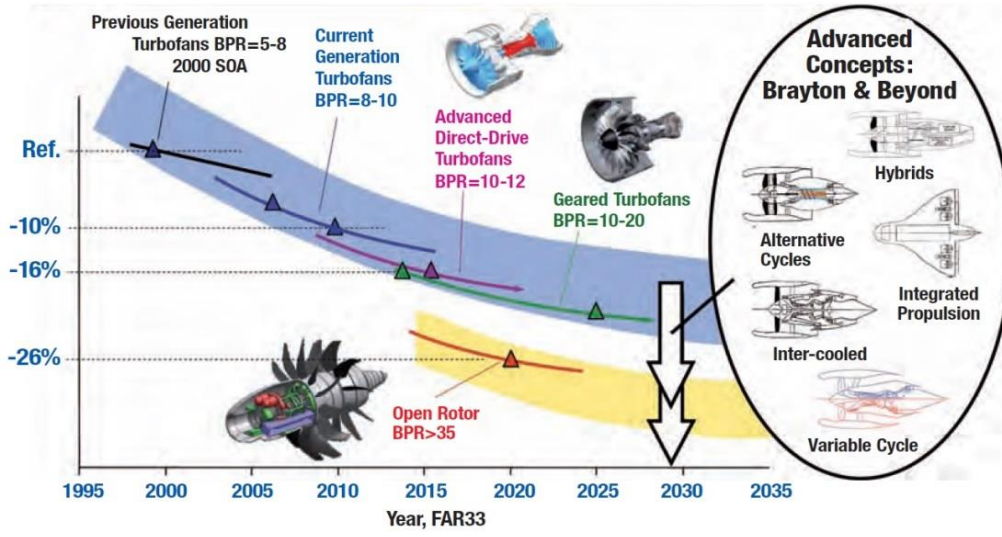

Fig. 11 History and future of engine fuel consumption trends (Source: International Council of Aerospace Industries Association)

Of course, in order to achieve the optimum improvements, massive investments have to be made in research programmes, and public/private partnerships are therefore essential.

Anyway, this chapter will introduce selected future aircraft architectures that can be expected to have in some cases more than 50% reduction in fuel burn after 2030.

3.2.1 The MIT D8 “Double Bubble“and”Hybrid Wing Body” concept aircraft

The Massachusetts Institute of Technology was a team lead on the N+3 project that developed both a domestic and international carrier concept, named the D-series “Double Bubble” and the H-series Hybrid Wing Body.

The aircraft is offering not only fuel burn advantages, but also decreased runway length, reduced noise, lower nitrogen oxide emissions and the ability to use shorter runways. This design uses long, skinny wings, a small tail and – hence the name – replaces the traditional cylindrical fuselage with a two partial cylinders placed side-by-side.

It is a plane that travels 10 % slower than the Boeing 737 and the engines sit at the rear of the fuselage rather than on the wing to make use of a technique called Boundary Layer Ingestion. These approach sees slower moving airs from the wake of the fuselage enter the engines, resulting in less fuel consumption for the same amount of thrust. The downside is slower speeds and more stress on the engine.

The long-range concept, the *Hybrid Wing Body*, employs many of the same technologies as the Double Bubble, but provides greater payloads and increased range.

Using a blended wing lifting body configuration, the distributed propulsion system is mounted on the top of the fuselage, ingesting large spans of the boundary layer. While this concept was unable to fuel burn and noise goals, it did meet the NOx and field length goals. The Boeing 777-200 LR series was used as the long range aircraft baseline. [13] [14]

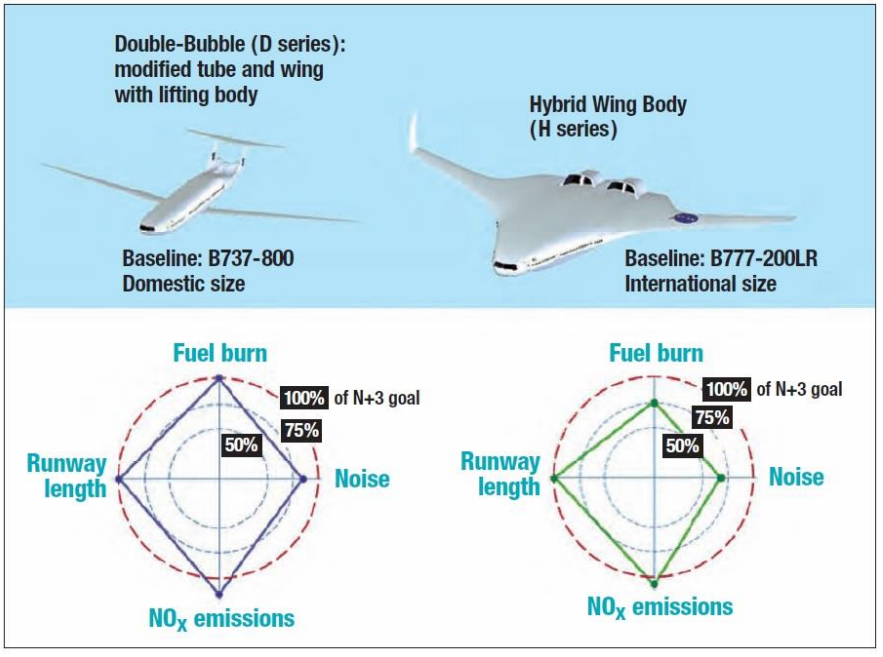

Fig. 12 MIT concepts, Double Bubble and HWB, respectively (Source: NASA website)

Let's take a look at Figure 12 above, where the bottom of the figure gives information about the estimated aircraft attributes compared against NASA N+3 targets. The red dashed line shows 100 % for each of the four NASA metrics, meaning that the goal has been met. The other lines are 50% and 75% of the goals respectively.

The points on the solid line show, at the four points of the compass, the calculated aircraft performance for each of the four metrics.

Unfortunately, we can say that this kind of aircraft is not very realistic in the short term, because the Double-Bubble is called an N+3, or 3 generations from now, and it means that we might fly on one no sooner than 2035 or so. [15] [18]

3.2.2 SUGAR VOLT concept aircraft

Through green aviation, NASA is helping create safer, greener and more effective travel for everyone. The Boeing subsonic tem, which include BR&T, Boeing Commercial Airplanes, General Electric and Georgia Tech, has looked at the SUGAR project (Subsonic Ultra Green Aircraft Research).

This concept consists of this configuration which are shown in Fig 13.

In addition, electric propulsion will be a game-changer and transform aeronautics in the next 20-30 years.

An aerospace engineer at NASA, Mark Moore said: "the first breakthroughs will occur with small aircraft, personal air vehicles that will replace the automobile on some trips; an expansion of unmanned aerial vehicles, currently used by the military, to civilian use; followed by much more environmentally responsible transport planes". It is designed to fly

at Mach 0.79, carry 154 passengers over a range of 3.500 nautical miles and achieve shorter take-off distance. Shortly, Volt concept will define the future of flight. [17]

Well, we have to realize one thing; "optimal" configuration depends on value of electricity vs. jet fuel and associated emissions. Emissions and their environmental impact depend on operational concept, as well.

It is clear that the benefits of many technologies being developed and utilized in the future should be significant, and certainly justify investing today for a large potential payoff years from now.

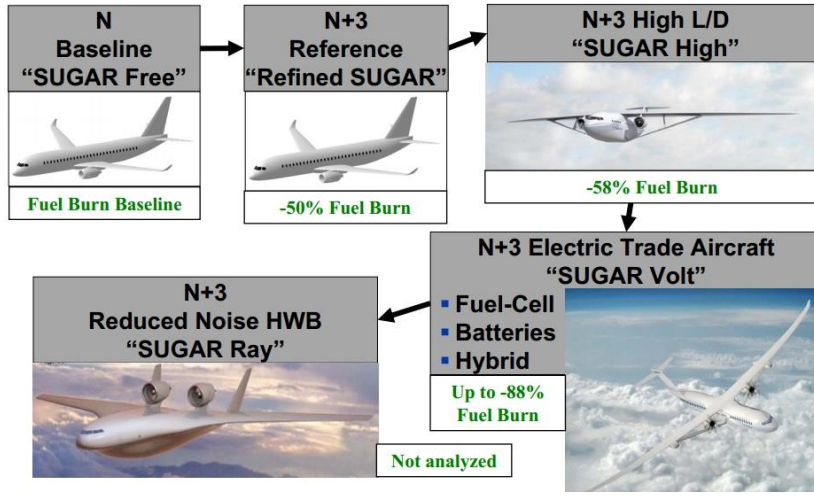

Fig. 13 Advanced concepts of future efficient aircrafts

However, the team has found that SUGAR Volt concept (which adds an electric battery gas turbine hybrid propulsion system) can reduce fuel burn by greater than 70 % and total energy use by 55% when battery energy is included. Hybrid electric propulsion also has the potential to shorten take-off distance and reduce noise. In addition, the SUGAR team identified hybrid electric engine technology as a "high-risk high-payoff technology".

Anyway, Boeing's SUGAR team is working to identify future commercial transport concepts for NASA. The SUGAR Volt, one of the mentioned concepts, shows potential to meet NASA's environmental goals, as the SUGAR Volt will emit les carbon dioxide and less nitrogen oxide than aircraft in operation today. [16] [17]

PARTIAL CONCLUSION

A lot of innovations may seem far-fetched – aircraft with open fan engines made of ceramic components, located above the fuselage instead of being located below the wings – these advancements are currently being developed by many manufactures. For instance, a NASA research team has developed a manufacturing process for an airplane that could cut fuel consumption in half compared to traditional aircraft. It was not easy way, because up until now one has been able to invent a manufacturing method that makes this design practical.

On the other hand, we cannot forget that environmental performance is key factor throughout many aircrafts have been designed. Simply, less is more, and taking bigger steps with a smaller footprint is a good strategy.

Moreover, solving problems related to fuel consumption is a matter that many institutions are considering. Of course, some ideas have to do with improvements in technology; others have to do with using new technology in new ways.

4. RESULTANT CONCLUSIONS

Many institutions work to solve the challenges that aviation industry faces. Thus, solutions to possible problems require innovative technical concepts and of course, dedicated research and development. From my point of view, it is necessary to keep up fuel efficient flight planning and continue to develop new aircraft designs to ensure fuel cost savings as much as possible. Also, it is necessary to make the airline industry less sensitive to high fuel prices, as well as addressing air pollution and noise.

GE has placed their bets on carbon-fiber and ceramic-matrix composites and other advanced technologies for fuel-burn improvements that airlines were waiting for. Whereas P&W puts its money on introducing a gearbox to provide a step change in fuel burn too, but also to ensure the engine to run cooler, and they were successful. The companies I already mentioned are still looking to the future, and their plans could be a challenge for the other manufacturers, and it should be another step to keep up to standards. From the other point of view, for the subsonic concept that nowadays is very popular, hybrid electric engine technology is a winner because it can potentially improve performance relative to all future goals and expectations.

However, one thing is abundantly clear – these innovations are aimed at not only improving aircraft by making them more fuel efficient and more comfortable for passengers, but also improving our planet by consuming less of our natural resources. No wonder the future seems so fascinating in aviation industry.

REFERENCES

[1] P. M. Petters, J. Middel, A. Hoolhorst, *Fuel efficiency of commercial aircraft*, November 2005. Available at: http://www.transportenvironment.org/sites/default/files//docs/Publications/2005pubs/2005-12_nlr_aviation_fuel_efficiency.pdf.

[2] *** *IATA Annual Report 2013*, 69th Annual General Meeting, June 2013. Available at: http://www.iata.org/Pages/default.aspx.

[3] W. A. Mair, D. L. Birdsall, *Aircraft performance*, pp. 77-80, Cambridge University Press, 2003.

[4] *** <http://www.purepowerengine.com/fuel_burn.html >

[5] *** Ninth USA/Europe ATM Research and Development Seminar. *Fuel Consumption and Operational Performance*. January 2011. Available at: http://www.atmseminar.org/seminarContent/seminar9/papers/72-Ryerson-Final-Paper-4-14-11.pdf.

[6] *** 50th AIAA Aerospace Sciences Meeting. Boeing ERA N+2 Advanced Vehicle Concept Results. January 2011. Available at: https://www.aiaa.org/uploadedFiles/About-AIAA/Press-Room/Key_Speeches-Reports-and-Presentations/2012/Bonet-John-Boeing-AVC-AIAA-GEPC2.pdf

[7] *** http://www.pw.utc.com/PurePowerPW1000G_Engine

[8] *** http://www.airbus.com/aircraftfamilies/passengeraircraft/a350xwbfamily/

[9] *** http://www.rolls-royce.com/civil/products/largeaircraft/trent_xwb/

[10] *** National Research Council, Committee on Aeronautics Research and Technology for Environmental Compatibility: *For Greener Skies – Reducing Environmental Imports for Aviation*, pp. 3-4, 2002.

[11] *** https://www.ge.com/stories/aviation-ge9x.

[12] Ch. Alcock, *GE Pushes Envelope with GE9X for New Boeing 777*, June 2013. Available at: http://www.ainonline.com/aviation-news/paris-air-show/2013-06-16/ge-pushes-envelope-ge9x-new boeing-777.

[13] N. McKeegan, *Double Bubble aircraft design would use 70% less fuel*, May 2010. Available at: http://www.gizmag.com/mit-double-bubble-green-aircraft/15142/.

[14] E. Acherman, *Double Bubble aircraft will boost fuel efficiency by 2035*, April 2012. Available at: http://www.dvice.com/archives/2012/04/double_bubble_a.php.

[15] *** ICAO Environmental Report, Aircraft Technology Improvements, December 2010. Available at: http://legacy.icao.int/icao/en/env2010/Pubs/EnvReport2010/ICAO_EnvReport10-Ch2_en.pdf.

[16] *** *NASA N+3 Subsonic Ultra Green Aircraft Review, Sugar Phase 1 Final Review*, April 2010. Available at: http://aviationweek.typepad.com/files/boeing_sugar_phase_i_final_review_v5.pdf.

[17] R. Faye, R. Laprete, M. Winter, Blended Winglets for Improved Airplane Performance, *Aero Magazine*, No. 17, pp. 16-31, January 2002.
[18] R. K. Agarwal, *Recent Advanced in Aircraft Technology*, ISBN 978-953-51-0150-5, pp. 7-15, Publisher: InTech, February 2012.
[19] J. Hilkevitch, *Electric aircraft generates buzz at Oshkosh Air Show*, August 2010. Available at: http://articles.chicagotribune.com/2010-08-01/travel/ct-met-getting-around-0802-20100801_1_current-battery-technology-air-show-oshkosh.