2014 3rd International Conference on Informatics, Environment, Energy and Applications
IPCBEE vol.66 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V66. 36

Mitigation Alternatives for Environmental Impacts of Aircraft Auxiliary Power Units

Ramazan Atılgan [+], Önder Turan

Faculty of Aeronautics and Astronautics, Anadolu University,TR-26470, Eskişehir, Turkey

Abstract. Aircraft operations have significant impact on the environment and human health. Primary sources of this impact are emissions from main engines and auxiliary power units (APUs). Air transportation activities cause almost 3% of total greenhouse gas (GHG) emissions by consuming approximately 3% of total fossil fuel consumption. More fossil fuel means more environmental impact, so recent studies are focused on reducing environmental impact by reducing fuel consumption of aircraft power plant systems, including APU. APU is a compact turbojet engine used on aircrafts for electric and pneumatic power generation while main engines are not running or unserviceable. In this study, APU related environmental impacts are defined. Recommendations to mitigate these impacts are given. Practical and applicable methods are collected into three categories: *reducing APU usage*, *design improvements* and *using alternative energy sources*.

Keywords: auxiliary power unit, environmental impact, emission

1. Introduction

Current growth rate of commercial air transportation increases concerns over environment and human health. Present contribution of aviation constitutes approximately 3% of overall greenhouse gas (GHG) emissions which are known as responsible for wide range of environmental impact from global warming and ozone depletion to bio-diversity loss. Although that 3% contribution seems relatively small, recent studies show that commercial aviation sector could become dominant contributor as soon as 2020 with the current growth rate. In addition, aircrafts mainly operates at between altitudes of 8-13 km which makes impact of GHG emissions more complex and more drastic (for example, formation of condensation trails) [1-4].

Commercial air transportation impacts the environment both local and international scale. Major sources of these impacts are aircraft main engines and auxiliary power units (APUs). APUs are used on aircrafts for electric and pneumatic power generation while main engines are not running or unserviceable. APUs are only used during flight (cruise flight) in case of emergency. Hence, APUs are assumed to be used only at landing and take-off cycle (LTO) in this study. Environmental impact of LTO cycle of flight effects local air quality and human health around airport surroundings [5-7].

This study aims to define environmental impacts of APUs and to reflect possible alternative applications to mitigate these impacts.

2. System Description

APU is a compact turbojet engine. It has a single shaft that connects turbine and compressor each other. It operates at a constant speed and drives an electric generator which produces 115 V-400 Hz electrical power. APU is generally installed on tail cone of aircrafts and consist of following main components similar to main engines: compressor, combustion chamber, turbine, exhaust and gearbox. Schematic of an APU which are used on B-737-800 aircraft is shown in Figure 1 [8].

[+] Corresponding author. Tel.: + (90 222 335 05 80); fax: +(90 222 322 16 19).
E-mail address: (ratilgan@anadolu.edu.tr).

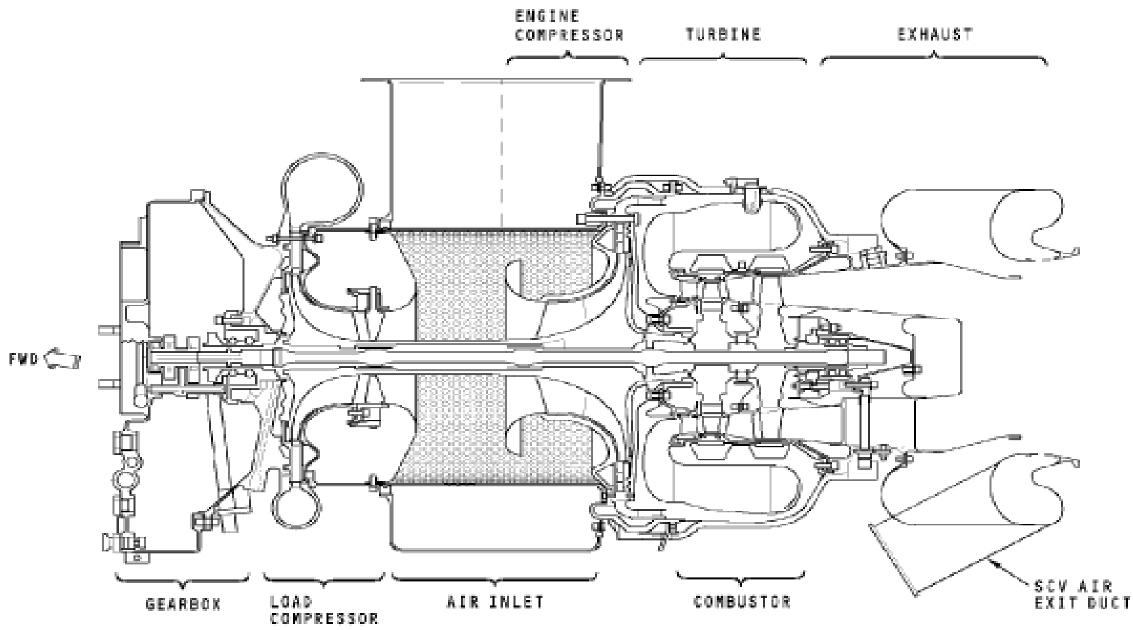

Fig. 1: Schematic of APU

APU has following main functions on aircraft:

- It is used to start aircraft main engines,
- It provides compressed air to aircraft pneumatic system,
- It provides electrical power to different aircraft systems when main engines are not running or unserviceable.

3. Environmental Impact and Mitigation Alternatives

3.1. Environmental Impacts

Aircraft operations have significant impact on the environment as a result of emissions from main engines and APU. Air transportation activities cause almost 3% of total GHG emissions by consuming approximately 3% of total fossil fuel consumption [9]. Modern commercial jet engines consume kerosene as fuel which is also a fossil fuel. More fossil fuel means more environmental impact. Recent study showed that an APU consumes approximately 110 kg fuel in an hour [10]. Also, British Airways performed an analysis to its own fleet and results showed that APU consumes 1% of total fuel consumption [11].

As stated before, APUs are mainly used during LTO cycle. Emissions from APU and main engines can be considered to have similar characteristics. Carbon dioxide ($\boldsymbol{CO_2}$), oxygen ($\boldsymbol{O_2}$), water vapor ($\boldsymbol{H_2O}$), nitrogen oxides ($\boldsymbol{NO_x}$), unburned hydrocarbons ($\boldsymbol{UHC}$), carbon monoxide ($\boldsymbol{CO}$) can be defined as typical APU related emissions during LTO cycle.

3.2. Mitigation Alternatives

Recently, airport related GHG emissions attract a great deal of attention by scientists, decision makers and operators. Primary sources of these emissions are main engines and APUs. Mitigation ways of APU impact are given in three main groups in this study.

3.2.1 Reducing APU Usage

One of the most practical and applicable methods to mitigate environmental impact of APU is reducing APU usage. Less APU usage means, less fuel consumption; and that means less GHG emission, and so less environmental impact. For example, British Civil Aviation Authority (CAA) is published a code of practice and recommended a hierarchy for the industry that stresses reducing APU usage [12]:

- First, fixed terminal based equipment should be used where it is available. These equipment provide electrical power from airport grid and pneumatic power from a central system. That is best option among others, but airport infrastructure should be suitable for these services.
- Second, mobile ground power units and pre-conditioned air vehicles should be used. These mobile vehicles generally powered by diesel engines and produces GHG emissions but not as much as APU produces.
- Third, if the two mentioned above are unavailable or unserviceable, APU can be used but usage times should be limited to minimum values.

APU usage reducing can be accomplished by cooperation between airline operators, airport operators, ground handling agents and pilots. Some suggestions for these groups are given below:

- Airline operators should publish directives to their pilots to minimize APU usage time,
- Airline operators should encourage GSE and fixed terminal based equipment usage,
- Airline operators should train their pilots to create awareness about environmental impacts,
- Airport operators and ground handling agencies should try to keep sufficient amount of ground support equipment (GSE) -including GPU and pre-conditioned air vehicles- well maintained and in service as much as possible,
- Airport operators and ground handling agencies should encourage a fault reporting mechanism to take back into service unserviceable GSE,
- Pilots should be aware of environmental impacts of APU usage,
- Pilots should switch off APU whenever GSE or fixed terminal based equipment is available on arrival,
- Pilots should not start APU until last possible moment before departure.

3.2.2 Design Improvements

New generation engine and APU technologies are estimated to save 15% of fuel compared to current ones. Design improvements improve thermal efficiency of APUs which decreases fuel consumption rates. Beside improved thermal efficiency, environmental impact of APUs can be upgraded by changing systematical architecture of the engine. For example, B 787 Dreamliner presents a new APU and technology which is defined by Boeing as *no-bleed system*. This technology offers a 3% fuel reduction and provides only electrical power. Components associated with pneumatic power generation are eliminated. Orange lined components shown in Figure 2 are eliminated parts of no-bleed system APU [13].

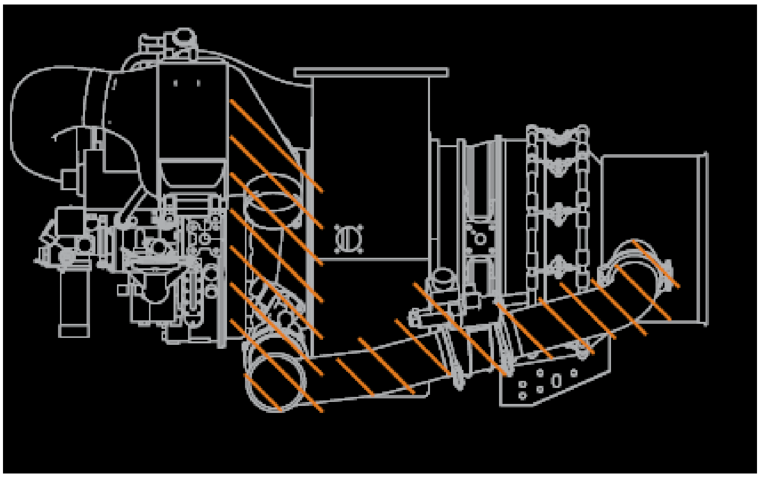

Fig. 2: Eliminated Components of No-Bleed System APU

3.2.3 Using Alternative Energy Sources

Aircraft engines use fossil fuels and aforementioned GHG emissions occur in consequence of combustion of that fossil fuel. As long as fossil fuels are used by aircraft main engines and APUs, environmental impact of aviation industry will continue to grow. So, scientists and policy makers pursue a strategy to develop alternative fuels to fossil fuels. The two prominent candidates are hydrogen and biofuels [14].

Hydrogen is a synthetic fuel and needs a *source* to be generated. This source is generally a fossil fuel, water or biomass. Recent studies and projects (such as NEXTCAP (Next Generation Clean Aircraft Project) by NASA Glenn Research Center) are focused on fuel cell powered and hydrogen fueled aircraft power plants. Hydrogen fueled APU is considered as first step of the way through all electric fuel cell powered commercial transport aircraft. NEXTCAP projects to develop fuel cell powered APU and full electric hydrogen powered aircraft by 2015 and 2030, respectively. Hydrogen can be defined as the most *environmentally benign* alternative, because its combustion products include negligible NO_x, significantly reduced CO_2 and water which can be used for onboard needs; if existing technical and logistical barriers would be overcome such as storage and sourcing [15-17].

Biofuels are fuels that are produced from biomass through biochemical and thermochemical processes. These fuels have emerged as potential substitutes for current energy sources like diesel and kerosene which are used in modern jet engines and APUs [18]. International Energy Agency (IEA) reported that 3% of total road transport fuel is provided by biofuels, however promoting current biofuel technologies to a *drop-in* alternative for aviation industry seems feasible but needs further development [19]. For instance, [20] states that new aircraft designs which have biofuel fueled powerplant system (main engines and APU) would have to be larger fuel tanks in order to meet range and payload requirements to compensate low energy density of biofuels.

4. Conclusion

Aircraft operations are responsible for 12% of $\boldsymbol{CO_2}$ emissions from all transport modes, and 80% of these are emitted over 1,5 kilometers. There is no alternative mode of transport at these altitudes. Not only $\boldsymbol{CO_2}$ emissions, but also other pollutant and particulate emissions make air transportation industry one of the prime suspects for global warming and ozone depletion with current grow rate. Sources of these emissions are aircraft powerplant systems including main engines and APU. This study stressed APU related environmental impact and reviewed mitigation alternatives for this impact such as operational reductions, design improvements and alternative energy source usage. Although contribution of APU related environmental impact is relatively small, it is non-ignorable. Results and statistics show that mitigation of APU related environmental impact can be defined as the first step of the way through green aircraft technologies. These mitigation alternatives will help the industy to meet green and sustainable aviaton targets.

5. Acknowledgments

The authors are grateful for the support provided for the present work by Anadolu University, Eskisehir, Turkey.

6. References

[1] Filippone A. Analysis of Carbon-Dioxide Emissions from Transport Aircraft. *Journal of Aircraft*. 2008, 45 (1): 85-197.

[2] Atılgan, R., Turan, O., Altuntas, O., Aydın, H. and Synylo, K. Environmental Impact Assessment of a Turboprop Engine with the Aid of Exergy. *Energy, The International Journal*. 2013 58():664-671.

[3] Graham A. The environmental impact of airports. In: Managing airports: an international perspective. Elseiver 2nd edition; pp.300-306, 2003.

[4] Altuntas O, Karakoc TH, Hepbasli A. Exergetic, exergoeconomic and sustainability assessment of piston-prop aircraft engine. *Int. J. Thermal Science and Technology*. 2012, 32 (2): 133-143.

[5] Mazaheri M, Johnson GR, Morawska L. An inventory of particle and gaseous emissions from large aircraft thrust engine operations at an airport, *Atmospheric Environment*. 2011, 45: 3500–3507.

[6] Kurniawan JS and Khardi S. Comparison of methodologies estimating emissions of aircraft pollutants, environmental impact assessment around airports, *Environmental Impact Assessment Review*. 2011, 31: 240–252.

[7] Song SK and Shon ZH. Emissions of greenhouse gases and air pollutants from commercial aircraft at international airports in Korea, *Atmospheric Environment*. 2012, 61: 148-158.

[8] Boeing, Chapter 49: Auxiliary Power Unit, *Aircraft Maintenance Manual.* 2006.

[9] IPCC, 4th Assessment Report. 2007, See also http://www.ipcc.ch/ [accessed 20/03/2013].

[10] Lobo P, Rye L, Williams PI, Christie S, Uryga-Bugajska I, Wilson CW, Hagen DE, Whitefield PD, Blakey S, Coe H, Raper D, Pourkashanian M. Impact of alternative fuels on emissions characteristics of a gas turbine engine − Part 1: Gaseous and particulate matter emissions. *Environmental Science and Technology*. 2012, 46: 10805-10811.

[11] IPCC, Special Report: Aviation and Global Atmosphere, 1999. See also http://www.ipcc.ch/ipccreports/sres/aviation/index.htm. [accessed 20/03/2013].

[12] CAA, Ground operations and departures code of practice. 2012, See also www.caa.co.uk. [accessed 22/03/2013].

[13] Sinnett M. 787 No-Bleed Systems: Saving Fuel and Enhancing Operational Efficiencies, *Boeing Aero Magazine*. 2007, (28): 6-11.

[14] Demirbas A. Progress and recent trends in biofuels, *Progress in Energy and Combustion Service*. 2007, 33: 1-18.

[15] Khandelwal B, Karakurt A, Sekaran PR, Sethi V, Singh R. Hydrogen powered aircraft: The future of air transport, *Progress in Aerospace Sciences*. 2013, 60: 45-59.

[16] Renouard-Wallet G, Saballus M, Schumann P, Kallo J, Friedrich KA, Müller-Steinhagen H. Fuel cells for civil aircraft application: On-board production of power, water and inert gas, *Chemical Engineering Research and Design*. 2012, 90: 3-10.

[17] NETL, U.S. National Energy Technology Laboratory. 2010, See also http://www.netl.doe.gov//. [accessed 15/04/2013].

[18] Gupta KK, Rehman A, Sarviya RM. Bio-fuels for the gas turbine: A review, *Renewable and Sustainable Energy Reviews*. 2010, 14: 2946-2955.

[19] IEA, International Energy Agency. 2012, See also http://www.iea.org/publications/. [accessed 20/03/2012].

[20] Ebbinghaus A and Wiesen P. Aircraft Fuels and their effect upon engine emissions. *Air and Space Europe*. 2001, 3 (1/2): 101-103.