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FULL PAPER

The Estimation of the Engine Emissions Ensuing from Jet Fuel Combustion and its Contribution to Worldwide Warming at Aden International Airport. Case Study

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Abstract

This paper is an try and have a look at the quantity of plane emissions due to the combustion of jet fuel for the duration of the touchdown and takeoff (LTO) operations at Aden International Airport (AIA) in 2018. All statistics changed into taken from the airport's statistic data. The have a look at centered on the subsequent emitted plane gases: (CO2,CH4, N2O, CO, NMVOCs and SO2). It was found that there were 3,148 LTO activities in the course of 2018 which resulted in an approximate amount of 4,747,940 kg CO2, 346.68 kg CH4, 166.2 kg N2O, 23482 kg CO, 3186.9 kg NMVOCs and 1495 kg SO2. Boeing 737, Airbus 310 and CRJ700 were found to be the most polluting aircraft, while other aircraft were less polluting. Furthermore, despite the fact that there was very little aircraft traffic in Aden International Airport compared with either Sana'a or any of the remaining airports who had always been a major aviation hub, however, it is possible to use these results as a useful scientific base for the assessment of aircraft emissions locally, regionally or internationally. Finally, a number of recommendations have been presented by the study aimed at enhancing and developing the environment in the vicinity of the airport.

Key words: Aden International Airport, aircraft emissions,

1. Introduction

Human beings, like different dwelling organisms, have usually inspired their environment. It is handiest seeing that the start of the Industrial Revolution, mid-18th century, that the effect of human sports has started to increase to a far large scale, continental or maybe global. Human sports, mainly the ones concerning the intake of fossil fuels for commercial or home usage, and biomass burning, produce greenhouse gases that have an effect on the composition of the surroundings[1]. Scientific proof shows that human sports consisting of burning fossil fuels and deforestation have appreciably extended the percentage of greenhouse gases within side the surroundings during the last a hundred and fifty years [2].

Research on climate change has recognized a big range of sources that cause the greenhouse effect. The biggest sources of those emissions, especially in developed economies, are electric powered utilities and the transportation sector (fig.1) [3]. Aviation is one of the transportation sorts producing emissions which have the capacity to effect air pleasant within side the local, local and international environments[4]. ICAO/CAEP's preliminary estimate is that the full extent of aviation CO_2 emissions in 2006 (both domestic and international) is within side the variety of six hundred million tones. At present, aviation accounts for approximately 2% of general international CO2 emissions (fig.1) and approximately 12% of the CO2 emissions of all transportation sources [5,6]. While the impact of noise on communities around airports has historically been the most prominent environmental issue of aviation, the local and global effects of aircraft emissions on air quality are emerging as issues of equal, if not greater, importance [7].

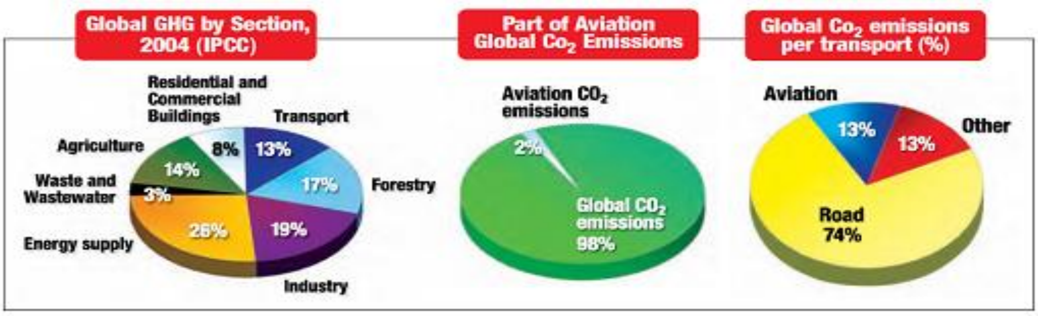


Figure 1: Aviation emissions and their contribution to global environment [6]

In the scientific literature there are many scientists and organizations carried out numerous studies considering estimation of the aircraft emissions at airports around a world. For example, EPA [8], Perl et al. [9] and Stefanou and Haralambopoulos [10] have studied and calculated annual environmental loads and proved that significant amounts of pollutants are received in areas around airports.

There are a lot of air pollution present as gaseous and particulate emissions from aviation and aviation- related activities which could probably effect human health and the environment. They are: NOx Nitrogen oxides along with (N2O); VOC Volatile natural compounds (along with non-methane unstable natural compounds (NMVOCs);

Carbon dioxide (CO_2); CO Carbon monoxide; SOx Sulphur oxides; and PM Particulate matter (fraction size PM 10 and PM10) [4].

The ability damaging consequences of air pollution released within an aircraft's landing and takeoff cycle (LTO) and airport-related sources of emissions can make contributions to the degradation of air quality in their close by communities. The table (1). indicates the representative health effects of a few emissions released from aircrafts.

Table 1. Potential effects on human health due to various species of emissions [11]

Pollutant	Health effect
CO – Carbon Monoxide	● Cardiovascular effects, especially in those persons with heart conditions
HC – Unburned Hydrocarbons (a primary component of Volatile Organic Compounds, or VOC)	● Eye and respiratory tract infection ● Headaches ● Dizziness ● Visual disorders ● Memory impairment
NOx – Nitrogen Oxides	● Lung irritation ● Lower resistance to respiratory infections
O_3 – Ozone (HC is a precursor for ground-level O3 formation)	● Lung function impairment ● Effects on exercise performance ● Increased airway responsiveness ● Increased susceptibility to respiratory infection ● Increased hospital admissions and emergency room visits ● Pulmonary inflammation, lung structure damage
PM – Particulate Matter (smoke is a primary component of PM.)	● Premature mortality ● Aggravation of respiratory and cardiovascular disease ● Changes in lung function ● Increased respiratory symptoms ● Changes to lung tissues and structure ● Altered respiratory defence mechanisms

During the past five years, in 2018 Aden International Airport had one of the maximum number of landing and take-off (LTO) aircraft operations. 3907 LTO-cycles were made [12]. Of course, this process left behind a lot of pollutants from aircraft engines. So this research is an attempt to estimate the aircraft emission gases such as: (CO_2,CH_4, N_2O, CO, NMVOCs and SO_2) at Aden International Airport to use them in any local, regional or even international inventories and also to help local authorities to improve environmental situation in the vicinity and surrounding areas by offering some helpful recommendations.

2. Materials and methods

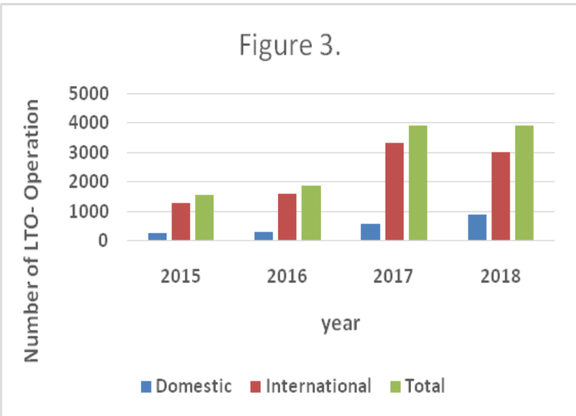
2.1. Study area

Aden International Airport is one of the most important airports in the Yemen Republic. Aden International Airport is an international airport in Aden, Yemen (IATA: ADE, ICAO: OYAA) and the oldest airport in the Arabian peninsula. Prior to its use as a civil air facility, the aerodrome was known as RAF Khormaksar, which opened in 1917 and closed as an RAF station in 1967. In the 1970s and 1980s it was both a civilian airport and a Soviet Air Force air base. It continues to be used for military purposes by the Yemeni Air Force.

(2005-2025), has population of 1,218,000 people [13]. During the last four years there were a noticeable increase in the aircraft movements and also in the number of arriving and departing passengers in the Aden airport (fig. 3 and 4).

From the figure 3 it is clear that the number of the aircrafts that used AIA increased from 1578 in 2015 to 3907 in 2018, i.e. more than twice. Despite this high increase in the number of aircrafts operation, the number of the arriving and departing passengers remained still very low comparing with aircraft movements. This is because Yemenia airlines has reduced the domestic flights since October 2015

Fig.2. Aden airport by Google map



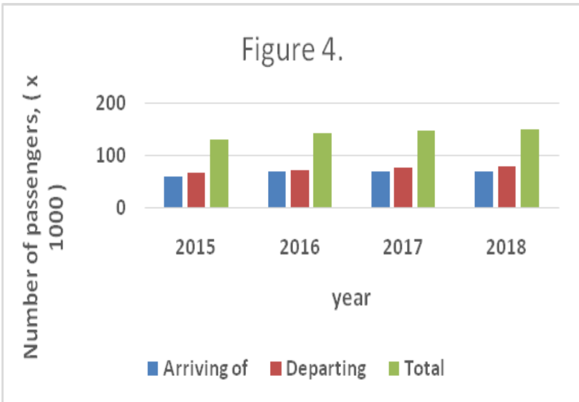


Fig.3. Annual distribution of aircraft

Airport movements at Aden International Airport

Fig. 4. Numberof arriving and departing passengers in Aden International

2.2. Flight operations:

Emissions from an plane originate from fuel burned in plane engines. The fuel utilization and emissions rely on the fuel type, plane type, engine type, engine load and flying altitude. Operations of an plane are typically divided into foremost parts [14].

1. ***The Landing/Take-off (LTO)*** cycle which includes all activities near the airport that take place below the altitude of 3000 feet (1000 m). This therefore includes taxi-in and out, take-off, climb-out, and approach-landing (fig.5).
2. ***Cruise*** which here is defined as all activities that take place at altitudes above 3000 feet (1000 m). No upper limit of altitude is given. Cruise, in the inventory methodology, includes climb to cruise altitude, cruise, and descent from cruise altitudes.

The focus of this study was to determine the aircraft emissions during aircraft LTO cycles (domestic and international) in 2018 at AIA. This is because the most emissions produced from aircrafts happen in this part of the flight.

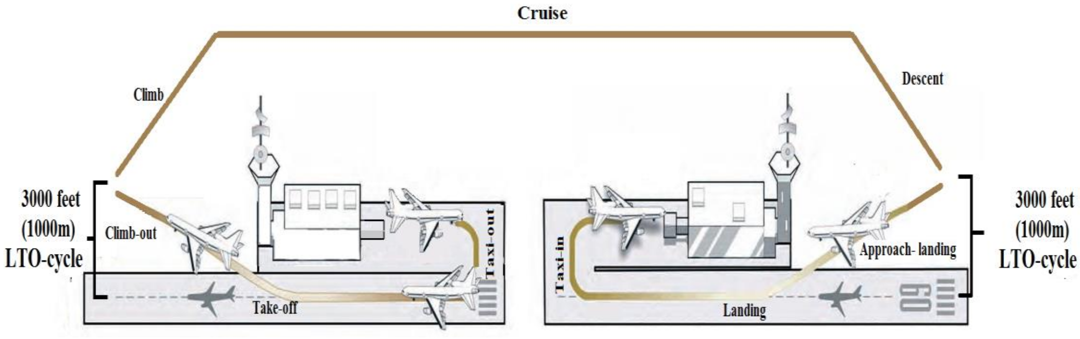


Figure 5: A typical flying cycle which includes LTO-cycle

2.3. Calculating aircraft emissions:

The ICAO emission stock methodologies constitute three approaches: Simple, Advanced and Sophisticate Approach [4]. The desire of any of those techniques relies upon especially on records availability and, of course, their accuracy will increase from the Simple to the Sophisticated Approach.

In this paper the Simple Approach turned into used, due to the fact for estimating plane engine emissions it calls for most effective the quantity of plane movements (over a certain period of time, together with a year) and the type of every plane involved in each movement. To calculate the emissions was used the equation [4]. For every plane type, the quantity of LTO cycles of that plane (over the evaluation length) multiplies with the aid of using the emissions aspect for every of the pollutant species posted in ICAO emissions stock after which upload up the values for all of the plane to get the quantity of general emissions (in kilograms) for every pollutant.

$$E_x = \Sigma \text{ (LTO cycles of y) X } EF_x$$

Where:

- *E_x- Emission of pollutant x, [kilograms], x- (CO_2 - CH_4- N_2O- CO-NMVOCs- SO_2);*
- *LTO- Number of the landing and take-off cycles of y, [LTO]*
- *Y- The aircraft types that landed and departed at MIA*
- *EF_x-Emission factor of pollutant x, [kg/LTO]*

For Aden International Airport there were 3907 LTO-cycles during 2018. But only 3148 LTO of particular type of aircrafts were known (data were available). In the rest 759 LTO-cycles operations the type of aircrafts was unknown. And also it's very important to mention that some aircrafts had no information about their emission factors, neither in ICAO data base nor in any other place. In this case it is helpful to use supplementary information such as weight, number of engines, size category, range, etc. to identify a suitable equivalent aircraft that has available data, as recommended by ICAO in such cases.

3. Results and discussion:

3.1. LTO-cycles operations:

During the 2018 at Aden International Airport there had been 3907 LTO-cycles operations. Of 3148 LTO-cycles become regarded every kind of plane that used the airport (desk 2), however 759 LTO – had been unknown (there had been no to be had data, perhaps they had been army airplanes). For this reason, the LTO emissions of those aircrafts had been now no longer calculated into the overall account of emissions.

Table 2: Shows the air traffic movements by the type at Aden International Airport during 2018

Aircraft type	Number of LTO-cycles	Aircraft type	Number of LTO-cycles	Aircraft type	Number of LTO-cycles
CRJ 700	1180	AN-32	15	EK 76592	1
PA-28/C170	765	C-55	14	CL-601	1
B 737-8	500	IL-76	11	A-33	1
A310	223	AN-12	10	BH-44	1
DH 8/9	152	DC-09	9	C-235	1
MD 82	112	ER 120	7	C-160	1
B-733	53	BE-20	3	BH-41	1
IL-18	36	GLF-4	2	JSS-41	1
AN-26	28	BELL 421	2	**Unknown**	**759**
DC-93	16	B-212	2	**Total**	**3907**

It is clear from the table 2 that CRJ-700, PA-28/C170, B 737 , A310 , DH 8/9 , MD 82 and B-733 were the most common aircrafts used the AIA in 2018. These aircrafts comprised more than 76% of all LTO cycles at AIA in 2018. And it's also obvious that

only CRJ-700 (AL-SAEEDHA) aircrafts comprised about 30% of the all LTO cycles operations at AIA (fig.6).

By comparison with Boeing or Airbus airplanes which are frequently used by Yemenia airline, CRJ-700 (AL-SAEEDHA) is small by size and it began to function in the end of 2008 [15]. This in turn explains the big jump in the traffic movements of aircrafts at AIA between 2014 and 2015, from 1891 LTO in 2014 to 3891 LTO in 2015 (see fig.3), but the motion of passengers were small, from 143000 passengers in 2014 to 148000 passengers in 2015.

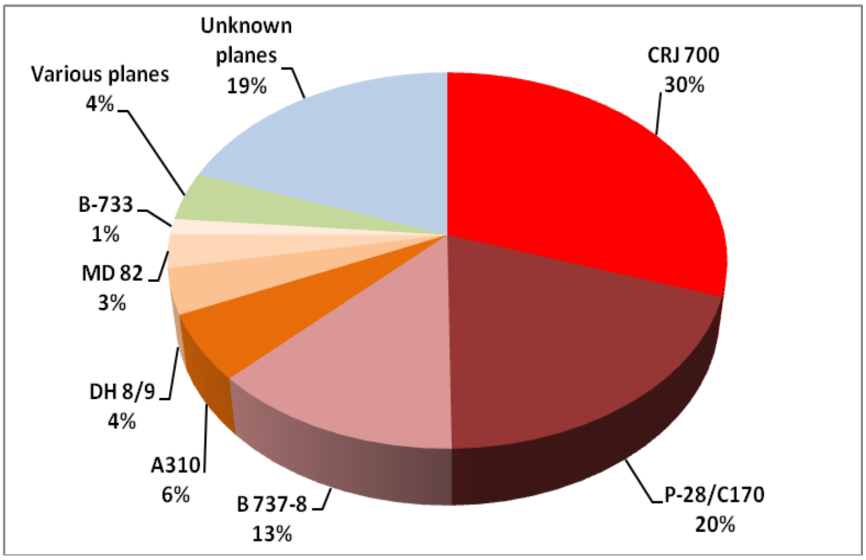


Figure 6: shows the most common aircrafts that made more than 50 LTO at AIA in 2018

3.2. <u>LTO-cycle calculated emissions:</u>

The total estimation of calculated aircraft pollutants (CO_2 - CH_4- N_2O- CO - NMVOCs- SO_2), emitted at Aden International Airport during 3148 LTO operations in 2018 were broken down into detailed analysis below.

- **CO_2 emissions:**

Although typically taken into consideration because the worst greenhouse gas, in fact carbon dioxide isn't the handiest greenhouse gas. However, as it has the very best attention within side the ecosystem as compared to all of the different greenhouse gases that human emit (besides water vapor), it's far the only that has the most important impact [16]. The overall emissions of the CO2 emitted from all aircrafts that used Aden International Airport for the duration of 2018 have been approximately 4747940 kg. The fig.-7A indicates the emissions from every sort of aircrafts.

It was found that the most common aircraft types that emitted about 93% of CO_2 emissions and which had more than 50 LTO operations at AIA in 2018 are CRJ-700, PA-28/C170, B 737 , A310 , DH 8/9 , MD 82 and B-733. Although Boeing 737 aircraft made less LTO operation (approximately 500) than CRJ-700 (about 1180 operations), but the CO_2 emissions per LTO cycle were the highest for Boeing 737 about 29% of all

CO_2 emissions (fig.7B). It happens because the large jet engines use a lot of fuel and of course emissions depend on the LTO emissions factors of each type of aircrafts.

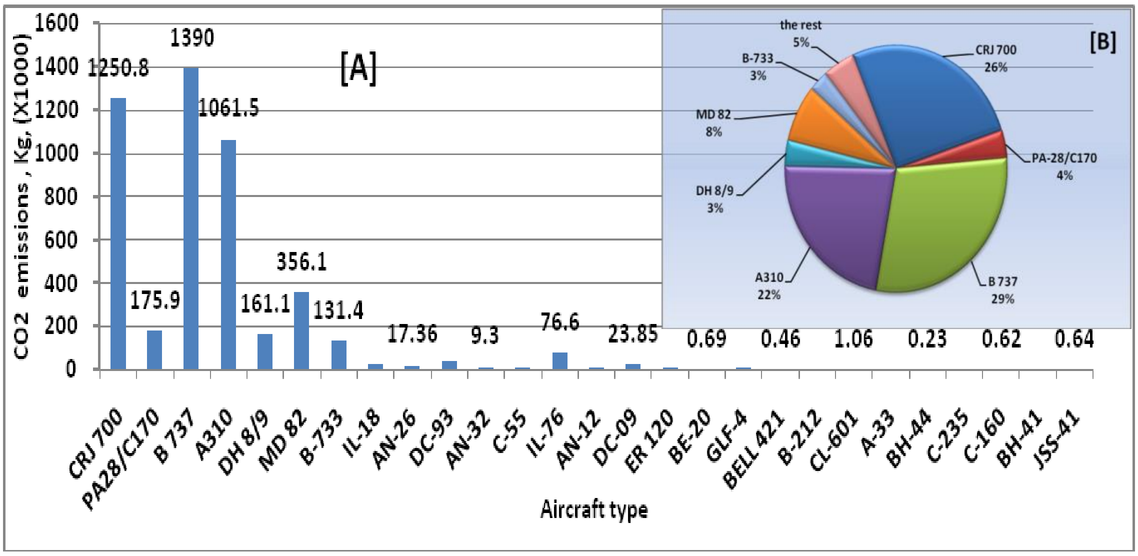


Figure 7: A- shows the CO_2 emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at AIA in2018

- **CH_4 emissions:**

Due to its exceptionally quick lifestyles time within side the atmosphere (9-15 years) and its worldwide warming potency — 20 instances greater powerful than carbon dioxide in trapping warmness within side the atmosphere, methane is at the pinnacle of greenhouse gases, as pronounced with the aid of using the Environmental Protection Agency [16].

The estimation of CH_4 emissions during all LTO operation of all aircrafts that used AIA in 2018 were about 346.68 kg. The figure 8A shows CH_4 emitted from each aircraft type. It's clear that the A310 aircraft type made the highest CH_4 emissions and that was about 41% of all CH_4 emissions at AIA (fig.8B).

- **N_2O emissions:**

N_2O is a greenhouse fuel line with incredible international warming potential (GWP). It has 298 instances greater impact 'in line with unit weight' (GWP) than carbon dioxide.

The total calculated N_2O emissions from all aircrafts were 166.2 kg and the figure 9A shows the N_2O emissions from each aircraft. Boeing 737, A310 and CRJ 700 emitted more emissions than all other aircrafts about 30%, 27% and 21% respectively (fig. 9B).

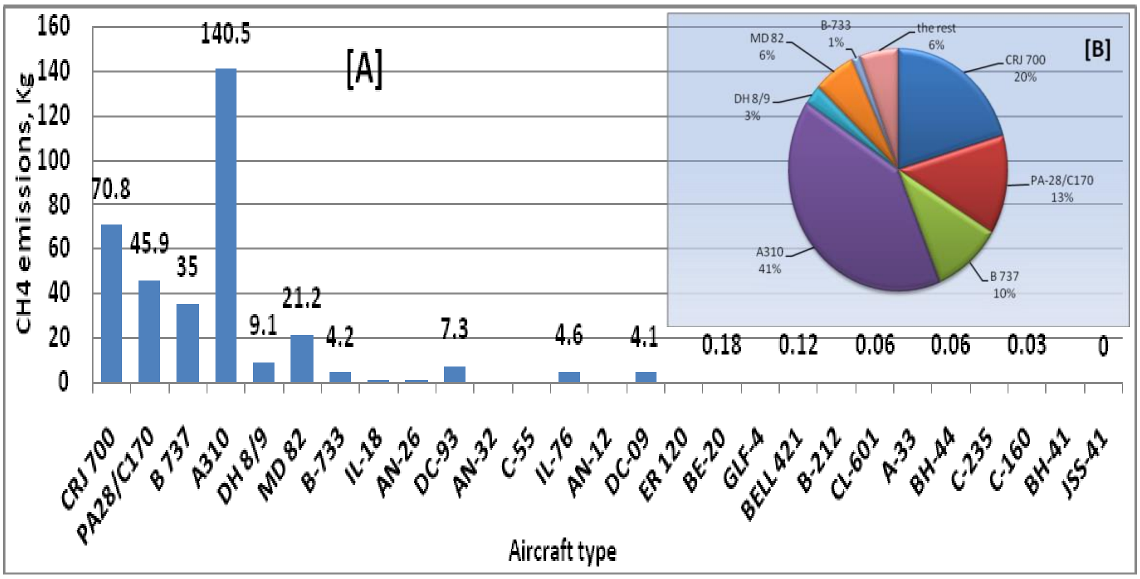


Figure 8: A- shows the CH_4 emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at AIA in2018

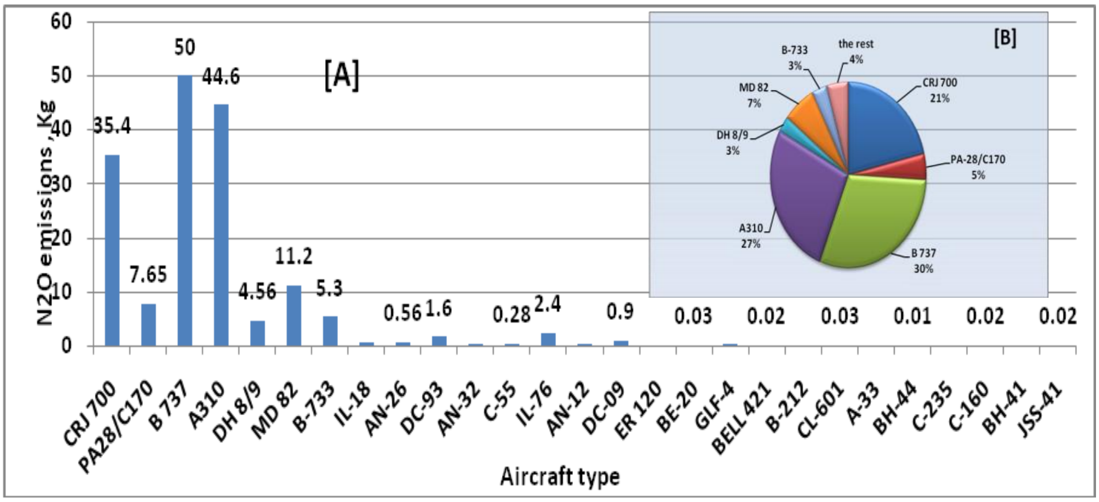


Figure 9: A- shows the N_2O emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at MIA

- **<u>CO emissions:-</u>**

Carbon monoxide is the maximum not unusual place sort of deadly air poisoning in lots of countries. It is highly toxic to humans and animals in higher concentrations. The total emissions of the CO emitted from all aircrafts that used AIA in 2018 were 23482 kg. The figure 10A shows the emissions from each type of aircrafts.

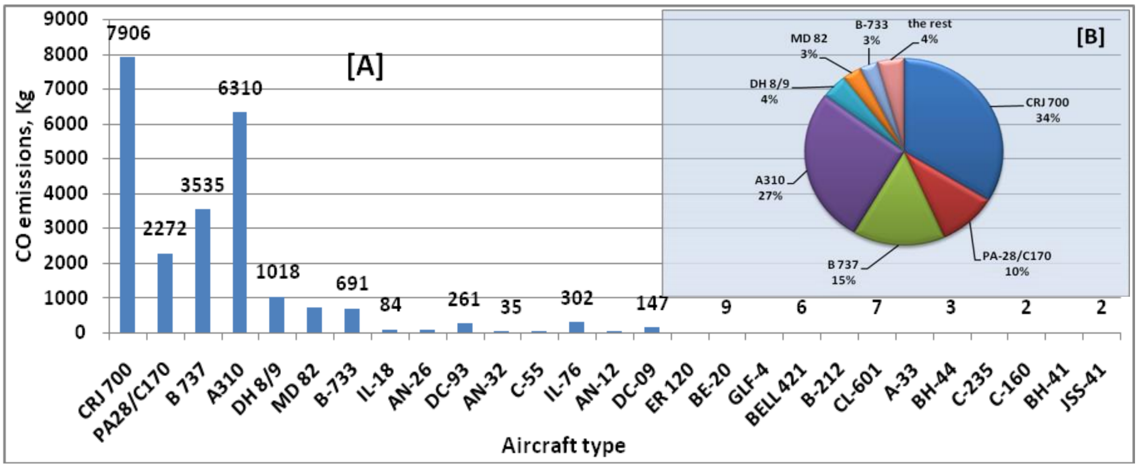


Figure 10: A- shows the CO emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at AIA in2018

In this case, it's clear that CRJ 700 aircraft emitted more than any aircraft type used by AIA, i.e. about 34% (fig.10B). Since the carbon monoxide is considered one of the most dangerous pollutants, it can be said that this type of aircraft is the most harmful to the environment and humans among all aircrafts.

- **NMVOC emissions:-**

Non-methane unstable natural compounds are a big sort of chemically one-of-a-kind compounds, like for example, benzene, ethanol, formaldehyde, etc. Essentially, NMVOCs are same to VOCs, however with methane excluded. Many of NMVOCs are poisonous to human beings and dangerous to the environment [17].

The total emissions of NMVOCs at AIA in 2018 were about 3186.91 kg. Each aircraft type emitted less or more as shown in fig.11A. However Airbus 310 emitted more than any other aircrafts, i.e. about 40% NMVOCs (fig.11B).

- **SO_2 emissions:-**

Sulfur dioxide is a poisonous gas that causes detrimental impacts on human health and the environment. The major health concerns associated with exposure to high concentrations of SO_2 include breathing difficulties, respiratory illness, and aggravation of existing cardiovascular disease. In addition to the health impacts, SO_2 leads to acid depositions in the environment [18].

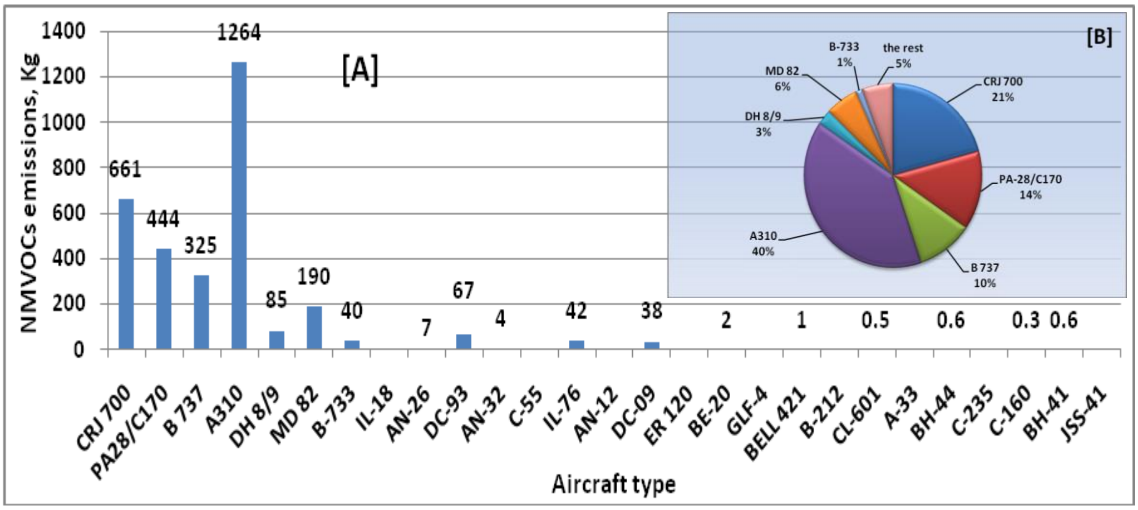


Figure 11: A- shows the NMVOCs emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at AIA in2018

The total SO_2 emissions in 2018 at AIA were 1495 kg. Figure 12A shows the quantities of SO_2 emitted from each kind of airplanes in 2018 at AIA. The most emissions of SO_2 were from B737 29%, CRI 700 26% and A310 22% respectively.

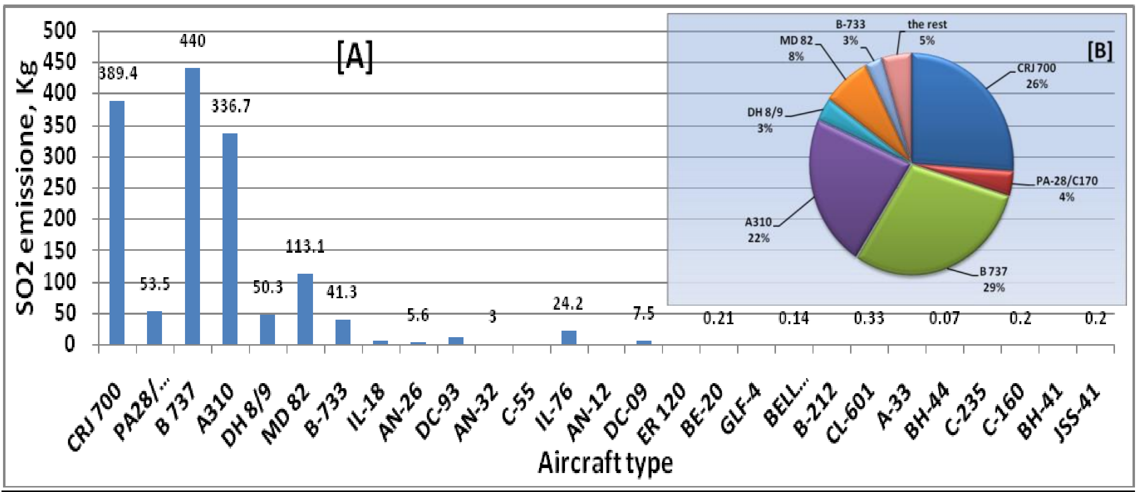


Figure 12: A- shows the SO_2 emissions from each aircraft, and B- the percentage of emissions from aircrafts that have made more than 50 LTO at AIA in2018

4. Conclusion and recommendations

From above-mentioned analysis, it is clear that the most damaging airplanes to the environment are B 737, Airbus 310 and CRJ700 (table 3). In 2018 at AIA during 500 LTO-operations Boeing 737-and its modifications have emitted about 29% CO_2, 30% N_2O and 29% SO_2. So, from an environmental perspective, this plane is the biggest polluter of the area.

Airbus 310 has been considered the second environmental polluter with two records of 41% of CH_4 and 40% of NMVOCs, and finally it's CRJ-700 with one greenhouse record of 34% of CO.

Table 3: The three most polluting aircrafts of AIA during LTO-operations in2018

Pollutants	The most polluting aircrafts at AIA in 2018 for specific emissions		The position of aircraft in terms of pollution	
	Aircraft type	Percentage, of all emissions	Aircraft type	Position
CO_2	B737	29%	B737	1
CH_4	A310	41%		
N_2O	B737	30%	A310	2
CO	CRJ-700	34%		
NMVOCs	A310	40%	CRJ-700	3
SO_2	B737	29%		

In general, it's found that 3148 LTO operations at Aden International Airport in 2018 have led to emissions of the following quantities of engine gases: 4747.940 ton of CO_2, 0.35 ton of CH_4, 0.17 ton of N_2O, 23.48 ton of CO, 3.19 ton of NMVOCs and 1.50 ton of SO_2 (fig. 13).

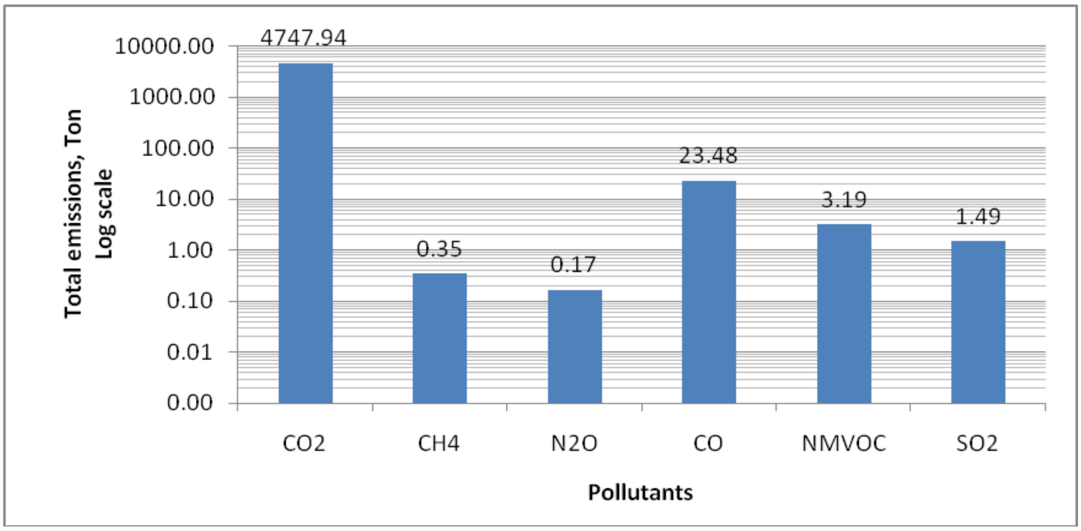


Figure 13: The total calculated aircraft engine emissions of 3148 LTO operations at Aden International Airport in 2018

If we take into account the aircrafts traffic at other airports such as in Sana'a or Al-Mukalla, or even neighboring countries, these quantities of gases are very low. But it must be noted that the effect on the surrounding areas of the airport with long term might be greater. Especially, since there are many studies that indicate the impact of airports on surrounding areas (on human health and on the environment). Therefore it is necessary:-

- To not allow the old aircraft to land and take off from the International Aden Airport because they usually have large rates of emissions.
- To Assess of the environmental situation of the airport zone and neighboring areas through a field study to measure the concentrations of pollutants.
- To establish of short corridors (taxiway) from/to the runway and last parking of the aircraft to minimize the amount of fuel used and thereby

- reduce engine emissions.

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