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Master en Aéronautique

Option : **Opérations Aériennes**

THEME

Study on the reduction of CO2 emissions from aircraft on the ground

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RESUME :

La sécurité des vols, l'économie et la protection de l'environnement sont des facteurs importants à prendre en compte lors de l'exploitation des avions de transport public. Les émissions de CO_2 des avions sont fortement influencées par les opérations aériennes. L'objectif de cette étude est de réduire les émissions de CO_2 des opérations au sol des avions dans les aéroports. Bien que les émissions de CO_2 des opérations au sol des aéronefs soient faibles par rapport aux opérations aériennes, mais elles restent importantes. Cette étude montre qu'il existe de réelles opportunités de réduction de ces émissions. Nous croyons que ces réductions sont importantes par mouvement pour les opérations au sol des aéronefs.

MOTS CLES :

Opérations au sol ; émissions de CO_2 ; Méthodes de calcul ; Méthodes de réductions.

ملخص:

تعتبر سلامة الطيران والاقتصاد وحماية البيئة من العوامل المهمة التي يجب مراعاتها عند تشغيل طائرات النقل العام. تتأثر انبعاثات ثاني أكسيد الكربون في الطائرات بشدة بعمليات الطيران. الهدف من هذه الدراسة هو تقليل انبعاثات ثاني أكسيد الكربون من العمليات الأرضية للطائرات في المطارات ولكننا نحتاج إلى معرفة طرق حساب هذه الانبعاثات. على الرغم من أن انبعاثات ثاني أكسيد الكربون من العمليات الأرضية للطائرات صغيرة مقارنة بعمليات الطيران ، إلا أنها لا تزال كبيرة. تظهر هذه الدراسة أن هناك فرصًا حقيقية لتحقيق تخفيضات في هذه الانبعاثات. نعتقد أن هذه التخفيضات كبيرة لكل حركة للعمليات الأرضية للطائرات.

الكلمات الدالة:

العمليات البرية انبعاثات CO_2 ؛ طرق الحساب؛ طرق التخفيض.

SUMMARY:

Flight safety, economy and environmental protection are important factors to consider when operating public transport aircraft. Aircraft CO2 emissions are strongly influenced by flight operations. The objective of this study is to reduce CO2 emissions from aircraft ground operations at airports but we need to kow the methods of calcul these emissions. Although CO2 emissions from aircraft ground operations are small compared to flight operations, they are still significant. This study shows that there are real opportunities to achieve reductions in these emissions. We believe these reductions are significant per movement for aircraft ground operations.

KEY WORDS:

Ground operations; CO2 emissions ; Methods of calcul; Reduction methods.

<u>REMERCIMENT:</u>

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بعد مسيرة دراسية دامت سنوات حملت في طياتها الكثير من الصعوبات والمشقات، السهر والتعب هاأنا اليوم أقف على عتبة تخرجي أقطف ثمار تعبي وأرفع قبعتي بكل فخر... أهدي عملي هذا:

الى من كانت سببا في كل شيء..

الى من صبرت وتعبت وقدمت ولا تزال..

الى من آمنت بي في أشد المراحل الصعبة..

الى من جُعِلت الجنة تحت أقدامها ولم تنسني في دعائها..

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الى من أحمل إسمه بإفتخار..

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الى من هم أنس وهدية...

الى من شاركت معهم حياتي..

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الى من انتظرت نجاحي بشغف جدتي الغالية اطال الله في عمرها..

الى اقاربي الذين وقفو الى جانبي كما وقف اهلي أهديهم هذا العمل، فأمنياتهم اللطيفة كانت سببا في دعمي وتشجيعي ونجاحي..

الى من كانو عونا لي ونورا يضيء الظلام..

الى من جمعتني بهم الحياة وتقاسمت معهم الذكريات..

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الى كل من مر في حياتي وكان لهم أثر..

الى كل من حملته ذاكرتي ولم تحمله مذكرتي..

الى كل هؤلاء أهدي ثمرة هذا الجهد المتواضع.

زياد

DEDICACE

Je dédie ce travail

A ma très chère maman

J’espère que je te rends fière, même si quoique je fasse je ne saurais point

te remercier comme il se doit. Pour ton affection, ta bienveillance, ta présence à mes côtés et tes douaas qui me guident pour affronter les différents obstacles.

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A toutes les personnes qui ont contribué de près et de loin dans ce travail et qui ont cru en moi, je vous dis merci.

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ACRONYMES:

BADA: Base of Aircraft Data

CO: Carbon Monoxide

CO2: Carbon dioxide

CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation

DAAG: Algiers Aeroport Huari Boumadiene

EI: Index emissions

GSE: Ground support equipment

H: The humidity correction factor H

HC: Hydrocarbon

ICAO: The International Civil Aviation Organization

ISA: International Standard Atmosphere

NO: Nitrogen monoxide

NO2: Nitrogen dioxide

NOx: Oxides Of Nitrogen

Pamb: Ambient pressure

Pv: Saturation vapour pressure

REI: L'indice d'émissions de référence

SET : Single engine taxi

Wf: Fuel Flow

Wff: Fuel Flow corrigé

ω: Specific humidity

Φ: Relative humidity

θamb: Ambient temperature correction

NOx: Oxides Of Nitrogen

Tamb: Ambient temperature

** Əamb:** Ambient pressure correction

The units of measurement used are:

Temperature: Kelvin (K).

Pressure: Pascal (Pa).

Fuel flow rate Wf: Kilogram per second (Kg/s).

Corrected fuel flow rate Wff: Kilogram per second (Kg/s).

Emission index EI: Gram per kilogram (g/Kg).

Reference emission index REI: Gram per kilogram (g/Kg).

Emission masses: Gram (g).

INTRODUCTION

INRODUCTION GENERAL

The study aims to investigate the calculation of emissions using the Boeing and ICAO method and explore strategies for reducing these emissions in the aviation industry. With increasing concerns about climate change and environmental sustainability, there is a growing urgency to address the impact of aircraft emissions on the environment. Emissions from aviation activities contribute to greenhouse gas emissions, air pollution, and their associated environmental and health impacts.

Calculating emissions accurately is crucial for understanding the environmental impact of aviation operations. The Boeing method provides a comprehensive approach to estimate emissions, taking into account various factors such as aircraft type, fuel burn rate, flight distance, and payload. By employing this method, airlines, researchers, and industry stakeholders can quantify and track emissions over time, facilitating informed decision-making and the development of targeted emission reduction strategies.

Reducing emissions in the aviation sector is a multifaceted challenge that requires a comprehensive approach. The study explores a range of strategies to address this issue, focusing on technological advancements, operational efficiency, infrastructure improvements, the use of sustainable aviation fuels, and supportive policy frameworks.

Operational efficiency is another key aspect of emission reduction. Optimizing flight routes, implementing more efficient air traffic management systems, and adopting practices such as continuous descent and climb procedures can minimize fuel consumption and emissions. Additionally, streamlining ground operations, including efficient taxiing and ground support equipment, contributes to overall emission reductions in airport environments.

Supportive policy frameworks and regulations play a critical role in driving emissions reductions in the aviation industry. Governments and international organizations are implementing measures such as emissions trading schemes, carbon pricing, and setting emission reduction targets to incentivize airlines to adopt cleaner technologies and practices. These policies provide a framework for the industry to prioritize sustainability and align their efforts towards achieving emission reduction goals.

By accurately quantifying emissions and implementing a range of approaches, including technological advancements, operational efficiency, infrastructure improvements, the use of sustainable aviation fuels, and supportive policies, the aviation industry aims to mitigate its environmental impact and contribute to a more sustainable future.

CHAPTER 1:

GENERALITE ABOUT TRANSPORT AVIATION AND POLLUTION

1.GENERALITE ABOUT TRANSPORT AVIATION AND POLLUTION:

1.1.THE HISTORY OF POLLUTION

The history of pollution associated with air transport dates back to the early 20th century, with the development of commercial aviation. In the early days, aircraft were powered by piston engines that burned leaded gasoline, which produced significant amounts of lead emissions and other pollutants.

As aviation technology progressed, jet engines became the norm, which increased the speed and range of aircraft but also resulted in higher emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM). The growth of air travel also led to increased airport operations, which caused noise pollution and air pollution from ground handling activities.

In the 1960s and 1970s, concerns about the environmental impacts of air transport began to grow, leading to the establishment of regulations and standards to limit emissions and noise. The International Civil Aviation Organization (ICAO) was founded in 1944 to regulate international air transport, and it has since developed a series of emissions standards for aircraft engines.

Despite these efforts, air transport remains a significant source of pollution. In recent years, there has been increasing concern about the impact of aviation emissions on climate change, particularly the CO_2 emissions associated with long-haul flights. In response, the aviation industry has developed alternative fuels, more fuel-efficient engines, and new technologies to reduce emissions, but there is still a long way to go to achieve a sustainable aviation system.

1.2. TYPES OF POLLUTION

There are several types of pollution, each with its own characteristics and impacts. Here are some common types of pollution:

1.2.1. WATER POLLUTION

Water pollution, the release of substances into subsurface groundwater or into lakes, streams, rivers, estuaries, and oceans to the point where the substances interfere with beneficial

Figure 1.1: De-icing an airplane [20]

use of the water or with the natural functioning of ecosystems. In addition to the release of substances, such as chemicals, trash, or microorganisms, water pollution may also include the release of energy, in the form of radioactivity or heat, into bodies of water.

Aircraft can contribute to water pollution through the release of de-icing fluids, which can contain chemicals that can harm aquatic life and contaminate drinking water sources.

Airports can generate significant water pollution due to their extensive use and handling of jet fuel, lubricants and other chemicals. Chemical spills can be mitigated or prevented by spill containment structures and clean-up equipment such as vacuum trucks, portable berms and absorbents.

Deicing fluids used in cold weather can pollute water, as most of them fall to the ground and the surface of the runoff can carry them to nearby streams, rivers or coastal waters. Deicing fluids contain two basic fluids ethylene glycol or propylene glycol. Airports use pavement deicers on paved surfaces including runways and taxiways. These fluids may contain potassium acetate, glycol compounds, sodium acetate, urea and other chemicals which are considered as a polluted fluids causing harm to the environment.

1.2.2.NOISE POLLUTION

Noise pollution is a significant concern associated with aviation, particularly for those living near airports or under flight paths. The noise from aircraft can have negative impacts on human health and well-being, including sleep disturbance, hearing damage, and increased stress levels.

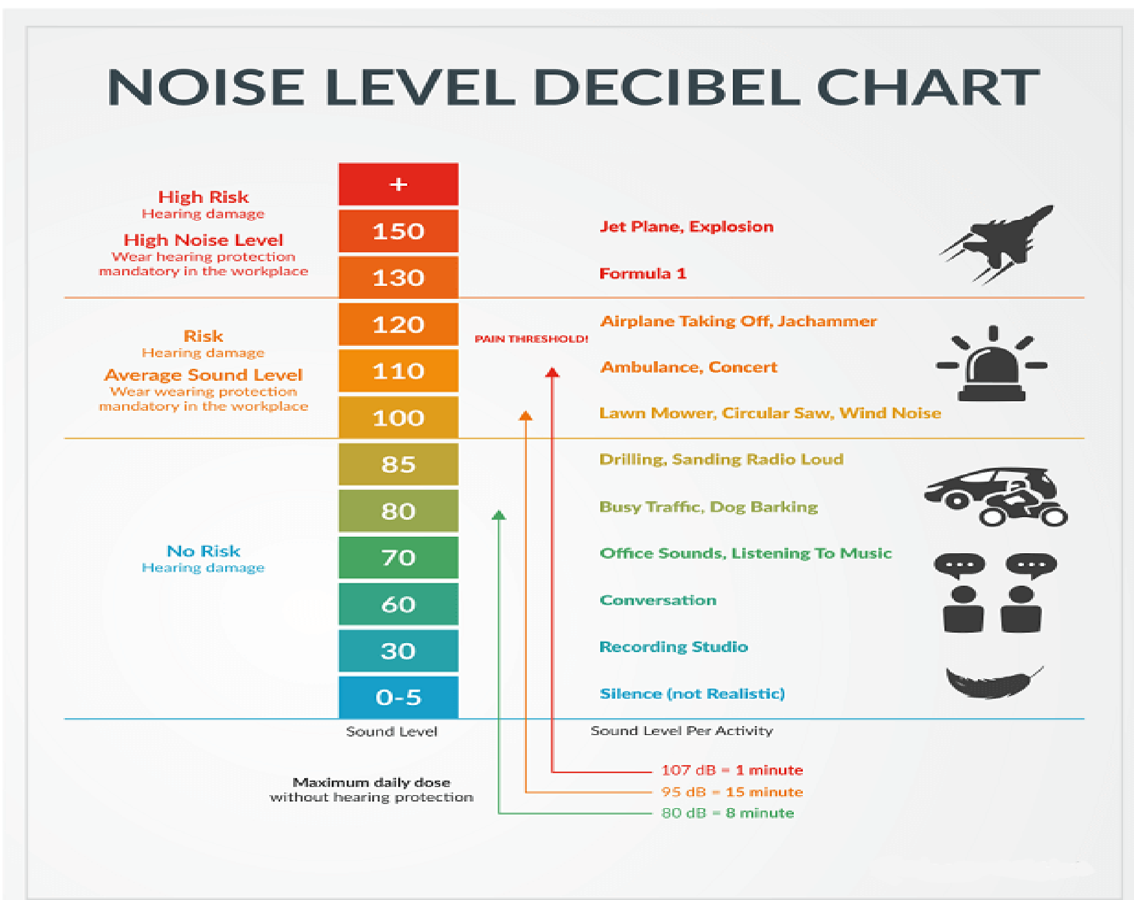


Figure 1.2: Noise Level Decibel Chart [21]

The noise from aircraft is primarily caused by the engines, but other factors such as airframe noise, aerodynamic noise, and auxiliary power units can also contribute to overall noise levels. The intensity and duration of the noise depend on several factors, including the aircrafts altitude, speed, and distance from the observer.

The ICAO Chapter 14 noise standard applies for airplanes submitted for certification after 31 December 2017, and after 31 December 2020 for aircraft below 55 t (121,000 lb), 7 EPNdB (cumulative) quieter than Chapter4. The FAA Stage 5 noise standards are equivalent. Higher bypass ratio engines produce less noise. The PW1000G is presented as 75% quieter than previous engines. Serrated edges or on the back of the nacelle reduce noise.

A Continuous Descent Approach (CDA) is quieter as less noise is produced while the engines are near idle power. CDA can reduce noise on the ground by ~1–5 dB per flight.

1.2.3. POLLUTION ATMOSPHERIQUE

Air pollution is a significant concern associated with aviation. Aircraft engines burn fossil fuels, such as jet fuel, which releases various pollutants into the atmosphere. The most significant of these pollutants are carbon dioxide (CO2), nitrogen oxides (NOx), sulfur dioxide (SO2), particulate matter (PM), and volatile organic compounds (VOCs).

Figure 1.3: Airplane emissions [22]

Carbon dioxide is the primary greenhouse gas released by aircraft and is a major contributor to climate change. Nitrogen oxides contribute to the formation of ground-level ozone, which can have negative impacts on human health, such as respiratory problems and heart disease. Sulfur dioxide contributes to acid rain and can have negative effects on human health and the environment. Particulate matter can have negative health impacts on people living near airports or under flight paths. Volatile organic compounds can contribute to the formation of ground-level ozone and can also have negative health impacts.

1.3. CLASSES OF AIR POLLUTION

1.3.1. PRIMARY POLLUTION

Primary pollution refers to the direct release of pollutants into the environment from sources such as factories, power plants, and vehicles. Examples of primary pollutants include carbon monoxide, sulfur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds.

- Nitrogen oxides (NOx).
- Carbon dioxide (CO2).
- Sulfur oxides (SO2).
- Carbon oxides (CO).
- Light hydrocarbons (HC).
- Volatile organic compounds (VOC).
- PM Particles containing or not metallic compounds (lead, mercury cadmium...) or organic (PM10 and PM2.5).

1.3.2. SECONDARY POLLUTION

Secondary pollution refers to pollutants that form as a result of chemical reactions between primary pollutants and other compounds in the atmosphere. For example, when nitrogen oxides and volatile organic compounds react in the presence of sunlight, they can form ground-level ozone. Similarly, when sulfur dioxide and nitrogen oxides react with water vapor and other compounds in the atmosphere, they can form acid rain.

Secondary pollution can also include the formation of secondary organic aerosols (SOA) from the oxidation of volatile organic compounds (VOCs) in the atmosphere. SOA can contribute to particulate matter pollution, which can have negative health effects on people living near pollution sources. And we have also Ozone(O3)

Ozone (O3): which is a naturally occurring gas composed of three oxygen atoms (O3). It is a molecule that plays a crucial role in the Earth's atmosphere and has both beneficial and harmful effects.

Ozone can be harmful because it is a major component of smog and is formed through complex chemical reactions involving pollutants from sources like vehicle emissions, industrial processes, and certain chemicals. High concentrations of ground-level ozone can be detrimental to human health, particularly for those with respiratory conditions like asthma. It can also damage crops, forests, and other vegetation.

Both primary and secondary pollutants can have negative impacts on human health and the environment. Primary pollutants are typically easier to regulate because they can be directly controlled at the source. Secondary pollutants, on the other hand, are more difficult to control because they form as a result of complex chemical reactions in the atmosphere. Addressing secondary pollutants often requires a more comprehensive approach that addresses both primary and secondary sources of pollution.

1.4.THE EMISSIONS OF THE POLLUTION

Aircraft contribute to pollution through various emissions released during their operation. Here are the major types of emissions associated with aircraft:

1.4.1.CARBON DIOXIDE (CO2)

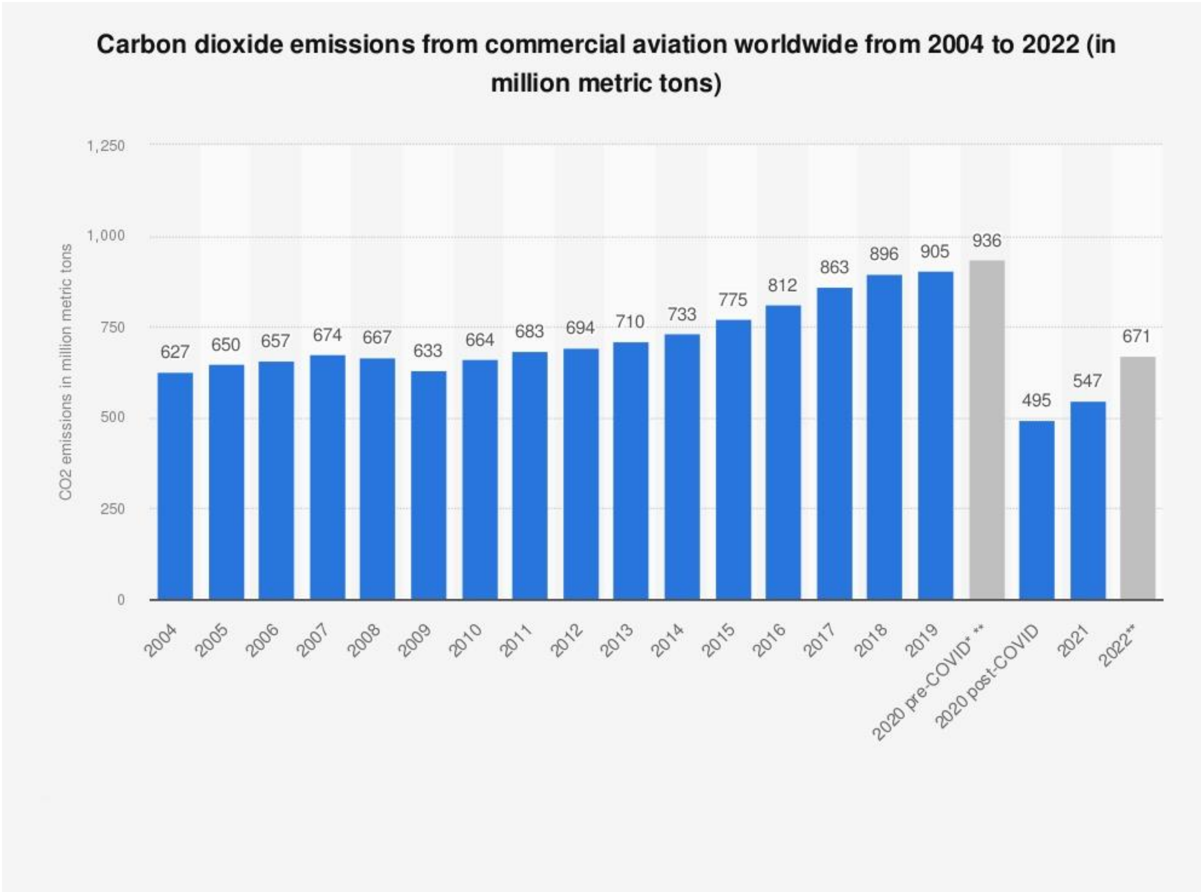
CO2 emission refers to the release of carbon dioxide (CO2) gas into the atmosphere as a result of human activities. Carbon dioxide is a greenhouse gas that contributes to the greenhouse effect and global warming. It is primarily released through the burning of fossil fuels such as coal, oil, and natural gas for electricity generation, transportation, industrial processes, and residential use.

CO2 emissions in the atmosphere can be of natural origin or of anthropogenic origin, that is to say resulting from human activities. The anthropogenic source has been growing rapidly for several decades. Once emitted, the gas is partly absorbed by natural carbon sinks. This absorption doubled from 1960 to 2010, but half of the CO2 released by human activities accumulates in the atmosphere, so that in November 2020 the concentration of atmospheric CO2 reached 413 ppm (parts per million), whereas it was around 280 ppm until the industrial revolution. This increase intensifies the greenhouse effect, which causes global warming.

According to the International Energy Agency (IEA), after a stabilization of global emissions in 2014, 2015 and 2016 thanks to progress in the field of energy efficiency, emissions then started to rise again, the average concentration of CO2 in the atmosphere reaching new records in 2017 and then in 2018. This increase is partly due to electricity consumption (increased by 4% in 2017), whose share in global energy demand is increasing. Thermal power plants running on coal or natural gas, in particular, saw their CO2 emissions increase (+2.5% in 2017).

The level of CO2 in the atmosphere has varied greatly long before the appearance of humans and industrial society, but never at such a rapid rate as that observed in recent decades, including the anthropogenic origin is established.

Carbon dioxide emissions are the primary driver of global climate change. It’s widely recognized that to avoid the worst impacts of climate change, the world needs to urgently reduce emissions. But how this responsibility is shared between regions, countries, and individuals has been an endless point of contention in international discussions. The Graph1.1. represent the global CO2 emissions from commercial aviation 2004to2022:



Graph 1.1: Global CO2 emissions from commercial aviation 2004 to 2022 [23]

1.4.2. NITROGEN OXIDES (NOX)

NOx is the nitrogen oxide emissions emitted by the combustion of fossil fuels.

NOx includes different nitrogen oxides: nitric oxide, nitrogen dioxide and nitrous oxide. These chemical compounds composed of oxygen and nitrogen are atmospheric pollutants that strongly contribute to the greenhouse effect.

Mobility is a major source of NOx emissions, which is why it is governed by European emission standards. Mobility solutions that pollute less than fossil fuels exist, such as bioNGV, whose NOx emissions are twice as low as the Euro VI standard.

Aircraft engines produce nitrogen oxides, primarily nitrogen dioxide (NO_2) and nitrogen monoxide (NO). NOx emissions contribute to the formation of ozone and the production of acid rain. They also have a warming effect on the atmosphere.

Nitrogen oxides (NOx) consist of two molecules: nitric oxide (NO) and nitrogen dioxide (NO_2). We can differentiate between three different categories of NOx since this gas can be formed in three different ways which are as follows:

- Combustible NOx.
- Thermal NOx.
- Early NOx.

Combustible NOx are nitrogen oxides that are formed as a result of the combustion process of certain fuels. Thermal NOx are nitrogen oxides that form when oxygen and nitrogen undergo a chemical combination in a combustion process at very high temperatures. As for early NOx, these are nitrogen oxides created by a chemical combination between hydrocarbon radicals and the nitrogen present in the air. These hydrocarbon radicals can be of the CH and CH_2 type, for example. At the end of the reaction, the NOx fuse with the oxygen present in the air.

Nitrogen oxides (NOx) continue to be a key pollutant of concern for aviation, and that concern has resulted in improved combustor emissions performance from new aircraft engines as new NOx standards have been adopted. There remains a strong push for higher core temperatures for better engine specific fuel consumption, which counterbalance combustor NOx improvements. Aviation NOx emissions have impacts on local air quality and human health, both through emissions in and around airports, but also from emissions at altitude affecting background concentrations. NOx emissions also affect climate by changing atmospheric ozone (O_3) and methane (CH_4) levels, two important greenhouse gases, thus affecting the Earth’s radiative balance.

1.4.3.SULFUR DIOXIDE (SO2):

It is a gas, it reacts on the surface of a variety of solid suspended particles, it is soluble in water and can be oxidized in water droplets carried by the wind. Sulfur dioxide comes mainly from the combustion of fossil fuels (coal, fuel oil, etc.), during which the sulfur impurities contained in the fuels are oxidized by the oxygen in the air O_2 to sulfur dioxide SO_2. This gaseous pollutant is thus released by multiple small sources (domestic heating installations, diesel engine vehicles, etc.) and by larger point sources (power or steam generation plants, district boiler rooms, etc.). Some industrial processes also produce sulfur effluents (production of sulfuric acid, oil refining, metallurgy of non-ferrous metals, etc.). Coal burning is the largest man-made source of sulfur dioxide accounting for about 50% of annual global emissions, with oil burning accounting for another 25-30%. Volcanoes are the most common natural source of sulfur dioxide.

Aircraft that use fuels with higher sulfur content, such as certain types of jet fuel, can release sulfur dioxide during combustion. SO_2 emissions contribute to the formation of acid rain and can have detrimental effects on human health and the environment.

1.4.4.PARTICULATE MATTER (PM):

Particulate matter is generic term to classify air pollutants comprising of suspended particles in air, varying in composition and size, resulting from various anthropogenic activities. Industrial facilities, Power plants, vehicles, incinerators, dust and fires are the major source of particulate matter. The particle size ranges between 2.5 mm (PM2.5) and 10 mm (PM10). The part of respiratory system affected by PM depends upon the size of particle. The upper respiratory tract is affected by PM10 while lung alveoli is affected by ultrafine particles (0.1 mm diameter). The size, surface, number and composition of particles play an important role in eliciting health effects. PM can absorb and transfer multitude of pollutants which results in its composition variation. However, PM mainly comprises of ions, reactive gases, organic compounds, metals, and particle carbon core. While relating to mortality, respiratory and cardiovascular effects it can be inferred that finer particles are more hazardous to human health than the coarser ones. Particulate matter can cause premature mortality in patients suffering from lung or heart disease, nonfatal heart attacks, aggravate asthma, reduced lung functionality, irritation in airways, coughing difficult breathing etc.

Aircraft engines emit particulate matter in the form of fine particles (PM2.5) and black carbon. These particles can have adverse health effects, contribute to reduced air quality, and affect climate by absorbing sunlight and altering cloud formation.

1.4.5. CARBON MONOXIDE (CO):

An odorless, colorless and flammable gas, carbon monoxide CO is formed during the incomplete combustion of organic matter (gas, coal, fuel oil or wood, fuels).

The main source is traffic. Significant levels of CO can be encountered when an engine is idling in an enclosed space or during traffic jams in covered spaces, as well as in the event of a malfunction of a domestic heating appliance.

CO participates in the formation mechanisms of tropospheric ozone. In the atmosphere, it turns into carbon dioxide CO_2 and contributes to the greenhouse effect.

- Effects on human health: carbon monoxide has a toxic effect from a volume concentration of less than 0.1%, in prolonged exposure. CO binds to hemoglobin to form a stable molecule, carboxyhemoglobin. Hemoglobin associates preferentially with CO rather than with oxygen, and this fixation is irreversible. For a concentration of 800 ppm of CO in the air, 50% of the hemoglobin is blocked in the form of carboxyhemoglobin. This results in a decrease in cellular oxygenation, which is harmful in particular to the central nervous system. CO is responsible for 300 to 400 deaths per year in France, in closed environments, and more than 5,000 hospitalizations.

1.4.6. VOLATILE ORGANIC COMPOUNDS (VOCS):

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions.

Aircraft engines emit VOCs, including unburned fuel compounds and other hydrocarbons. VOCs can contribute to the formation of ground-level ozone and the production of smog.

1.4.7. HYDROCARBON(HC):

A hydrocarbon is an organic compound containing exclusively carbon (C) and hydrogen (H) atoms. They therefore have a crude formula of type: $C_n H_m$, where n and m are two natural numbers.

A distinction is made between saturated hydrocarbons (alkanes) and hydrocarbons with one or more unsaturations (alkenes, alkynes, and aromatic compounds).

A distinction can also be made between linear and branched hydrocarbons.

They are flammable and do not mix with water. Refined from petroleum, they are used as fuel for internal combustion engines.

And for the secondary gazes we have:

1.4.8. OZONE (O_3)

It is an allotropic gaseous variety of oxygen (O), heavier than air.

We talk about the “good”, that is to say stratospheric ozone, and the “bad”, that is to say, ozone at the surface of the earth, also called tropospheric ozone.

Stratospheric ozone or “good ozone” is found in fairly high concentrations in the Earth's stratosphere, mainly at an altitude of between 15 and 20 km. This ozone, which strongly absorbs ultraviolet rays, protects living organisms from UV radiation. It is destroyed by aerosols, in particular from human activity, including CFCs, thus causing a hole in the ozone layer.

Tropospheric ozone or “bad ozone” is generated by pollution near the earth's surface. Initially, tropospheric ozone was thought to be stratospheric ozone that had descended, since ozone is much heavier than air. However, it is recognized today that, if the phenomenon of the descent of part of the ozone from the stratosphere towards the troposphere does exist, it is only responsible for a small part of the tropospheric ozone. Lower atmospheric ozone is an extremely irritating, colorless gas that forms just above the earth's surface.

Ground-level ozone is formed by a chemical reaction involving nitrogen dioxide with oxygen in the air. However, to form nitrogen dioxide (NO2), you need nitric oxide (NO) directly released by cars, combined with volatile organic compounds (VOCs) mainly from industries.

Ozone is a greenhouse gas, just like carbon dioxide. It is likely to block part of the telluric radiation and send it back to the ground. It is currently estimated that the relative share of ozone in the additional greenhouse effect could be between 10 and 20%.

The levels of photochemical pollution recorded in France in August 2003 have never been so high since 1991, the date of the generalization of ozone measurements in France, according to the Agency for the environment and control of energy (ADEME). Ozone reaches levels above 180 micrograms per cubic meter of air (µg/m3) in cities and rural areas, and levels are often high for nitrogen dioxide and fine particulates.

1.5. SOURCES OF EMISSIONS

All of those emissions are caused by:

1.5.1. ENGINE

The combustion of kerosene in aircraft engines produces carbon dioxide (CO2), water vapor (H2O), nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC), sulfur oxides (SOx) and soot particles.

Nitrogen oxides are formed by oxidation of nitrogen in the air at high temperature and pressure values at the engine combustion chamber outlet during take-off and climb phases.

Carbon monoxide and unburned hydrocarbons result from the incomplete combustion of kerosene when the engine is operated at reduced power (parking and taxiing).

Sulfur oxides come from the oxidation of sulfur contained in kerosene during combustion. Carbon dioxide and water vapor are products of the normal combustion of kerosene. Emissions of these pollutants do not depend on the phase of flight, but on the amount of fuel consumed and the sulfur content of the kerosene.

Soot is the solid residue from the exhaust gases. Their production increases with the engine speed, that is to say during the take-off and climb phases. In addition, fuels rich in aromatic compounds increase the formation of soot.

Despite the work undertaken to date, it has not been possible to determine a species allowing emissions from aircraft to be traced.

In its 1999 report on "aviation and the planetary atmosphere", the IPCC gives the proportions of gases leaving the reactor:

Table1.1: percentages (%) of reactor gases

Gazes	percentages (%)
O2	16.3
N2	75.2
Other combustion products	8.5

So, we represent this table1.1 in the pichart below in figure1.4:

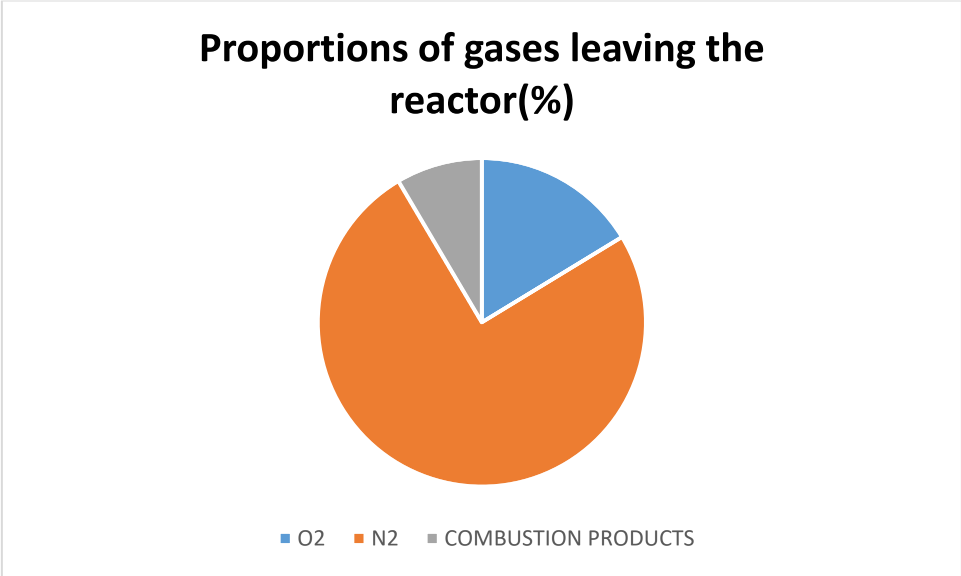


Figure1.4: Percentages (%) of reactor gases

The other combustion products (8.5%) broken down as follows:

Table1.2: Percentages (%) of the other combustion products

Combustion Products	Percentages (%)
H_2O	27.6
CO_2	72
SO_2	0.02
Residual products	0.4

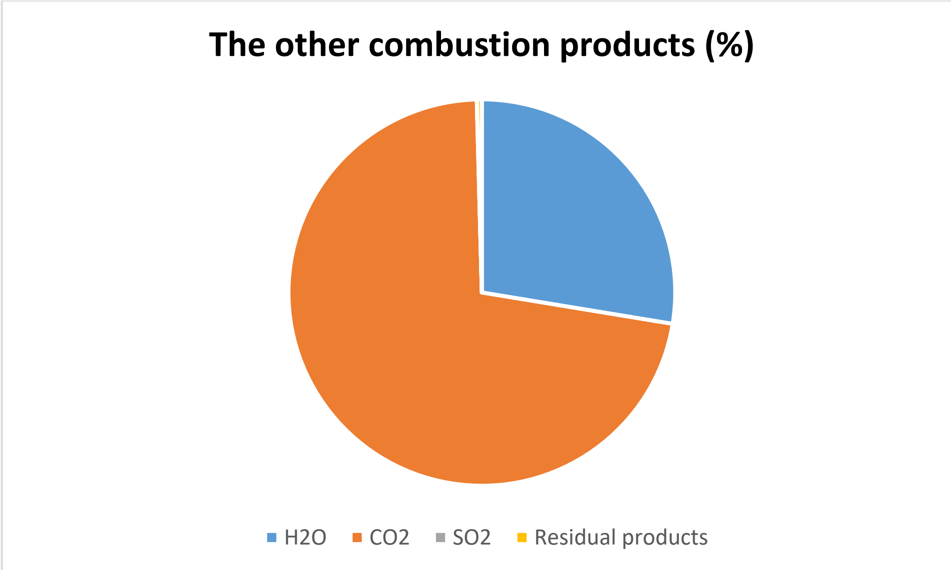


Figure1.5: Percentages (%) of the other combustion products

And 0.4% residual products, which themselves break down into:

Table1.3: Percentages (%) of the residual products

Residual Products	**Percentages (%)**
CO	**11.8**
Nox	**84**
CH	**4**
Soot	**0.1**

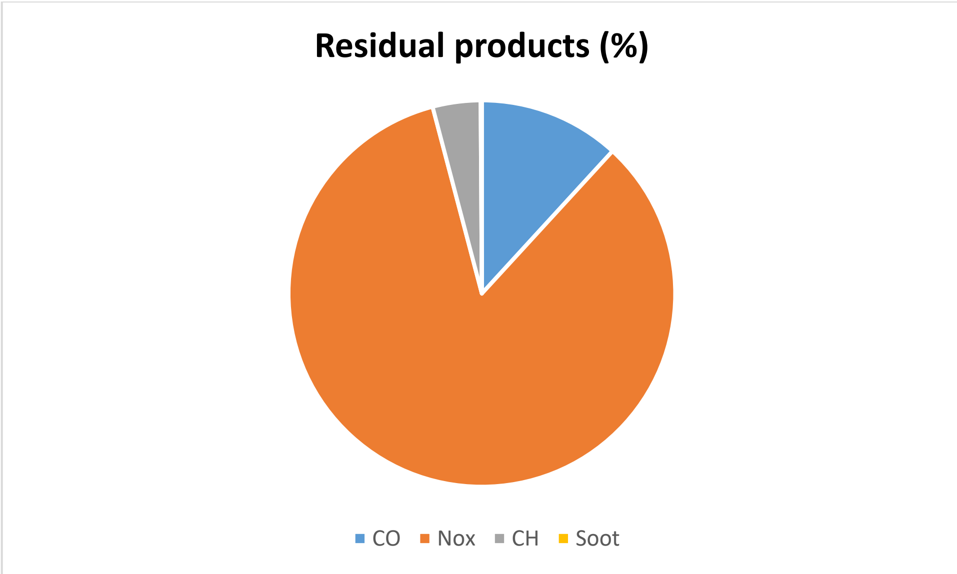


Figure1.6: Percentages (%) of the residual products

1.5.2.ON AEROPORT

Airports also release contaminants from activities such as:

- Ground service equipment.
- Motor vehicles (parking, road traffic).
- Construction.
- Boilers.
- Generators.
- Airport fire training facility.
- Food preparation.
- Engine testing.
- Electricity.
- De-icing.
- Fuel storage facilities.

The contaminants listed above can also been found emitting from airport sources. The VOCs emitted may vary for those emitted by aircraft depending on the fuels used in ground service and road traffic vehicles, and fire training exercises.

1.6.IMPACT

The fallout, in the form of particles (soot) represents 0.1% of the residual products which themselves represent 0.4% of the combustion products.

There is an American civil aviation (FAA) study showing that above 3000 feet (900 meters), the pollutants emitted no longer have an impact on the ground1.

But to date, there is no known study giving a quantification of the fallout on sites near airports. The studies carried out by INRA in 2000 and 2001, based on plant bio-indicators, on the Orly site did not make it possible to measure the additional pollution generated by aeronautics.

1.6.1. HEALTH EFFECTS

Exposure to the contaminants listed above can result in serious health effects. The table presented below lists some of these effects. Local and regional air quality officials are responsible for creating standards to protect human health from the adverse effects of these contaminants.

The following diagram illustrates the percentage of deposition of particulate matter of a specified particle diameter that will reach different segments of the respiratory system.

Table1.4: Representative health effects of air pollutants

Pollutant	Representative Health Effects
Ozone	Lung function impairment, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and pulmonary inflammation, lung structure damage
Carbon Monoxide	Cardiovascular effects, especially in those persons with heart conditions (e.g., decreased time to onset of exercise-induced angina)
Nitrogen Oxides	Lung irritation and lower resistance to respiratory infections

Particulate Matter	Premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms
Volatile Organic Compounds	Eve and respiratory tract irritation, headaches, dizziness. visual disorders, and memory impairment

1.6.2. ENVIRONMENTAL EFFECTS

Aircraft and airport emissions can also have serious effects on the environment. These contaminants can affect crop productivity and ecosystem response. In particular, NOx in the troposphere can contribute to ground-level ozone, excess nitrogen loads to sensitive water bodies, and acidification of sensitive ecosystems according to the U.S. Environmental Protection Agency.

Particulate matter contributes to visibility and soiling issues. They play a key role in creating the hazy smog often found surrounding cities on sunny, warm, dry days.

VOCs also contribute to ozone formation and damage plants, crops, buildings and materials when released at high levels.

Table1.5: Representative environmental effects of air pollutants

Pollutant	Representative environmental Effects
Ozone	Crop damage, damage to trees and decreased resistance to disease for both crops and other plants
Carbon Monoxide	Similar health effects on animals as on humans
Nitrogen Oxides	Acid rain, visibility degradation, particle formation. contribution towards ozone formation
Particulate Matter	Visibility degradation and monument and building soiling, safety effects for aircraft from reduced visibility.
Volatile Organic Compounds	safety effects for aircraft from reduced visibility. Contribution towards ozone formation, odors, and some direct effect on buildings and plants.

CHAPTER 2:

THE METHODS OF CALCUL EMISSIONS

2.THE METHODS OF CALCUL EMISSIONS:

2.1. INTRODUCTION

The aviation industry is responsible for a significant portion of global greenhouse gas emissions, primarily from carbon dioxide (CO2) and other pollutants that contribute to climate change. As a result, there has been increasing pressure to reduce the environmental impact of aircraft operations.

One way to address this challenge is by calculating and tracking the emissions of aircraft. Calculating aircraft emissions involves analyzing several factors, such as the type of aircraft, the distance flown, the fuel used, and the operational efficiency of the aircraft.

There are several methods for calculating aircraft emissions, each with its own advantages and limitations. These methods include the fuel consumption method, engine certification data method, flight data method, and default values method.

It's crucial to accurately measure aircraft emissions as this information is essential for developing effective policies and regulations to reduce the environmental impact of aviation. By calculating aircraft emissions, airlines, governments, and other stakeholders can work together to develop strategies to reduce greenhouse gas emissions and mitigate the impact of aviation on climate change.

In this chapter we will see the different methods of the calculation and the important things that relate to it, which we need to know before we use those methods and specially the ones we will use in our study (Boeing method B2) on chapter 3.

2.2. FLIGHT PHASES

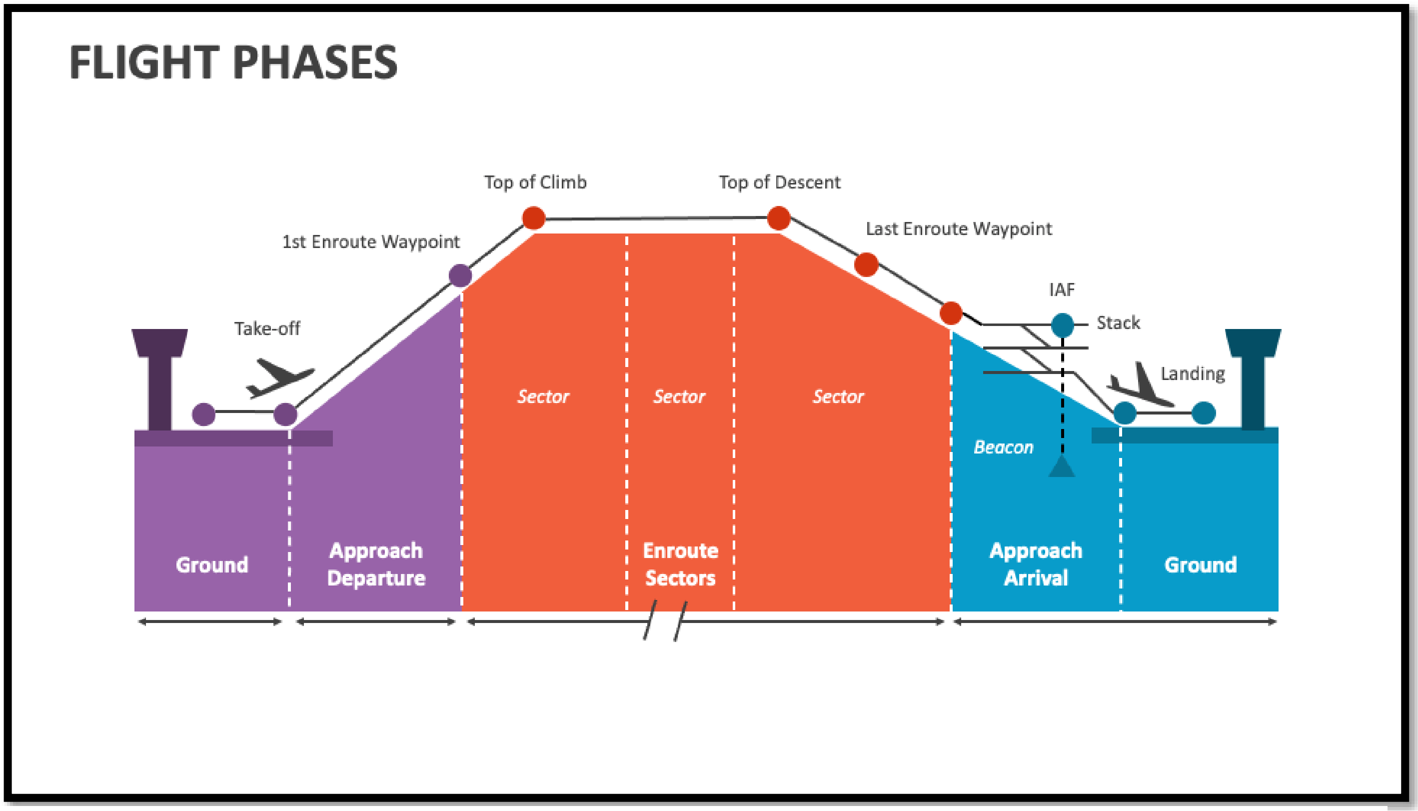


Figure 2.1: The phases of flight

The phases of a typical flight:

- **Ground Phase:** This phase includes all activities that take place on the ground before the aircraft takes off. It involves pre-flight inspections, fueling, loading of cargo and passengers, and other necessary preparations.
- **Takeoff:** The aircraft accelerates along the runway, gradually gaining speed until it reaches a speed called rotation speed. At this point, the pilot pulls back on the control column, causing the aircraft to lift off the ground and enter the next phase.
- **Climb:** After takeoff, the aircraft continues to gain altitude while maintaining a climb angle. During this phase, the aircraft retracts its landing gear, adjusts its flaps, and increases engine power to reach the desired cruising altitude.
- **Enroute:** Once the aircraft reaches its cruising altitude, it enters the enroute phase. This is the portion of the flight where the aircraft flies in a straight line towards its destination. The pilots follow a designated flight plan and communicate with air traffic control for any necessary updates or changes.

- **Descent:** As the aircraft approaches its destination, it begins the descent phase. The pilot reduces engine power and adjusts the aircraft's pitch to descend gradually towards the destination airport.
- **Approach:** During the approach phase, the aircraft navigates towards the destination airport while following specific procedures and guidelines. The pilot establishes communication with air traffic control, prepares the aircraft for landing, and aligns it with the runway.
- **Landing:** The landing phase occurs when the aircraft touches down on the runway. The pilot reduces speed, extends the flaps and landing gear, and guides the aircraft to a safe landing. Once the aircraft slows down, it exits the runway and enters the final phase.
- **Ground Phase:** After landing, the aircraft taxis to the terminal or designated parking area. The engines are shut down, and passengers and cargo are unloaded. This phase involves post-flight procedures, such as shutdown checks and securing the aircraft.

2.3. CYCLE LTO (LANDING – TAKE OFF)

The International Civil Aviation Organization (ICAO) defines the LTO cycle (Landing

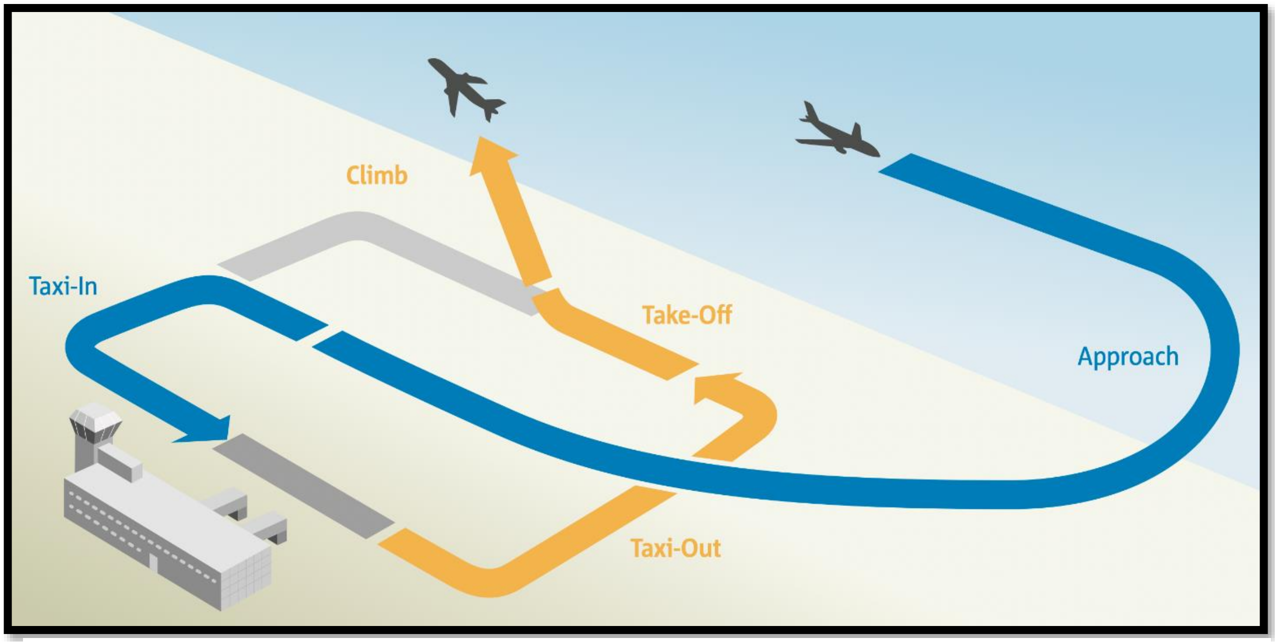


Figure 2.2: The cycle (Landing – Take Off)

and Take-off), which includes four modes of engine operation: idle, approach, climb out, and take-off. Each mode is associated with a specific engine thrust setting and a time in that mode.

- **IDLE:** This mode occurs when the aircraft is on the ground or taxiing at low power settings. The engines are operating at idle thrust, providing the minimum power required to keep the aircraft moving.
- **APPROACH:** During the approach phase, the aircraft is descending towards the runway for landing. The engines operate at a relatively low thrust setting to maintain a controlled descent.
- **CLIMB OUT:** After the aircraft lands, it goes through a brief idle phase before beginning the climb-out phase. In climb out, the engines apply increased thrust to ascend rapidly and gain altitude.
- **TAKE-OFF:** This mode corresponds to the initial acceleration and lift-off of the aircraft from the runway. The engines operate at maximum thrust to achieve the necessary power for take-off.

The specific thrust settings and time in each mode may vary depending on the aircraft type, weight, weather conditions, and other factors. The LTO cycle is important for assessing the environmental impact of aircraft operations, including noise levels and emissions, as different engine modes can have varying levels of impact on the environment.

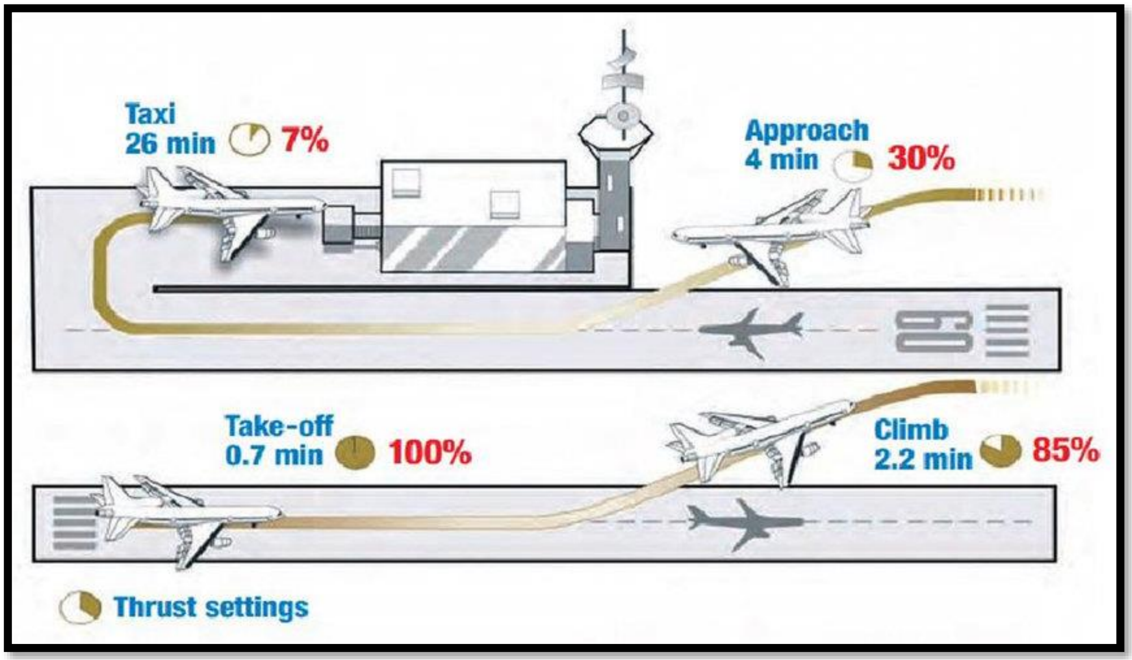


Figure 2.3: Engine settings and time in each mode

2.4. ENGINE CARACTERISTIQUE

For our study we need many parameters that are related to the engine and before that we will confirm the certification of that, this data is from ICAO base data:

2.4.1 ENGINE EMISSIONS CERTIFICATION

Engine emissions certification is the process by which engines, particularly those used in vehicles, undergo testing and evaluation to determine their compliance with specific emission standards set by regulatory authorities. The certification ensures that engines meet the prescribed limits for various pollutants to minimize their impact on the environment and public health.

The certification process involves the following steps:

- **TEST PROCEDURES:** Regulatory authorities, such as the Environmental Protection Agency (EPA) in the United States, establish standardized test procedures that manufacturers must follow. These procedures outline the specific tests to be conducted, including measuring emissions during different driving conditions, such as urban, highway, and cold-start scenarios.
- **TESTING FACILITIES:** Manufacturers conduct emissions testing in specialized facilities equipped with the necessary equipment and instrumentation to measure pollutants accurately. These facilities are designed to simulate real-world driving conditions to obtain representative emissions data.
- **EMISSIONS MEASUREMENT:** During testing, various pollutants are measured, including nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and hydrocarbons (HC). The engines are subjected to different operating conditions and load profiles to assess emissions across a range of scenarios.
- **COMPLIANCE EVALUATION:** The measured emissions data are compared against the emission standards set by the regulatory authorities. If the engine's emissions fall within the prescribed limits, it is considered compliant. Otherwise, the manufacturer may need to make adjustments or improvements to meet the standards.
- **CERTIFICATION DOCUMENTATION:** Upon successful compliance, manufacturers submit the emissions test results and other required documentation to the regulatory authorities. The authorities review the data and issue the necessary certification or approval, allowing the engine to be used in vehicles legally.

It's important to note that the specific certification requirements and procedures may vary among different countries or regions, as each has its own regulations and standards for engine emissions.

2.4.2 THE EMISSION INDEX

In aviation, the emission index refers to the measure of pollutant emissions per unit of aircraft activity. It quantifies the environmental impact of aircraft emissions by expressing the amount of pollutants emitted relative to a specific unit of activity, such as distance flown, fuel burned, or payload carried.

The emission index is commonly used to assess and monitor the environmental performance of aircraft and to evaluate compliance with emission regulations. It helps in understanding the efficiency of engines and emission control systems, as well as the overall environmental impact of aviation operations.

The emission index typically includes pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), unburned hydrocarbons (HC), and other species that contribute to air pollution and climate change.

The emission index is expressed in units of mass or mass equivalent of pollutants emitted per unit of activity. Some common units for emission indexes in aviation include grams per kilogram of fuel burned (g/kg), grams per kilometer flown (g/km), or grams per passenger-kilometer (g/passenger-km).

Emission indexes play a vital role in aviation environmental assessments, policy-making, and emission modeling. They help track emissions trends, evaluate the effectiveness of emission reduction strategies, and guide the development of more fuel-efficient and environmentally friendly aircraft and engine technologies.

Regulatory bodies such as the International Civil Aviation Organization (ICAO) set emission standards and guidelines that specify maximum allowable emission indexes for different types of aircraft, considering factors such as engine type, aircraft size, and operational characteristics. These standards aim to mitigate the environmental impact of aviation and promote sustainable practices within the industry.

2.4.3 THE FUEL FLOW

In aviation, fuel flow refers to the rate at which fuel is consumed by aircraft engines during flight or while on the ground. It represents the amount of fuel passing through the engine per unit of time and is typically measured in units like kilograms per hour (kg/h) or pounds per hour (lb/h).

Fuel flow is a critical parameter in aviation for several reasons including:

- **Performance Monitoring:** Monitoring fuel flow allows pilots and operators to assess the performance of the aircraft and its engines. Deviations in fuel flow from expected values can indicate issues with engine efficiency, fuel system problems, or other operational considerations.
- **Flight Planning:** Fuel flow data is crucial for flight planning, including determining the fuel requirements for a specific flight. By considering factors such as distance, altitude, wind conditions, and aircraft weight, pilots can calculate the expected fuel consumption and plan accordingly to ensure they carry sufficient fuel for the journey.
- **Fuel Management:** Accurate fuel flow measurements during flight help pilots manage fuel consumption and make adjustments as necessary. This includes optimizing throttle settings, adjusting altitude or speed to maximize fuel efficiency, and making informed decisions about potential fuel-saving measures.
- **Operational Costs:** Fuel is one of the significant operational expenses for airlines and other aviation operators. Monitoring fuel flow allows them to track fuel consumption, identify trends, and make informed decisions to optimize fuel usage and reduce operational costs.

It should be noted that fuel flow can vary based on factors such as aircraft type, engine configuration, altitude, airspeed, and throttle settings. Efficient fuel management is crucial for maximizing range, reducing emissions, and ensuring the safe operation of aircraft.

In modern aircraft, fuel flow measurements are typically captured by onboard fuel flow sensors and integrated into the aircraft's engine management system. These sensors provide real-time fuel flow data to the flight crew and other systems for monitoring, optimizing performance, and supporting decision-making during flight.

2.4.4 THE RELATION BETWEEN EMISSION INDEX AND THE FUEL FLOW

In aviation, the emission index and fuel flow are two related concepts that provide insights into the environmental impact of aircraft operations. Here's how they are connected:

The relation between fuel flow and emission index lies in the efficiency of the aircraft's engines and the emissions control systems. Generally, more efficient engines and advanced emission control technologies can result in lower fuel burn and lower emission indexes. Reduced fuel flow generally leads to lower emissions of greenhouse gases and other pollutants.

To assess the environmental impact of aviation operations, both fuel flow and emission index data are crucial. Monitoring and optimizing fuel flow can help minimize fuel consumption, reduce emissions, and improve the overall efficiency of aircraft operations. By calculating the emission index based on fuel flow data and emission factors, the environmental impact of aviation activities can be quantified and evaluated.

The International Civil Aviation Organization (ICAO) have established emission standards and guidelines for aviation to limit the emission index of aircraft and encourage the development and adoption of more fuel-efficient and environmentally friendly technologies.

2.5. THE CALCUL OF EMISSIONS MOTOR

The calculation of engine emissions involves estimating the amount of pollutants released by an aircraft engine during its operation. These emissions typically include nitrogen oxides (NOx), carbon dioxide (CO_2), fine particles (PM), carbon monoxide (CO), and other volatile organic compounds (VOCs).

To perform this calculation, several factors need to be taken into account, such as the engine type, its configuration, flight conditions (altitude, speed, etc.), and the characteristics of the fuel used.

Aircraft engine manufacturers generally provide data on the specific emissions of their engines, which serve as a basis for estimating actual emissions. This data is often consolidated in mathematical models and databases, such as the Emissions and Dispersion Modeling System (EDMS) developed by Euro control.

By using these models and data, it is possible to calculate the specific emissions of an engine for different flight phases, such as takeoff, climb, cruise, and landing. These estimates are then used to assess the environmental impact of aviation operations, support the development of emission reduction policies, and guide the design of cleaner and more efficient engines.

It is important to note that environmental regulations impose strict limits on aircraft engine emissions, and airlines are required to comply with these standards to reduce their impact on the environment.

2.6. METHODS OF CALCULATION

There are many methods of calculation used to quantify emissions including:

2.6.1 METHOD OF ICAO FOR CALCUL EMISSIONS (CO2):

Air Algeria uses a method made by ICAO for calculating and monitoring emission, The CO2 calculation formula is the same as in the Europe system, which changes its fuel conversion factor F to become equal to 3.16 (kg of CO2/kg of fuel). The formula plus two ways of using it are show below:

$$\boldsymbol{CO_2 = \sum MF \times FCFf} \qquad (\mathbf{1})$$

• **CO2:** CO2 emissions (in tons).

• **MF:** Mass of fuel f used (in tons).

• **FCFf:** Fuel conversion factor f given

- Equal to 3.15 (in kg of CO2/kg of fuel) For Europe.
- Equal to 3.16 (in kg of CO2/kg of fuel) For ICAO in the rest of the world.

METHOD A:

$$\mathbf{FN = TN - TN{+}1 + UN{+}1} \qquad \mathbf{(2)}$$

• **FN:** Quantity of fuel consumed for the planned flight (=flight N) determined by Method A (in tons).

• **TN:** Quantity of fuel contained in the tanks of the aircraft once boarded for the planned flight (flight N) (in tons).

• **TN+1:** Quantity of fuel contained in the tanks of the aircraft one times boarded for the following flight (flight N+1) (in tons).

• **UN+1:** Sum of the quantities of fuel on board for the following flight (volN+1) measured in volume and multiplied by a density value (in tons).

METHOD B:

$$\mathbf{FN = RN\text{-}1 - RN + A} \qquad \mathbf{(3)}$$

• **FN:** Fuel consumed for the flight under consideration (i.e., flight N) determined by Method B (in tons).

• **RN–1:** Quantity of fuel remaining in the aircraft's tanks at the end of the previous flight (i.e., flight N–1) with the chocks in place before the occurrence flight, (in tons);

• **RN:** Quantity of fuel remaining in the aircraft's tanks at the end of the previous flight (i.e., flight N) with the chocks in place after the flight (in tons).

• **UN:** Quantity of fuel on board for the flight under study, measured in Volume and multiplied by a density value (in tons).

Air Algeria uses method B for the calculating fuel consumption for all its flights without exception,

In air Algeria department, they use the following format:

$$\mathbf{AFc=Qfr\text{-}Qfa+Qfb} \qquad \mathbf{(4)}$$

Actual fuel consumption for each flight (ton)= quantity of fuel remaining in the tanks of the aircraft on arrival block at the end of the previous flight (ton)+ on-board fuel for the flight (ton)– quantity of fuel contained in the tanks on arrival block at the end of the flight (ton)

AFc: Actual fuel consumption for each flight (ton).

Qfr: quantity of fuel remaining in the tanks of the aircraft on arrival block at the end of the previous flight (ton).

Qfa: quantity of fuel contained in the tanks on arrival block at the end of the flight (ton)

Qfb: onboard fuel for the flight (ton).

NB:

- Fuel which Air Algerie use is Jet A1
- They use those Documents for the data of the method:

ATL (Aircraft Technical Log): is used to determine the quantities of fuel in the tanks for each flight (document concerning the Air Algérie fleet and filled in by the Technical flight personnel).

FRL (Fuel Record Log): is used to determine the quantities of fuel in the tanks for each flight (document concerning the Chartered fleet and filled in by the Technical flight personnel).

BLF (Fuel Delivery Note): is used to determine the quantities of fuel removed for each flight (document filled in by the supplier and given to the flight crew).

2.6.2 BOEING METHOD FOR CALCULATING (CO, NO, AND HC) EMISSIONS:

Boeing offers a method for calculating CO, NOx and HC emissions for aircraft, this method uses data specific to each aircraft engine type depending on the engine performance, which is fuel flow and Index emission. Emission factors for each pollutant are then calculated based on these data. The calculation method takes into account several factors, such as the phase of flight, the configuration of the aircraft and the weather conditions. CO, NOx and HC emissions are calculated for each phase of flight, including taxi, take-off, climb, cruise, approach and landing phase. The results of the emissions calculation can be used to assess compare environmental performance between different types of aircraft and design an emission reduction strategy.

The Advanced Emission Model 3 (AEM3) uses a modified version of the Boeing Method 2 (BM2) to estimate emission calculations (NOx, CO and HC).

The International Civil Aviation Organization (ICAO) has established standards and recommended practices (Annex 16 to the ICAO Conference, "Environmental Protection") for the testing of aircraft emissions on turbojet and turbofan engines. The world's jet engine manufacturers have been required to report to ICAO the results of required testing procedures, which pertain to aircraft emissions. ICAO regulations require reporting of emissions testing data on the following gaseous emitters: NOx, HC, CO and smoke. In addition to this, ICAO requires that information be reported on the rate of fuel flow at various phases of flight. Hence,

ICAO maintains a database of this where information is available for each of the phases of flight, ICAO defines them as the following:

Table 2.1: Operating Mode Throttle Setting (percent of maximum rated output)

Take off	100%
Climb out	85%
Approach	30%
Taxi/ground idle	7%

The Boeing 2 Method is an empirical procedure developed for this study which computes in-flight aircraft emissions using, as a base, the measured fuel flow and the engine ICAO data sheets. Whereas the first Boeing method took into account ambient pressure, temperature and humidity, the second method was more complicated (and accurate). This new method allowed for ambient pressure, temperature and humidity as well as Mach number.

METHODOLOGY:

This is a method that empirically calculates the production of Nitrogen Oxides (NOx), Hydrocarbons (HC), and Carbon Monoxide (CO) emissions during the flight phases. Carbon Dioxide (CO2), Water (H2O), and Sulfur Oxides (SOx) emissions are obtained directly by multiplying the fuel consumption by the corresponding emission index:

$$\boldsymbol{Emissions(Kg)=Indice\ d'Emission\ \left(\frac{Kg}{Kg}\right) \times Carburant\ consommé(Kg)} \quad \textbf{(5)}$$

This calculation method uses fuel flow and emission production data measured on aircraft engines and listed in the ICAO database as a basis. It makes it possible to extrapolate existing data for the LTO cycle to the in-flight phases.

NB: The Boeing Method uses English units and not S.I. therefore the first step is to convert the Fuel Flow (Wf) from the ICAO data for a specific engine from kg/s to lbs/hr (multiply by 7936). The Emission Index (EI) values from ICAO are to be read as lbs/1000 lbs (same number as g/kg).

Table 2.2: The ICAO fuel flow values are then to be modified by a correction for aircraft installation effects (Wf)

Take off	1.010
Climb out	1.013
Approach	1.020
Taxi/ground idle	1.100

With this equation to get wf correct:

$$Wf(corrected) = Wf \times r \qquad (6)$$

r: is the correction for Wf

- **STEP 1: Curve fitting the Data:**

The Emission Indices (NOx, HC, CO) are to be plotted (log-log) against the corrected fuel flow (Wf).

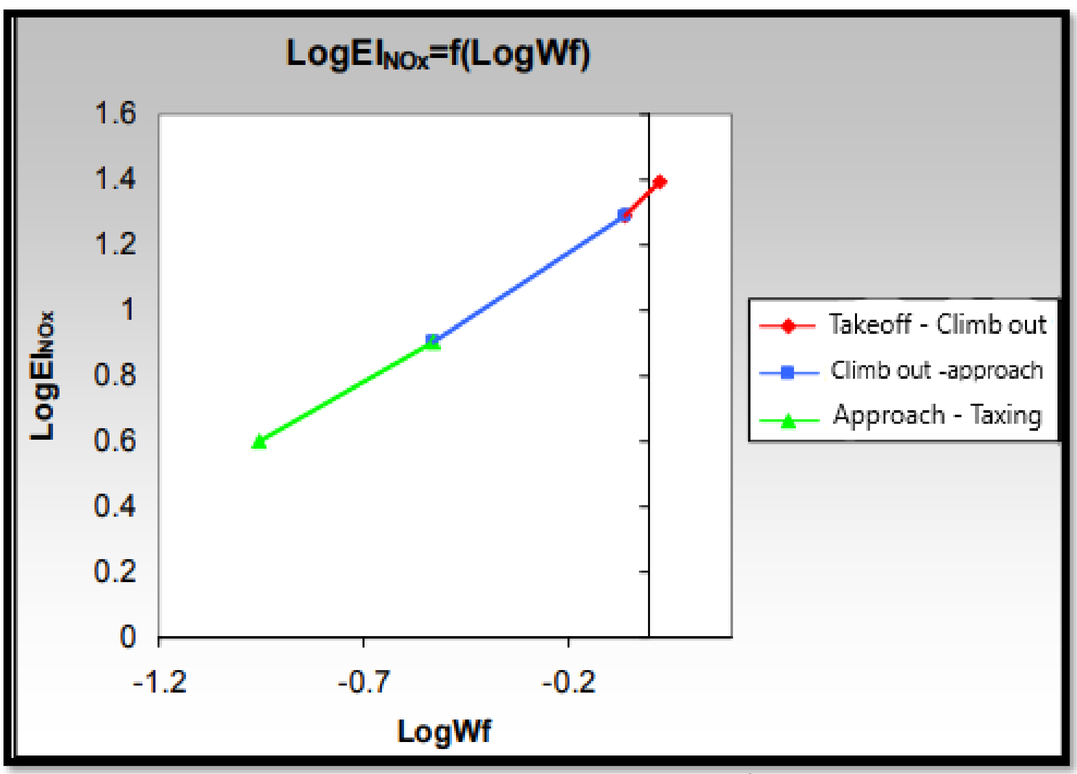


Figure 2.4: Log EI NOx against Log Fuel flow

- **STEP 2: Fuel Flow Factor:**

a) Calculate the values ∂amb (ambient pressure correction factor) and θamb (ambient temperature correction factor) where:

$$\boldsymbol{\partial amb} = \frac{\boldsymbol{Pamb}}{\mathbf{14.696}}\ \boldsymbol{Pa} \qquad (7) \qquad \text{(Pamb = ambient pressure)}$$

and

$$\boldsymbol{\theta amb} = \frac{\boldsymbol{Tamb}}{\mathbf{288.15}}\ \boldsymbol{k} \qquad (8) \qquad \text{(Tamb = ambient temperature)}$$

b) The fuel flow values are further modified by the ambient values:

$$\boldsymbol{Wff} = \left(\frac{\boldsymbol{Wf}}{\boldsymbol{\partial amb}}\right) \times \boldsymbol{\theta amb}^{\mathbf{3.8}} \times \boldsymbol{e}^{\left(\mathbf{0.2}\boldsymbol{M}^{\mathbf{2}}\right)} \qquad \mathbf{(9)}$$

, where M is the Mach number.

After calculating the value of Wff, the value of its logarithm log Wff and projecting this Valeur on the graphs of steps 1, we found the values of:

- log $REI\ NOx$
- log $REI\ HC$
- log $REI\ CO$

then we calculate the inverse of the logarithm to obtain their values:

- $REI\ NOx\ (\frac{g}{kg})$
- $REI\ HC\ (\frac{g}{kg})$
- $REI\ CO\ (\frac{g}{kg})$

c) Calculate the humidity correction factor H:

First, we calculate each parameter in order to calculate the one after it,

- we calculate β to use for calculating Pv.
- Pv for calculating w.
- finally, w for calculating H.

$$\boldsymbol{\beta} = \mathbf{7.90298} \times \left(\frac{\mathbf{1-373.16}}{\mathbf{Tamb}}\right) + \mathbf{3.00571} + \mathbf{5.02808} \times \mathbf{log}\left(\frac{\mathbf{373.16}}{\mathbf{Tamb}}\right) + (\mathbf{1.3816} \times \mathbf{10^{-7}}) \times \left[\mathbf{1} - \mathbf{10}^{\left(\mathbf{11.344} \times \left(\mathbf{1} - \frac{\mathbf{Tamb}}{\mathbf{373.16}}\right)\right)}\right] + (\mathbf{8.1328} \times \mathbf{10^{-3}}) \times \left[\mathbf{10}^{\left(\mathbf{3.49149} \times \left(\mathbf{1} - \frac{\mathbf{373.16}}{\mathbf{Tamb}}\right)\right)} - \mathbf{1}\right] \qquad \mathbf{(10)}$$

For a correction to this formula, please see the EUROCONTROL corrected Boeing 2 Method below.

$$Pv = (0.014504)10^{\beta} \quad (11)$$

, and

, ω = specific humidity,

$$\omega = \frac{(0.62198 \times (\Phi) \times Pv)}{(Pamb - (\Phi) \times Pv)} \quad (12)$$

$$H = -19.0\,(\omega - 0.0063) \quad (13)$$

, where Φ is relative humidity and Pv = saturation vapor pressure in psia.

- **<u>STEP 3: Compute EI:</u>**

Calculate the emission indices of HC, CO and NOx:

$$EIHC = REIHC \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}} \left(\frac{g}{kg}\right) \quad (14)$$

$$EICO = REICO \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}} \left(\frac{g}{kg}\right) \quad (15)$$

$$EINOx = REINOx \times \left(\frac{\theta amb^{1.02}}{\partial amb^{3.3}}\right)^{0.5} \times e^{H} \left(\frac{g}{kg}\right) \quad (16)$$

Where the REIHC, REICO, and REINOX values are read off the graph (STEP 1) by substituting Wff for Wf.

- **<u>STEP 4: Total Emission:</u>**

$$Total\,(HC, CO, NOx) = Nb\ of\ Engines \times \Sigma i\,(EIHC, EICO, EINOX)i \times Wfi \times Timei \times 10^{-3}$$

(17) , in lbs.

Timei: is time moyen of operation (Take off-Climb Out-Approach-Taxi/ground idle)

CHAPTER 3:

METHODS STUDY

3. METHODS STUDY :

3.1. STUDY ZONE

So, our study will be about the emissions and especially about the emissions on ground and we choose Air Algerie as zone of study and year 2021 as year of study on airport of Algiers.

3.2. PRESENTATION OF THE ORGANIZATION

Air Algerie is an airline company that provides regular and non-scheduled air transport services, both internationally and domestically. Its main purpose is to transport passengers, baggage, freight, and mail for a fee. It plays a significant role in contributing to economic development and territorial planning. Air Algerie is a joint-stock company with a capital of 43 billion Algerian dinars. The company annually transports nearly 3 million passengers on its regular routes. This table presented the Air Algerie company:

Table 3.1: The company of Air Algerie

Founded	**15 March 1947**
Main aéroport	**Houari Boumediene-Airport**
Fleet size	**55**
Destinations	**75**
Parent company	**Government of Algeria**
Headquarters	**1Place Morice Audin 16000-Algiers, Algeria**
Code ICAO	**DAH**

3.2.1. CREATION AND EVOLUTION OF THE COMPANY

The airline was founded fifteen years before independence. Indeed, the company AIR ALGERIE was created in 1947 to operate the network of airlines between Algeria and France.

This same network was served by the company AIR TRANSPORT whose lines extended to the former French West Africa.

Air Algerie, also known as Compagnie Algerienne de Transport Aérien, is the national flag carrier airline of Algeria. Here are details about Air Algerie:

3.2.2. CREATION AND DEVELOPMENT OF THE COMPANY

The airline company was established fifteen years before independence. In fact, Air Algerie was created in 1947 to operate a network of air routes between Algeria and France.

This same network was served by the company AIR TRANSPORT, whose routes extended to the former French West Africa.

In 1953, following the merger of these two organizations, the airline company AIR ALGERIE began its operations. In 1954, at the start of the national liberation war, AIR ALGERIE had a fleet consisting of four conventional piston-engine DOUGLAS (DC4) aircraft.

In 1956, the introduction of LOCKHEED "Constellation" increased the fleet size to 10 aircraft.

In 1957, the company acquired two additional DC4s, as well as two DC3s and two Nord Atlas cargo aircraft.

In 1959, the first Caravelle, a jet-powered aircraft, was put into service.

By 1962, the year of Algeria's attainment of national independence following the national liberation war against France, the existing fleet comprised:

- 4 Caravelles.

- 10 DC4.
- 03 DC3.

In 1963, AIR ALGERIE became a national company under the supervision of the Ministry of Transport.

Algeria's independence led to the departure of French national personnel and a gradual "Algerianization" process. AIR ALGERIE gradually expanded its network by establishing new international routes to countries with which Algeria had established diplomatic and commercial relations (Europe, Africa, and the Middle East). It served 35 foreign destinations and 26 domestic destinations.

In 1966, the "Algerianization" of the cabin crew was completed.

In 1968, the remaining shares held by foreign companies were repurchased by the Algerian state. Four CONVAIR G60 aircraft were acquired, and the DC4 and DC3 aircraft were retired.

In 1971, the first SUPERJET BOEING aircraft entered service. The efforts made to train Algerian cabin crew allowed for the formation of the first entirely Algerian crews.

In 1972, the company achieved a new success: the first major maintenance visit on a CARAVELLE aircraft was conducted at the DAR EL BEIDA maintenance workshops.

By 1984, the "Algerianization" of technical flight crew could be considered complete, with 98% of the flight crew being Algerian nationals.

In 1987, Air Algerie was separated from airport management.

In 1997, Air Algerie became a joint-stock company with a capital of 2.5 billion dinars.

In 1998, the liberalization of air transport took place.

1999: A plan for upgrading and modernizing the company was developed, which includes:

- Replacing the B727-200 with new-generation NG aircraft.

- Completing the basic maintenance works.
- Implementing a new commercial strategy adapted to the new rules of the market economy.
- Developing and strengthening coordination with other carriers.
- Establishing an internal communication system (intranet).

Since 2000, the capital of Air Algerie has gradually increased from 6 billion dinars to 43 billion dinars in 2010.

2004: Acquisition of 5 A330 aircraft.

2007: Opening of the direct route between Algiers and Montreal.

2009: Opening of the direct route between Algiers and Beijing.

2010: Fleet reinforcement with the acquisition of 4 ATR and 3 Boeing B737-800 aircraft, bringing the company's capital to 43 billion dinars that year.

2014: Air Algerie equipped itself with new aircraft, including two Boeing 737-700 C and eight Boeing 737-800, reflecting its intention to make Houari Boumediene Airport in Algiers a hub with the objective of reaching 10 million passengers per year. Planned routes include a redeployment towards Africa, which will enter its active phase, as well as the opening of new routes to the United States and Asia.

2015: On April 2, 2015, Air Algerie received one of the three Airbus A330-200 aircraft ordered in 2014 as part of its 2013-2017 development plan.

2016: Air Algerie acquired a convertible 737-700 for cargo purposes.

2019: In January,2019, Air Algerie reached an agreement to sell its three Boeing 767-300 aircraft to a private American company. The last one departed from Houari Boumediene Airport in Algiers on January 27, 2019, heading towards the United States.

On July 2, 2019, Air Algerie introduced online payment via CIB and Gold cards from Algerie Poste31. They also launched the Air Algerie application on iOS and Android platforms since March 2019.

2020: On March 3, 2020, an Air Algerie Airbus A330-200 repatriated 130 Algerian, Tunisian, Libyan, and Mauritanian nationals from Wuhan, China, due to the Covid-19 pandemic and suspended its flights to Beijing.

On March 16, 2020, Air Algerie suspended its flights to Italy, Spain, France, and Morocco due to the Covid-19 pandemic. A few days later, on March 21, Air Algerie decided to suspend all its domestic and international flights.

2021: On June 1, 2021, after more than a year of suspension of its domestic and international flights due to the Covid-19 pandemic, Air Algerie partially resumed its flights to local regions and later to France (Paris and Marseille), Spain (Barcelona), Turkey (Istanbul), and Tunisia (Tunis).

In total, throughout the year 2021, Air Algerie recorded fewer than 2 million passengers, representing a 30% decrease in traffic compared to 2019, the last year before the pandemic. Domestic flights accounted for 80% of the company's total activity.

Air Algerie also plans to purchase an initial series of 15 aircraft and eventually around 30 aircraft, for which 1.6 billion euros have already been allocated.

2022: Air Algerie announced its intention to significantly expand its services by opening over 108 new international destinations for the high season. Five months later, the company indicated that it would further increase its offerings for the summer by adding around thirty additional destinations due to high demand.

2023: Air Algerie placed an order with Boeing for eight Boeing 737 Max 9 aircraft, with delivery scheduled for 2027. On June 1, 2023, Air Algerie placed an order with Airbus for 5 Airbus A330-900 neo and 2 Airbus A350-1000 aircraft.

Subsequently, Air Algerie issued a tender for the dry lease of 4 Airbus A330 ceo, 2 Airbus A330-900, 2 Boeing 737-800, and 2 Boeing 737 Max aircraft.

3.2.3. CURRENT FLEET

The Air Algerie fleet consists of the following aircraft (as of April 2023):

Table 3.2 : Air Algerie fleet

Aircraft	In fleet	Total Passengers
Airbus A330-200	8	From 232
		To 251
ATR 72-500	12	From 66
		To 70
ATR 72-600	3	68
Boeing 737-600	5	101
Boeing 737-700C	2	112
Boeing 737-800	24	162
Boeing 737-800BCF	1	Cargo
Lockheed L-100-30T	1	Cargo
Total	55	

3.2.4. MISSIONS OF THE COMPANY

Air Algerie is a service-oriented company in the field of air transportation for passengers and cargo. It is responsible for:

In terms of air transport: Operating domestic and international air routes to ensure public transportation of passengers, baggage, freight, and mail.

In terms of air operations: Providing service offerings for commercial and scientific purposes, catering to the needs of agriculture, civil protection, public hygiene, and health.

In terms of commercial operations: Selling and issuing transport tickets, purchasing and chartering aircraft, providing presentation, assistance, and refueling services for aircraft.

In terms of technical operations: Obtaining licenses, permits, and authorizations for overflight in foreign airspace, conducting maintenance, repairs, and inspections of aircraft equipment, both for its own operations and on behalf of third parties. Since transitioning to autonomy and transforming into a joint-stock company, Air Algerie has become a public airline that, directly or indirectly, in Algeria or abroad, aims to:

- Organize and operate all public transport services by aircraft, including passengers, cargo, and mail, whether on regular or non-regular routes, both internationally and domestically.
- Manage and operate all maintenance operations.
- Manage any operation, regardless of its nature: economic, legal, financial, movable and immovable property, industrial, civil, or commercial.

3.2.5. DEPARTMENTS OF AIR ALGERIE

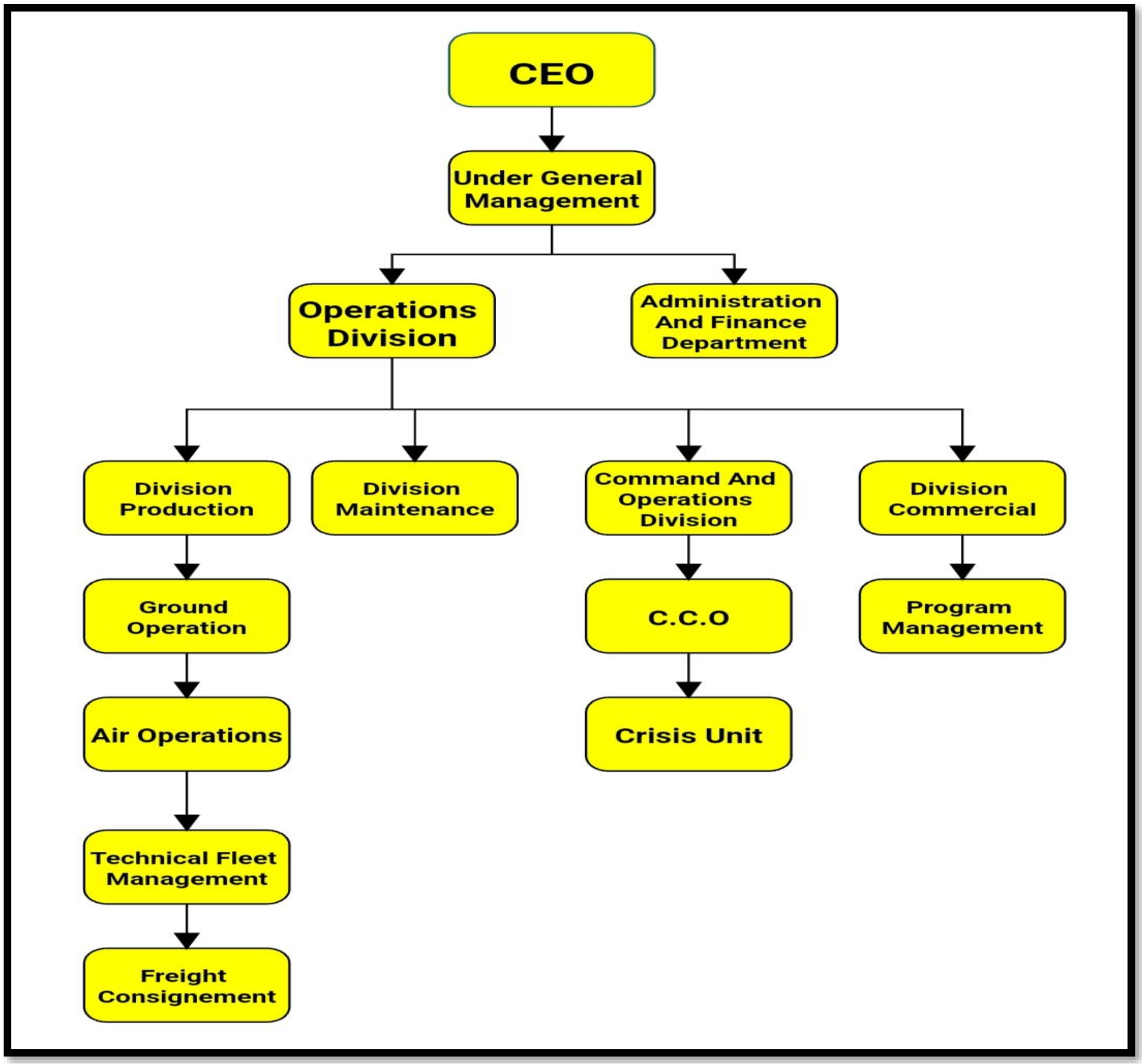


Figure 3.1: The structure of Air Algerie

3.2.6. THE FUEL AND CARBON DIOXIDE DEPARTMENT OF AIR ALGERIE

Air Algerie established the Fuel and CO2 Management sub-directorate to meet international regulatory requirements in 2010. It operates as part of the Air Operations Directorate. The sub-directorate's objectives include monitoring fuel consumption and costs per flight, preparing and approving annual reports on emissions and TKT, developing fuel procurement strategies, ensuring regulatory compliance, and centralizing flight-related data.

3.3. THE DATA OF THE STUDY

So, our study will be about the emissions and especially about the emissions on ground and we choose Air Algerie as zone of study in airport Houari Boumediene and year 2021 as year of study:

The year was a year after COVID-19 begin so still some effect of that.

We use the data from the fuel and carbon dioxide department of Air Algerie. We have table (number) that have all the vols declared CORSIA 2021 and all present in Algeria.

In this table that have number of 4297 fly from and to Airport of Algiers and for just Air Algerie.

And we use them to calculate the sum the emissions for the fleet of Air Algerie on ground and in the airport.

3.3.1.FLIGHT INFORMATION

That have flight number, time and date, aircraft type, departure and destination, registration in this declared flights and previous flights by Air Algerie in 2021:

Liste des vols de l'année 2021

Date Vol	N° Vol	Heure Dép.	Heure Arr.	Avion	Type Avion	Dep. (IATA)	Arr. (IATA)	Dep. (OACI)	Arr. (OACI)	Type de vol	Pays Dep	Pays Arr
3/25/2021	1226	09:05	11:40	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
3/25/2021	1227	13:15	16:15	7T-VHL	C130	LYS	ORN	LFLL	DAOO	Fret	FRANCE	ALGERIA
4/2/2021	1800	09:10	11:15	7T-VHL	C130	ALG	MRS	DAAG	LFML	Fret	ALGERIA	FRANCE
4/2/2021	1801	12:40	15:40	7T-VHL	C130	MRS	HME	LFML	DAUH	Fret	FRANCE	ALGERIA
4/4/2021	1524	08:05	10:35	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/4/2021	1525	12:15	14:45	7T-VHL	C130	LYS	ALG	LFLL	DAAG	Fret	FRANCE	ALGERIA
4/8/2021	1226	08:00	10:35	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/8/2021	1227	11:50	14:50	7T-VHL	C130	LYS	ORN	LFLL	DAOO	Fret	FRANCE	ALGERIA
4/13/2021	1224	08:10	10:50	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/13/2021	1225	15:15	12:45	7T-VHL	C130	LYS	ALG	LFLL	DAAG	Fret	FRANCE	ALGERIA
4/15/2021	1226	07:10	09:45	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/15/2021	1227	11:00	14:00	7T-VHL	C130	LYS	ORN	LFLL	DAOO	Fret	FRANCE	ALGERIA
4/20/2021	1224	08:00	10:20	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/20/2021	1225	11:40	14:10	7T-VHL	C130	LYS	ALG	LFLL	DAAG	Fret	FRANCE	ALGERIA
4/22/2021	1226	07:05	09:35	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/22/2021	1227	11:00	14:00	7T-VHL	C130	LYS	ORN	LFLL	DAOO	Fret	FRANCE	ALGERIA
4/23/2021	1800	09:55	08:00	7T-VHL	C130	ALG	MRS	DAAG	LFML	Fret	ALGERIA	FRANCE
4/23/2021	1801	11:20	14:30	7T-VHL	C130	MRS	HME	LFML	DAUH	Fret	FRANCE	ALGERIA
4/27/2021	1224	08:10	10:35	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/27/2021	1225	11:45	14:10	7T-VHL	C130	LYS	ALG	LFLL	DAAG	Fret	FRANCE	ALGERIA
4/29/2021	1226	07:10	09:40	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE
4/29/2021	1227	11:00	14:15	7T-VHL	C130	LYS	ORN	LFLL	DAOO	Fret	FRANCE	ALGERIA
5/4/2021	1224	08:30	10:55	7T-VHL	C130	ALG	LYS	DAAG	LFLL	Fret	ALGERIA	FRANCE

Figure 3.2: The flights information

3.3.2. THE FLEET USED

This table of the fleet that we get their parameters of their motors with their matriculation:

Table 3.3: The used fleet of Air Algerie

Aircraft	Matriculation	Motor
B737-600	7T-VJU	CFM56-7B22
B737-600	7T-VJQ	CFM56-7B22
B737-600	7T-VJR	CFM56-7B22
B737-600	7T-VJS	CFM56-7B22
B737-600	7T-VJT	CFM56-7B22
B737-700C	7T-VKT	CFM56-7B26
B737-700C	7T-VKS	CFM56-7B26
B737-800W	7T-VJL	CFM56-7B24
B737-800W	7T-VJP	CFM56-7B24
B737-800W	7T-VJK	CFM56-7B24
B737-800W	7T-VJN	CFM56-7B24
B737-800W	7T-VJM	CFM56-7B24
B737-800W	7T-VJO	CFM56-7B24
B737-800W	7T-VCA	CFM56-7B24
B737-800W	7T-VCB	CFM56-7B24
B737-800W	7T-VCD	CFM56-7B24
B737-800BCF	7T-VJJ	CFM56-7B26
B737-800W	7T-VKT	CFM56-7B26
B737-800W	7T-VKS	CFM56-7B26
B737-800W	7T-VKR	CFM56-7B27
B737-800W	7T-VJJ	CFM56-7B27
B737-800W	7T-VKP	CFM56-7B27
B737-800W	7T-VKQ	CFM56-7B27
B737-800W	7T-VKM	CFM56-7B27

B737-800W	7T-VKN	CFM56-7B27
B737-800W	7T-VKO	CFM56-7B27
B737-800W	7T-VKK	CFM56-7B27
B737-800W	7T-VKJ	CFM56-7B27
B737-800W	7T-VKL	CFM56-7B27
B737-800W	7T-VKI	CFM56-7B27
B737-800W	7T-VKB	CFM56-7B27
B737-800W	7T-VKA	CFM56-7B27
B737-800W	7T-VKC	CFM56-7B27
B737-800W	7T-VKD	CFM56-7B27
B737-800W	7T-VKF	CFM56-7B27
B737-800W	7T-VKE	CFM56-7B27
B737-800W	7T-VKG	CFM56-7B27
B737-800W	7T-VKH	CFM56-7B27
A330-202	7T-VJB	CF6-80E1A4
A330-202	7T-VJC	CF6-80E1A4
A330-202	7T-VJA	CF6-80E1A4
A330-202	7T-VJV	CF6-80E1A4
A330-202	7T-VJW	CF6-80E1A4
A330-202	7T-VJY	CF6-80E1A4
A330-202	7T-VJX	CF6-80E1A4
A330-202	7T-VJZ	CF6-80E1A4

3.3.3. METEOROLOGICAL DATA

We get the metrological data that we use for the calcul (Pressure, Relative humidity, Temperature) from the fuel and carbon dioxide department of Air Algerie.

Table 3.4: Table of meteorological data

Time	Temperature(K)	Temperature(C)	Relative Humidity(Φ)	Pressure(Pa)	Pressure(hpa)
2021-01-01 00:00:00	276,65	3.5	96	102830	1028.3
2021-01-01 01:00:00	283,15	10	94	103100	1031
2021-01-01 02:00:00	280,15	7	93	103000	1030
2021-01-01 03:00:00	279,15	6	99	103000	1030
2021-01-01 04:00:00	283,65	10,5	96	103240	1032,4
2021-01-01 05:00:00	285,35	12,2	88	103190	1031,9
2021-01-01 06:00:00	277,15	4	94	102890	1028,9
2021-01-01 07:00:00	290,15	17	72	103000	1030
2021-01-	287,15	14	82	103100	1031

01 08:00:00					
2021-01-01 09:00:00	278,15	5	93	102800	1028
2021-01-01 10:00:00	276.15	3	89	102900	1029
2021-01-01 11:00:00	286.15	13	90	103000	1030

3.3.4. THE PARAMETRES OF THE MOTORS

From our base of data of the ICAO we get the fuel flow and emission index for (HC, CO, NOx) with their correction after installation:

Table 3.5: Table of emission index and fuel flow for B737 - 600 that have motor CFM56-7B22

	Fuel flow	Correction factor	Corrected fuel flow Wf	Emission index EI Nox	Emission index EI CO	Emission index EI HC
Taxi	0.105	1.1	0.1155	4.5	22.8	2.5
Take off	1.021	1.01	1.03121	23.1	0.5	0.1
Climb	0.844	1.013	0.854972	19	0.6	0.1
Approach	0.298	1.02	0.30396	10	2.5	0.1

Table 3.6: Table of emission index and fuel flow for B737 - 800W (7T-VJM/JN/JO/JP) that have motor CFM56-7B24

	Fuel flow	Correction factor	Corrected fuel flow Wf	Emission index EI Nox	Emission index EI CO	Emission index EI HC
Taxi	0.109	1.1	0.1199	4.4	22	2.4
Take off	1.103	1.01	1.11403	25.3	0.4	0.1
Climb	0.91	1.013	0.92183	20.5	0.6	0.1
Approach	0.316	1.02	0.32232	10.1	2.2	0.1

Table 1.7: Table of emission index and fuel flow for B737 – 700C that have motor CFM56-7B26

	Fuel flow	Correction factor	Corrected fuel flow Wf	Emission index EI Nox	Emission index EI CO	Emission index EI HC
Taxi	0.113	1.1	0.1243	4.7	18.8	1.9
Take off	1.221	1.01	1.23321	28.8	0.2	0.1
Climb	0.999	1.013	1.011987	22.5	0.6	0.1
Approach	0.338	1.02	0.34476	10.8	1.6	0.1

Table 3.8: Table of emission index and fuel flow for B737 – 700C that have motor CFM56-7B27

	Fuel flow	Correction factor	Corrected fuel flow Wf	Emission index EI Nox	Emission index EI CO	Emission index EI HC
Taxi	0.116	1.1	0.1276	4.8	17.9	1.7
Take off	1.284	1.01	1.29684	30.9	0.2	0.1
Climb	1.043	1.013	1.056559	23.7	0.5	0.1
Approach	0.349	1.02	0.35598	11	1.4	0.1

Table 3.9 : Table of emission index and fuel flow for A330-200 that have motor CF6-80E1A4

	Fuel flow	Correction factor	Corrected fuel flow Wf	Emission index EI Nox	Emission index EI CO	Emission index EI HC
Taxi	0.227	1.1	10.35	4.62	38.09	10.35
Take off	2.904	1.01	0.06	43.15	0.34	0.06
Climb	2.337	1.013	0.07	30.3	0.3	0.07
Approach	0.744	1.02	0.18	10.13	1.33	0.18

3.4. THE GRAPHES OF LOG(WF) WITH LOG EMISSION INDEX

For the calcul by boeing method and in the step 1 we need to trace LOG(WF) WITH LOG EMISSION INDEX:

Table 3.10: Table of log (Wf) with log EI (HC, CO, NOx) for CFM56-7B22

	LOG Wf	LOG EI Nox	LOG EI CO	LOG EI HC
Taxi	-0.9374	0.6532	1.3579	0.3979
Take off	0.0133	1.3636	-0.301	-1
Climb	-0.068	1.2787	-0.2218	1
Approach	-0.5171	1	0.3979	-1

Table 3.11: Table of log (Wf) with log EI(HC,CO,NOx) for CFM56-7B24

	LOG Wf	LOG EI Nox	LOG EI CO	LOG EI HC
Taxi	-0.9211	0.6434	1.3424	0.3802
Take off	0.0468	1.4031	-0.3979	-1
Climb	-0.0353	1.3117	-0.2218	-1
Approach	-0.4917	1.0043	0.3424	-1

Table 3.12: Table of log (Wf) with log EI(HC,CO,NOx) for CFM56-7B26

	LOG Wf	**LOG EI Nox**	**LOG EI CO**	**LOG EI HC**
Taxi	-0.9055	0.672	1.2741	0.2787
Take off	0.091	1.4593	-0.6989	-1
Climb	0.0051	1.3521	-0.2218	-1
Approach	-0.4624	1.0334	0.2041	-1

Table 3.13: Table of log (Wf) with log EI(HC,CO,NOx) for CFM56-7B27

	LOG Wf	**LOG EI Nox**	**LOG EI CO**	**LOG EI HC**
Taxi	-0.8941	0.6812	1.2528	0.2304
Take off	0.1128	1.4899	-0.6989	-1
Climb	0.0238	1.3747	-0.301	-1
Approach	-0.4485	1.0413	0.1461	-1

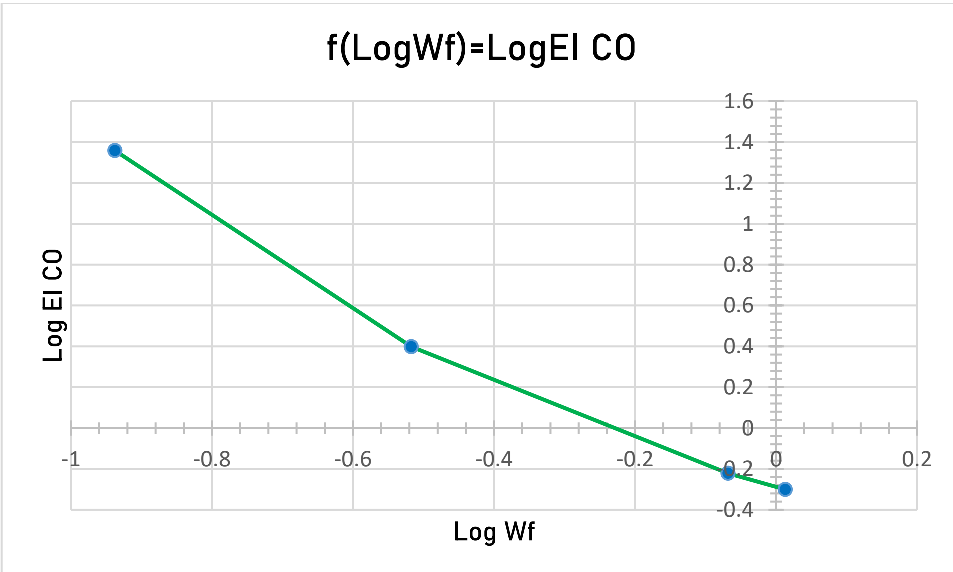
Table 3.14: Table of log (Wf) with log EI(HC,CO,NOx) for CF6-80E1A4

	LOG Wf	**LOG EI Nox**	**LOG EI CO**	**LOG EI HC**
Taxi	-0.6025	0.6646	1.5808	1.0149
Take off	0.4673	1.6349	-0.4685	-1.2218
Climb	0.3742	1.4814	-0.5228	-1.1549
Approach	-0.1198	1.0056	0.1238	-0.7447

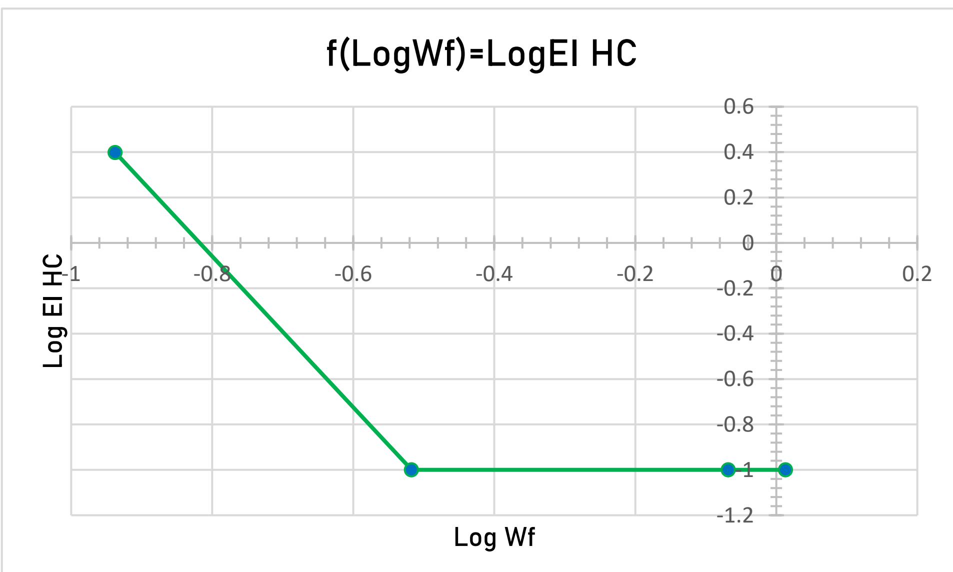
3.3.5.THE GRAPHS OF LOG INDEX EMISSIONS WITH FUEL FLOW

This graphs represent the previous tables, each blue point represent phase of flight, the first point is for the takeoff, the second for the climb, the third for the approach and the fourth for the taxing .

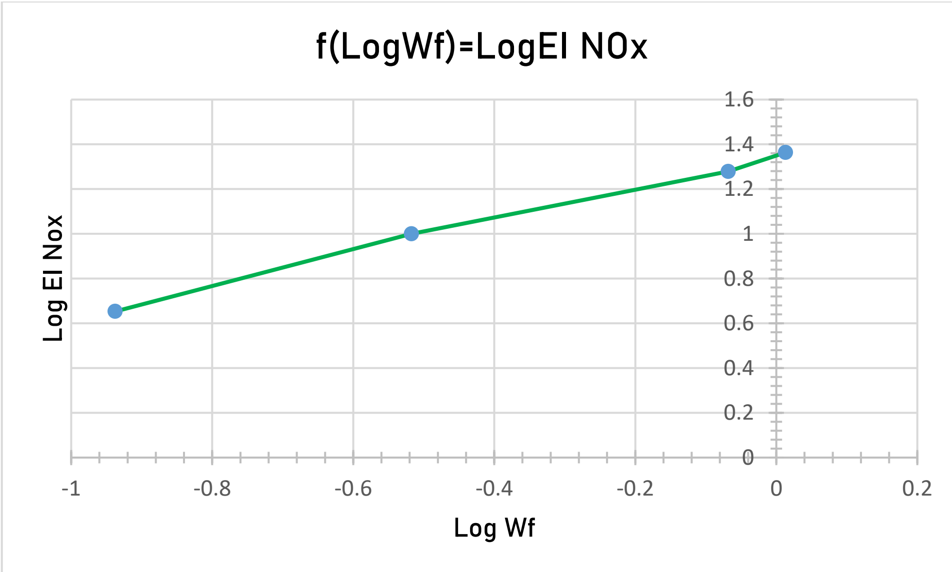
CFM56-7B22 Engine:



Graph 3.1: Graph of Log index emission CO against Log fuel flow corrected for CFM56-7B22

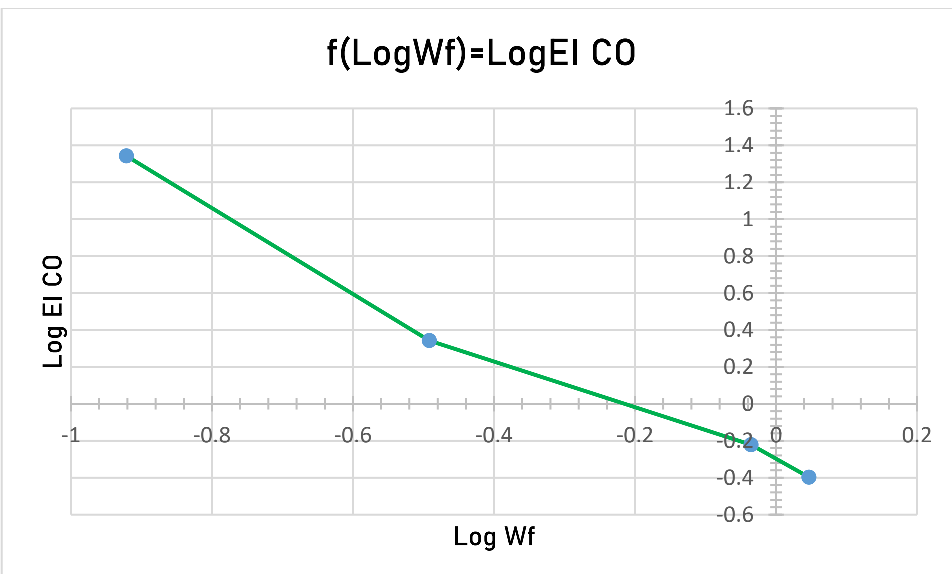


Graph 3.2: Graph of Log index emission HC against Log fuel flow corrected for CFM56-7B22

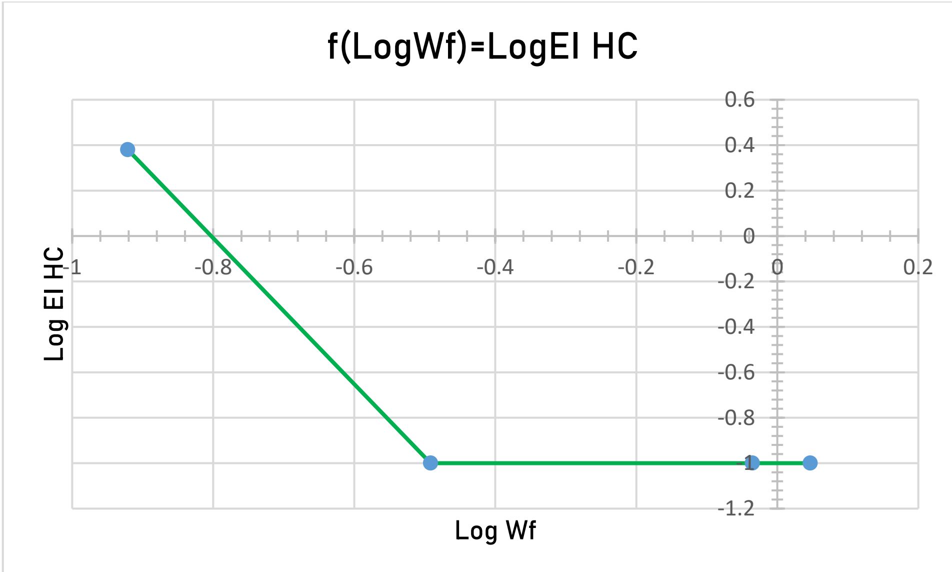


Graph 3.3: Graph of Log index emission NOx against Log fuel flow corrected for CFM56-7B22

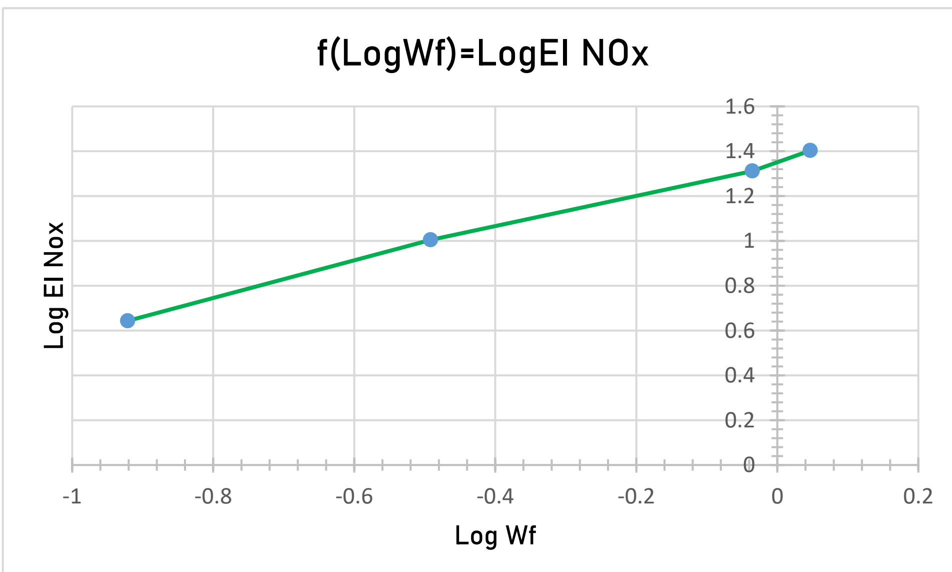
CFM56-7B24 Engine:



Graph 3.4: Graph of Log index emission CO against Log fuel flow corrected for CFM56-7B24

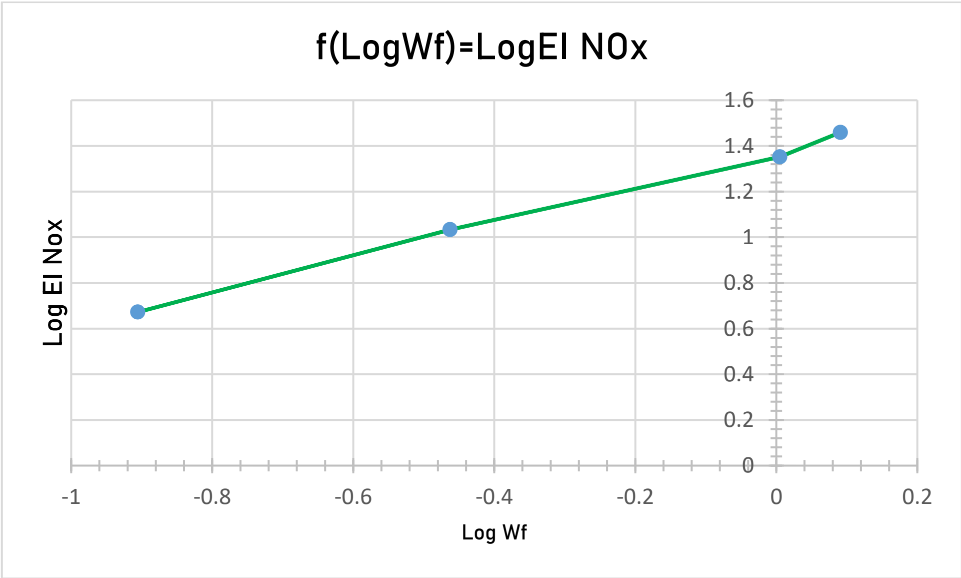


Graph 3.5: Graph of Log index emission HC against Log fuel flow corrected for CFM56-7B24

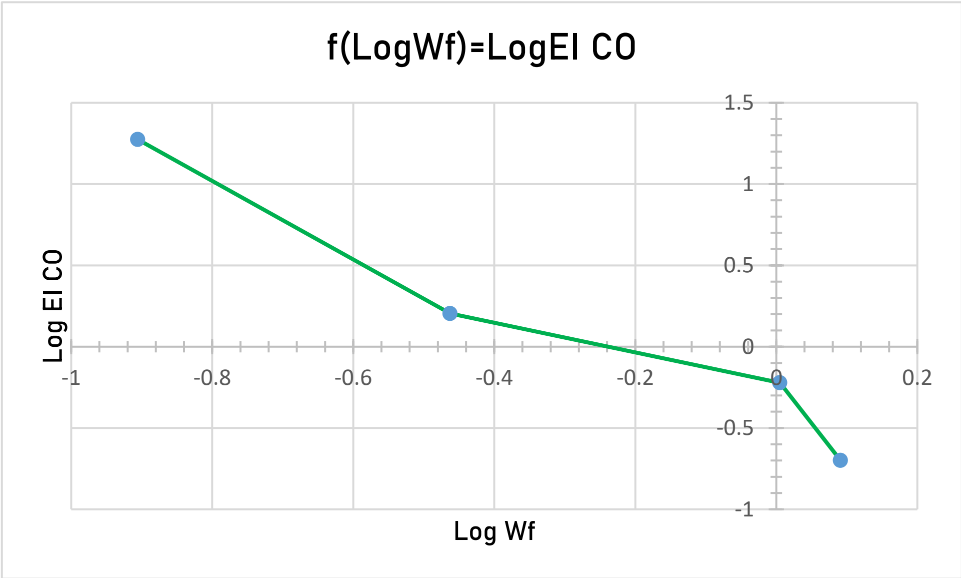


Graph 3.6: Graph of Log index emission NOx against Log fuel flow corrected for CFM56-7B24

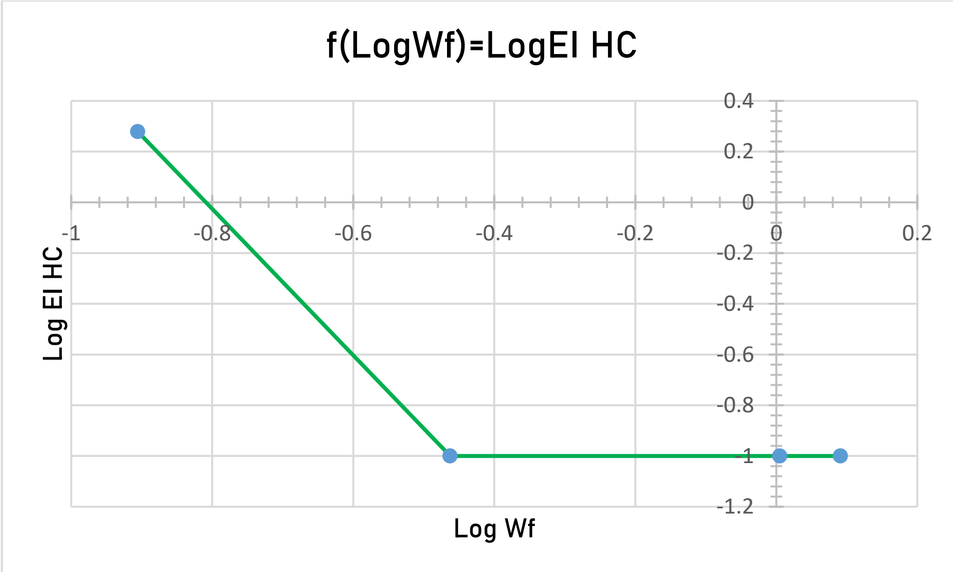
CFM56-7B26 Engine:



Graph 3.7: Graph of Log index emission NOx against Log fuel flow corrected for CFM56-7B26

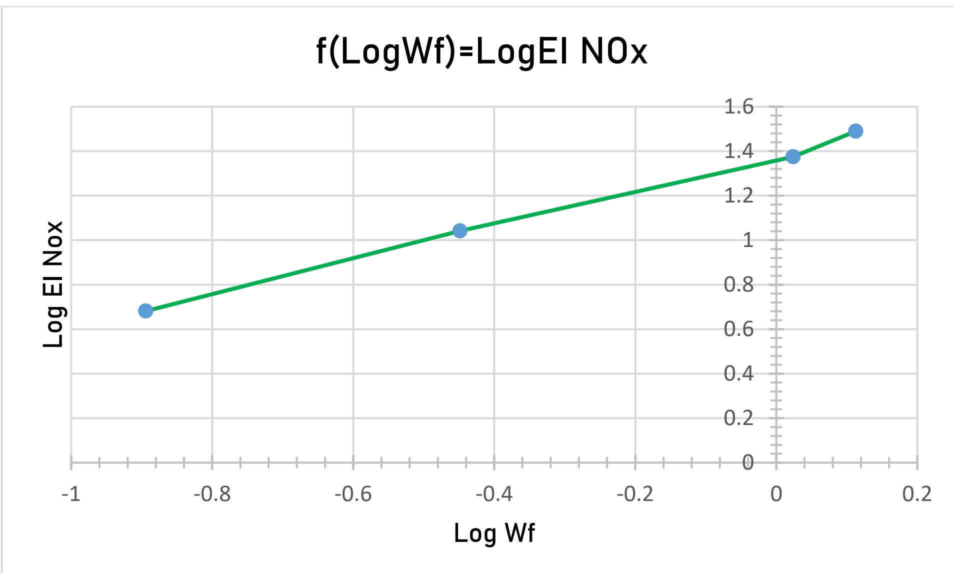


Graph 3.8: Graph of Log index emission CO against Log fuel flow corrected for CFM56-7B26

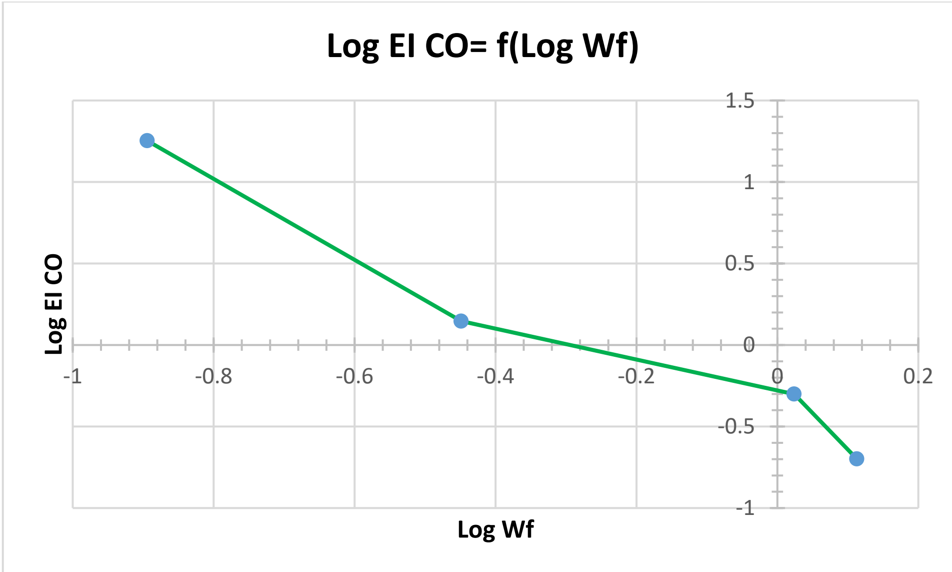


Graph 3.9: Graph of Log index emission HC against Log fuel flow corrected for CFM56-7B26

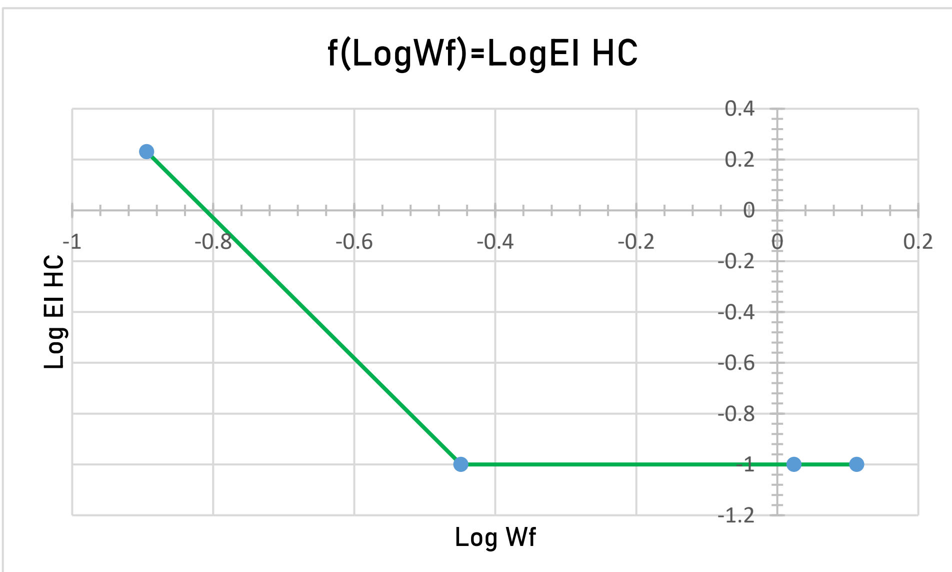
CFM56-7B27 Engine:



Graph 3.10: Graph of Log index emission NOx against Log fuel flow corrected for CFM56-7B27

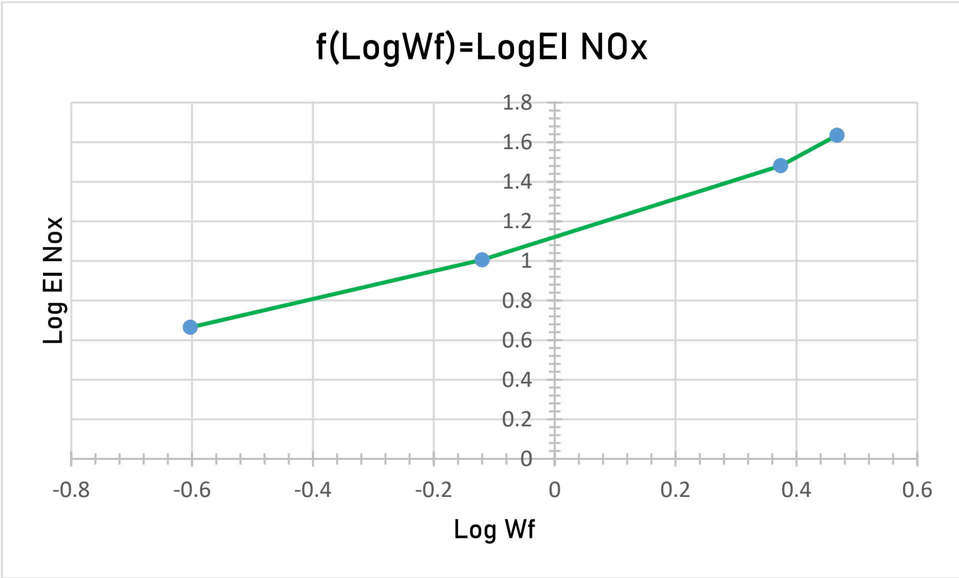


Graph 3.11: Graph of Log index emission CO against Log fuel flow corrected for CFM56-7B27

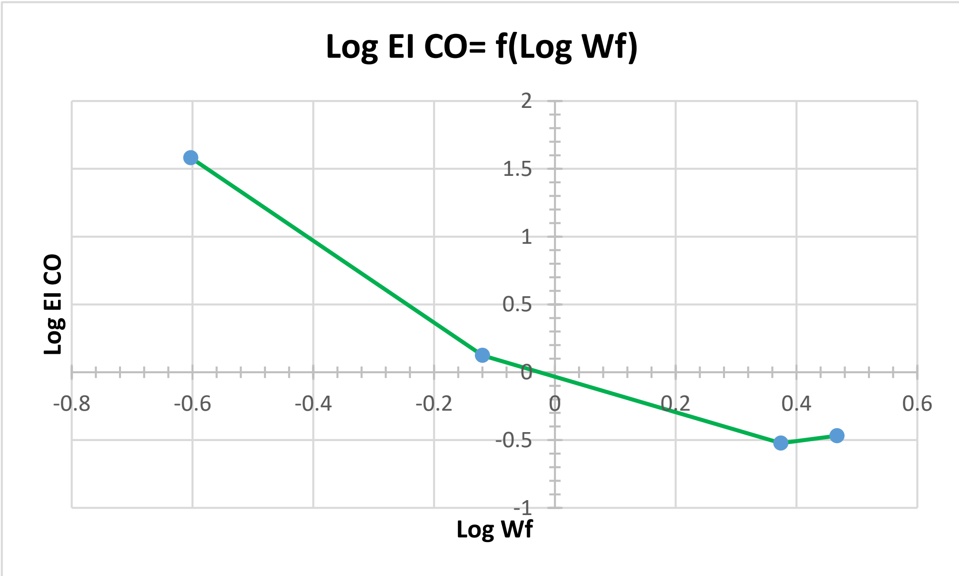


Graph 3.12: Graph of Log index emission HC against Log fuel flow corrected for CFM56-7B27

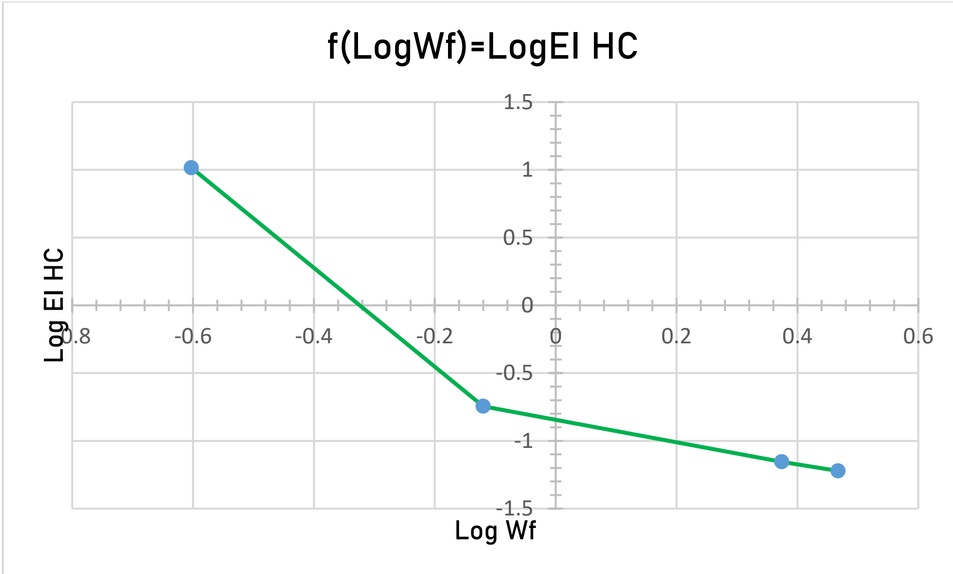
CF6-80E1A4 Engine:



Graph 3.13: Graph of Log index emission NOx against Log fuel flow corrected for CF6-80E1A4



Graph 3.14: Graph of Log index emission CO against Log fuel flow corrected for CF6-80E1A4



Graph 3.15: Graph of Log index emission HC against Log fuel flow corrected for CF6-80E1A4

3.4. THE PROGRAM USED FOR GRAPHS AND CALCULATION

We choose the excel for creating the graphs and the hard and complex calculation, Excel is used for making graphs and performing complex calculations is a common choice in many studies and research projects. Excel provides a user-friendly interface and a wide range of functionalities that make it suitable for these tasks.

3.5. EXAMPLES OF THE CALCULATION

Because the number of trips is too much on his account (4297), so we calculated some examples

Example 1:

The flight information is:

Flight no: 4200 was flown by a B737-700 registered 7T-VKS. The 2 engines associated with it are CFM56-7B26.

Date and time and destination: 27/03/2021 departure at 14 :07 Alger to Morocco 16:08

Weather situation:

Pressure (Pa): 1021hpa
Temperature (K):297.15
Relative humidity Φ (%):48
Fuel flow per engine (Kg/s): 0.1243
Fuel flow for 2 engines (Kg/s):0.2486
Fuel flow for 2 engines (Kg/min): 14.916
Mach number: 0.78
Fuel Flow Factor:
Calculate the values ∂amb (ambient pressure correction factor) and θamb (ambient temperature correction factor) where:

$\partial amb = \frac{Pamb}{14.696} = \frac{102100}{101325} = 1.007648\ Pa$ (Pamb = ambient (inlet) pressure) and

$\theta amb = \frac{Tamb}{288.15} = \frac{297.15}{288.15} = 1.031233\ k$ (Tamb = ambient (inlet) temperature)

The fuel flow values are further modified by the ambient values:

$$Wff = \left(\frac{Wf}{\partial amb}\right) \times \theta amb^{3.8} \times e^{(0.2M^2)} = \left(\frac{0.1243}{1.007648}\right) \times 1.0312333^{3.8} \times e^{0.2\times(0.78^2)} = 0.196042$$

$\log Wff$ =-0.707649 → $\log REI\ NOx$ =0.83351224

$\log REI\ HC$ = -0.292412

$\log REI\ CO$ =0.796213

So

$$REI\ NOx = 6.815727\ (\frac{g}{kg})$$

$$REI\ HC = 0.510020\ (\frac{g}{kg})$$

$$REI\ CO = 6.254793\ (\frac{g}{kg})$$

Calculate the humidity correction factor H:

$$\beta = 7.90298 \times \left(1 - \frac{373.16}{297.15}\right) + 3.00571 + 5.02808 \times \log\left(\frac{373.16}{297.15}\right) + (1.3816 \times 10^{-7}) \times \left[1 - 10^{\left(11.344 \times \left(1 - \frac{297.15}{373.16}\right)\right)}\right] + (8.1328 \times 10^{-3}) \times \left[10^{\left(3.49149 \times \left(1 - \frac{373.16}{297.15}\right)\right)} - 1\right] = 1.692847322$$

$$Pv = (0.014504)10^{1.692847322} = 0.229131$$

and

$$\omega = \frac{(0.62198 \times (\Phi) \times Pv)}{(Pamb - (\Phi) \times Pv)}$$

$$\omega = \frac{(0.62197058 \times 0.48 \times 0.229131)}{(14,80835 \times 0.48 \times 0.229131)} = 0.041996$$

$$H = -19.0\ (\omega - 0.0063)$$

$$H = -19.0\ (0.041996 - 0.00634) = -0.67735$$

, where Φ is relative humidity and Pv = saturation vapour pressure in psia.

STEP 3: Compute EI

Calculate the emission indices of HC, CO and NOx:

$$EIHC = REIHC \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EIHC = 0.510020 \times \frac{1.0312333^{3.3}}{1.0076486^{1.02}}$$

$$EIHC = 0.7007315 \left(\frac{g}{kg}\right)$$

$$EICO = REICO \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EICO = 6.254793 \times \frac{1.0312333^{3.3}}{1.0076486^{1.02}}$$

$$EICO = 6.9623543 \left(\frac{g}{kg}\right)$$

$$EINOx = REINOx \times \left(\frac{\theta amb^{1.02}}{\partial amb^{3.3}}\right)^{0.5} \times e^{H}$$

$$EINOx = 6.815727 \times \left(\frac{1.0312333^{1.02}}{1.0076486^{3.3}}\right)^{0.5} \times e^{-0.67735}$$

$$EINOx = 3.2864419 \left(\frac{g}{kg}\right)$$

Where the REIHC, REICO, and REINOX values are read off the graph (STEP 1) by substituting Wff for Wf.

STEP 4: Total Emission

$$Total\ (HC, CO, NOx) = Number\ of\ Engines\ x\ \Sigma i\ (EIHC, EICO, EINOX)i\ x\ Wfi\ x\ timei\ x\ 10-3$$

, in lbs.

$Emission\ NOx$=2×3.28644 ×0.1243×26

$Emission\ NOx$= 42.80052 (g)

$Emission\ HC$=2×0.70073 ×0.1243×26

$Emission\ HC$=0.36547 (g)

$Emission\ CO$ =2×6.96235 ×0.1243×26

$Emission\ CO$ =36.48443 (g)

Example 2:

The flight information is:

Flight no.: 2024 was flown by a B737-800W registered 7T-VKR. The 2 engines associated with it are CFM56-7B27.

Date and time and destination: 23/12/2021 departure at 9 :37 Alger to Italy 11:21

Weather situation:

Pressure (Pa): 1022hpa
Temperature (K):291.15
Relative humidity Φ (%):72
Fuel flow per engine (Kg/s): 0.1276
Fuel flow for 2 engines (Kg/s):0.2552
Fuel flow for 2 engines (Kg/min): 15.312
Mach number: 0.78
Fuel Flow Factor:
Calculate the values ∂amb (ambient pressure correction factor) and θamb (ambient temperature correction factor) where:

$\partial amb = \frac{Pamb}{14.696} = \frac{102200}{101325} = 1.008635\ Pa$ (Pamb = ambient (inlet) pressure) and

$\theta amb = \frac{Tamb}{288.15} = \frac{291.15}{288.15} = 1.010411\ k$ (Tamb = ambient (inlet) temperature)

The fuel flow values are further modified by the ambient values:

$$Wff = \left(\frac{Wf}{\partial amb}\right) \times \theta amb^{3.8} \times e^{(0.2M^2)} \exp(0.2\ M2)$$

$$= \left(\frac{0.1276}{1.008635}\right) \times 1.010411^{3.8} \times e^{0.2\times(0.78^2)} = 0{,}148612$$

log $REI\ NOx$ =0.734771

log Wff =-0.8279458 → log $REI\ HC$ =0.0476723

log $REI\ CO$ =1.0884517

So
$$REI\ NOx\ =\ 5.429652\ (\frac{g}{kg})$$
$$REI\ HC\ =\ 1.116015\ (\frac{g}{kg})$$
$$REI\ CO\ =\ 12.258851(\frac{g}{kg})$$

Calculate the humidity correction factor H:

$$\beta = 7.90298 \times \left(1 - \frac{373.16}{291.15}\right) + 3.00571 + 5.02808 \times \log\left(\frac{373.16}{291.15}\right) + (1.3816 \times 10^{-7}) \times \left[1 - 10^{\left(11.344\times\left(1-\frac{291.15}{373.16}\right)\right)}\right] + (8.1328 \times 10^{-3}) \times \left[10^{\left(3.49149\times\left(1-\frac{373.16}{291.15}\right)\right)} - 1\right] = 1.850$$

$$Pv\ =\ (0.014504)10^{1.850} = 1.026804566$$

and

$$\omega\ =\frac{(0.62198\ \times (\Phi) \times\ Pv)}{(\ Pamb - \ (\Phi) \times\ Pv)}$$

$$\omega\ =\frac{(0.62197058\ \times 0.72 \times\ 1.026804)}{14.8228 \times (0.72 \times\ 1.026804)} = 0.042196$$

$$H\ =\ -19.0\ (\omega\ -\ 0.0063)$$

$$H\ =\ -19.0\ (0.042196 -\ 0.00634) = -0.681264$$

, where Φ is relative humidity and Pv = saturation vapour pressure in psia.

STEP 3: Compute EI

Calculate the emission indices of HC, CO and NOx:

$$EIHC\ =\ REIHC \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EIHC = 1.11601517 \times \frac{1.0104112^{\ 3.3}}{1.0086355^{1.02}}$$

$$EIHC = 1.1447328602\ (\frac{g}{kg})$$

$$EICO = REICO \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EICO = 12.25885169 \times \frac{1.0104112^{\ 3.3}}{1.0086355^{1.02}}$$

$$EICO = 12.5624625049(\frac{g}{kg})$$

$$EINOx = REINOx \times (\frac{\theta amb^{1.02}}{\partial amb^{3.3}})^{0.5} \times e^{H}$$

$$EINOx = 5.4296520 \times (\frac{1.0104112^{\ 1.02}}{1.0086355^{3.3}})^{0.5} \times e^{-0.681264754}$$

$$EINOx = 3.55786953664(\frac{g}{kg})$$

Where the REIHC, REICO, and REINOX values are read off the graph (STEP 1) by substituting Wff for Wf.

STEP 4: Total Emission

$Total\ (HC, CO, NOx)$

$= Number\ of\ Engines\ x\ \Sigma i\ (EIHC, EICO, EINOX)i\ x\ Wfi\ x\ timei\ x\ 10 - 3$

, in lbs.

$Emission\ NOx$=2×3.55786×0.1276×26

$Emission\ NOx$=18.26299 (g)

$Emission\ HC$=2×1.14473 ×0.1276×26

$Emission\ HC$= 7.49355 (g)

$Emission\ CO$ =2×12.56246×0.1276×26

$Emission\ CO$ =80.27193 (g)

Example 3 :

The flight information is:

Flight no.: 3026 was flown by an A330-202 registered 7T-VJZ. The 2 engines associated with it are d CF6-80E1A4.

Date and time and destination: 2/9/2021 departure at 12 :59 Alger to Turkey 16:24

Weather situation:

Pressure (Pa): 1017hpa

Temperature (K):299.15

Relative humidity Φ (%):83

Fuel flow per engine (Kg/s): 0.2497

Fuel flow for 2 engines (Kg/min):29.964

Fuel flow for 2 engines (Kg/s):0.4994

Mach number: 0.78

Fuel Flow Factor

Calculate the values ∂amb (ambient pressure correction factor) and θamb (ambient temperature correction factor) where:

$\partial amb = \frac{Pamb}{14.696} = \frac{101700}{101325} = 1.003700\ Pa$ (Pamb = ambient (inlet) pressure) and

$\theta amb = \frac{Tamb}{288.15} = \frac{299.15}{288.15} = 1.038174\ k$ (Tamb = ambient (inlet) temperature)

The fuel flow values are further modified by the ambient values:

$$Wff = \left(\frac{Wf}{\partial amb}\right) \times \theta amb^{3.8} \times e^{(0.2M^2)} \exp(0.2\ M2)$$

$$= \left(\frac{0.2497}{1.003700}\right) \times 1.038174^{3.8} \times e^{0.2\times(0.78^2)} = 0.584389$$

log $REI\ NOx$ =0.9254223

log Wff =-0.233297 → log $REI\ HC$ =-0.3311091

log $REI\ CO$ =0.4662903

So
$$REI\ NOx = 8.422136\ (\frac{g}{kg})$$
$$REI\ HC = 0.4665421\ (\frac{g}{kg})$$
$$REI\ CO = 2.926107(\frac{g}{kg})$$

Calculate the humidity correction factor H:

$$\beta = 7.90298 \times \left(1 - \frac{373.16}{299.15}\right) + 3.00571 + 5.02808 \times \log\left(\frac{373.16}{299.15}\right)$$
$$+ (1.3816 \times 10^{-7}) \times \left[1 - 10^{\left(11.344 \times \left(1 - \frac{299.15}{373.16}\right)\right)}\right]$$
$$+ (8.1328 \times 10^{-3}) \times \left[10^{\left(3.49149 \times \left(1 - \frac{373.16}{299.15}\right)\right)} - 1\right] = 1{,}52617$$

$$Pv = (0.014504)10^{1{,}52617} = 0.487144$$

and

$$\omega = \frac{(0.62198 \times (\Phi) \times Pv)}{(Pamb - (\Phi) \times Pv)}$$
$$\omega = \frac{(0.62197058 \times 0.83 \times 0.487144)}{14{,}7503379 \times (0.83 \times 0.487144)} = 0.042166$$

$$H = -19.0\ (\omega - 0.0063)$$

$$H = -19.0\ (0.042166553 - 0.00634) = -0.680704$$

, where Φ is relative humidity and Pv = saturation vapour pressure in psia.

STEP 3: Compute EI

Calculate the emission indices of HC, CO and NOx:

$$EIHC = REIHC \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$
$$EIHC = 0.46654216 \times \frac{1.0381745^{\ 3.3}}{1.0037009^{1.02}}$$

$$EIHC = 0.667720\ (\frac{g}{kg})$$

$$EICO = REICO \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EICO = 2.9261079 \times \frac{1.0381745^{3.3}}{1.0037009^{1.02}}$$

$$EICO = 4.184262(\frac{g}{kg})$$

$$EINOx = REINOx \times (\frac{\theta amb^{1.02}}{\partial amb^{3.3}})^{0.5} \times e^{H}$$

$$EINOx = 8.4221369 \times (\frac{1.0381745^{\ 1.02}}{1.0037009^{3.3}})^{0.5} \times e^{-0.680704}$$

$$EINOx = 4.321859\ (\frac{g}{kg})$$

Where the REIHC, REICO, and REINOX values are read off the graph (STEP 1) by substituting Wff for Wf.

STEP 4: Total Emission

$$Total\ (HC, CO, NOx)$$
$$= Number\ of\ Engines\ x\ \Sigma i\ (EIHC, EICO, EINOX)i\ x\ Wfi\ x\ timei\ x\ 10 - 3$$

, in lbs.

$Emission\ NOx$=2×4.32185 ×0.2497×26

$Emission\ NOx$=57.96163 (g)

$Emission\ HC$=2×0.66772 ×0.2497×26

$Emission\ HC$=8.82503 (g)

$Emission\ CO$ =2×4.18426×0.24976×26

$Emission\ CO$ =53.09413 (g)

Example 4 :

The flight information is:

Flight no.: 4606 was flown by a B737-800W registered 7T-VJN. The 2 engines associated with it are CFM56-7B24.

Date and time and destination :31/05/2021 departure at 15 :56 Alger to Libya 17:30

Weather situation:

Pressure (Pa): 1016hpa

Temperature (K):300.15

Relative humidity Φ (%):51

Fuel flow per engine (Kg/s):0.1199

Fuel flow for 2 engines (Kg/s):0.2398

Fuel flow for 2 engines (Kg/min): 14.388

Mach number: 0.78

Fuel Flow Factor

Calculate the values ∂amb (ambient pressure correction factor) and θamb (ambient temperature correction factor) where:

$\partial amb = \frac{Pamb}{14.696} = \frac{101600}{101325} = 1.002714\ Pa$ (Pamb = ambient (inlet) pressure) and

$\theta amb = \frac{Tamb}{288.15} = \frac{300.15}{288.15} = 1.041644\ k$ (Tamb = ambient (inlet) temperature)

The fuel flow values are further modified by the ambient values:

$Wff = \left(\frac{Wf}{\partial amb}\right) \times \theta amb^{3.8} \times e^{(0.2M^2)}\ \exp(0.2\ M2) = \left(\frac{0.1199}{1.002714}\right) \times 1.041644^{3.8} \times e^{0.2\times(0.78^2)} = 0.157696$, where M is the Mach number.

log Wff =-0.80021781 $\rightarrow$

log $REI\ NOx$ =0.745076

log $REI\ HC$ =-0.00856

log $REI\ CO$ =1.060807

So

$REI\ NOx = 5.560015\ (\frac{g}{kg})$

$REI\ HC = 0.980482\ (\frac{g}{kg})$

$$REI\ CO\ = 11.502895\ (\frac{g}{kg})$$

Calculate the humidity correction factor H:

$$\beta = 7.90298 \times \left(1 - \frac{373.16}{300.15}\right) + 3.00571 + 5.02808 \times \log\left(\frac{373.16}{300.15}\right) + (1.3816 \times 10^{-7}) \times \left[1 - 10^{\left(11.344 \times \left(1 - \frac{300.15}{373.16}\right)\right)}\right] + (8.1328 \times 10^{-3}) \times \left[10^{\left(3.49149 \times \left(1 - \frac{373.16}{300.15}\right)\right)} - 1\right] = 1.55467$$

$$Pv\ =\ (0.014504)10^{1.55467} = 0.520184$$

and

$$\omega\ =\frac{(0.62198\ \times (\Phi) \times\ Pv)}{(\ Pamb - \ (\Phi) \times\ Pv)}$$

$$\omega\ = \frac{(0.62197058\ \times 0.51 \times 0.520184)}{14{,}7358342 \times (0.51 \times\ 0.520184)} = 0.042208$$

$$H\ =\ -19.0\ (\omega\ -\ 0.0063)$$

$$H\ =\ -19.0\ (0.0422080 -\ 0.00634) = -0.681492$$

, where Φ is relative humidity and Pv = saturation vapour pressure in psia.

STEP 3: Compute EI

Calculate the emission indices of HC, CO and NOx:

$$EIHC\ =\ REIHC \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EIHC\ = 0.9804828\ \times \frac{1.0416449^{\ 3.3}}{1.0027140^{1.02}}$$

$$EIHC\ = 1.477998\ (\frac{g}{kg})$$

$$EICO\ =\ REICO \times \frac{\theta amb^{3.3}}{\partial amb^{1.02}}$$

$$EICO \ = 11.502895 \times \frac{1.0416449^{3.3}}{1.0027140^{1.02}}$$

$$EICO \ = \ 17.803607(\frac{g}{kg})$$

$$EINOx \ = \ REINOx \times (\frac{\theta amb^{1.02}}{\partial amb^{3.3}})^{0.5} \times e^{H}$$

$$EINOx \ = \ 5.5600154 \times (\frac{1.0416449^{1.02}}{1.0027140^{3.3}})^{0.5} \times e^{-0.68149263}$$

$$EINOx \ = 2.839155 \ (\frac{g}{kg})$$

Where the REIHC, REICO, and REINOX values are read off the graph (STEP 1) by substituting Wff for Wf.

STEP 4: Total Emission

$$Total\ (HC, CO, NOx)$$
$$= \ Number\ of\ Engines\ x\ \Sigma i\ (EIHC, EICO, EINOX) i\ x\ Wfi\ x\ timei\ x\ 10 - 3$$

, in lbs.

$Emission\ NOx$=2×2.839155×0.1199 ×26

$Emission\ NOx$=15.207737 (g)

$Emission\ HC$=2×1.477998 ×0.1199×26

$Emission\ HC$=7.828841 (g)

$Emission\ CO$ =2×17.803607×0.1199×26

$Emission\ CO$ =96.634444(g)

3.6. THE RESULTS

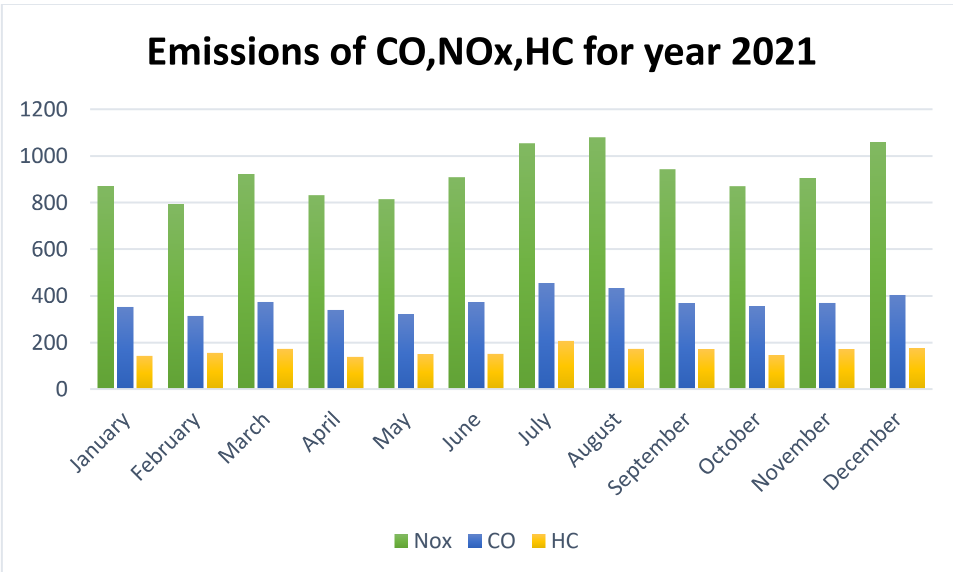
After utilizing the Boeing method to calculate the monthly ground emissions of CO, NOx, and HC for Air Algerie's fleet, the findings are presented in the table below. The total cumulative emissions for the year 2021 amount to 17879.30075.

Table 3.15: The result of calcul emissions (CO, NOx, HC) for year 2021

Month	NOx (Kg)	CO (Kg)	HC (Kg)	Total (Kg)
January	**870.95**	**352.38**	**143.20**	**1366.53**
February	**793.70**	**313.48**	**156.29**	**1263.48**
March	**922.95**	**373.03**	**172.19**	**1468.18**
April	**830.86**	**340.34**	**137.98**	**1309.20**
May	**813.11**	**321.24**	**149.67**	**1284.04**
June	**906.97**	**370.78**	**151.21**	**1429.98**
July	**1053.14**	**453.25**	**206.65**	**1713.06**
August	**1077.74**	**433.11**	**172.65**	**1683.51**
September	**941.38**	**368.55**	**170.24**	**1480.18**
October	**868.03**	**355.21**	**144.87**	**1368.12**
November	**904.64**	**369.85**	**170.80**	**1445.30**
December	**1059.46**	**403.78**	**175.12**	**1638.37**

NOx emissions are incomparable with CO and HC emissions. In order to clarify the previous results, we have drawn a graph (3.16) which groups together the three pollutants SOx, CO, HC.

Graphs:



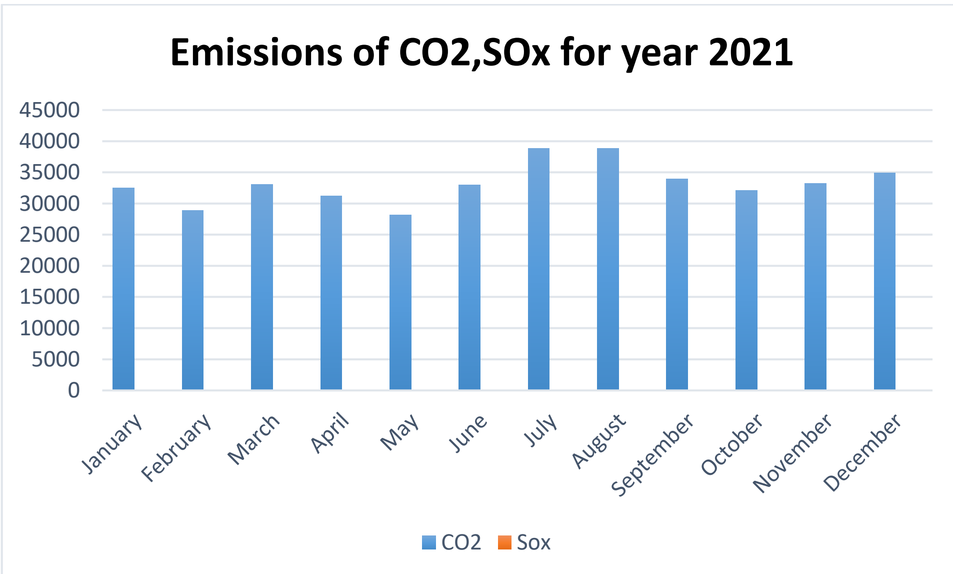
Graph 3.16: graph of emissions of CO, NOx, HC for year 2021

Table 3.16: The result of calcul emissions (CO2, SOx) for year 2021

Month	CO2	SOx	Total (Kg)
January	32490	12.66	32502.7
February	28871.1	11.69	28882.8
March	33074.8	13.81	33088.6
April	31257.4	12.33	31269.7
May	28157.8	11.5	28169.3
June	32952.5	12.78	32965.3
July	38810.4	14.34	38824.8

August	**38853.1**	**14.36**	**38867.5**
September	**33950**	**13.05**	**33963.1**
October	**32100**	**12.55**	**32112.5**
November	**33203**	**12.85**	**33215.8**
December	**34943.7**	**13.31**	**34957.1**

And we represent those results on graph 3.17:



Graph 3.17: graph of emissions of CO2, SOx for year 2021

From the perspective of pollutant emissions, CO2 emissions are the largest, followed by NOX, and SOx, CO emissions are relatively low, and HC emissions are the lowest.

And for the emissions of CO_2, the result of the emissions of the year 2021 with ICAO method in Air Algerie zone represent in figure 3.4:

Figure 3.3: Example from Air Algerie data for emissions CO2 fleet 2021

Date Vol	N° Vol	Hour Dép.	Hour Arr.	aircraft	Type aircraft	Dep. (OACI)	Arr. (OACI)	Qte Before vol "QTE01" (T)	Enlèv. (HL)	Dens. (KG/1)	Enlèv. (T)	Qte After vol "QTE02" (T)	CONS FUEL(T) Method B	Emissions CO2(T)
3/25/2021	1226	09:05	11:40	7T-VHL	C130	DAAG	LFLL	11.3	0.0	0.8	0.0	5.7	5.7	17.9
3/25/2021	1227	13:15	16:15	7T-VHL	C130	LFLL	DAOO	5.7	84.8	0.8	6.8	6.4	6.1	19.3
4/2/2021	1800	09:10	11:15	7T-VHL	C130	DAAG	LFML	6.8	82.1	0.8	6.4	8.2	5.0	15.8
4/2/2021	1801	12:40	15:40	7T-VHL	C130	LFML	DAUH	8.2	54.9	0.8	4.4	6.4	6.2	19.6
4/4/2021	1524	08:05	10:35	7T-VHL	C130	DAAG	LFLL	8.2	43.0	0.8	3.4	6.8	4.7	15.0
4/4/2021	1525	12:15	14:45	7T-VHL	C130	LFLL	DAAG	6.8	51.9	0.8	4.2	6.4	4.6	14.5
4/8/2021	1226	08:00	10:35	7T-VHL	C130	DAAG	LFLL	6.4	70.3	0.8	5.5	6.8	5.0	15.8
4/8/2021	1227	11:50	14:50	7T-VHL	C130	LFLL	DAOO	6.8	74.5	0.8	6.0	6.4	6.4	20.3
4/13/2021	1224	08:10	10:50	7T-VHL	C130	DAAG	LFLL	7.3	62.5	0.8	4.9	6.8	5.4	17.0
4/13/2021	1225	15:15	12:45	7T-VHL	C130	LFLL	DAAG	6.8	50.2	0.8	4.0	5.9	4.9	15.5
4/15/2021	1226	07:10	09:45	7T-VHL	C130	DAAG	LFLL	5.9	70.5	0.8	5.5	6.8	4.6	14.6
4/15/2021	1227	11:00	14:00	7T-VHL	C130	LFLL	DAOO	6.8	71.0	0.8	5.7	5.9	6.6	20.8
4/20/2021	1224	08:00	10:20	7T-VHL	C130	DAAG	LFLL	7.3	102.0	0.8	8.0	10.4	4.8	15.2
4/20/2021	1225	11:40	14:10	7T-VHL	C130	LFLL	DAAG	10.4	0.0	0.8	0.0	5.4	5.0	15.8
4/22/2021	1226	07:05	09:35	7T-VHL	C130	DAAG	LFLL	5.4	79.1	0.8	6.2	6.4	5.3	16.7
4/22/2021	1227	11:00	14:00	7T-VHL	C130	LFLL	DAOO	6.4	73.8	0.8	5.9	6.6	5.7	17.9
4/23/2021	1800	09:55	08:00	7T-VHL	C130	DAAG	LFML	7.3	108.6	0.8	8.5	11.8	4.0	12.6
4/23/2021	1801	11:20	14:30	7T-VHL	C130	LFML	DAUH	11.8	0.0	0.8	0.0	5.0	6.8	21.5

Figure 3.4: Result of year 2021 for emission CO2 for Air Algerie fleet

12/23/2021	2207	21:05	23:20	7T-VUJ	ATR72	LEMD	DAAG	2.9	0.0	0.8	0.0	1.7	1.2	3.9
12/30/2021	2206	17:10	19:20	7T-VUJ	ATR72	DAAG	LEMD	1.7	31.7	0.8	2.5	2.9	1.3	4.1
12/30/2021	2207	21:05	23:15	7T-VUJ	ATR72	LEMD	DAAG	2.9	0.0	0.8	0.0	1.7	1.2	3.8
10/13/2021	4920	00:50	02:25	7T-VUK	ATR72	DAAG	DTTA	1.6	12.1	0.8	1.0	1.5	1.1	3.3
10/13/2021	4921	03:10	05:00	7T-VUK	ATR72	DTTA	DAAG	1.5	16.0	0.8	1.3	1.7	1.1	3.4
8/26/2021	2512	10:05	11:50	7T-VUO	ATR72	DAAG	LEBL	1.5	27.8	0.8	2.2	2.5	1.1	3.6
8/26/2021	2513	15:15	16:50	7T-VUO	ATR72	LEBL	DAAG	2.5	0.0	0.8	0.0	1.6	0.9	2.8
6/14/2021	4908	17:20	19:00	7T-VUP	ATR72	DAAG	DTTA	1.5	36.9	0.8	2.9	3.3	1.1	3.3
6/14/2021	4909	20:45	23:20	7T-VUP	ATR72	DTTA	DAOO	3.3	0.0	0.8	0.0	1.8	1.6	4.9
6/18/2021	4908	10:15	12:45	7T-VUP	ATR72	DAOO	DTTA	1.6	34.3	0.8	2.7	2.7	1.6	5.0
6/18/2021	4909	13:30	15:20	7T-VUP	ATR72	DTTA	DAAG	2.7	0.0	0.8	0.0	1.8	0.9	2.8
10/17/2021	4920	19:00	20:40	7T-VUS	ATR72	DAAG	DTTA	1.6	28.8	0.8	2.3	2.8	1.0	3.3
10/17/2021	4921	22:25	00:00	7T-VUS	ATR72	DTTA	DAAG	2.8	0.0	0.8	0.0	1.9	1.0	3.0
7/18/2021	2512	10:20	12:05	7T-VUQ	ATR72	DAAG	LEBL	1.3	28.0	0.8	2.2	2.4	1.1	3.4
7/18/2021	2513	12:40	14:10	7T-VUQ	ATR72	LEBL	DAAG	2.4	0.0	0.8	0.0	1.4	1.0	3.2
2/26/2021	2512	12:52	14:25	7T-VUV	ATR72	DAAG	LEBL	1.6	26.5	0.8	2.1	2.6	1.1	3.4
2/26/2021	2513	15:10	16:34	7T-VUV	ATR72	LEBL	DAAG	2.6	0.0	0.8	0.0	1.7	0.9	2.8
10/6/2021	4902	13:27	15:02	7T-VUV	ATR72	DAAG	DTTA	1.5	20.1	0.8	1.6	2.1	1.0	3.1
10/6/2021	4903	17:53	20:26	7T-VUV	ATR72	DTTA	DAOO	2.1	13.9	0.8	1.1	1.6	1.6	5.0
10/10/2021	4902	05:52	07:33	7T-VUV	ATR72	DAAG	DTTA	1.5	34.2	0.8	2.7	2.9	1.4	4.3
10/10/2021	4903	08:34	10:12	7T-VUV	ATR72	DTTA	DAAG	2.9	0.0	0.8	0.0	1.9	1.0	3.1
11/23/2021	2512	13:04	14:32	7T-VUV	ATR72	DAAG	LEBL	1.4	30.8	0.8	2.4	2.9	0.9	2.8
11/23/2021	2513	15:28	17:04	7T-VUV	ATR72	LEBL	DAAG	2.9	0.0	0.8	0.0	2.0	0.9	2.8
NBR VOLS	**4297**										**TOTAL**		**40938.7**	**129366.2**

- The result total for CO2 emissions for 2021 is: 129366.2 (Tons)

CHAPTER 4:

METHODS OF REDUCTION EMISSIONS

4. METHODS OF REDUCTION EMISSIONS:

4.1. INTRODUCTION

The airplane carbon footprint refers to the emissions of carbon dioxide and other greenhouse gases that occur when an airplane operates during a flight. Aircraft are a significant source of greenhouse gas emissions, especially carbon dioxide, which is produced through the combustion of jet fuel.

In 2016, a final determination was made that greenhouse gas emissions from aircraft contribute to air pollution that poses a potential threat to public health and welfare. It was found that aircraft emissions account for approximately 2 to 3% of global CO2 emissions. Considering the projected doubling of air travel within the next 15 years, these emissions are expected to increase significantly.

As a result, finding ways to take off without adding greenhouse gases to the atmosphere requires considerable effort. Here are some of the strategies being explored to address this challenge:

4.2. EVALUATION OF SINGLE ENGINE TAXING OPERATIONS

Taxi times are forecast to increase alongside the growing number of air traffic movements, primarily due to airport congestion. Consequently, increased fuel consumption and CO2 emissions are expected. Standard operating procedures (SOPs) for many airlines state that all engines operate at an 'idle' thrust setting during aircraft taxiing, often assumed to be 7% of maximum rated engine thrust. However, certain airlines have adopted SET.

After completing the necessary post-landing checks, the SET (Single Engine Taxi) procedure is initiated for taxi-in. The taxi-in process consists of two components: first, after the wheels touch the ground, the pilots set the engines to an appropriate thrust setting for taxiing. This thrust setting is maintained while the post-landing checks are performed. During these checks, the pilots determine if it is suitable to use SET. If deemed appropriate, SET begins by turning off one or more engines for the remaining duration of the taxi-in. For two-engine aircraft, one engine is switched off, while for four-engine aircraft, two engines are turned off. Both cases are referred to as SET to ensure consistency in discussions, while taxiing with all engines active is referred to as total engine taxi (TET). Please refer to Figure 4.1for a diagrammatic representation of the taxi-in process for a two-engine aircraft.

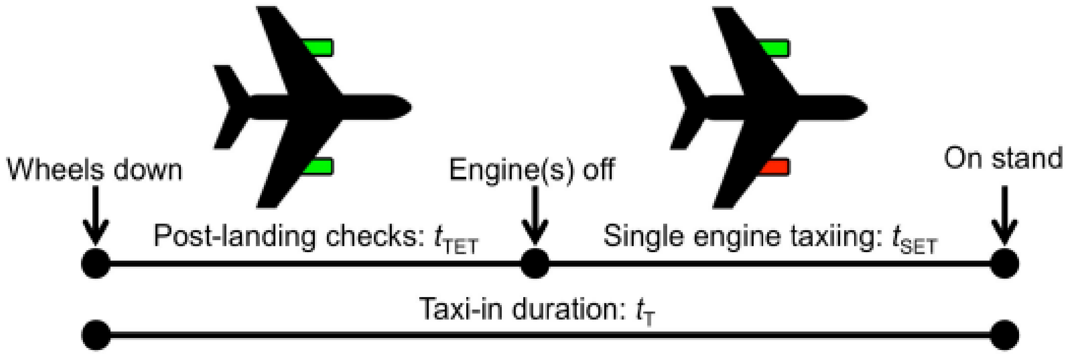


Figure 4.1: Diagrammatic representation of the taxi-in process[16]

Before initiating SET (during the post-landing checks), the aircraft operates in TET, with both engines running at the active taxi-in thrust setting. It is assumed that this thrust setting remains constant, as pilots prefer to control ground speed using brakes rather than reducing engine thrust each time the aircraft needs to stop. Once the post-landing checks are completed and if operational conditions permit, the secondary engine(s) is turned off until arrival at the stand. However, the use of SET is subject to safety factors and operational constraints, including crew workload, impact on aircraft systems, and breakaway thrust levels. There are various conditions where SET is not possible or used to a lesser extent, such as aircraft operational and technical limitations, airport restrictions (e.g., taxiway/ramp gradients), weather conditions, and taxiway/ramp contamination. To determine the duration of SET taxiing activity, the time during which each taxi-in activity operated with half of the engines inactive (thrust setting less than 1%) was recorded.

While this chapter focuses on observing SET during taxi-in, similar trends are expected during taxi-out. However, an additional warm-up time for the engines is required during taxi-out. Typically, for SET during taxi-out, engines remain switched off after pushback from the stand and are then turned on at least 2 minutes before takeoff (or 5 minutes if the engine has been off for more than 2 hours). Future studies should extend the analysis to include taxi-out operations. For taxi-in operations a saving of between 20-40% per aircraft movement has been estimated (see Figure)

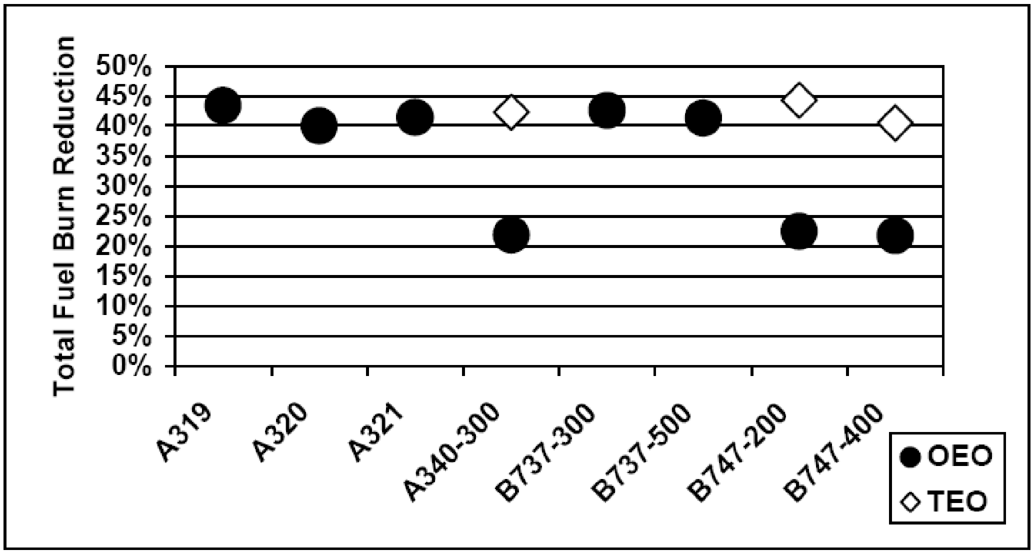


Figure4.2: Reported stabilised fuel flow reductions for taxi with one engine (OEO) and two engines (TEO) shut down, from IATA 2005 study – APU fuel burn not included[17]

4.3. APU SUBSTITUTION OF (APU) BY (FEGP) AND (PCA)

The Auxiliary Power Unit (APU) of an aircraft is a self-contained unit that provides power to support various onboard systems when the main engines are not operating. It is typically located in the tail section of the aircraft. The APU is responsible for supplying electrical power for functions such as lighting, air conditioning, and other electrical systems, as well as providing compressed air for starting the main engines. It operates independently and uses its own fuel source, such as jet fuel or aviation gasoline, to generate power. The APU is commonly used during ground operations, including aircraft startup, taxiing, and while the aircraft is parked at the gate. It helps ensure the availability of essential services and reduces the reliance on ground power sources, enhancing the aircraft's autonomy and operational flexibility.

Hamilton Sundstrand APS 3200 APU for A320 family	Hamilton Sundstrand APS 500R APU for ERJ 135/140/145	Honeywell 36-150CX APU for Do328
		

Figure4.3: Example APU for commercial aircraft[17]

The usr of (APU) is not restricted beyond 3.0 hours per wide-body aircraft operation and 1.2 hours per narrow-body aircraft .because of this stadies have shown that use of the The Auxiliary Power Unit (APU) contributes to 3000 ton of CO2 emisions and looking at a selection of major European airports has estimated the existing and future potential for APU substitution by ground powered systems such as FEGP and PCA to reduce aircraft ground emissions.

In many instances, the electrical and air conditioning demands typically fulfilled by an APU can be effectively met by ground-based systems. These systems utilize grid electricity, which is generated with higher efficiency, resulting in lower carbon emissions and reduced costs per kilowatt-hour.The utilization of aviation jet fuel in APUs is both costly and inefficient. Therefore, a ground power hierarchy can be implemented to achieve fuel, cost, CO2, and NOX emissions savings:

- Whenever available, airport terminals or ground-based facilities like FEGP (Fixed Electrical Ground Power) and PCA (Pre-Conditioned Air) should be utilized.
- In the absence of terminal facilities, GPUs (Ground Power Units) and air-conditioning units should be used as they offer fuel, emissions, and noise reductions compared to APUs.

By following this hierarchy, significant fuel and cost savings can be achieved, along with reduced emissions of CO2 and NOX.

4.3.1. GROUND POWER (FEGP AND GPU)

Supply of ‘fixed electrical ground power’ (FEGP) at the stand is a primary substitute for electrical supply from an aircraft’s APU. An electrical supply cable is plugged into the underside of the aircraft and draws its power from the airport’s electrical supply

Figure4.4: Example use of FEGP at Stansted airport[17]

This system converts grid electricity to power suitable for supply (3 phase 400Hz), through standardised connectors, to the aircraft.

Mobile ground power units (GPUs), which often run on diesel fuel, are also a better substitute where fixed systems are not present, are inoperable or cannot supply sufficient power to completely satisfy the aircraft’s requirements.

4.3.2. PRECONDITIONED AIR (PCA)

FEGP cannot substitute the APU where air-conditioning is required in the cabin. Therefore to restrict the use of the APU for this purpose a ground supply of cooled or heated air to the cabin air-conditioning systems is necessary.

This is termed “preconditioned air” (“PCA”). Some airports are able to supply this air either from their central energy plant or through decentralised, gate mounted chiller/heater units on or near each airbridge.

Figure4.5: Example of Preconditioned Air[9]

4.4. LOW EMISSIONS GSE AND VEHICLES

In addition to FEGP and PCA, other options are available to substitute APUs.

The utilization of low emissions Ground Support Equipment (GSE) is an important aspect of reducing environmental impact in aviation. Low emissions GSE refers to ground handling equipment and vehicles that are designed to minimize their carbon footprint and contribute to sustainable operations on the ground.

Low emissions GSE can include various types of equipment, such as baggage tugs, aircraft pushback vehicles, fuel trucks, and catering trucks. These vehicles are often powered by alternative fuels or advanced technologies to reduce emissions and promote energy efficiency.

Here are some key aspects and benefits of low emissions GSE:

Alternative Fuels: Low emissions GSE may utilize alternative fuels, such as biodiesel, natural gas, or electric power, instead of traditional fossil fuels. These fuels emit fewer greenhouse gases and pollutants, contributing to lower carbon emissions and improved air quality.

Electric GSE: Electric-powered GSE, including electric baggage tugs and aircraft pushback vehicles, have gained popularity due to their zero-emission nature when powered by clean electricity sources. They offer reduced noise levels and improved energy efficiency compared to conventional diesel-powered equipment.

Hybrid Technology: Some GSE vehicles employ hybrid technology, combining traditional internal combustion engines with electric power systems. This hybridization enables lower fuel consumption, reduced emissions, and improved energy management.

Efficient Design: Low emissions GSE often incorporates energy-efficient design features, such as regenerative braking, idle-reduction systems, and optimized aerodynamics. These design elements help to minimize energy waste and enhance overall operational efficiency.

Regulatory Compliance: Many airports and regulatory authorities have introduced standards and guidelines to encourage the use of low emissions GSE. Compliance with these regulations promotes the adoption of cleaner and more sustainable ground handling practices.

The implementation of low emissions GSE requires collaboration between airport operators, ground handling companies, and equipment manufacturers. It involves assessing the available options, considering the specific operational requirements, and ensuring appropriate infrastructure and support systems are in place.

By utilizing low emissions GSE, airports can significantly reduce their carbon footprint and contribute to overall emissions reduction in the aviation industry. The adoption of cleaner technologies and fuels in ground operations plays a crucial role in achieving sustainability goals and working towards a more environmentally friendly aviation sector.

4.5. CONTINUOUS DESCENT OPERATIONS (CDO) AND CONTINUOUS CLIMB OPERATIONS (CCO)

Encouraging efficient aircraft operations during take-off and landing is a highly effective approach to reducing emissions near the ground. Optimal climb and descent procedures known as Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) play a crucial role in achieving this goal. These procedures involve flying aircraft in a low drag configuration, minimizing fuel consumption, emissions, and noise simultaneously.

A study conducted by EUROCONTROL in 2018 specifically focused on CCO-CDO optimization in Europe. The findings revealed that implementing these procedures could potentially save up to 340,000 tons of fuel annually, which is equivalent to over 1 million tons of CO_2 emissions. By eliminating inefficient level flight segments at intermediate altitudes, aircraft can spend more time at higher cruising levels that are more fuel-efficient, resulting in reduced emissions. Figure4.7 illustrates the difference between an optimal CDO approach (blue) and a non-optimal approach (yellow).

In summary, incentivizing and implementing CCO and CDO procedures offer significant benefits in terms of fuel savings, emissions reduction, and noise mitigation during aircraft operations. By adopting these practices, the aviation industry can contribute to a more sustainable and environmentally friendly air transport system.

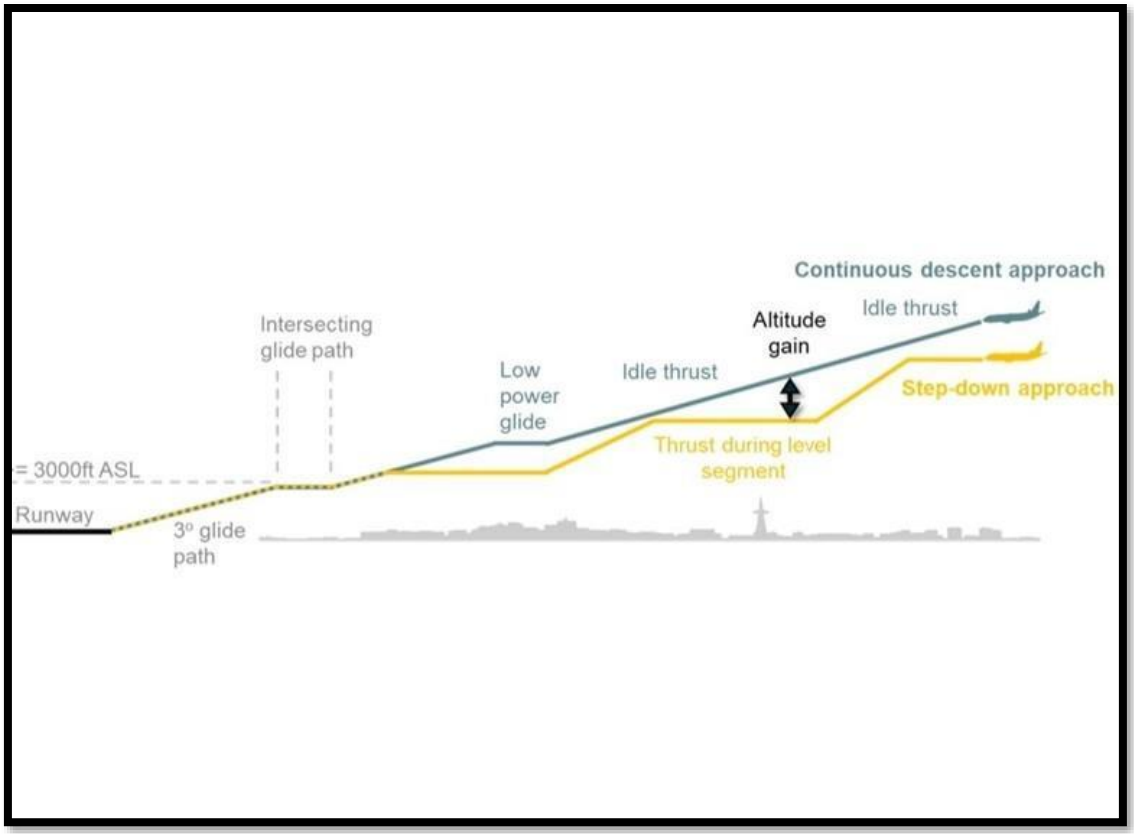


Figure4.6: Optimal CDO Approach (blue) versus an example Non-Optimal Approach (yellow)[10]

4.6. NEW IMPROVE AIRCRAFT TECHNOLOGIES

Aircraft manufacturers are constantly working on developing new technologies to reduce CO_2 emissions and improve fuel efficiency. Some of the new technologies being developed or implemented in modern aircraft include:

- ✓ Advanced materials: Advanced materials, such as lightweight composites and alloys, are being used to reduce the weight of aircraft and improve fuel efficiency.
- ✓ Improved aerodynamics: Aircraft design is being optimized to reduce drag and improve aerodynamics, which can lead to lower fuel consumption.
- ✓ More efficient engines: Newer aircraft are equipped with more efficient engines that produce less CO_2 and other emissions, and are quieter than older engines.
- ✓ Electric and hybrid-electric propulsion: Manufacturers are developing electric and hybrid-electric propulsion systems for smaller aircraft, which could eventually be used in larger commercial planes.

4.7. SUSTAINABLE AVIATION FUEL

Sustainable Aviation Fuel (SAF) represents the future of aviation fuel, derived from 100% renewable waste and residue materials, including sources like used cooking oil. Throughout its life cycle, SAF offers a substantial reduction of up to 80%* in greenhouse gas (GHG) emissions compared to fossil jet fuel. This remarkable reduction contributes significantly to combating climate change by preventing the release of significant amounts of fossil-based emissions into the atmosphere.

SAF can serve as a direct replacement for fossil jet fuel, as it shares similar chemical properties. It seamlessly integrates into existing jet engines and fueling infrastructure without requiring any additional investments. This compatibility allows for a smooth transition to SAF without the need for substantial modifications or upgrades.

The adoption of SAF has been gaining traction in the aviation industry. Since 2016, more than 450,000 commercial flights have already utilized SAF. Over 50 airlines and 13 major airports have embraced and supplied SAF, with the number steadily increasing. The growing demand for SAF reflects the industry's commitment to reducing its environmental impact.

Neste, a leading producer of SAF, currently boasts an annual production capacity of 100,000 tons (approximately 34 million gallons). However, their ambitions are far-reaching. By the end of 2023, Neste aims to significantly scale up its production capacity to 1.5 million tons (515 million gallons) of SAF annually. Furthermore, Neste's commitment extends to a total renewable product capacity of 5.5 million tons by the same timeframe. This expansion solidifies Neste as the sole global provider of renewable products with production facilities spanning North America, Asia, and Europe.

In summary, SAF offers a sustainable alternative to traditional fossil jet fuel, derived from renewable waste and residue materials. Its remarkable emissions reduction, compatibility with existing infrastructure, and growing industry support make SAF a vital component in the aviation industry's efforts to combat climate change and create a more sustainable future.

4.8. CONCLUSION

In conclusion, reducing CO2 emissions on the ground is a critical component of achieving sustainability and environmental goals in the aviation industry. By implementing various strategies and measures, significant progress can be made in mitigating the environmental impact of aircraft operations on the ground.

Efforts such as substituting Auxiliary Power Units (APUs) with more sustainable alternatives like Fixed Electrical Ground Power (FEGP) and Pre-Conditioned Air (PCA), as well as utilizing electric Ground Power Units (GPU) and exploring hydrogen-based solutions, contribute to substantial reductions in CO2 emissions. These solutions offer the potential for significant emission savings and are compatible with existing infrastructure, making them practical options for widespread adoption.

The use of low emissions Ground Support Equipment (GSE) further contributes to reducing CO2 emissions on the ground. GSE, such as electric baggage tractors, tugs, and vehicles, minimize fuel consumption and emissions, promoting a cleaner and more sustainable ground operation environment. Collaborating with ground handling companies and ensuring the availability of necessary infrastructure are crucial roles for airport operators in facilitating the adoption of low emissions GSE.

Optimizing aircraft operations during take-off and landing, specifically through Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO), offers another effective approach to reducing emissions on the ground. These procedures optimize climb and descent profiles, minimizing fuel burn, gaseous emissions, and noise. By eliminating inefficient level flight segments and promoting smoother descents, CCO and CDO result in fuel savings and enhanced overall environmental performance.

Furthermore, the development and utilization of Sustainable Aviation Fuel (SAF) offer a promising solution to reduce CO2 emissions. SAF, derived from renewable feedstocks, significantly decreases greenhouse gas emissions compared to conventional fossil jet fuels. With increasing adoption and production capacity, SAF can play a vital role in achieving net-zero emissions in aviation.

In summary, a combination of strategies including the use of sustainable alternatives to APUs, low emissions GSE, optimized aircraft operations, and SAF can collectively contribute to the reduction of CO2 emissions on the ground. Implementing these measures requires collaboration among stakeholders, supportive policies, technological advancements, and ongoing commitment from the aviation industry to drive meaningful change and create a more sustainable future for air travel.

CONCLUSION

CONCLUSION:

In conclusion, this dissertation extensively examined the impact of gas emissions from aircraft on pollution and climate change. The first chapter provided a comprehensive overview of the environmental implications of aircraft emissions, emphasizing the need for effective strategies to address this pressing issue.

The subsequent chapters focused on quantifying pollutant emissions from Air Algerie aircraft activities using two distinct methods: the Boeing method and the ICAO method. The application of these methodologies provided a detailed understanding of the emissions profile specific to Air Algerie's operations. The Boeing method, which primarily focused on fuel burn and emissions during flight, offered a detailed analysis of the pollutants emitted directly from the aircraft. On the other hand, the ICAO method took a broader approach, considering various industry factors to provide a comprehensive assessment of emissions associated with Air Algerie's activities.

Building upon the emission quantification, the final chapter proposed a range of practical solutions and recommendations to Air Algerie to reduce carbon dioxide emissions on the ground. These solutions include fleet modernization, investing in more fuel-efficient aircraft, and exploring the use of sustainable aviation fuels (SAFs). Additionally, optimizing operational efficiency, implementing infrastructure upgrades, and participating in carbon offset programs were suggested as effective measures to mitigate emissions.

The findings of this dissertation contribute valuable insights into the environmental impact of aircraft emissions, with a specific focus on Air Algerie's activities. The quantification of emissions using the Boeing and ICAO methods provides a comprehensive understanding of the airline's emissions profile. Moreover, the proposed solutions and recommendations offer practical strategies for Air Algerie to adopt sustainable practices and contribute to reducing carbon dioxide emissions on the ground.

This study not only enhances our understanding of the aviation industry's impact on pollution and climate change but also provides a foundation for future research and policy development in the field. By implementing the suggested solutions, Air Algerie can actively contribute to a more sustainable aviation sector, aligning its operations with environmental objectives and fostering a greener and more responsible approach to air travel.

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