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Research Paper

Software modeling of aircraft engine emissions using Piano -X models

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Abstract— *Human had invented many components and some of that had revolutionized the way they live and also changed their life style. One of those inventions are traveling mode and in that invention of aircrafts played a key role. Because of the invention of aircraft and air travel human beings crossed oceans, traveled across time zones, made impossible things possible and hence air travel is a boon to human kind in all ways. Aviation sector had seen enormous growth from the day of its invention and it become an important sector supporting growth of any country. This growth does not comes without any compromise, the compromise being increased level of air pollution which is a serious hazard affecting human health across continents. Unlike other type of pollution air pollution affects human health seriously and aviation sectors contributes a lot to surge in air pollution because of increasing number of aircrafts and air travel usage. This article aims to address the issue of air pollution issue created by aircrafts and also explains about a model called as Piano-X which is used to estimate aviation pollution of different aircrafts. Software models which are custom made according to the need of the industry serve better in modeling and predicting impacts. The studies conducted using the model shows considerable impact to the environment and hence its to be abated.*

Key words*: Air pollution, Mathematical model, Piano-X etc.*

Introduction

As given in Webster dictionary the literal meaning of Pollution is the introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem i.e. physical systems or living organisms. Pollution can take the form of chemical substances or energy, such as noise, heat, or light. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring; when naturally occurring, they are considered contaminants when they exceed natural levels. Pollution is often classed as point source or nonpoint source pollution. The Blacksmith Institute issues annually a list of the world's worst polluted places. In the 2007 issues the ten top nominees are located in Azerbaijan, China, India, Peru, Russia, Ukraine, and Zambia (Blacksmith institute report, 2007).

Air Pollution

According to wikipedia air pollution is defined as liberating or introduction of harmful chemicals, particulate matter, or biological materials that may cause harm or discomfort to humans or other living organisms, or cause damage to the natural environment or built environment, into the atmosphere. The atmosphere is a complex dynamic natural gaseous system that is essential to support life on planet Earth. Due to the development and surge in number of vehicles the overall pollution level is also steadily increasing. Unlike other pollutants and pollution air pollution directly affect human health and it is instantaneous. Some of the air pollutants which are harmful includes Carbon di oxide, Aerosols, Asbestos, Carbon Monoxide, Chlorofluorocarbons (CFCs), Criteria Air Pollutants, Ground Level Ozone, Hazardous Air Pollutants (HAPs), Hydro chlorofluorocarbons (HCFCs), Lead, Mercury, Methane, Nitrogen Oxides (NOx), Particulate Matter (PM), Propellants, Radon, Refrigerants, Substitutes, Sulfur Oxides (SO_2), Volatile Organic Compounds (VOCs)are the air pollutants which contribute to the global air pollution. These pollutants are divided into various groups, including particulate matter, volatile organic compounds (VOCs) and halogen compounds. The levels of these compounds are being monitored regularly by statuary authorities across the continents at various check points and in important places.

Increasing air pollution and its impact

Air pollution has been aggravated by developments that typically occur as countries become industrialised: growing cities, increasing traffic, rapid economic development and industrialisation, and higher levels of energy consumption. The high influx of population to urban areas, increase in consumption patterns and unplanned urban and industrial development have led to the problem of air pollution (CPCB,2010). Pollutants are divided into various groups, including particulate matter, volatile organic compounds (VOCs) and halogen compounds. Also included are more commonly-known pollutants such as lead, mercury and asbestos. The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution, with 1.5 million of these deaths attributable to indoor air pollution. Epidemiological studies suggest that more than 500,000 Americans die each year from cardiopulmonary disease linked to breathing fine particle air pollution. A study by the University of Birmingham has shown a strong correlation between pneumonia related deaths and air pollution from motor vehicles. Worldwide more deaths per year are linked to air pollution than to automobile accidents. Published in 2005 suggests that 310,000 Europeans die from air pollution annually Causes of deaths include aggravated asthma, emphysema, lung and heart diseases, and respiratory allergies The US EPA estimates that a proposed set of changes in diesel engine technology could result in 12,000 fewer premature mortalities, 15,000 fewer heart attacks, 6,000 fewer emergency room visits by children with asthma, and 8,900 fewer respiratory-related hospital admissions each year in the United States . The United Kingdom suffered its worst air pollution event when the December 4 Great Smog of 1952 formed over London. In six days more than 4,000 died, and 8,000 more died within the following months.

A new economic study of the health impacts and associated costs of air pollution in the Los Angeles Basin and San Joaquin Valley of Southern California shows that more than 3800 people die prematurely (approximately 14 years earlier than normal) each year because air pollution levels violate federal standards. The number of annual premature deaths is considerably higher than the fatalities related to auto collisions in the same area, which average fewer than 2,000 per year. Diesel exhaust (DE) is a major contributor to combustion derived particulate matter air pollution. In several human experimental studies, using a well validated exposure chamber setup, DE has been linked to acute vascular dysfunction and increased thrombus formation. This serves as a plausible mechanistic link between the previously described association between particulate matter air pollution and increased cardiovascular morbidity and mortality.

Aircrafts and air pollution

The debate about aviation and its strong growth trajectory is very highly developed, like its fellow machines aircrafts are also contributing more to the air pollution, even though the air dynamics makes measuring air pollution due to aircraft emission unpredictable but they are also contributing much to the air pollution. Increasing number of aircrafts and aviation companies puts thrust in the increased amount of pollutant emission due to aircraft operations. Unlike other transportation mode aircrafts are highly sophisticated machines which are liked by many but also hazardous equally while compared with any other machines. Also there is an unquestioning acceptance in government that the rising demand for air travel will continue and that the land use planning implications (especially more terminals and runways) of this can be managed with minimal harm to the environment .The aviation industry has been very successful in its adoption of an environmental agenda (environmental reports, support of exotic, threatened environments, appointment of environmental managers, financial support for a professorship of "sustainable aviation") but has been less forthcoming on questions of growth and the need for reductions in greenhouse gases. The industry has benefited from a well developed system of public support. Airports can expect to be linked at public expense by very expensive infrastructure to the motorway system, aviation fuel is not taxed and a great deal of public money at EU and UK levels goes into air traffic control systems. Equally the industry does become involved in direct funding of this infrastructure e.g. the Heathrow Express. Nevertheless in the language of environmental economics aviation does not meet the full external costs generated by its own activities (noise and pollution) and fails to pay for direct costs generated by the activity itself (e.g. the motorway links to Manchester and Heathrow airports).

Trends in growth of aviation industry

According to a survey World's airlines offer 114,000 more flights and 17.7 million more seats year on year, The global airline industry shows no sign of reducing its activities; with a 5% increase in the number of flights scheduled for May 2007 compared with the same month last year. According to the latest statistics from OAG, the world's authority on flight information, this represents an additional 113,827 flights and an astonishing 17.7 million extra seats available to travellers. (OAG report,2009). A total of 2.51 million flights are timetabled this month, topping the previous industry high of 2.49 million reported for August 2006. Within this global figure of all scheduled passenger flight operations, the low cost sector shows a 22% increase of over 70,000 more flights year on year and a 26% rise in the number of seats available, representing an extra 12 million low cost seats. Aviation demonstrates very strong growth rates. Forecasts of this growth are described and reviewed. On a 1995 base global forecasts of miles flown in t he year 2015 range from a low growth of 181% to a high growth of 380%. In the UK where forecasts are made of terminal passenger numbers the latest government forecasts predict a 239% change on 1995 by 2015.

Aviation has the highest growth rates of all modes of transport. Annual global growth rates of aviation (total number of kilometres flown by all passengers) were approximately 10% in the 1960s and had values of 5% -7% in the 1990s. Between 1960 and 1995 global tonne –

kilometres (total weight of freight carried multiplied by the distance flown) increased by a factor of 23, while the global gross domestic product increased by a factor of 3.8. Global revenue passenger kilometres (RPK) rose by a factor of 4.6 between 1970 and 1995. Air traffic in and from/to North America and Europe dominates the world demand. In 1995

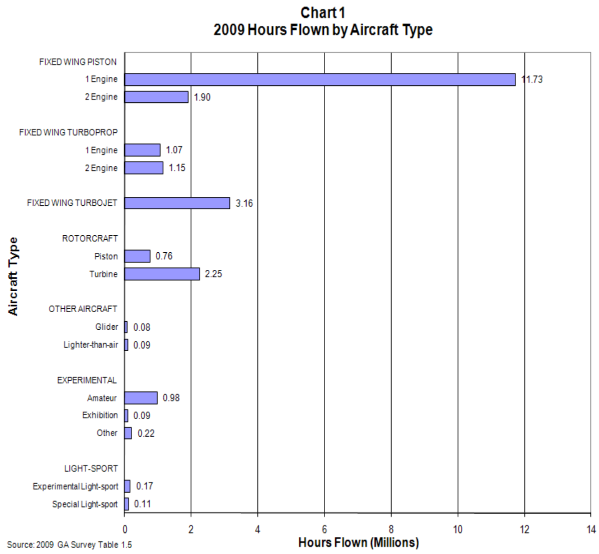

Figure 1: Hours flown by various aircrafts (Source FAA, 2009)

intra North American aviation accounted for 27.5% of global RPK, intra Europe 12.5%, North America - Europe 11%, Asia to North America and Europe 12.7%, and all the rest 36.5% of global RPK. How ever, the highest growth rates are found today in Asia (intra Asian RPK rose by 20% p.a. between 1970 and 1995). These data are the main input for all demand forecasts.

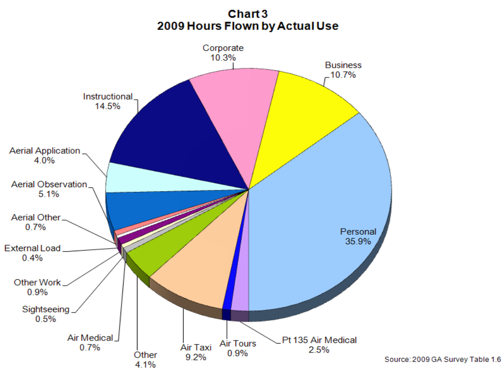

Figure 2: Purpose of travel of air passengers (Source: FAA, 2009)

The UK air traffic forecasts (DETR, 1997) predict that there will be 310 million passengers going Through UK airports in 2015, up from 129.6 million in 1995. This is a change of 239% and an actual increase of 180.4 million passengers, the equivalent of an extra 3 -4 airports the size of Heathrow.

Estimation of pollution due to aircrafts

New Delhi, April 30 (IANS) concerned over the rise in carbon emissions by aircraft and the boom in the aviation industry compounding the problem, the government will soon undertake a study to ascertain air pollution caused by planes, an official said Wednesday. The Bureau of Energy Efficiency (BEE), under the power ministry, will look at the impact of emissions by aircraft on environment. According to official estimates, over 1,100 aircraft are expected to be added to the Indian aviation industry, sharply raising the level from the current 530.“This is why there is a need for conducting a study of emissions by aircrafts. Once we have over 1,500 aircraft by the end of 2011, it will drastically affect the environment,” said the ministry official. Globally, the aviation industry contributes over two percent of the total pollution. Also, the airline industry emissions have gone up dramatically in the past decade with the rise in the number of flights due to the emergence of low-cost air travel. The International Civil Aviation Organization (ICAO) forecasts that airline emissions will rise to three percent of total carbon emissions by 2050, if not checked. The government’s move in this regard is considered significant, as most countries have already imposed strict emission norms and noise restrictions on airplanes. At the third aviation and environment summit held in Geneva recently, 13 organizations including the International Air Transport Association (IATA) and aircraft manufacturers Airbus, Boeing and Bombardiers pledged for a campaign against global warming and adopt strategies against pollution. Last year, the European Union (EU) proposed tax on all flights that arrived or departed from any EU airport, and argued this would help curb the growth in carbon emissions. The airline industry objected to the EU’s proposal at the ICAO. The industry accused the EU of singling them out and said their emissions were negligible when compared to the auto industry.

Aircraft emissions

Emissions can arise from different modes of aircraft operation, namely idle, taxi, take-off, approach and landing. The mode of operation puts differing demands on the aircraft engines resulting in fluctuating pollution emissions. For example carbon monoxide and hydrocarbons, which arise from incomplete or poor combustion, are generally largest during taxi / idle operations. (Many hydrocarbons are odorous; the typical airport smell of unburned and partially burned kerosene is testament to this.) Emissions of NOx, however, are generated largely by the oxidation of atmospheric nitrogen in the combustion process. As such their production is proportional to the combustion temperature, and emissions of NOx are therefore at their highest during the take-off phase when the engine is generally producing maximum power. During the landing phase the combustion is delivering some 30% power; at such a setting NOx is still an important pollutant, whilst CO and hydrocarbon emissions become increasingly important as the combustion thrust output falls.

Aircraft emission calculation

Aircraft emissions (HC, CO, NOx, SO_2) at airports are calculated for the LTO consisting of four operation modes: approach, taxi, take-off and climb. A typical LTO cycle described by ICAO is shown in Fig. 1 [24]. ICAO defined the climbing as the interval between the end of take-off and the moment the plane exits the atmospheric boundary layer (ABL) and landing. ICAO's norms therefore take air traffic emissions into account from the surface to the top of the ABL, whose height is defined to be 915 m (3000 ft) by default.

Scientific modeling and its uses

A model is a simple system which reveals important properties of a more complex system that you wish to understand better. More than one type of model can be used to study the same complex system, each model shedding light on some different aspect of the complex system but each model has limitations on what kind of information it can give you. Some of the basic rules and limitations of modeling are presented in the following series of models. Models are created to answer specific questions, how you design your model depends on the question(s) you want it to answer. The more specific the question, the better the chances of achieving a satisfactory answer. An important part of modeling is experimental verification; where you compare the predictions of your model against actual observations on the complex system that you are studying. (Brien Sparling,2001). There are many ways a model is created and analysed, the best way is software modeling which answers many queries rapidly with less amount of resource consumption. Because of this advantages software modeling is rapidly replacing generic method of mathematical modeling. In software modeling the mathematical modeling concepts, formula were only used but the analysis part is done by the specific software and many software based models were successfully created to analyse air pollution like MARKAL models, EPA models etc.

Aircraft pollution modeling

To analyse the quantum of aircraft emission few airlines operational details were collected and a simple thump rule based calculations were done to find out how much amount of pollutants may be released to the atmosphere. Considering the altitude the aircrafts are flying and the speed at which they travel and the air dynamics at that altitude calculating the pollutant dynamics is highly impossible but the amount of pollutants emitted remains hence a calculation was done in the baseline based on the fuel consumption per aircraft. The following tables containing details about various aircraft and their fuel consumption / passenger/ km is given along with their CO2 emission. Also a software model was used to analyse the aircraft emission called as Piano-X

Piano-X- A model to estimate aviation pollution

Piano is a unique professional tool for the analysis of commercial aircraft. It is used in preliminary design, competitor evaluation, performance studies, environmental emissions assessments and other developmental tasks by airframe and engine manufacturers, aviation research establishments and governmental or decision-making institutions throughout the world. Piano was conceived as a preliminary aircraft sizing and analysis tool. It has contributed to several real-world design projects, including internal Airbus conceptual studies of the UHCA (which led to the A380), a number of 70-100 seater designs, and at least one new mid-sized business jet currently in production. A major influence has come from engine manufacturers. Piano does not design the engine, but it is ideal for studying the application of different powerplants to both existing and projected aircraft. Consequently, engine + airframe evaluation is one the most extensive areas of usage for Piano. It has served as a 'common reference' tool between airframers and engine makers during cooperative studies.

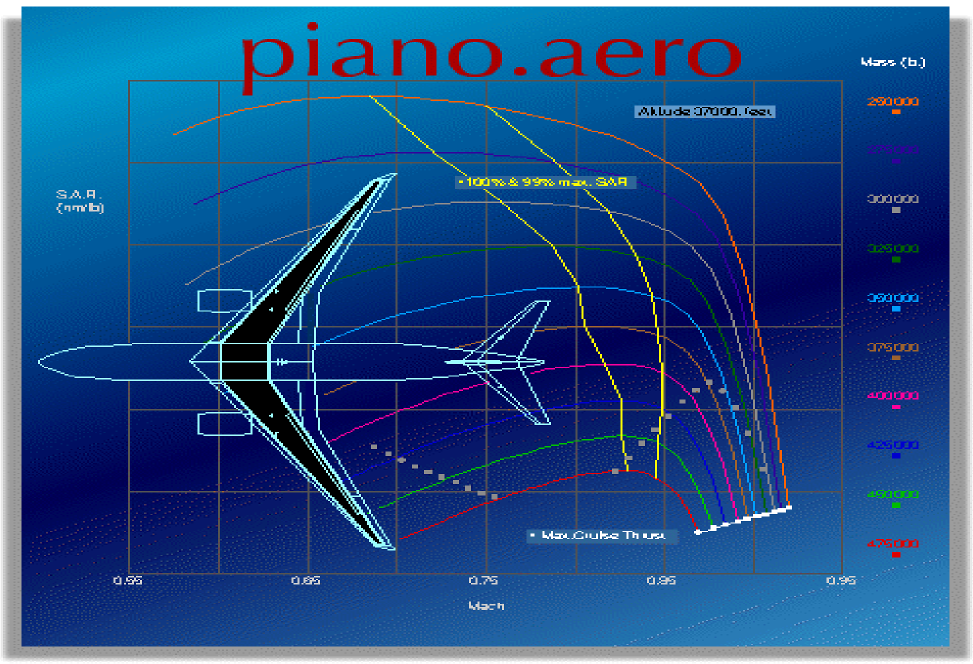

Figure 3: Image showing output of Piano Software

The performance capabilities of Piano also proved to be perfectly matched to flight profile analysis focused on the environment. A number of major studies have used it to examine the global effects of aircraft fleet operations. Piano can easily calculate the spatial distribution of fuel flows and associated emissions of atmospheric pollutants (NOx, CO and hydrocarbons) along a flightpath, given the standard engine emission indices published for newly certificated engines. You can try Googling "piano aircraft emissions" to see various high-level reports it was used in. Flightpath modelling can include arbitrary landing/takeoff cycle (LTO) or Air Traffic Control (ATC) considerations. One major advantage of Piano is that both projected and existing aircraft can be modelled and compared using similar standards and technological baselines. Piano's large database of aircraft is of vital significance, since aircraft design does not take place in a vacuum. The user can modify any aircraft already in the database, or create entirely new ones from scratch. Available knowledge of specific aircraft types varies, ranging from simple press releases or brochures to explicit aerodynamic, engine and performance data. Whatever the situation, Piano offers appropriate adjustments for maximising the fidelity of each model. Research and Governmental institutions have used Piano in-house as part of their independent evaluations of various future projects, which can influence major decisions on questions of policy and funding.

Capabilities of Piano-X

• Piano is an integrated tool for analysing and comparing existing or projected commercial aircraft. It generates fast, accurate, industrial-quality evaluations (even on a laptop) covering geometry, mass, aerodynamics, flight performance and other aspects.

• Piano benefits from more than fifteen years of software development expertise, methodology evolution and customer feedback. It is backed up by a long-term commitment and is widely used by many prestigious Aerospace organisations.

• It is applicable to conventional commercial subsonic aircraft ranging in size from small business jets to the largest airliners currently envisaged.

• It includes a large and continually updated database of more than 250 aircraft, calibrated with the best available data collected over many years.

• Piano can be used to generate new conceptual designs through single-point or 'family' analysis, multi-variable numerical optimization, or parametric sensitivity studies.

• Projected and existing aircraft are compared impartially within a single environment using consistent standards.

• Aircraft models can be adjusted in many ways to match known specifications or claimed performance levels.

• Piano can execute detailed flight performance calculations. Off-design missions and time/distance/altitude/fuel data rarely quoted in brochures can be evaluated easily.

• Piano is a highly interactive and intuitive package. The analyst is fully in charge at all times.

• Extra utilities (airports database, airspeed conversions etc) constitute a designer's everyday toolkit.

Input parameters

An aircraft contains many parts and a huge list of engine performance parameters are there but Piano-X models use certain parameters only to determine the performance characteristics of aircraft engines and also to calculate their emission standards which are

1. Input Parameters
2. Geometry and Balance
3. Mass Estimation
4. Aerodynamic Characteristics
5. Engine Modeling
6. Ranges & Mission Performance
7. Takeoff & Landing Field Lengths
8. Parametric Studies & Numerical Optimisation
9. Flight Manoeuvres & Sequences
10. Environmental Emissions & Costs
11. Size of the aircraft
12. No of passenger on board
13. Distance of the journey.

Calculation

In the modeling software we had given various aircrafts input parameters and calculated the results, a sample calculation for a particular type of aircraft is given below, table 1 indicates the fuel consumption of Fokker F70 in its various leg and table 2 indicates the amount of various pollutant emission during its travel.

Loading plane: Fokker F70

Range Report {design range & standard payload}

{TOW 36741.kg./ OEW 22672.kg./ Fuel 6902.kg./ Payload 7167.kg.}

Range mode: max.SAR, step-up cruise

Climb schedule: 246.kcas/ Mach 0.709 above 33611.feet

Cruise at Mach = 0.678 {FL 350}

ICA 35000.feet, 391.ktas, 227.kcas, CL=0.49, 11191.newtons/eng=MCR-15%

FCA 35000.feet, 391.ktas, 227.kcas, CL=0.44, 10503.newtons/eng=MCR-20%

From the tables it is found that more than the permissible limit of pollutants were released to the atmosphere by operating a single aircraft and thus if we consider the total number of aircrafts operated by one particular company it amounts to considerable quantity of pollutant emissions.

Table 1: Indicating the amount of fuel burned at each stage of flight course

	Distance(miles)	Time(min)	Fuel burn(kg)
Climb	135	24	1158
Cruise	869	133	3323
Descent	85	16	113
Trip total	1090	173	4595
Block total	-	191	4917

Table 2: Indicating the emission of various gases at each course

Emissions	Taxi, t/o (kg)	Climb (kg)	Cruise (kg)	Descent (kg)	App, Taxi (kg)	Total (kg)
NO_x	1.5	15.9	24.2	0.2	0.7	42.4
HC	0.40	0.68	4.31	0.60	0.29	6.28
CO	2.7	2.3	17.9	4.4	1.8	29.1
CO_2	549	3660	10502	359	469	15538

From the outputs of the piano X software we understood that the emission of carbon di oxide from an aircraft starting from its taxing till to its landing is about in 8hrs 7min an Airbus A 300 releases 124.72 kilograms of CO_2. And while comparing to Airbus A 300 Boeing baseliner 747 releases about 237398 kilograms of CO_2 in 16hrs 2 min. another fighter aircraft called Fokker F 70 which releases 15538 kilograms of CO_2 in 3hrs 18 min.

Suggestions

The atmosphere is a complex dynamic natural gaseous system that is essential to support life on planet Earth. Stratospheric ozone depletion due to air pollution has long been recognized as a threat to human health as well as to the Earth's ecosystems. Airplane emissions are a critical contributor to the greenhouse effect.The effect of air pollution on human is hazardous and the global health impact from toxic pollutants such as heavy metals, pesticides and radionuclide, is greater than previously thought. Today, more than 100 million people are estimated to be at risk from toxic pollution at levels above international health standards. This is a public health issue as salient as tuberculosis, malaria, and HIV/ AIDS, and one that should receive considerable attention and resources. Thus its proved beyond doubt that airplanes due to their mass consumption of natural fuels release large quantum of pollutants in the higher levels of atmosphere which need to be controlled by various means such as implementing standard operating practices, engine modifications, usage of non polluting bio fuels, etc.

Suggestions and Conclusions

By using an emission calculating software (piano-X) we are calculating emission rates for about eight aircrafts whish has been commercially used in aviation industry. This piano-X software helps us to find the emission rates by giving the inputs of fuel consumption in various conditions like idle, take off run, cruise and etc. And this software tells about the angle of flaps, landing gear position, and engine speed at that altitude. There are about 14-15 segments for each aircraft that tells about all its flight conditions according to their altitude and their range. reference' tool between airframes and engines makers during cooperative studies.

The performance capabilities of Piano also proved to be perfectly matched to flight profile analysis focused on the environment. A number of major studies have used it to examine the global effects of aircraft fleet operations. Piano can easily calculate the spatial distribution of fuel flows and associated emissions of atmospheric pollutants (NOx, CO and hydrocarbons) along a flightpath, given the standard engine emission indices published for newly certificated engines. In our studies we had taken few types of aircrafts, calculated the input parameters which are required to be given to Piano-X and the basics of those parameters were found out. From the outputs of the piano X software we understood that the emission of carbon di oxide from an aircraft starting from its taxing till to its landing is about in 8hrs 7min an

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