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CO_2 Emission of Aircraft at Different Flight-level (Route: Jakarta-Surabaya)

Ratih Sekartadji[a,b], Ali Musyafa[c], Lalu M. Jaelani[d], Muh. Khamim Asy'ari[c], Ervina Ahyudanari[a,*]

[a]Civil Engineering Department, Faculty of Civil, Planning and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[b]Civil Engineering Department, Faculty of Civil and Planning Engineering, Institut Teknologi Adhi Tama Surabaya, Indonesia
[c]Physic Engineering Department, Faculty of Industrial Engineering, Institut Teknologi Teknologi Sepuluh Nopember, Surabaya, Indonesia
[d]Geomatics Engineering Department, Faculty of Civil, Planning and Geo Engineering, Institut Teknologi Teknologi Sepuluh Nopember, Surabaya, Indonesia
ervina@ce.its.ac.id

Emissions from aircraft became the subject of previous research since the 1960s. Aircraft emissions come from burn fuel from an aircraft engine, which contains elements that effect in global warming. Aircraft emissions during cruise occur because of the influence of temperature at the cruise level. The elements of carbon dioxide (CO_2) give the greatest impact on all components of the aircraft exhaust gas. The route Jakarta-Surabaya flight is the busiest route in the Indonesian airspace. This research uses the International Civil Aviation Organization (ICAO) emission carbon calculation method. Flight data is needed to determine the distance and type of aircraft. Those data are used to determine the amount of fuel consumption needed so that estimated emissions due to aircraft can be calculated. The result of the calculation is the number of aircraft emissions per day and the uncertainties of type A and B in the level of confidence 95%.

1. Introduction

The activities of flight have an impact on the environment. Combustion from aircraft fuel produces chemical products that have been emitted from the high-speed aircraft engine. This gas and particle flow processes chemically and dynamically then affects the initial composition and mixes with ambient air. Furthermore, the amount of ozone in the atmospheric layer will change if there are chemicals and anthropogenic that enters the atmospheric layer (Prather *et al.*, 1999). In recent times, increased aviation carbon emissions have become a serious concern (Xu et al., 2016).

ICAO (International Civil Aviation Organization) is an organization commission to stately identify regular consumption of emissions. Indonesia is one of the countries whose aviation industry is growing rapidly in the world. Soekarno-Hatta Airport was ranked 11th in the world for the number of passengers both departures and arrivals according to Airport Council International towards the end of 2014. Meanwhile, the Jakarta-Surabaya route became the world's 4th busiest route in October 2014, with 819 flights per week according to Centre of Aviation in 2015. Flight of the Jakarta-Surabaya route have increased more than 40% from 2012 to 2015 (Sekartadji et al., 2017). This high-frequency flights dominated by aircraft type Airbus 320 (A 320) and Boeing 738 (B 738). These two aircraft produced high emission of CO_2. The emission will react directly or process atmospherically to radiative forcing and cause climate change, such as rising temperatures of the earth's surface, rising sea levels and melting polar ice. Therefore, one of the causes of global warming is the result of emissions from aircraft exhaust gases (Lee *et al.*, 2009).

This paper is aimed to estimate the contribution of the flight traffic route Jakarta-Surabaya to the accumulation of emission, that will affect climate change. Both global warming and climate change are currently hot issues that have affected the growth of the physical, social, and economic environment. Continuous human activities that greatly affect the greenhouse gases in the earth's atmosphere (Miphokasap, 2017).

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2. Climate Change, Air Transport and Atmospheric Process

Climate change has defined by The Intergovernmental Panel on Climate Change (IPCC) as a continuous change to the climate due to not only natural processes but also due to human activities. The United Nations Framework Convention on Climate Change (UNFCCC) has a different view, climate change has changed the composition of the global atmosphere and is in addition to natural climatic processes.

UNFCCC argues that human activities directly and indirectly greatly affect climate change. Natural processes that occur on the earth increase with changes caused by human activities. The global warming trends recently are likely due to human activities. Most are the production of carbon dioxide and other greenhouse gases (Miphokasap, 2017).

IPCC and UNFCCC were extremely sure that a global warming caused by the increase of greenhouse gases. Greenhouse Gases (GHG) is a gas that absorbed by Earth and then emitted a part of it. Human activities of products CO_2 from combustion make the concentration of GHG in the atmosphere increases, the radiant energy that trapped will cause the atmosphere temperature high. The primary GHG in Earth's atmosphere is carbon dioxide, water vapor, methane, nitrous oxide, and ozone (Hindarto et al., 2018). CO_2 that causing greenhouse has become one of the most concerned environmental problems in the world (Jian *et al.*, 2019).

Aviation currently contributes about 3% of fossil fuel energy and has been forecast to grow at an average of 5% per year until 2027, and effects on air quality and human health globally. The aircraft emissions was estimated only for landing and take-off cycle (LTO), conventionally up to an elevation of 3,000 ft or approximately 1 km. This corresponds to a typical planetary boundary layer height, which pollutants mix rapidly. However, a recent study shows that cruise emissions have a significant effect on increasing global air pollution on ground elevation (Barrett et al., 2010).

According to David Lee the first emissions from aviation operations and the atmospheric processes will lead to changes in radiative forcing components and lead to climate change (Lee *et al.*, 2009). Currently, emissions due to flights that have occurred over the past few decades have accumulated in the atmosphere. Flights generally occur at altitudes between 9 and 13 kilometres. The flight level range is in between two layers of the earth's atmosphere: the upper troposphere and lower stratosphere. Emissions due to aircraft that occur will react directly to the earth's atmosphere. The CO_2 emitted by airplanes will increase its concentration in the atmosphere and last in the atmosphere for almost one hundred years. The results of the study of IPCC showed a 25% increase in atmospheric CO_2 concentrations over the past 200 years and caused tropospheric warming (Prather *et al.*, 1999). Report for the IPCC is that the concentration of CO_2 in the atmosphere is a direct cause of climate change. This is because CO_2 molecules can bind infrared radiation that is reflected by the earth into space. So that in the atmosphere there is an increase in CO_2 levels by 25-30% for 200 years and causes the troposphere to heat up and the stratosphere to cool (J.E.Penner *et al.*, 1999).

3. Traffic Patterns

As one of the contributions of Green House Gas (GHG), the air traffic patterns become one important component. Traffic pattern involves type of aircraft and distance of the route. The type and distance influence the emission load produced. This study explores the accumulation of GHG emissions at cruise level with an approach to demand growth. The estimated emission production for each aircraft for Jakarta-Surabaya Routes. The choice of this route is because this route is the busiest in Indonesia. The frequency of flights from Jakarta's Soekarno-Hatta International Airport to Juanda International Airport Surabaya was ranked 4th in the world at the end of October 2014 according Airport Council International (ACI) 2016.

In this study, the first step taken was to obtain traffic flow data that occurred on the Jakarta-Surabaya and Surabaya-Jakarta routes. The flight route from Jakarta's Soekarno-Hatta International Airport to Juanda International Airport Surabaya (origin-destination) and the opposite direction. The flight route data is needed to get the flight distance and type of aircraft used on this route. The flight distance and the type of aircraft are variable for fuel consumption and aircraft elevation. The flight distance is used to calculate the amount of fuel needed by the plane to take the route. While the aircraft type datas will be used to determine the flight level and performance of each aircraft. This data can be founded from the Aircraft Performance Database from Euro Control. Those variables can calculate CO_2 emissions of the plane. Emission calculations for each aircraft and flight level will be carried out by the International Civil Aviation Organization (ICAO) method.

The flight data for the Surabaya-Jakarta and Jakarta-Surabaya routes taken on September 12, 2018, with the type of aircraft and the frequency of each kind of it, can be seen in Table 1. There are six types of aircraft in the Jakarta-Surabaya route and five types of aircraft used in the Surabaya-Jakarta route. Each type of aircraft has its characteristics, one of which is the maximum flight level. Some aircraft types have the same maximum flight elevation.

Table 1: Type of Aircraft and Frequencies Flight Surabaya-Jakarta Route

Origin	Destination	Aircraft	Frequency	Origin	Destination	Aircraft	Frequency
Surabaya	Jakarta	A 320	25	Jakarta	Surabaya	A 320	22
Surabaya	Jakarta	A 333	1	Jakarta	Surabaya	A 333	1
Surabaya	Jakarta	B 733	1	Jakarta	Surabaya	B 733	3
Surabaya	Jakarta	B 735	2	Jakarta	Surabaya	B 738	19
Surabaya	Jakarta	B 738	23	Jakarta	Surabaya	B 739	10
Surabaya	Jakarta	B 739	8				

Figure 1 shows the performance of aircraft Airbus 320 (A 320). It describes the capability of the aircraft from take-off phase, climb phase, cruise phase, descent phase, and ends with landing phase. Every step has a maximum flight level of the plane. The A 320 has a maximum flight level at 390 FL (Flight Level) or 39.000 ft in the cruise phase. Flights of Jakarta-Surabaya and Surabaya-Jakarta use six types of aircraft, which have three different flight levels: flight level 37,000 ft (FL 370), 39,000 ft (FL 390) and 41,000 ft (FL 410). Flight frequency of each aircraft type and the flight frequency of each flight level are shown in Figure 2. It can also be understood that the most flight level used by the flight route Jakarta-Surabaya and Surabaya-Jakarta is FL 410 for 62 flights a day.

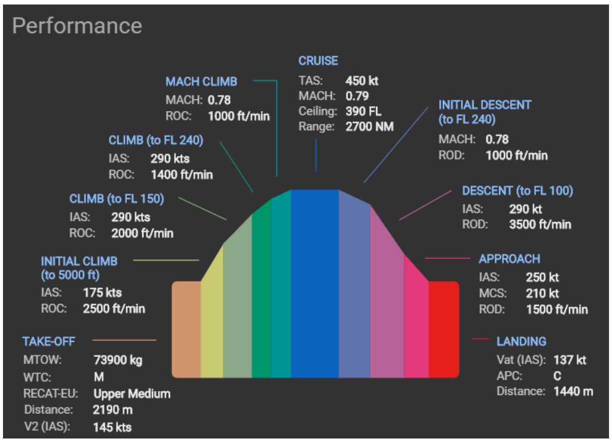

Figure 1: Aircraft Performance A 320 (eurocontrol, 2018)

4. Estimation of Emissions CO_2 Product

ICAO (International Civil Aviation Organization) issued a general methodology for estimating the number of carbon emissions (CO_2) generated by a passenger on a flight (ICAO, 2018). In the CO_2 calculation methodology using the ICAO Carbon Emissions Calculator, it is necessary to know the flight route in advance, namely the origin airport and destination airport. From this route, scheduled flights will appear that have been published, complete with the type of aircraft and the flight distance. Each of these aircraft will be mapped into one of 312 types of aircraft of the same type so that the fuel requirements for the route can be calculated. ICAO has collected data on traffic and flight operations. Then the existing data will be used to calculate the average fuel requirement for the flight. To get the amount of CO_2 that has been generated from the flight, the fuel requirement is multiplied by 3.16 for each flight from the two airports (ICAO, 2018).

$$CO_2 \text{ per pax} = 3.16 \times (\text{total fuel} \times \text{pax to freight factor}) / (\text{number of seat} \times \text{pax load factor}) \quad (1)$$

Where: Total fuel = the weight average of the fuel used for each equivalent aircraft type, Pax to freight factor = ratio calculated from ICAO statistical database on number of passengers and the tonnage of mail and freight, Number of Y-seats = total number of economy equivalent seats available on all flights serving the given city pair, Pax load factor = the ratio calculated from ICAO statistical database based on number of passengers transported and the number of seats available, 3.16 = constant representing the number of tonnes of CO_2 produced by burning a tonne of aviation fuel. To perform calculations with the ICAO carbon calculator, open the link https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx . ICAO's carbon calculator aims to find the total carbon emissions per passenger on a flight, but in the calculation process, the program shows the amount of fuel burn in a flight before calculating the emissions. So in this study, the value of the program taken is the fuel burn in a flight, not the end result (amount of carbon emission per airplane passenger).

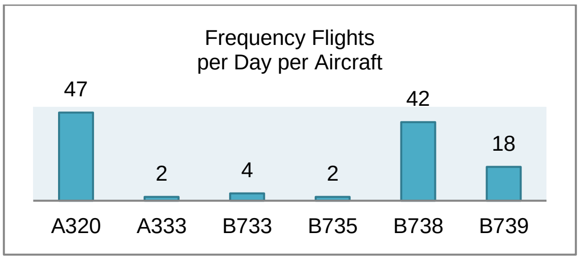

Figure 2: Flights Frequency per Day per Aircraft

Flight activity data in Figure 2 will be used to calculate the amount of CO_2 emissions due to flights from the Jakarta-Surabaya and Surabaya-Jakarta routes. The data is entered and will produce the distance between two airports, fuel burn consumption, and the amount of CO_2 emissions that occurs on the flight. For example, Surabaya-Jakarta route, using aircraft A 320. For city pair, Surabaya and Jakarta will obtain 690 km distance from GCD (Great Circle Distance).

Table 2: Emission CO_2 of Each Aircraft

Route	Aircraft	Frequency	Emissions CO2 / journey (kg- CO_2)	Cruise Emission (kg- CO_2)	Total Cruise Emission (kg-CO_2)
Surabaya – Jakarta	A 320	25	13,013	10,440	325,325
Surabaya – Jakarta	A 333	1	24,220	12,915	24,220
Surabaya – Jakarta	B 733	1	10,772	8,573	10,772
Surabaya – Jakarta	B 735	2	9,977	7,809	19,954
Surabaya – Jakarta	B 738	23	11,712	9,122	269,376
Surabaya – Jakarta	B 739	8	13,698	10,668	109,376
Jakarta – Surabaya	A 320	22	13,013	10,440	286,286
Jakarta – Surabaya	A 333	1	24,220	12,915	24,220
Jakarta – Surabaya	B 733	3	10,772	8,573	32,316
Jakarta – Surabaya	B 738	19	11,712	9,122	222,528
Jakarta – Surabaya	B 739	10	13,698	10,668	136,975

From the ICAO Fuel Consumption Formula, this route has fuel burn 4,127 kg. ICAO carbon calculator's output contains of distance of flight, the fuel consumption and CO_2 emission per journey. The amount of CO_2 emissions per trip of each type of aircraft will be obtained. Before this result will be multiplied by the frequency of flights, must reduce with CO_2 emissions in LTO phase (Chilongola, 2019). So, that occurs on that day the amount of CO_2 emissions per day that occurs due to flights on this route can be obtained for each flight. Then, the total CO_2 emissions at cruise phase can be seen in Table 2 above. Figure 3 shows estimation of total CO_2 emissions at different flight level according aircraft types that used in Surabaya-Jakarta and Jakarta-Surabaya Routes daily. The CO_2 emissions at FL 370 was the smallest caused the frequency of the aircraft was the fewest compared with the others.

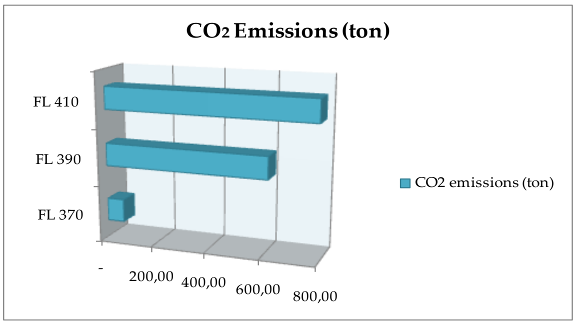

Figure 3: Estimation of Emission CO_2 at Different Flight Level Daily

5. Uncertainty of CO_2 Emissions Measurement

Uncertainty is the doubt that exists about the result of any measurement or calculation however there is a margin of doubt. There are two numbers to quantify an uncertainty, the width of the margin or interval and a confidence level. It is important to make good quality measurement and to understand the results (Bell, 1999).
The results of measurement or calculation contain of the estimation and the uncertainty. There are two types of uncertainty: type A and type B. Type A is the uncertainty when the data was taken from several repeating readings. The mean and estimated standard deviation will be calculated for the set (Musyafa, 2016).
The estimated standard uncertainty for A_1, A_2 and B also the combined uncertainty C will be calculated from (Musyafa, 2016):

$$UA_1 = \frac{\mu}{\sqrt{x}}, \quad UA_2 = \sqrt{\frac{SSR}{X-2}}, \quad UB = \frac{a}{\sqrt{3}}, \quad UC = \sqrt{UA_1^{\,2} + UA_2^{\,2} + UB^2} \tag{2}$$

The estimated calculation of the CO_2 emissions from aircraft for Jakarta-Surabaya and Surabaya-Jakarta routes were just approximation and estimation of measuring value. It contains uncertainty of the measurement and errors. Table 3 shows calculation of uncertainty of estimation CO_2 emissions from aircraft.

Table 3: Calculation of Standard Deviation for Emission CO_2 of Surabaya-Jakarta Route

Aircraft	CO_2 emissions	Frequency	FX	x	Deviation	Square Dev	Sq Dev Freq
A 320	13,013	47	611,611	12.71	0.30	0.09	4.34
A 333	24,22	2	48,44	12.71	11.51	132.5	265
B 733	10,772	4	43,088	12.71	-1.94	3.75	15.01
B 735	9,977	2	19,954	12.71	-2.73	7.46	14.93
B 738	11,712	42	491,904	12.71	-1	0.99	41.76
B 739	13,698	18	246,555	12.71	0.99	0.98	17.58
Total		115	1,461,552				358.62

The square deviation total is 358.62 and the calculation of the standard deviation is:
μ = 1,774 then, the Uncertainty type A_1 (UA_1) = $\frac{\mu}{\sqrt{x}} = \frac{1{,}774}{\sqrt{115}}$ = 0.165 tonnes
To calculate the uncertainty A_2 the data of flight should be breakdown according to time of flight. Jakarta-Surabaya and Surabaya-Jakarta flight takes place at 4 am to midnight every day. So, the total time flight per day were about 20 hours. The time will be divided by 5 group of time, as seen at Table 4.
The calculation of Sum Square Residual and Uncertainty Type A1 of the emission CO_2 per group time and the estimated uncertainty Type A_2 was found as:

$$V_{eff} = \frac{UC^4}{\frac{UA1^4}{V1} + \frac{UA2^4}{V2} + \frac{UA3^4}{V3}} \quad ; \quad U_{exp} = UC \times k \quad = 0.322 \tag{3}$$

The results of estimated CO_2 emissions range calculation with the uncertainty were ± 0.322 tonnes or ± 322 kg for route Jakarta-Surabaya per day. The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k=1.6779, providing a level of confidence of approximately 95 %.

Table 4: Calculation of Standard Deviation and Uncertainty Type A_1 of The Emission CO_2 of Each Aircraft per Group Time

Time	Total Emission per Aircraft							Standard Deviation	UA_1
	A 320 13,01	A 333 24,22	B 733 10,77	B 735 9,98	B 738 11,71	B 739 13,7	Average		
04.00-08.00	182	-	11	-	70	27	12.64	0.76	0.16
08.00-12.00	78	-	-	10	117	41	12.31	0.97	0.22
12.00-16.00	104	24	11	-	94	55	13.07	2.64	0.56
16.00-20.00	143	24	22	-	129	82	12.9	2.29	0.41
20.00-24.00	104	-	-	10	82	41	12.48	0.98	0.22

6. Conclusions

The results of this study that the CO_2 emissions from aircraft on Surabaya-Jakarta route daily at FL 370 is 49,909 kg-CO_2, at FL 390 is 490,657 kg-CO_2, and at FL 410 is 600,986 kg-CO_2 in one way per day.

The aviation for commercial flights in Indonesia started in the 1960s, so the accumulation of CO_2 emissions until nowadays will be burdened the air of Indonesia air space. The measurement and calculation of CO_2 emissions from aviation contain the estimated and uncertainties. In this study, the uncertainty was about ±0,322 tonnes. It means the results of the calculation lies between the CO_2 emissions x – 0.322 tonnes and the CO_2 emissions x + 0.322 tonnes, each flight for route: Jakarta-Surabaya or Surabaya-Jakarta at one day.
Aviation has a vital role in affecting climate change. One of the Greenhouse Gas is CO_2, which is produced by aircraft. The effect of aviation emissions is not only on-air quality around airports, but also on greenhouse gases in the atmosphere. So, limitation aircraft engine emissions must be done. One of them is aircraft engines must meet mandatory certification requirements established by ICAO's Committee on Aviation Environmental Protection. Almost all governments around the world are concerned about air pollution emissions. One possible way to reduce CO_2 emissions is to decrease the fuel consumption of commercial airplanes by improving engines, reducing their weight, or changing the aircraft configuration (Sanchez-carmona and Cuerno-rejado, 2021). The Kyoto Protocol, an international treaty that commits state parties to reduce greenhouse gas emissions. It implemented the objective of the United Nations Framework Convention on Climate Change (UNFCCC) to fight global warming by reducing greenhouse gas concentrations in the atmosphere. Any effort to reduce or limit the accumulation of carbon dioxide is worth to be explored. This research attempts to identify one of many causes of climate changes. This research hopefully drives any idea related to emission produced from aviation industry.

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