Aviation and Aircraft Engine Emissions at Juanda International Airport

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Abstract. Aviation industry growth has increased continuously over the years. Air transport demand continues to increase due to the reliability, time saving and efficiency. Aviation industry has impact on environment as a source of pollutant emissions. The estimation of pollutant emissions at taxi/idle, approach, climb out and take off of Carbon dioxide (CO₂) and Nitrogen dioxide (NOₓ) at Juanda International Airport Indonesia was calculated using Advanced ICAO landing and take-off (LTO) cycle method. The CO₂ emissions were 23.02 tons, 10.52 tons, 17.27 tons and 6.73 tons during taxi/idle, approach, climb out, take off respectively while NOₓ emissions were 0.03 tons, 0.03 tons, 0.12 tons and 0.06 tons for taxi/idle, approach, climb out and take-off respectively. Based on the results of the discussion it can be concluded that pollutant emissions and fuel consumption are positively related to amount of flight operation. The aircraft emissions affect the air quality around the vicinity of airport and lead to climate change.

1. Introduction
The Aviation industry growth has increased continuously over the years. Air transport demand continues to increase due to the reliability, time saving and efficiency. Indonesia as Asean country has been the one of fastest growing economic country in the world. According to the Asean aviation markets will be duplicated in the coming years [1]. Global aviation increasing annual at the rate of 5% in recent years and forecasted to increase [2,3]. Aviation industry has impact on environment as a sources of pollutant emissions.

The fuel burned by aircraft engines emits pollutants such carbon dioxide (CO₂), carbon monoxide (CO), water vapors (H₂O), hydrocarbons (HC) nitrous oxide (NOₓ), Sulphur dioxide and particle matter which are the key to the environmental impact on the atmosphere. Carbon dioxide and water vapour emitted when complete fuel combustion occurs. Carbon dioxide is the greenhouse gases which has a great effect on earth climate warming [4]. In is founded that in aviation fuel the ratio of carbon to hydrogen lies within the range of 3148-3173g kg Fuel-1 [5]. [6] proposed international aviation carbon dioxide (CO₂) emissions will rise by more than 110% between 2005 and 2025. Global aviation's CO₂ emissions denoted at 22%coming from European aviation [7]. Nitrogen oxides are produced when air passes through high temperature or high-pressure combustion and nitrogen and oxygen present in the air combine to form NOx. A five tons heavier aircraft on cruising at a 2000 ft higher altitude yields in 11.2% (12.3%) more or 2.7% (2.4%) less NOx emissions (NOx intensity), respectively [8].

The emitted pollutant from aircraft engines have environmental impact on air quality in the vicinity of airport and climate changes. The health problems caused by emitted pollutants are such as premature
mortality, lung function impairment, eye and respiratory tract infections [9]. Current aircraft operations at cruise altitude (about 80%) and the landing and takeoff cycle (LTO) (about 20%) contributed approximately 10,000 premature mortalities per year [10]. Aviation impacts on global climate changes due to emissions of greenhouse gases such as CO$_2$ and water vapor impact include higher average temperatures, ocean warming, ocean acidification, sea level rise, changes in precipitation, decreasing sea ice, and changes in physical and biological systems which lead to effect on airport and aircraft activities such as aircraft performance, heat damage to infrastructure, delays, cancellations, flooding of airport and access route, crossing wind changes affecting airport capacity and network disruption. The wealth loss is also the damage caused by climate changes [11].

There are several studies dealing on emission of pollutant from aircraft engine exhaust due to the significant growth of air traffic around the world. Other applied an advanced approach using a landing and take-off cycle (LTO) assessing aircraft emissions and pollutant trends at Nikola Tesla International Airport in Belgrade, Serbia, found that the number of LTO cycle increased by 54% which lead the increase in local air pollution, as presented on Fig. 1 [12], as well as other researcher was using three models (EDMS, LASPORT and ALAQS-AV) to calculate Zurich Airport emissions, the outputs of the comparison showed that all the models have similar global outcomes for aircraft and stationary source emissions [13]. In another study, it presents a detailed review of the global civil aviation industry for reducing CO$_2$ emissions from aircraft [14].

In order to know the extent to which action is required, it is necessary to determine the level of air pollution near the airport. Presidential Regulation Republic of Indonesia No. 61 of 2011, which aims to reduce the levels of greenhouse gases, only by 26% -46% in all areas, but more focus placed on emission produced by land transportation while by air transportation is still lacking. This paper deal with estimating the pollutant emissions of carbon dioxide (CO$_2$) and Nitrogen oxide (NO$_x$) at LTO cycles at a Juanda International Airport during peak hour.

2. Methods

2.1 Flight operation modes

Aircraft operation can be branched into two parts landing and take-off cycle (LTO cycle) and cruise part [15]. Other researchers defined the LTO cycle as all the operations that occur when aircraft is below 3000 ft above field elevation (equivalent to 914 m) over a specific range of certifiable operating conditions [16]. The LTO cycle has four operation mode. It is starting by aircraft landing below 3000 ft
and then processing tax in towards airport terminal, after loading and unloading aircraft start to tax out and prepare for take-off. Then entering climb out phase until to the 3000 ft above field elevation. The schematic diagram off LTO cycle operation is shown on Fig. 1. The time spend on each mode is known as Time-in-mode (TIM) and is proportional to the amount of emissions during stage of the LTO cycle. Thrust setting and time in mode on each operation as shown on Table 1. This study will use time in mode provided by ICAO as reference because ICAO as a key holder and international accepted standard in aviation industry. However, duration of approach and take off depend on local meteorological conduction while taxing time depend on the operating procedure and the size of the airport. All activities of the aircraft occur above 1000m categorized as cruise part.

| Table 1. Time in mode on LTO cycle ICAO (2011) [17] |
|----------------|-----------------|----------------|
| Operation Mode | Thrust Setting (%) | Time in Mode (min) |
| Taxi/idle      | 100             | 26             |
| Approach       | 30              | 4              |
| Climb out      | 85              | 2.2            |
| Take off       | 100             | 0.7            |

2.2 Aircraft Emission calculation

To calculate landing and take-off pollutant of emission at Juanda International Airport International Civil Aviation Organization (ICAO) methodology was used. This methodology is common and have been used in most airport all over the world due to ICAO is the key and reputable authority on aviation industry. Advanced approached was used to calculate the emission of Nitrogen dioxide (NOx) as on the following equation (1) [17].

\[ E_{IJ} = \sum (TIM_{jk} \times 60) \times (FF_{jk} / 1000) \times E_{jk} \times N_E \]

Where;
- TIM\(_{jk}\): time-in-mode k for the aircraft type j. in minutes (min)
- FF\(_{jk}\): the fuel flow for mode k in kilograms of fuel per second (kg/s), for each engine used on the aircraft type j.
- E\(_{jk}\): the emission index for pollutant i given in grams of pollutant per kilogram of fuel (g/kg fuel) in mode k (during take-off, climb, idle, and approach) for each engine used on the aircraft type j,
- NE\(_j\): the number of engines used on the aircraft type j.

ICAO does not set standard for CO\(_2\). hence using emission indices provided by [18] as 3155 g.kg\(^{-1}\). Since the emission indices based on fuel composition, the following expression can be used to calculate emission of carbon dioxide as below.

\[ E_j = \sum (TIM_j \times 60) \times ER_j \times NE_j \]

Where;
- TIM\(_j\): time-in-mode in minutes (min) for the aircraft type j,
- ER\(_j\): the emission rate of total CO\(_2\) emitted per second per the mode (g/s); for aircraft j:
- \( ER_j = 3155 \times FF_j \),
- FF\(_j\): the fuel consumption per mode for each engine on the aircraft type j (kg/s).

2.3 Aircraft movement and Engine

Aircraft usual fly under two types of flight rules namely, Instrument flight rules (IFR), aircraft flying under IFR are typically assigned altitudes of odd/even thousand feet (example 10000 ft, 20000 ft, etc.) Above Mean Sea Level (AMSL) and Visual flight rules (VFR), aircraft flying using VFR assigned odd/even thousands of feet plus 500 ft. of altitude. About 60% to 80% of emissions coming from IFR
flights while VFR flights represent less than 5% of fuel consumption and pollutant emissions caused by air traffic [17, 18].

Aircraft engine are divided into three different category turbofan (jet), turboprop and piston engine. According to previous result, the turboprop and turbofan engines are powered by aviation kerosene also known as jet fuel while piston engines are fueled by aviation gasoline also namely as avigas [17]. Turbofan engines, the main reference is made to bypass ratio which is defined as the ratio of the mass airflow through the fan to the mass airflow through the core of the engine or the turbojet portion In civil aviation for a good fuel efficiency and low noise, high-bypass ratios are preferred [19].

Emission Index is defined as the mass of the pollutant emitted per unit mass of fuel burned for a specified engine. The emission indices depend on conditions and measurements procedure during aircraft engine certifications. Emission indices vary according to type of an engine mounted on an aircraft, life expectancy (age) of aircraft and metrological conditions [20]. This research used flight data from www.flightradar24.com to obtained schedule movement at Juanda International which contain aircraft types, airline, date of operation, origin and destination. On peak hour on 21/09/2018. Official aircraft engine manufactures were used to obtain typical engine combination mounted on the different types of aircraft. The ICAO Emission indices databank 2018 was used for fuel flow factor and emission indices of each engine. This paper assesses only turbofan engine.

3. Results and Discussions
The fuel consumptions during peak hour at Juanda international Airport were estimated around 7307 kg, 3338kg, 5482kg and 2135kg for idle/taxi, approach, climb out and take off respectively. The fuel consumption is higher during taxi/idle due the time aircraft spend during taxi in and taxi out. Results shown on Fig. 2 to Fig. 6 and Table 2 and Table 3.

Figure 2 shows the types of aircraft at Juanda International airport during peak hour. Boeing 737-800 (B738) contribute 33% of all aircraft movements followed by Airbus 320-214 (A320) which made up 24% of all movements. The pollutant emission of carbon dioxide CO₂ during taxi/idle was 40% of the total amount of LTO cycle, highest during taxi/idle because the emission of carbon dioxide depends solely on the amount of fuel consumption and during taxi/idle the amount of fuel consumption was high. The distribution of amount of carbon dioxide emission during tax//idle/ approach. Climb out and take off shown on Fig. 3. As pollutant emissions are positively correlated with the fuel consumption [21].

Figure 4 depicts the Nitrogen dioxide emission which is 48% at climb out and 25% during take-off. The NOx emissions are high when the power setting and temperature increase. Hence during climb out and take off the emissions were high. The same results shown by others, where taxi/idle, approach, climb out and take-off was 49%, 13%,13% and 25% respectively [22].

Boeing 737-800 (B738) contribute maximum amount of 33% while B733 minimum at 4% of total CO₂ at LTO cycle. This is because B738 is the most frequently operated during peak hour as seen on Figure 5. The research results give a picture on how much emission has been loaded into the air from aircraft movement at Juanda International airport.

| Mode     | Fuel Consumption (kg) |
|----------|-----------------------|
| Taxi/Idle| 7307                  |
| Approach | 3338                  |
| Climb out| 5482                  |
| Takeoff  | 2135                  |
| TOTAL    | 18263                 |
Table 3. Pollutant emission at Juanda International airport.

| Mode         | CO₂ Emission (tons) | NOₓ Emission(tons) |
|--------------|---------------------|--------------------|
| Taxi/Idle    | 23.02               | 0.03354            |
| Approach     | 10.52               | 0.03448            |
| Climb out    | 17.27               | 0.12248            |
| Takeoff      | 6.73                | 0.06209            |
| TOTAL        | 57.53               | 0.25260            |

Figure 2. Aircraft movement distributions.

Figure 3. CO₂ emissions distribution.

Figure 4. NOₓ emissions distribution.

Figure 5. CO₂ emissions by aircraft type.

Figure 6. Total fuel consumptions during peak hour.
4. Conclusion
This paper estimates the amount of fuel consumption and pollutant emission of CO₂ and NOₓ during LTO cycle by using ICAO advanced approach methodology. The estimation of total fuel consumption during taxi/idle, approach, climb out and takeoff was 7307 kg, 3338 kg, 5482 kg and 2135 kg respectively. The high amount of fuel consumption was during taxi/idle therefore the time spent in each mode is positively correlated to amount of fuel consumptions. The CO₂ emissions were 23.02 tons, 10.52 tons, 17.27 tons and 6.73 tons during taxi/idle, approach, climb out, take off respectively while NOx emissions were 0.03354 tons, 0.03448 tons, 0.12248 tons and 0.06209 tons for taxi/idle, approach, climb out and take off respectively. The aircraft emissions affect the airport air quality that may lead to environmental climate changes.

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