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# Modeling of aircraft pollutant emissions of LTO cycles around Soekarno Hatta international airport

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## ABSTRACT

Assessment of pollutant emissions (CO, HC and $NO_x$) and fuel consumption of aircraft LTO cycles at Soekarno Hatta International Airport is carried out for the first time. We stressed, by aircraft type, the large aircraft which represent the greatest contribution of pollutant emissions in and around this airport. Analysis is performed to precise their magnitude in relationship with fuel consumption. Distribution of aircraft pollutants for different operational modes (taxiing and takeoffs) is provided and comparisons are performed. Their dispersion and impact is also confirmed. To improve environmental impact of aircraft, specific guidance relevant to air navigation functions is needed. Air traffic authorities should update the existing guidance, and Indonesian government should extend a revision of the existing environmental policy. Airport operators, governmental environmental committees, airlines, air traffic managers and aircraft manufacturers should be actively engaged to assess the potential benefits of the possible solutions reducing emission impacts on communities living around this airport. Both government and aircraft operators should address actions toward greenhouse gas emission reduction from aircraft and fuel saving. Sustainability is a key issue for aviation which is united in its commitment to develop global solutions for the sustainable future of this international airport. 

## KEYWORDS

Pollutants;
Airport;
Aircraft operations;
Main engines;
Environment;
Sustainability.

## INTRODUCTION

Air transportation growth has increased continuously over the years. However, the growth has not been uniform and varies from country to country. The general increase in air transport activity has been accompanied by a rise in the amount of energy used to provide air transportation services. Along with the increase in air transport activity and energy consumption increased environmental impacts are assumed[17]. Traditionally, environmental impact of atmospheric emissions from aircraft has been addressed in two separate ways. On the one hand, air quality impacts from aviation have been considered by regulators, airports and aircraft manufacturers, focusing mainly on the emissions from aircraft occurring during the landing and takeoff phases (LTO cycle) of aircraft operations (local pollutant emissions). On the other hand, studies on the environmental impact of aircraft emissions occurring in other flight phases such as climb and cruise (non-LTO cycle) have focused mainly on their influence on climate change, stratospheric ozone and UV-radiation (global/regional pollutant emissions). The environmental impact of air traffic is often mainly associated with noise nuisance, smoke and gaseous emissions of carbon monoxide (CO), unburned hydrocarbons (UHC), including methane and nitrogen oxides ($NO_x$ - include nitrogen oxide and nitrogen dioxide), sulphur oxides ($SO_2$) in the vicinity of airports. Particles (such as particulate matter $PM_{2.5}$ and $PM_{10}$) present the most serious adverse health impacts from aircraft pollutant emissions. These have been controlled by implementation of standards and certification of aircraft engines. For this purpose the International Civil Aviation Organization (ICAO) has defined reference emissions LTO cycle, with specific thrust settings and so-called Time in Modes for each operating mode, which reflects all aircraft operations in the boundary layer below the so-called inversion height (usually at about 1 km)[11,12,18]. Over the last decade, the growth of commercial air traffic has led to an increased contribution to the local inventory of aircraft pollutant emissions from the operations associated with airports. Aircraft pollutant emissions have been of concern since the beginning of commercial aviation. The continuing growth in air traffic and increasing public awareness have made environmental considerations one of the most critical aspects of commercial aviation. This means that pollutant emissions from aviation activity are expected to grow and increase by factors 1.6 to 10, depending on the fuel use scenario[1,5,14].

Conscious of this problem, engine manufacturers have developed low-emission combustors, and made them available as options. These combustors have been adopted by the airlines operating in European airports with strict pollutant emissions controls, in Sweden and Switzerland, for example[1,2]. Pollutant emissions from aircraft originate from fuel burned in aircraft engines. Aircraft jet engines produce $CO_2$, $H_2O$, $NO_x$, CO, $SO_x$, unburned or partially combusted hydrocarbons also known as VOC, particulates and other trace compounds. Over the past several years, the pollutant emission indices have declined steadily. However, considerably more progress has been made with HC and CO than $NO_x$[5].

Aircraft engines have two quite different requirements. The first is for very high combustion efficiency at low power, because of the large amounts of fuel burned during taxiing and ground maneuvering. The primary problem here is the reduction of UHC. The main concern of the second requirement mentioned above is $NO_x$ at takeoff power, climb and cruise. The ICAO sets standards on a worldwide basis, for both takeoff and landing cycles and also for cruise at high altitude; the first is concerned with air quality in the vicinity of airports and the second with ozone depletion in the upper atmosphere. It has been shown that for a modern twin-engine transport operating over an 800 km range approximately 25% of the emissions are produced during the takeoff/landing cycle, with the remainder during climb/cruise/descent; approximately 86% of the total emissions are $NO_x$[16]. Current emission regulations have focused on local air quality in the vicinity of airports. ICAO has set an environmental goal to limit and reduce the effects of aircraft pollutant emissions on local air quality from aircraft operations[11].

Operations of aircraft are usually divided into two main parts[4]:

- The LTO cycle defined by ICAO (1993) includes all activities near the airport that take place below the altitude of 3000 ft (914 m). This therefore includes taxi-in and out, takeoff, climb-out and approach-landing.
- Cruise is defined as all activities that take place at altitude above 3000 ft (914 m). No upper limit altitude is given. Cruise includes climb from the end of climb-out in the LTO cycle to the cruise altitude, cruise, and descent from cruise altitudes to the start of LTO operations of landing.

Idle and takeoff is two extreme points, each with differing demands, relative to the nominal cruise operation point. Cruise is most commonly achieved in the middle and upper troposphere, but the emissions at cruise are not indicative of emissions near airports[9]. Method for measurement, prediction and assessment of environmental problems such as aircraft pollutant emissions have been carried out. The use of certain methods will require justification and reliability that must be demonstrated and proven. Various methods have been adopted for the assessment of aircraft pollutant emissions. The use of different and separate methodologies causes a variation in results and there is some lack of information. This is because the gaps or differences in data availability, accuracy data input, and incertainties in knowledge on the influence of engine ageing, the operational aircraft configuration, and atmospheric conditions on the pollutant emissions and their dispersions[14,15,20]. Studies estimating present and future aircraft emissions have been performed[3]. Present a global three-dimensional dynamic-chemical model to estimate present and future subsonic and supersonic aircraft $NO_x$ emissions on ozone[7]. Performed a study investigating the impact of air-traffic-induced $NO_x$ and water vapor emissions on the chemical composition of the global troposphere and stratosphere for 1991 and a future scenario for 2015[15]. Present a study on the future development of air traffic and the expected changes and improvements in specific fuel consumption and air pollutant emissions for 2010 and 2020[21]. Give long term scenarios for aviation through the year 2100.

Assessments of the impact of the airport related emissions on the local scales require an inventory that accurately reflects real-world emissions. The FAA's Emissions and Dispersion Modeling System (EDMS)[1], performs emissions inventories for individual airports based on its internal database and user data entry. Nearly two-thirds of EDMS's aircraft engine data originate from the ICAO databank. The user inputs the aircraft fleet present at an airport and the annual number of LTO cycles for each aircraft. Additionally, the user can specify each aircraft's takeoff weight, approach glide slope angle and the taxi and queue time, which determine the time in mode (TIM) values[8]. In order to provide reliable information on the impacts of aircraft pollutant emissions, this report assessing aircraft pollutant emissions deals with estimating aircraft in the LTO emissions (CO, $NO_x$ and HC) at Soekarno Hatta International Airport which is the biggest airport in Indonesia. The airport is located about 20 km west of Jakarta as the main airport serving the greater Jakarta area on the island of Java, Indonesia. The land area of the airport is 18 $km^2$. It has two independent parallel runways separated 2,400 m connected by two cross taxiways. The first runway was built in 1984, which also can meet the needs for takeoff of the B747-400. The second runway was built in 1992, which can meet the needs for takeoff of the B747-400. In order to meet the needs of 18 million passengers per annum, the terminal 2 airport has been constructed in that year. The required computer tool for assessing emissions at Soekarno Hatta International airports is the EDMS which performs emissions inventories accurately. The EDMS is used for estimating of aircraft LTO emissions at airports related emissions on local scales. The calculation of pollutant emissions is based on flight data recorded by the Airports Authority (PT. Angkasa Pura 2)[2]. The flight data include the type and number of aircraft, which depend on day-time and date.

## EDMS DESCRIPTION

Since 1998, the FAA's EDMS (Figure 1) has been the required model for assessing the air quality impacts and for air quality analyses of airport emission sources. Such an analysis may include an emissions inventory and/or a dispersion analysis for both aviation and non-aviation sources at the airport. The FAA considers aviation sources to include aircraft, auxiliary power units (APU) and ground support equipment (GSE). EDMS also offers the capability to model other airport emission sources that are not aviation-specific, such as power plants, fuel storage tanks and ground access vehicles. EDMS is a multiple emissions source model that calculates total airport emissions that vary both in space and time. The four dimensional approach allows for airport emissions to be dispersed for compliance demonstrations with local and national ambient air quality standards[13]. The latest available model version is EDMS 5.1.3, and includes significant enhancements such as: replication of real aircraft movements, estimation of emissions of speciated TOG (including known hazardous air pollutants) and $PM_{2.5}$ for all airport emission sources and $CO_2$ emissions from aircraft activities within the LTO cycle; interface to MOBILE version 6.2; databases and methodology for NONROAD source emissions and the latest versions of AERMET, AERMOD and AERMAP. EDMS has also been configured to provide digital outputs for enhanced data analysis and tabulation Aircraft fleet data have been harmonized with INM, and a common dynamic flight performance module exists in both tools as well, that accounts for aircraft weight and meteorological conditions[6].

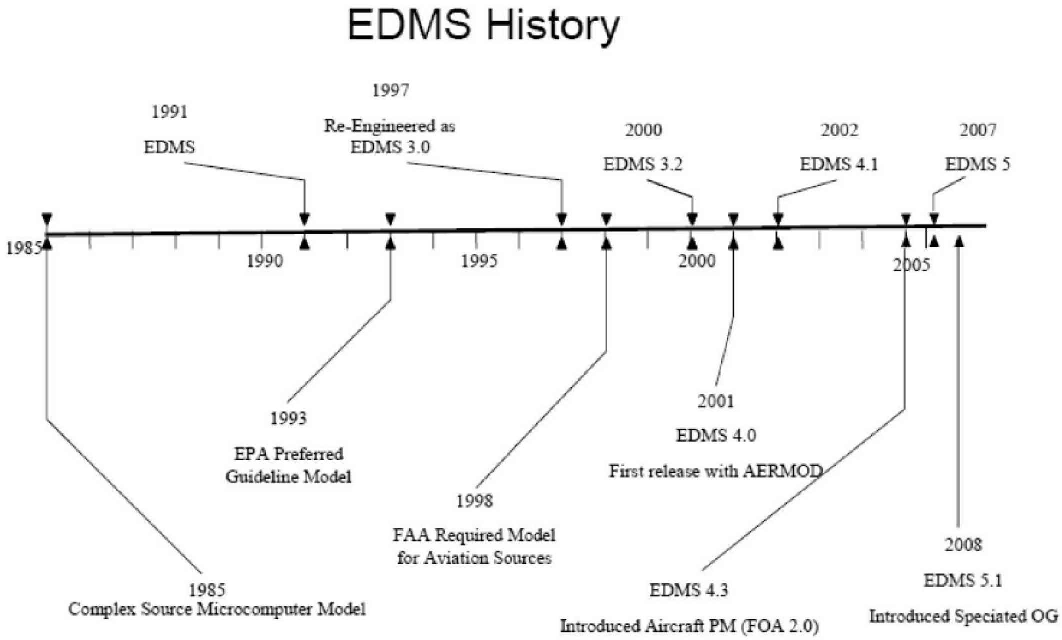


**Figure 1 : History of EDMS.**

## Emissions Inventories

An emissions inventory is a summary of the total pollutants generated by all active sources in the study. Using EDMS to perform an emissions inventory requires the user to identify the emission sources, the annual activity for each of these sources and, in the case of user-defined sources, the emission factors. EDMS then calculates the total annual pollutant emissions for each of the identified sources and presents it in both a summarized report and a detailed report[6]. EDMS can be used to create an emissions inventory for any individual airport emission source or combination of emission sources. To create an aircraft emissions inventory, the user inputs the aircraft fleet present at an airport and the number of LTO cycles for each aircraft within the timeline of the desired study period.

The user can specify each aircraft's taxi and queue time, as well as the takeoff weight and approach glide slope angle, which are used in conjunction with meteorological data to determine the aircraft's trajectory. The aircraft performance calculations originate from methodology presented in the Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) 18455 and account for aircraft-engine specific performance. Similar to aircraft, the user has the ability to define and include adjunct APU and GSE activity, roadway traffic, parking lot throughput, and stationary source and training fire operations. EDMS includes emission factors for the various airport sources. For example, it incorporates all aircraft engine emissions data contained in the most recent version of the ICAO Engine Exhaust Emissions Data Bank, representing over two-thirds of EDMS's aircraft engine emissions data. The remaining third of EDMS's aircraft engine emission data originate from U.S. military reports, shared manufacturer data, and U.S. Environmental Protection Agency (USEPA) documents. Since January 2007, EDMS has utilized ICAO's refined First Order Approximation version 3.0 (FOA3) for aircraft particulate matter (PM) emissions. GSE emissions are derived from emission factors from the latest version of USEPA's NONROAD model. EDMS also includes USEPA's on-road models: PART5, MOBILE5a, MOBILE5b and MOBILE6.2. The dispersion-modeling generates input for the EPA-developed dispersion model, AERMOD[6].

## Dispersion analyses

For dispersion analyses, EDMS generates input files to be processed by USEPA's AERMOD, which has been bundled with EDMS since May 2001. Currently, EDMS5.1.3 uses AERMOD build 04300 which became USEPA's promulgated, preferred air dispersion model on December 9th, 2005. The manner in which AERMOD is applied by EDMS is based on guidance from the American Meteorological Society/USEPA Regulatory Model Improvement Committee (AERMIC), which is responsible for developing AERMOD and introducing state-of-the-art modeling concepts into USEPA local-scale air quality models.

AERMOD is a steady state plume model, but has many state of the art improvements. It has better characterization of the planetary boundary layer (PBL) and allows dispersion to be accomplished using continuous functions rather than with discrete stability classes that do not change with height. Instead of a Gaussian distribution for both the horizontal and vertical directions, AERMOD uses a bi-Gaussian probability density function to characterize the dispersion in the vertical direction. Additionally, AERMOD incorporates a new method to model airflow and dispersion in complex terrain[6,13].

AERMOD can be run from within EDMS, however the user may choose to run AERMOD external to EDMS with the generated input files. Because AERMOD requires both surface and upper air meteorological data, AERMET is also bundled with EDMS. AERMET is AERMOD's meteorological preprocessor which transforms many different formats of "raw" weather data into an "AERMOD-ready" format. Similar to AERMOD, AERMET can be run either internally or externally to EDMS. EDMS also includes an interface to AERMAP, the terrain processor for AERMOD. Once the dispersion analysis is initiated within EDMS, the execution and control of AERMET, AERMAP and AERMOD is entirely transparent to the user[6].

The options for weather are Use Annual Averages and Use Hourly Meteorological Data. Regardless of that choice, the user can also set the mixing height to anything from 1,000 to 10,000 feet. The mixing height provides a vertical cutoff for EDMS's modeling of aircraft emissions. Hourly meteorological data must be processed through AERMET. Hourly weather data is required for dispersion.

The pollutants currently included in EDMS for dispersion analysis are CO, THC, NMHC, VOC, TOG, $NO_x$, $SO_x$, $PM_{2.5}$ and $PM_{10}$.

The dispersion modeling calculation in EDMS is to assess the air pollutant concentrations at/or near the airport resulting from identified emissions sources. These pollutant concentrations are calculated to determine whether emissions from the site result in unacceptably high air pollution levels downwind by comparison with relevant air quality standards. To perform dispersion modeling, EDMS requires the coordinates (in meters or feet relative to the user-specified origin) of each emissions source, the specification of an emissions rate (derived from emission factors) and its variation through time. For some sources, the release height, temperature and gas velocity are also required. The identification of spatial points in the coordinate system for concentration estimation (receptors), and the availability of weather data for individual hours are also required.

The basic Gaussian equation, a mathematical approximation that simulates the steady state dispersion of pollutants from a continuous point source is given below[6]:

$$C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u} exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\left\{exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

where:

C = point concentration at receptor, in $\mu g/m^3$

(x, y, z) = ground level coordinates of the receptor relative to the source and wind direction, in meters

H = effective release height of emissions, in meters (m)

Q = mass flow of a given pollutant from a source located at the origin, in $\mu g/s$

u = wind speed, in m/s

$\sigma_y$ = standard deviation of plume concentration distribution in y plane, in m

$\sigma_z$ = standard deviation of plume concentration distribution in z plane, in m

The results of the AERMOD dispersion calculations are the concentrations, given in micrograms per cubic meter ($\mu g/m^3$), at receptors for each hour.

## EDMS sources and pollutants

The current version EDMS5.1.3 quantifies total airport emissions from all sources within airport environs. This includes aircraft main thrust engines, APUs, GSE, mobile surface transportation sources on roadways and parking facilities, boilers, fuel storage tanks, emergency generators, and training fires. The pollutants quantified are $NO_x$, CO, VOC, NMHC, total organic gases (TOG), $SO_x$, $PM_{10}$, $PM_{2.5}$, and up to 400 individual speciated hydrocarbons including up to 44 known hazardous air pollutants (HAPs) across all airport emission sources. Speciated hydrocarbon profiles for all airport emission sources were obtained from the latest version of the USEPA's SPECIATE database, with the exception of turbofan, turbojet, and turboprop aircraft engines. In addition, fuel burn and $CO_2$ emissions are quantified for aircraft engines only.

## Soekarno-Hatta airport and aircraft activities

Soekarno-Hatta was ranked 16th in 2010 amongst the world's busiest airports by passenger traffic (5th busiest in Asia) and has surpassed Singapore Changi Airport. Growth of passenger traffic was more than 15 percent a year by mostly domestic passenger. The airport is located about 20 km west of Jakarta as the main airport serving the greater Jakarta area on the island of Java, Indonesia. The land area of the airport is 18 km². It has two independent parallel runways separated 2,400 m connected by two cross taxiways. The first runway was built in 1984, which also can meet the needs for takeoff of the B747-400. The second runway was built in 1992, which can meet the needs for takeoff of the B747-400. In order to meet the needs of 18 million passengers per annum, the terminal 2 airport has been constructed in that year. There are a lot of residential, industrial, schools and hospitals located around the Airport. The aircraft noise will produce a influence on these sensitive receptors. In order to assess the influence and to put forward an environmental protection, the assessment must be taken into account. There are two runways, more than ten air routings and several types of aircraft in Soekarno Hatta International Airport, such as a series of Boeings, Airbus and McDonnell Douglas. So the noise assessment of the Soekarno Hatta International Airport is complicated.

### (a) Flight tracks/procedures

Flight tracks which describe the flight route corridors that lead to and from Soekarno Hatta International Airport were developed. The flight tracks are based on airport information provided by Jeppesen and Aeronautical Information Publication (AIP). The tracks were developed to reflect the common patterns and to account flight track dispersions around the airport.

**Figure 2 : The layout and surroundings of Soekarno Hatta international airport.**

Flight procedures Soekarno Hatta airport - Jakarta is described below:

1. Arrival Procedures (Arrival Procedure)
   a. Landing Runway 25L: ILS Runway 25L VOR Approach Capital, NDB 258CL 248° direction, straight distance of 9.4 NM.
   b. Landing Runway 07R: ILS Runway 07R VOR Approach CKG, NDB 282GR 68° direction, straight distance of 9.2 NM.
   c. Landing Runway 25R: ILS Runway 25R VOR Approach Capital, NDB 242CR 248° direction, straight distance of 6 NM.
   d. Landing Runway 07L: ILS Runway 07L VOR Approach CKG, 324GL NDB 068° direction, straight distance of 6.9 NM.
2. Departure Procedures (Departure Procedure)
   a. PURWAKARTA TWO CHARLIE (W45, G461)
   Takeoff the Runway 07R and 07L: after passing Locator CL or CR 090° turn right towards, intercept and proceed on the 132° bearing to PW (toward joining QDM-132 "PW") cross RDL-095 NDB "HLM" VOR/DME to an altitude of 6000 ft then join W45/G461.
   b. KARAWANG ONE DELTA (W17, A585, B469, R206)

Takeoff the Runway 07R and 07L: after passing Locator CL or CR 090° turn right towards, intercept and proceed on DKI R-180 to join assigned ATS route (join the direction of RDL-180$^0$ "DKI" VOR/DME), for route W17 intercept the R314$^0$ "BND" VOR/DME, for route A585 intercept the R142$^0$ "HLM" VOR/DME, for route R206: at D30 "DKI" VOR/DME turn right Kea direction toward the direction of RDL 230$^0$ to intercept R196$^0$ "HLM" VOR/DME, for route B469 intercept R160$^0$ "HLM" join the route B469.

c. CENGKARENG ONE GOLF (W11, W12, A585, G462, G579)
Takeoff the Runway 07R and 07L: after passing Locator CR 090° (for runway 07R at 1500 ft) turn right towards intercept DKI R241 outbound until passing an altitude of 6000 ft then proceed to "CKG" VOR/DME to join assigned route.

d. JAKARTA TWO CHARLIE (G220, W14, W15, W18, W26E, W38)
Takeoff the Runway 07R and 07L: after passing Locator CL or CR then towards, proceed to "DKI" VOR/DME to an altitude of 6000 ft then join assigned ATS route.

e. CENGKARENG TWO GOLF (W11, W12, A585, G462, G579)
Takeoff the Runway 25R and 25L: after passing the GL or GR Locator turn right toward 280$^0$, join and the direction of RDL-330$^0$ "CKG" VOR/DME to SIKAD then follow assigned ATS route.

f. HALIM TWO GOLF (W45, G461, W17, A585, B469, R206, B325)
Takeoff the Runway 25R and 25L: after passing the GL or GR Locator turn right and follow/intercept HLM R306, passing the "HLM" VOR / DME and then follow assigned ATS route.

g. HALIM ONE JULIET (W45, G461, W17, A585, B469, R206, B325)
Takeoff the Runway 25R and 25L: after passing the GL or GR Locator turn left and follow/intercept RDL 285$^0$ "HLM" inbound, passing the "HLM" VOR / DME and then follow assigned ATS route.

h. JAKARTA TWO GOLF (G220, W14, W15, W18, W26E, W38)
Takeoff the Runway 25R and 25L: after passing the GL or GR Locator turn right to intercept DKI R265 to DKI, passing the "DKI" VOR / DME and then follow assigned ATS route.

EDMS models aircraft activity with 6 modes of operation corresponding to the following portions of a LTO cycle. These modes of operation only apply to the aircraft main engines; APU emissions are calculated and presented separately.

1. **Approach:** The airborne segment of an aircraft's arrival extending from the start of the flight profile (or the mixing height, whichever is lower) to touchdown on the runway.
2. **Taxi In:** The landing ground roll segment (from touchdown to the runway exit) of an arriving aircraft, including reverse thrust, and the taxiing from the runway exit to a gate.
3. **Startup:** Aircraft main engine startup occurs at the gate. This methodology is only applied to aircraft with ICAO certified engines. All other aircraft will not have startup emissions. Aircraft main engine startup produces only THC, VOC, NMHC, and TOG emissions. A detailed speciated organic gases profile does not exist for main engine startup emissions.
4. **Taxi Out:** The taxiing from the gate to a runway end.
5. **Takeoff:** The portion from the start of the ground roll on the runway, through wheels off, and the airborne portion of the ascent up to cutback during which the aircraft operates at maximum thrust.
6. **Climb Out:** The portion from engine cutback to the end of the flight profile (or the mixing height, whichever is lower).

Each aircraft activity is expressed as an Arrival, a Departure, an LTO cycle, or a Touch and Go (TGO), and each type consists of different modes of operation. An Arrival consists of the Approach and Taxi In modes. A Departure consists of the Startup, Taxi Out, Takeoff, and Climb Out modes. An LTO cycle consists of an Arrival and a Departure, and therefore consists of one of each of the six modes of operation. A TGO consists of the Approach mode, followed immediately by the Takeoff and Climb Out modes. TGO operations are generally performed for training purposes, usually occur at military bases or smaller civilian airports, and generally have a flight profile that starts and ends at a much lower altitude than a regular LTO cycle. EDMS offers two ways of calculating the amount of emissions released in the airborne segments and approach ground roll:

1. Using the ICAO and Environmental Protection Agency (EPA) Times in Mode, or
2. Using the aircraft performance module, which dynamically models the flight of the aircraft, based a flight profile using the methodology presented in the SAE Aerospace Information Report (AIR) 1845.

## LTO EMISSION ASSESSMENT METHODOLOGY

Aircraft pollutant emissions of CO, $NO_X$ and HC at airports are assessed for the LTO consisting of four operation modes: approach, taxi, takeoff and climb. A typical LTO cycle described by ICAO is shown in Figure 3. ICAO defined the climbing as the interval between the end of takeoff 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[10].

## EDMS INPUT

The EDMS inputs are described in detail with all assumptions and information documented in the following sections.

### Set-up of the airport layout

The airport layout was given an x and y coordinates to let EDMS know the layout of all the important features of the airport. EDMS requires coordinates be entered for all buildings, runways, taxiways, and gates that need to be considered during the modeling process. All gates were given a height of 4.92 feet and 33.9 feet of elevation, the minimum height for the gates to still be considered a source of emissions. Gate information had to be entered for every aircraft entering or leaving during the study.

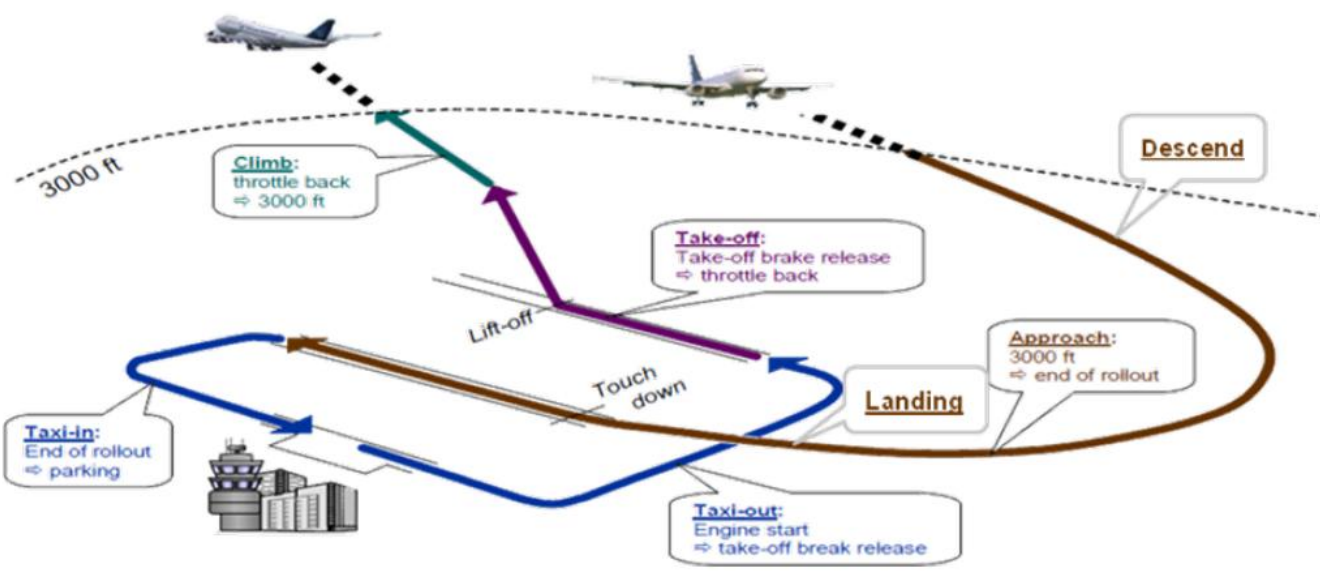


**Figure 3 : A typical LTO cycle.**

Soekarno Hatta International Airport has two runways: 07L-25R and 07R-25L (Figure 2). The end points of the runways were entered as x and y coordinates.

- The first runway (North Runway) is 3,600 m long and 60 m wide. The runway designator is 07L – 25R, located at (-6191.44, 1632.04) and (4789.31, 6011.71). Elevation runway is 29 ft and 21 ft (MSL).
- The second runway (South Runway) is 3,660 m long and 60 m wide. The runway designator is 07R – 25L, located at (-4457.44, -6184.88) and (6710.46, -1730.48). Elevation runway is 34 ft and 27 ft (MSL).

All taxiway are 65.62 feet wide and are set as such in EDMS. It is assumed that all aircraft will travel down the taxiway at a speed of 17.26 mph (15 knots). This is a typical speed at which to leave the gate and approach the runway.

## Set-up of aircraft operation and assignments

The aircraft types (only Commercial/Civil aircraft in this study) used in pollutant emissions assessment at Soekarno Hatta International Airport include: B737, B747, B757, B767 and B777 of Boeing series, A300, A310, A319, A320, A330, and A340 of Airbus series, MD81, MD82, MD83 and MD90 of McDonnell Douglas series, F100 and F28 of Fokker series, Bae146 of British Aerospace series, DHC8 of Dash series and HS748. The classes of aircraft type are shown in TABLE 1. Each class has been represented by one or a number of aircraft types for use in the standard EDMS modeling program. The aircraft types were selected to be representative of the aircraft currently using Soekarno Hatta International Airport. The pollutant emissions characteristics of future aircraft types are not known, but it can be reasonably assumed that they will not be higher than those of current equivalent types, and in general they are expected to be lower. Within the current aircraft fleet operating at Soekarno Hatta International Airport, it can be expected that older generation aircraft will be phased out over time and replaced by newer-generation aircraft. The use of a specific runway is typically influenced by wind direction. The runway directions at Soekarno Hatta International Airport are 07L-25R and 07R-25L. The ILS on Runway 25L and 25R is typically preferred for arrivals and departure. The majority of movements at Soekarno Hatta International Airport occur during the day. The runway use percentages for the 2009 analysis are summarized in TABLE 2 and TABLE 3.

## Flight operations

The distribution of aircraft operations among various categories, users, and types of aircraft is part of the basic input data required for the model. Operational and fleet mix is based on information from Air Traffic Controller (ATC) at the Soekarno Hatta International Airport[19].

Flight period of the setup airport is a year. Annual flight number of runway 07L – 25R and 07R – 25L are 138,799 and 138,657 of aircraft movement. Annual flights ratio of day (07:00~19:00), evening (19:00~22:00) and night (22:00~07:00) are 50.03% and 49.97%.

**TABLE 1 : Aircraft types modeled.**

| Aircraft Class | Types in model |
|---|---|
| Large Wide-Body | 747200, 74720B, 747400 777300 |
| Medium Wide-Body | 777200, 777300, A330, A340, A310 |
| Small Wide-Body | 757, 767200, 767300, 777200 |
| Large Narrow-Body | 737400, 737800, 737900, A320 |
| Small Narrow-Body | 737200, 737300, 737500, 737700, F28, F100 |
| Regional Jet | BAE300 |
| Large Turbo-Prop | DHC830, ATR72 |
| Medium Turbo-Prop | DHC8, F50 |

**TABLE 2 : Percentage of runway use (Year 2009).**

| Runway | | Business Jet & Turboprop | |
|---|---|---|---|
| | | Arrivals | Departures |
| North | 07L | 18.41% | 16.64% |
| | 25R | 31.73% | 33.27% |
| South | 07R | 18.22% | 15.81% |
| | 25L | 31.64% | 34.28% |

**TABLE 3 : Percentage (%) of runway use per time period operations (Year 2009).**

| Runway | | Arrivals | | | Departures | | |
|---|---|---|---|---|---|---|---|
| | | Day | Evening | Night | Day | Evening | Night |
| North | 07L | 80.13 | 18.48 | 1.40 | 83.91 | 14.68 | 1.42 |
| | 25R | 83.41 | 16.02 | 0.57 | 85.50 | 13.84 | 0.66 |
| South | 07R | 74.30 | 16.27 | 9.43 | 70.26 | 11.66 | 18.07 |
| | 25L | 67.34 | 19.39 | 13.27 | 61.82 | 12.70 | 25.48 |

The provide numbers or proportions of aircraft arrivals and departures in a year by aircraft classes (TABLE 4) shows the large narrow body are the most used by airlines at Soekarno Hatta International Airport. This affected by geographically condition in Indonesia that airlines need the medium range of aircraft type and prefers to use large narrow body class.

The distribution of aircraft types at Soekarno Hatta International airport in 2009 as shown in TABLE 4, large narrow body comprise 68% of the aircraft movements at Soekarno Hatta International airport. The ûeet mix is dominated by aircraft equivalent to 737-400. However, the future aircraft with pollutant emissions equivalent to (or better than) A320 and 777-200 aircraft would be the dominant source of emissions.

TABLE 4 : Aircraft classes and proportions.

| Aircraft classes | Types in model | Proportions |
|---|---|---|
| Large Wide-Body | 747200, 74720B, 747400 777300 | 1.87% |
| Medium Wide-Body | 777200, 777300, A330, A340, A310 | 7.22% |
| Small Wide-Body | 757, 767200, 767300 | 0.33% |
| Large Narrow-Body | 737400, 737800, 737900, A320 | 68.03% |
| Small Narrow-Body | 737200, 737300, 737500, 737700, F28, F100 | 21.78% |
| Regional Jet | BAE300 | 0.76% |
| Large Turbo-Prop | DHC830, ATR72 | 0.00% |
| Medium Turbo-Prop | DHC8, F50 | 0.00% |

Figure 4 shows total aircraft movements per hour. The majority of movements at Soekarno Hatta International Airport occur during the day and this pattern is assessed. The most significant hours are between 17.00 and 18.00 as busy hours with 18,549 aircraft movement during a year.

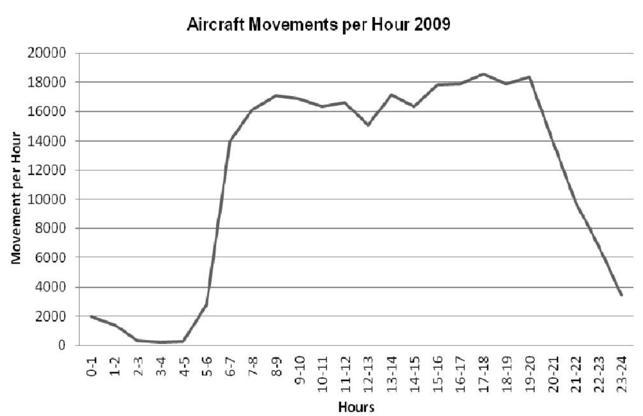


Figure 4 : Aircraft movements per hour in 2009.

TABLE 5 shows the aircraft engine combination at Soekarno Hatta International airport in 2009 as assigned in EDMS.

## Operational LTO cycle

Emissions are determined by fuel flow and emission indices and the fuel flow itself is determined by the engine thrust setting. Thus, it has to be determined at which points below the average mixing height the thrust settings of an aircraft change considerably. Based on the evaluation of the existing data, it is suggested to define an operational LTO cycle with four phases. Alternatively, the takeoff phase could be split into the phases from brake release to lift-off and from lift-off to throttle back and the approach phase could be split into 3000 ft to touchdown and from touchdown to end-of-rollout.

| | |
|---|---|
| Takeoff: | Average thrust setting from takeoff brake release to the point of main engine throttle back. This point is variable and dependent on a number of parameters (takeoff weight, meteorological conditions, and flight procedures). |
| Climb: | Thrust setting from the point of throttle back to the mixing height altitude, or more generally 3000 feet. |
| Approach: | Average thrust setting from mixing height altitude (or 3000 ft) over the touchdown point to the end of the rollout on the runway. |
| Taxi / Ground Idle | Average thrust setting from engine start to the point of takeoff brake release for taxi-out and from the end of rollout after landing to parking and main engine turn-off for taxi-in. |

TABLE 5 : Aircraft/engine combination.

| Aircraft | Engines | Aircraft (cont.) | Engines (cont.) |
|---|---|---|---|
| 737300 | CFM56-3-B1 | A330 | CF6-80E1A2 |
| 737400 | CFM56-3-C1 | A340 | CFM56-5C2 |
| 737500 | CFM56-3-C1 | BAE46 | ALF-502R-5 |
| 737800 | CFM56-7B26 | ATR42 | PW121 |
| 737900ER | CFM56-7B26 | F50 | PW-127-A |
| 737200 | JT8D-17-reduced emissions | F100 | TAY-Mk620-15 |
| 747200 | JT9D-7 | F28 | RR SPEY-MK555-15 |
| 747300 | JT9D-7R4G2 | ATR72 | PW127C |
| 747400 | PW 4056 | MD81 | JT8D-217 series |
| 757 | RB211-535E4 | MD82 | JT8D-217A environmental |
| 767300 | PW 4060 reduced emissions | MD83 | JT8D-219 |
| 767200 | CF6-80A | MD90 | V2525-D5 |
| 777200 | GE90-90B DAC II | A310 | CF6-80C2A2 |
| 777300 | Trent 892 | A319 | V2524-A5 |
| A306 | PW4158reduced | A320 | CFM56-5-A1 |

## Meteorological data

EPA's AERMET is the meteorological preprocessor to EPA's AERMOD, the dispersion algorithms used in EDMS. AERMET requires all weather data to be in a one of four formats. The data used was NOAA's TD-3280 format, which is commonly available. NOAA maintains a surface and upper air meteorological station in the immediate vicinity of the airport, (WIII station 96749). Hourly meteorological surface data in a year (2009) was obtained from Meteorological station at Soekarno Hatta

International Airport for the study period. A study was done on the weather including a complete wind angle search of the upper air data. This study showed negligible effects in the predicted output concentration from EDMS with any variation of wind angle using the upper air meteorological file from NOAA website[3].

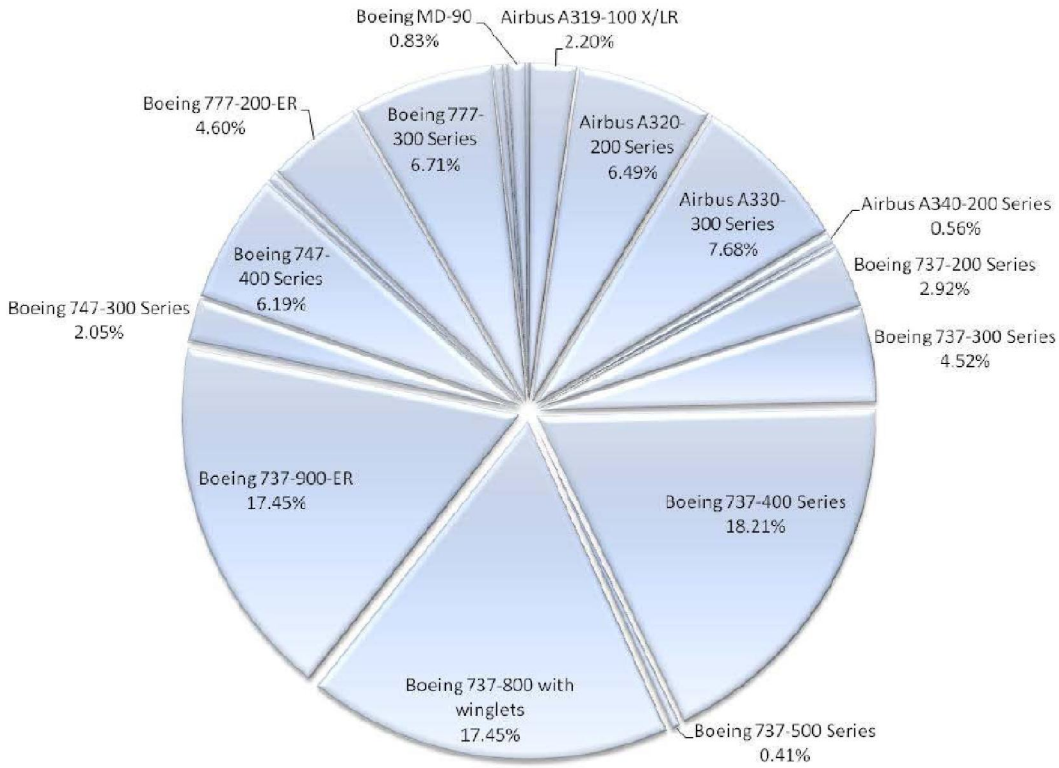


**Figure 5 : Distribution of $NO_x$ emission.**

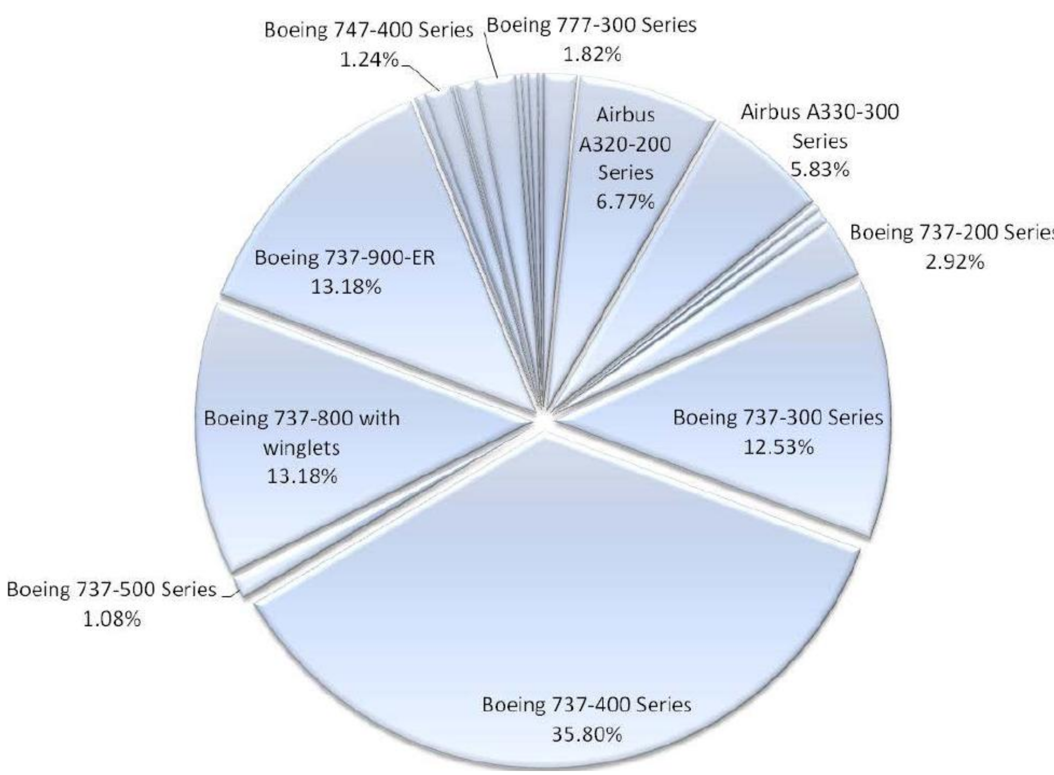


**Figure 6 : Distribution of CO emission.**

## RESULTS

The assessment of total LTO emissions from aircraft in each pollutant emissions at Soekarno Hatta International Airport are shown in TABLE 6. The amount of total aircraft emissions in each pollutant emissions are estimated to be CO = 1036.871 t/year, HC = 87.170 t/year and $NO_x$ = 1424.393 t/year and the aircraft fuel consumption for LTO cycles at Soekarno Hatta International airport is estimated around 114149.555 t in 2009. The distribution of pollutant emissions from each type of aircraft is shown in table (annex), Figures 5, 6 and 7.

**TABLE 6 : Total Emissions and fuel consumption in t/year.**

| Total Emissions at Soekarno Hatta International Airport | LTO | | | |
|---|---|---|---|---|
| | CO | $NO_x$ | HC | Fuel Consumption |
| Amount | 1036.9 | 1424.4 | 87.2 | 114149.6 |

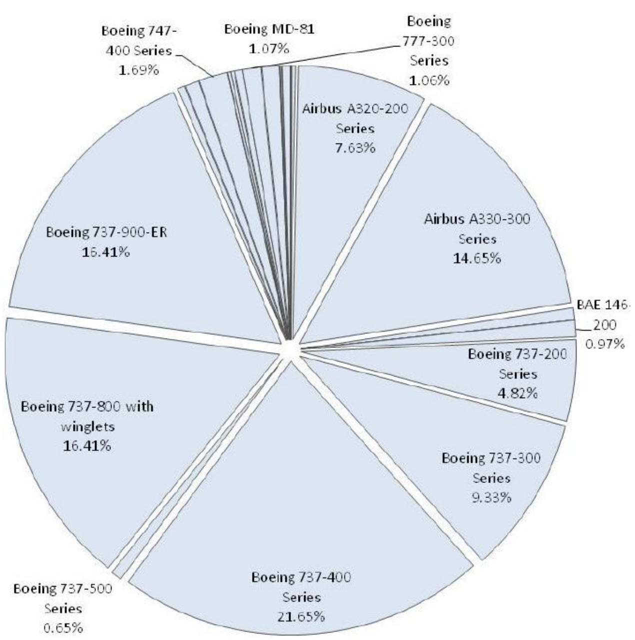


**Figure 7 : Distribution of HC emission.**

**TABLE 7 : Distribution of aircraft emissions for each operation mode.**

| Pollutant Emissions | Mode | | | |
|---|---|---|---|---|
| | Taxi | Climb-out | Takeoff | Approach |
| CO | 88.03% | 1.18% | 2.53% | 8.25% |
| $NO_x$ | 10.22% | 23.17% | 56.12% | 10.49% |
| HC | 86.26% | 1.94% | 4.63% | 7.17% |

As describe above the B737-400 has more than 60% of the aircraft movements at Soekarno Hatta International airport. This B737-400 has a contribution of total emissions of 35.80% of CO, 21.65% of HC and 18.21% of $NO_x$. The B737-400 contribution of fuel consumption is about 24.41% of total fuel consumption in LTO cycles.

**Annex: Distribution LTO emissions and fuel consumption.**

| Aircraft Type | LTO | | | |
|---|---|---|---|---|
| | CO | $NO_x$ | HC | Fuel onsumption (t) |
| ATR 42-200 | 0,6 | 0,06 | 0,002 | 17,2 |
| ATR 72-500 | 2,8 | 2,0 | 0,012 | 226,5 |
| Airbus A300F4-600 Series | 231,3 | 607,3 | 19,9 | 38760,1 |
| Airbus A310-300 Series | 216,4 | 71,1 | 48,0 | 8306,5 |
| Airbus A319-100 X/LR | 15948,4 | 31366,0 | 204,6 | 2674217,8 |
| Airbus A320-200 Series | 70170,9 | 92427,1 | 6649,3 | 8397952,2 |
| Airbus A330-300 Series | 60457,6 | 109397,1 | 12774,6 | 5464405,0 |
| Airbus A340-200 Series | 4196,5 | 7918,5 | 630,6 | 459950,0 |
| BAE 146-200 | 6683,7 | 3239,8 | 846,7 | 468934,5 |
| Boeing 737-200 Series | 30273,5 | 41555,7 | 4198,5 | 5143759,2 |
| Boeing 737-300 Series | 129881,2 | 64447,8 | 8130,0 | 8102890,7 |
| Boeing 737-400 Series | 371181,3 | 259400,1 | 18874,9 | 27858767,6 |
| Boeing 737-500 Series | 11249,6 | 5798,3 | 567,1 | 732879,5 |
| Boeing 737-800 with winglets | 136661,9 | 248627,6 | 14302,7 | 18993297,7 |
| Boeing 737-900-ER | 136661,9 | 248627,6 | 14302,7 | 18993297,7 |
| Boeing 747-200 Series | 850,3 | 1079,5 | 363,9 | 52775,2 |
| Boeing 747-300 Series | 4986,1 | 29155,0 | 713,7 | 1427371,4 |
| Boeing 747-400 Series | 12830,7 | 88232,1 | 1471,6 | 5052690,2 |
| Boeing 757-200 Series | 48,1 | 172,0 | 1,3 | 9120,9 |
| Boeing 767-200 Series | 719,7 | 1124,3 | 156,8 | 82004,2 |
| Boeing 767-300 Series | 2159,0 | 6420,1 | 184,1 | 382443,8 |
| Boeing 777-200-ER | 9295,5 | 65478,0 | 376,5 | 2652498,3 |
| Boeing 777-300 Series | 18873,1 | 95633,9 | 927,0 | 5011721,8 |
| Boeing MD-81 | 3194,9 | 6418,1 | 931,9 | 549267,1 |
| Boeing MD-82 | 3000,5 | 3035,6 | 0,047 | 398155,0 |
| Boeing MD-83 | 45,5 | 41,3 | 13,9 | 5631,3 |
| Boeing MD-90 | 4818,5 | 11882,9 | 70,3 | 957016,6 |
| Fokker F100 | 2211,4 | 2232,0 | 391,8 | 230600,1 |
| Fokker F28-4000 Series | 18,4 | 1,7 | 17,8 | 403,9 |

It can be seen that CO, HC and $NO_x$ emissions and fuel consumption of the B737-400 are slightly higher than other aircraft types. This is due to the facts that the aircraft has often operated at Soekarno Hatta International airport.

The distribution of aircraft pollutant emissions for different operation modes presented in TABLE 7 shows that the taxiing mode has the biggest portion of CO pollutant emission, which portion is around 88%. The biggest portion of $NO_x$ around 56% belongs to the take-off mode.

## CONCLUSIONS

The estimation of pollutant emissions (CO, HC and NOx) of aircraft LTO cycles at Soekarno Hatta International airports is presented for the first time. The following conclusions can be drawn from the results of this study:

The amount of total aircraft emissions in each pollutant emissions at Soekarno Hatta International airports are estimated to be CO = 1036.871 t/year, HC = 87.170 t/year and $NO_x$ = 1424.393 t/year.

The aircraft fuel consumption for LTO cycles at Soekarno Hatta International airport is estimated around 114149.555 t in 2009.

The B737-400 has a biggest contribution of pollutant emissions per aircraft type with 35.80% of CO, 25.90% of HC and 18.21% of $NO_x$. About 24% of fuel consumption has been contributed.

The distribution of aircraft pollutant emissions for different operation modes shows that the taxiing mode has the biggest portion of CO pollutant emission, which portion is around 88% and the biggest portion of $NO_x$ around 56% belongs to the takeoff mode.

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