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Commercial Aircraft Emission Estimates with 1 km x 1 km Resolution: A Case of Departure Flights at Suvarnabhumi Airport

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Abstract

This study aims to quantify commercial aircraft emissions, CO, NO_x and HC, with 1 km × 1 km resolution at Suvarnabhumi airport based on 2015 data. The number of actual departure flights and aircraft engines were acquired and the emission factors were applied to calculate the emissions of overall flying cycle, namely aircraft taxi, take-off, initial-climb and climb-out. In addition, the route map and each flying cycle were created from XY coordinates with a Geographic Information System. The emissions at each coordinate within 1 km × 1 km grid along with route map were interpolated to provide the spatial emissions for each spatial layer of the flying cycle. The overall results showed that annual emissions were about 598 ktons for CO, 4220 ktons for NO_x, and 112 ktons for HC. The aircraft taxi mode accounted about 545 ktons of CO emission, 104 ktons of NO_x, and 100 ktons of HC annually, while the emission during take-off mode of CO was 24 ktons, 2200 ktons for NO_x, and 6 ktons for HC. The annual emission during the initial-climb mode accounted about 12, 990 and 3 ktons of CO, NO_x and HC, respectively. In climb-out mode, the annual emissions of CO, NO_x and HC were 17, 926 and 3 ktons, respectively. The highest emissions of CO, NO_x and HC from spatial analysis occurred during taxi mode for CO and HC at the end of the runway, northward of the airport. The highest NO_x found during the take-off mode, at the center of the runway.

Keyword: commercial aircraft emission; spatial emission; flying cycle; Suvarnabhumi; Thailand

1. Introduction

Thailand's air transportation has increased in recent year from economic expansion and aviation development. Thailand had positioned itself as the Asean's aviation hub. Suvarnabhumi is the busiest and biggest airport in Thailand and it is one of the most crowded airports in the world (ACI, 2012). In 2015, the aircraft movements at Suvarnabhumi airport were 317,066 flights accounted about 9.50% increased from 2014 (AOT, 2015). The emissions from the commercial aviation are also on the rise. The emissions from the commercial aircraft related to the aircraft engine types and flying cycle. International Civil Aviation Organization (ICAO) defines the term of flying cycle as the aircraft operations lower than 1,000 meters and the flying cycle consists of aircraft taxi, take-off, initial-climb and climb-out (Graver and Frey, 2009). Taxi and take-off are the modes of flying cycle operated on the ground level, initial-climb and climb-out flying at the altitude ranged from 0 to 450 and more than 450 to 1000 meters, respectively (Watterson *et al*., 2004). In addition, the cruise mode is one of flying mode, while the aircraft flying up to the level above 1,000 meters, but the highest altitude is not defined (IPCC, 2000). Moreover, fuel used in aircraft engines affects the emissions from the aircraft (Winther and Rypdal, 2014). The ideal combustion emits carbon dioxide and water, whereas, actual combustion emits more pollutants. Carbon monoxide, nitrogen oxide and hydrocarbon are the pollution emitted from actual combustion in the aircraft's engine (Weubbles *et al*. 2007; Norton, 2014). Intergovernmental Panel on Climate Change (IPCC) reported that the commercial aircraft's engine emitted approximately 99.5 – 99.9% of N_2, O_2, CO_2 and H_2O (Lewis et al., 1999; Masiol and Harrison, 2014). The pollutants emitted less than 1%, mostly 84% of NO_x, 11.8% of CO, 4% of HC and 0.2% other (Lewis *et al*., 1999; Masiol and Harrison, 2014). About 70% of HC and CO were emitted in cruise mode, the remaining emitted during take-off and ground level operations (FAA, 2005). NO_x was emitted more than CO and HC, two-thirds of NO_x produced during the LTO cycle at the low altitude (Airfrance, 2009), when compared with CO and HC. NO_x emission is a result of combustion compositions. Nitrogen is one of fuel element, aviation kerosene or jet fuel used in the turbine engine (ICAO, 2011). Fuel was burned at temperature higher than 1200 Celsius and at high pressure in the engine's chamber (FAA, 2005). Moreover, the emissions were related to the conditions of fuel combustion in each mode of the flying cycle because the aircraft's energy consumption from engine combustion was different in each mode (Belgian Science Policy, 2007). From a study at Raleigh-Durham International Airport in 2006, HC, CO and NO_x emissions during flying accounted for 60.2, 514 and 492 tons per year, respectively (Graver and Frey, 2009). This study focused on the spatial estimation of the emissions at Suvarnabhumi airport during taxi, take-off, initial-climb and climb-out using available emission factors and a Geographic Information System.

2. Materials and Methods

2.1 Data collection

This study collected two sets of data. The first set was the aircraft's flight number and number of flights from the official website of the Airport Authority of Thailand (AOT). The second set was the actual flight's routes derived from a flight tracking program using the flight number to find a flight's routes (latitude and longitude data series). And the aircraft's engine types on the website "Flight aware" (https://flightaware.com/).

The number of flights, engine types and the flight routes were the input data in emissions calculations and route map creation.

2.2 Emissions Calculations

The number of actual departure flights was used to estimate the emissions of the flying cycle of pollutant *p*, each mode in LTO cycle *m*, for aircraft type *s*, at the airport type *a*, followed the equation (Watterson *et al*., 2004).

$$E_{LTO_{a,m,p,s}} = N_s \times T_{a,m,s} \times F_{a,s}(t_{a,m,s}) \times I_{a,p,s}(t_{a,m,s})$$

where $E_{LTOa,m,p,s}$ is the emissions in mode *m* of pollutant *p* for a specific aircraft type *s* at airport type *a*. *a* is the airport type. *m* is the flying mode. *p* is the type of pollutant *s* is the specific aircraft type. N_s is the number of engines on aircraft type *s*, $T_{a,m,s}$ is time in mode *m* for *a* specific aircraft type *s* at airport type *a* (s), $F_{a,s}(t)$ is weighted average fuel flow for an engine on aircraft type *s* at airport type *a* for thrust t (kg s^{-1}). $I_{a,p,s}(t)$ is weighted average emission factor of pollutant *p* for an engine on aircraft type *s* at airport type *a* for thrust t (kg/kg fuel). $T_{a,m,s}$ is engine thrust setting during mode m for aircraft type *s* at airport type *a* (%).

The default thrust setting values for each mode in the flying cycle used to calculate in the equation shows in Table 1.

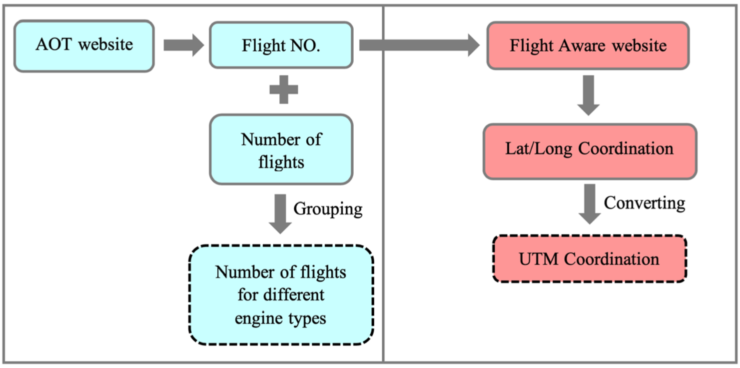


Figure 1. Data collection processes

Table 1. Default thrust setting for each operating mode (Watterson *et al.*, 2004)

Operating mode	Default thrust setting (%)
Taxi-out, Hold and Taxi-in	7
Take-off	100
Initial-climb	100
Climb-out	85

2.3 Route Map Creation

Route map was created using a function in the GIS program with the coordinate data in UTM. The route map of each flight was digitized and added as an attribute in the table of the emission data.

2.4 Spatial Analysis

Route map and emissions data were created and used as the input in the GIS program. The emissions were interpolated using the spatial analysis tool. All the emission points were interpolated for each flying cycle mode.

3. Results and Discussion

3.1 Annual aircraft emissions

The emissions of CO NO_x and HC for the commercial aircraft were calculated with the number of actual departure flight data based on 2015 data. The aircraft engines were classified and the emission factors were used to estimate the emissions of the flying cycle during aircraft taxi, take-off, initial-climb and climb-out. The annual emissions were showed in the table 2

The values in Table 2 are the overall of annual emissions. The annual CO emission was about 598 ktons. NO_x emission was 4220 ktons, higher than CO and HC. HC was about 112 ktons. When consider each flying cycle, CO accounted about 545 ktons during the aircraft taxi mode, 104 ktons for NO_x and 100 ktons for HC. During the take-off mode, annual NO_x emission was the highest at 2200 ktons, 24 ktons for CO, and 6 ktons for HC. The annual NO_x emission during the aircraft initial-climb mode was 990 ktons, 12 ktons for CO, and 3 ktons for HC.

The aircraft climb-out mode accounted about 926 ktons of NO_x, 17 ktons of CO, and 3 ktons of HC.

Percent estimate of the annual emissions is in Fig. 4. The aircraft taxi mode accounted most of CO and HC emissions, 91 and 89%, respectively. More than a half of the annual NOx emission occurred in the take-off mode, 52% (or 2200 ktons).

3.2 Spatial emissions

The spatial emission maps in the airport were created from the annual aircraft emissions and the coordinate data and interpolated on the satellite image. The emissions map of NO_x is showed in Fig. 5.

The annual emission of NO_x ranged from 2 – 9178 tons. The highest concentrations of NOx occurred during the take-off mode. The spatial emissions were high between both runways. The highest NO_x emissions ranged between 7342 and 9178 tons. During the take-off mode, NO is primarily emitted because high temperature combustion over 1,300 Celsius (US.EPA., 1999).

The annual spatial emission of CO ranged from 1 to 1956 tons, the highest emissions of CO occurred at the end of runway in the north.

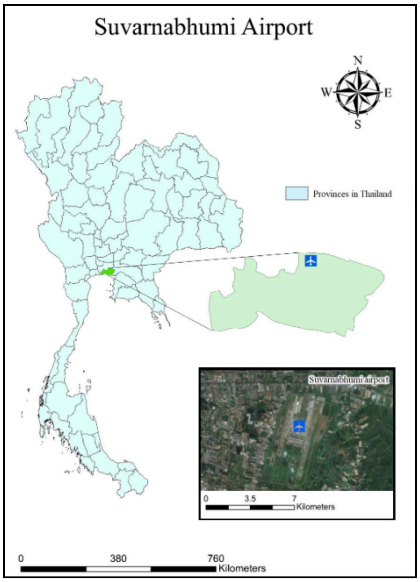


Figure 2. Suvarnabhumi airport located in the center of Thailand

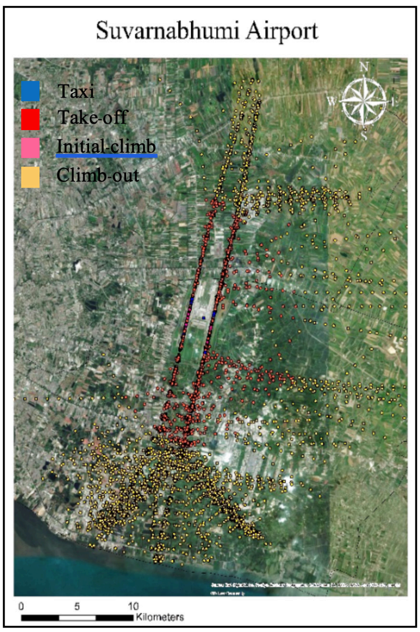
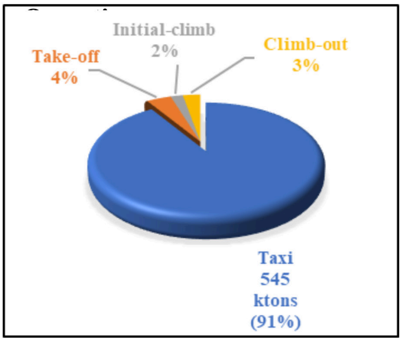


Figure 3. Departure flight route map form Suvarnabhumi airport

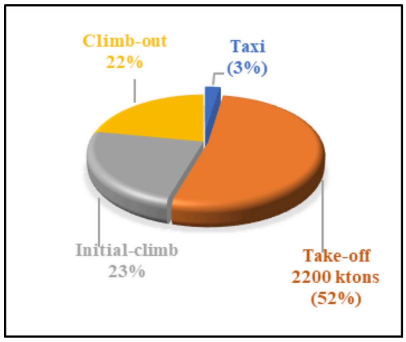
Table 2. The annual emissions from the commercial aircraft during flying cycle mode on departure flight

Operating mode	**The annual emissions (ktons)**		
	CO	**NO_x**	**HC**
Taxi	545	104	100
Take-off	24	2200	6
Initial climb	12	990	3
Climb-out	17	926	3
Total	598	4220	112

(a) CO



(b) NO_x



(c) HC

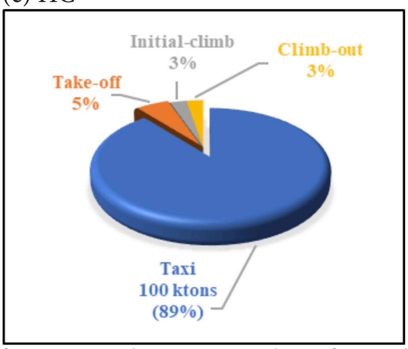


Figure 4. The percentage of emissions during taxi, take-off, initial-climb and climb-out for CO (a), NO_x (b) and HC (c)

The annual emission of CO was between 1566 and 1956 tons. HC emission was up to 108 tons and the highest emission found during the aircraft taxi mode.

The spatial emission of HC as well as CO was high at the end of the runway in the north. High HC emissions were between 436 and 546 tons. Emissions of CO and HC were high during the aircraft taxi mode because of incomplete combustion (Jacobson, 2012).

4. Conclusion

In 2016, estimated annual emissions of the commercial aircrafts based on the departure flight at Suvarnabhumi airport were 598 ktons for CO, 4220 ktons for NO_x, and 112 ktons for HC. During the aircraft taxi mode, the annual emission of CO was 545 ktons, 104 ktons for NOx, and 100 ktons for HC. The emissions of CO was the highest when compared to NO_x and HC at the result of incompletion combustion.

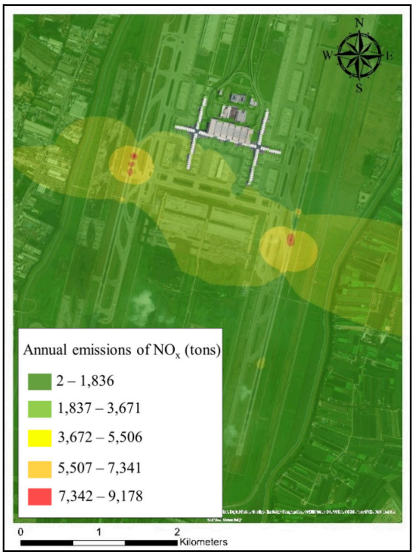


Figure 5. The spatial emissions during flying cycle for NO_x

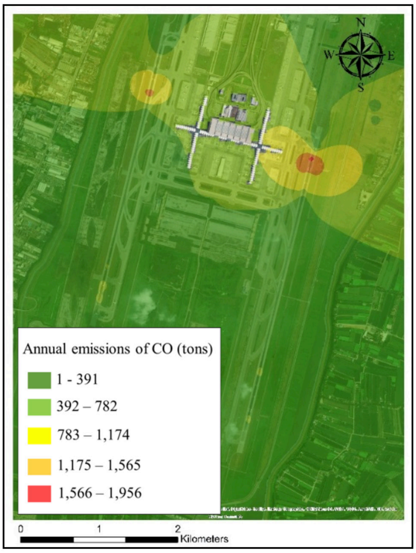


Figure 6. The spatial emissions during flying cycle for CO

The aircraft take-off mode accounted about 24 ktons of CO, 2200 ktons of NO_x, and 6 ktons of HC. The excess air in high temperature combustion was the cause of high NO_x during the aircraft take-off mode. The annual emissions occurred during the initial-climb mode accounted about 12, 990 and 3 ktons of CO, NO_x and HC, respectively. In the finally mode, climb-out, the annual emissions of CO, NO_x and HC were 17, 926 and 3 ktons, respectively. The amount of NO_x was found higher than CO and HC in both initial-climb and climb-out modes. The spatial analysis showed that the highest emissions of CO, NO_x and HC occurred during the taxi for CO and HC at the end of the runway northward and some area of aircraft parking stands and taxiway. The take-off mode was a mode that emitted the highest NO_x at the center of both runways and the area near the aircraft parking stands and taxiway.

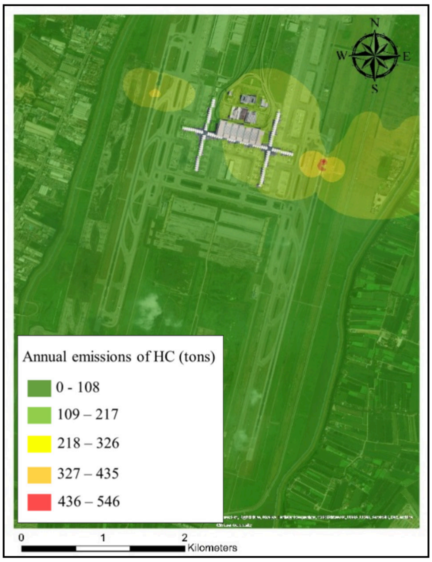


Figure 7. HC spatial emissions during the flying cycle

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