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Emissions of NO_x, particle mass and particle numbers from aircraft main engines, APU's and handling equipment at Copenhagen Airport

Morten Winther [a,*], Uffe Kousgaard [b], Thomas Ellermann [a], Andreas Massling [a], Jacob Klenø Nøjgaard [a], Matthias Ketzel [a]

[a] Aarhus University, Department of Environmental Science, Frederiksborgvej 399, 4000 Roskilde, Denmark
[b] Routeware, Trægården 9, 4000 Roskilde, Denmark

HIGHLIGHTS

- 5 × 5 m high resolution NO_x, PM and PN emission inventory for Copenhagen Airport.
- Detailed aircraft and handling equipment results; entire airport and inner apron area.
- Handling is a large NO_x and PM source, and a small PN source at the inner apron.
- ICAO FOA3.0 PM results suggest that over half of aircraft PM stems from fuel sulphur.
- High/low sets of emission factors change the aircraft PN emissions by a factor of 14.

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ABSTRACT

This paper presents a detailed emission inventory for NO_x, particle mass (PM) and particle numbers (PN) for aircraft main engines, APU's and handling equipment at Copenhagen Airport (CPH) based on time specific activity data and representative emission factors for the airport. The inventory has a high spatial resolution of 5 m × 5 m in order to be suited for further air quality dispersion calculations. Results are shown for the entire airport and for a section of the airport apron area ("inner apron") in focus. The methodology presented in this paper can be used to quantify the emissions from aircraft main engines, APU and handling equipment in other airports. For the entire airport, aircraft main engines is the largest source of fuel consumption (93%), NO_x, (87%), PM (61%) and PN (95%). The calculated fuel consumption [*NO_x, PM, PN*] shares for APU's and handling equipment are 5% [*4%, 8%, 5%*] and 2% [*9%, 31%, 0%*], respectively. At the inner apron area for handling equipment the share of fuel consumption [NO_x, PM, PN] are 24% [*63%, 75%, 2%*], whereas APU and main engines shares are 43% [*25%, 19%, 54%*], and 33% [*11%, 6%, 43%*], respectively. The inner apron NO_x and PM emission levels are high for handling equipment due to high emission factors for the diesel fuelled handling equipment and small for aircraft main engines due to small idle-power emission factors. Handling equipment is however a small PN source due to the low number based emission factors. Jet fuel sulphur-PM sensitivity calculations made in this study with the ICAO FOA3.0 method suggest that more than half of the PM emissions from aircraft main engines at CPH originate from the sulphur content of the fuel used at the airport. Aircraft main engine PN emissions are very sensitive to the underlying assumptions. Replacing this study's literature based average emission factors with "high" and "low" emission factors from the literature, the aircraft main engine PN emissions were estimated to change with a factor of 14.

1. Introduction

In the recent years an increased concern about the health effects in humans due to airport emissions is observed. Aircraft main engines, APU's (Auxiliary Power Units) and handling equipment are the most important sources of air pollutant emissions in an airport, and among the vast number of emitted pollutants a special focus is given to NO_x, particle mass (PM) and particle number (PN). NO_x is emitted in high quantities and traditionally considered as a good tracer for all kind of engine emissions while PM and PN are considered to cause various adverse health effects (e.g. Pope and Dockery, 2006; Schwarze et al., 2006). Particle size is a crucial

* Corresponding author.
E-mail address: mwi@dmu.dk (M. Winther).

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parameter and often are smaller particles – being emitted in large numbers during engine combustion – considered to cause larger effects on human health, due to their ability to penetrate deeper into the lungs and translocate inside the human body to other organs (e.g. Oberdörster et al., 2004; Diapouli et al., 2007). A link between elevated air pollutant concentrations of NO_x and particles (especially mass based) and a large number of diseases such as cardiovascular diseases, pulmonary diseases, various cancer types, asthma, and diabetics could be established (Raaschou-Nielsen et al., 2012; Hertel et al., 2013).

During the recent years several air quality measurement campaigns have been conducted in order to assess the impact of airport emissions on the air quality in airports and in the vicinity of airports. Some important examples of such measurement studies are listed in the following.

Carslaw et al. (2006) measured the NO_x concentration at seven geographical sites around London Heathrow Airport in order to determine the emission impact from aircraft activities. Schürmann et al. (2007) measured NO_x and other emissions from airport sources on the air quality in Zurich Airport. For Los Angeles International Airport Westerdahl et al. (2008) measured NO_x and ultra fine particle (UFP) concentrations in the vicinity of the airport to determine the impact of airport emissions, and Zhu et al. (2011) made detailed $PM_{2.5}$ and UFP measurements in the airport and at a background reference site in order to determine the emission impacts from aircraft take offs. Hsu et al. (2012) made UFP measurements at four monitoring sites surrounding T.F. Green Airport in Warwick in order to determine impact from aircraft landing and take off activities (LTO's). At Copenhagen Airport Ellermann et al. (2011) conducted long term air quality measurements of $PM_{2.5}$ and NO_x at the apron and two background measurement sites and made screening measurements of UFP in order to assess the air quality in the airport.

The air quality measurements performed at Copenhagen Airport were a part of a larger air quality assessment project "Investigation of the air pollution on the inner apron at Copenhagen Airport Kastrup in relation to working environment" initiated due to the health concern of the airport staff working at the airport apron (Ellermann et al., 2011). In order to carry out the most reliable air quality assessment for the airport and to support future emission abatement measures, it was a project goal from the beginning to create a precise source specific emission inventory in a high temporal (minutes) and spatial (5 m × 5 m) resolution for the entire airport and for a part of the airport apron area in focus referred to as "inner apron area". This area is located between the terminal fingers and is characterized by aircraft movements to/from the gates, and large activities made with APU and handling equipment.

The inventory covered the source categories aircraft main engines, APU, handling equipment, and road transportation vehicles as a minor source, and included the emissions of CO_2, SO_2, CO, HC, NO_x, NO_2 and PM. In a follow-up study "Inventory of emissions including particle numbers at the inner apron area in Copenhagen Airport" documented by Winther et al. (2014), estimates of particulate numbers (PN) were added to the inventory.

This paper aims to explain the emission inventory for Copenhagen Airport. Source specific results are presented as totals for the entire airport and for the inner apron area. Emissions are also presented in a 5 m × 5 m spatial resolution suited for the subsequent modelling of air quality in the airport. In this paper, the inventory results will focus on fuel consumption and the emissions of NO_x, PM and PN due to their important health effects as outlined in the beginning of this paper.

The temporally and spatially very detailed inventory for Copenhagen Airport and the inner apron area, and the derived source contributions for main engines, APU's and handling equipment, serve as a valuable new contribution to the research field. The precise emission estimates for handling equipment in the airport based on equipment type and technology specific activity data also bring important new knowledge to the research community.

Section 2 presents the inventory's activity data, emission factors and the emission calculation method. Section 3 explains the emission results for the inner apron area and for the total airport and spatial distributions of the emissions are shown as well. Moreover a sensitivity analysis is presented that examines the PM emission changes due to the use of zero sulphur jet fuel. The sensitivity of PN emissions on the use of "low" and "high" PN emission factors from the literature is shown as well.

2. Method

The emission inventory uses detailed activity data for aircraft main engines, APU's and handling equipment together with the time-in-modes and location of their use at Copenhagen Airport (CPH). The flight activity data for CPH represent four days in 2009 with preferable use of each of the four runways, chosen to produce emission results suited as input for subsequent air quality dispersion modelling depending on wind direction. Handling activities are specified by equipment types and grouped according to aircraft size. The time resolved airport activities are digitalized in a 5 m × 5 m resolution on a GIS map of the airport as shown in Fig. 1. The vertical limit of the considered emissions is 100 m. Emissions above 100 m are not regarded as relevant for local airport air quality impacts due to the high dilution of the emissions during the turbulent transport from these height levels down to earth surface level.

Engine/power mode specific fuel flows (g/s) and NO_x and PM emission indexes (EI's, g/kg fuel) are prepared in this study, and for particulate numbers (PN) more general number emission indexes (*EIn*'s, #/kg fuel) have been established. Emission rates for NO_x and PM in g/s and number based emission rates for PN in #/s are derived from the fuel flows, emission indexes and the time-in-mode for each engine/power mode obtained from the real time specific activity data for CPH. The emissions per grid cell are calculated as the product of the emission rate and the time interval calculated by the digital activity map.

The digital activity map at CPH uses a number of assumptions regarding priority taxiways, taxi speed, runway acceleration/deceleration and climb/landing gradients for aircraft and the spatial location of handling activities and APU usage close to the gates. For further details please see Winther et al. (2006, 2014). The digital activity map is a further development of the one used to investigate the odour nuisances from aircraft main engines and APU's (Fenger et al., 2006; Winther et al., 2006).

Fig. 1 shows a map of CPH. Terminal gates are numbered (e.g. B7 or C28) and marked with a small (black) dot. The main engine start-up marks are designated with larger (brown) dots (e.g. P or Q1). The aircraft taxi ways close to the gates are visible as (green and red) lines and connect to the shared taxiways that lead from/to the runways (blue lines).

A map of the inner apron (area in pink frame) at CPH also in focus in this study is shown in Fig. 2.

2.1. Activity data

2.1.1. Flight operations

The airport has provided flight activity data for four days in 2009 with preferable use of each of the runways 12, 30, 04L + 04R and 22L + 22R. The data consist of aircraft type, registration number, airline operator, gate, off/on block time, specification of start/