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The relationship between aviation activities and ultrafine particulate matter concentrations near a mid-sized airport

Hsiao-Hsien Hsu[a,*], Gary Adamkiewicz[a], E. Andres Houseman[a,b], Jose Vallarino[a], Steven J. Melly[a], Roger L. Wayson[c], John D. Spengler[a], Jonathan I. Levy[a,d]

[a] Harvard School of Public Health, Department of Environmental Health, Landmark Center 4th Floor West, 401 Park Drive, Boston, MA 02215, USA
[b] The Warren Alpert Medical School of Brown University, 121 South Main St., Providence, RI 02912, USA
[c] Volpe National Transportation Systems Center, 55 Broadway St., Cambridge, MA 02142, USA
[d] Boston University School of Public Health, Department of Environmental Health, Talbot T4W, 715 Albany St., Boston, MA 02118, USA

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A B S T R A C T

Aircraft contribute to emissions of ultrafine particulate matter (UFP) and other air pollutants, with corresponding impacts on community-level exposures near active airports. However, it is challenging to isolate the contribution of aircraft from local road traffic and other nearby combustion sources. In this study, we used high-resolution monitoring and flight activity data to quantify contributions from landing and take-off operations (LTO) to UFP concentrations. UFP concentrations were monitored with 1-min resolution at four monitoring sites surrounding T.F. Green Airport in Warwick, RI, in three one-week campaigns across different seasons in 2007 and 2008. Along with pollutant monitoring, wind data were collected and runway-specific LTO data were obtained from airport officials. We developed regression models in which wind speed and direction were included as a nonparametric smooth spatial term using thin-plate splines applied to wind velocity vectors and fitted using linear mixed models. To better pinpoint the timing in the LTO cycle most contributing to elevated concentrations, we used regression models with lag terms for flight activity (ranging from 5 min before to 5 min after the departure or arrival). Results suggest positive associations between UFP concentrations and LTO activities, especially for departures when an aircraft moves near or passes a monitoring site. Departures of jet engine aircrafts on a runway proximate to one of the monitors have a maximal impact 1 min prior to take-off, with median absolute contributions during those minutes of 7400 particles cm^{-3} (range: 1100–70,000 particles cm^{-3}). Across all observations, our models indicate median (95th, 99th percentile) percent contribution for all LTO activities of 9.8% (54%, 72%) and 6.6% (39%, 55%) for the two sites proximate to the airport's principal runway, and 4.7% (24%, 36%) and 1.8% (22%, 31%) for the remaining two sites. Our analysis illustrates the complexity of aviation impacts on local air quality and allows for quantification of the marginal contribution of LTO activity relative to other nearby sources.

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1. Introduction

Aviation-related air pollution, including both emissions from aircraft and other airport-related activities, can potentially contribute to elevated exposures in communities near airports for multiple air pollutants. Detailed plume characterization studies in experimental settings have shown that aircraft engines have power-dependent emissions of multiple air pollutants, with the highest emission rates typically under thrust and increased fuel flow rate conditions commonly associated with take-off (Agrawal et al., 2008; Kinsey et al., 2010; Wey et al., 2006, 2007). Field studies have also demonstrated potential influences of aviation activity on a variety of VOCs, PAHs, and criteria pollutants (Carslaw et al., 2006; Herndon et al., 2008, 2005; Yu et al., 2004).

However, it can be difficult to quantitatively separate the contributions of aviation from other local sources and background concentrations. This is in part because distinguishing aircraft emissions from other local combustion sources such as roadway traffic during monitoring studies is difficult and requires correlation over time and space with aviation activity. Studies that have attempted to evaluate the marginal contribution of airports to ambient pollutant levels have generally either not quantitatively estimated marginal contributions (Hu et al., 2009; Westerdahl et al., 2008; Yu et al., 2004) or have done so with 1-h or longer averaging times (Adamkiewicz et al., 2010; Dodson et al., 2009), which are more challenging to interpret given the correlations among sources and complex and rapidly changing source characteristics. Dispersion models are often

* Corresponding author. Tel.: +1 617 384 8806; fax: +1 617 384 8859.
E-mail address: leonhsu@hsph.harvard.edu (H.-H. Hsu).

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applied in this context to determine marginal contributions, and some studies have applied chemistry-transport models (Arunachalam et al., 2011) or attempted to understand the physics of the aerosol dynamics of aircraft plumes (Graham and Raper, 2006; Wong et al., 2008). However, high-resolution dispersion modeling studies remain challenging, given emission uncertainties and complex source characteristics including sources' movements in 3-dimensions, sources moving at high speed, and the high velocity and temperature of emissions.

The question of aviation contributions is particularly challenging for UFP (ultrafine particulate matter), a pollutant of interest in aircraft plumes and other settings proximate to combustion sources (Herndon et al., 2008; Yu et al., 2004). UFP concentrations are typically dominated by local non-stationary sources, which have highly variable emissions and dispersion patterns over space and time. UFP emission rates have been shown to vary by more than an order of magnitude as a function of fuel flow (Kinsey et al., 2010) and therefore the stage of the landing and take-off (LTO) operation, implying the need for highly resolved source, pollutant, and meteorological information, as well as statistical approaches that can adequately capture these high-resolution dynamics. Studies to date of near-airport UFP concentrations (Hu et al., 2009; Westerdahl et al., 2008; Yu et al., 2004) provided valuable insight but did not formally characterize the conditions that led to high concentrations or the marginal contribution from aviation to ambient concentrations. While there are no ambient concentration regulations at present for UFP in the United States, growing evidence has linked UFP with adverse health outcomes (Delfino et al., 2005; Englert, 2004; Ibald-Mulli et al., 2002; Nemmar et al., 2001; Oberdorster, 2001; Utell and Frampton, 2000), and determining marginal contributions of aviation could help determine the most logical interventions to reduce community exposures.

To address these questions, a field study was conducted in the neighborhoods surrounding T.F. Green International Airport (PVD) in Warwick, RI, from October 2007–June 2008. In this study, real-time flight activity data, meteorology, and UFP concentration measurements at multiple sites surrounding the airport were used. The flight activity data allowed determination of the moments when each aircraft landed or took off, and we apply statistical approaches that can isolate the portions of the LTO cycle (including taxiing, take-off, and landing) contributing most to elevated concentrations. These models allow us to determine the contribution of flight activity to ambient UFP concentrations at multiple sites in the neighborhoods near the airport.

2. Methods

2.1. Study design and data collection

UFP concentration data were collected by our field team and the Rhode Island Airport Corporation (RIAC), as a part of a larger study. The overall goal was to understand the impact of airport activity on air quality near PVD, including air toxics concentrations, particulate matter concentrations, and related health risks.

PVD is a medium-sized airport with average operations of 300 flights per day. These flights are roughly divided into 45% commercial flight, 30% air taxis, 22% transient general aviation, 3% local general aviation, and <1% military (GCR and Associates, 2011). Runway 5/23 is the main runway (dimensions: 2184.2×45.7 m), and runway 16/34 serves as a secondary runway (dimensions: 1853.5×45.7 m). Both runways have the same weight capacity, but runway 5/23 handles more than 81% of the aviation activities due to its greater length and given the prevailing wind direction (aircraft usually take off into the wind to reduce the energy and take-off distance required for obtaining sufficient relative speed).

Monitoring was conducted over three one-week periods in October 2007, March 2008, and June 2008 at four stationary monitoring sites (Field View, Fire Station, Lydick, Pembroke) around PVD, as shown in Fig. 1.

The Field View site was located less than 0.16 km west of the main taxiway for the main runway and 0.16–0.32 km south of airport parking areas. The Fire Station site was located approximately 0.9 km north–northwest of the airport terminal building and 0.4 km north-northwest of the end of the airport's secondary runway (Runway 16–34). This site may also be impacted by road traffic as it is located near two major roadways (average daily road traffic of approximately 30,000 and 34,000) (Dodson et al., 2009). The Lydick site was located on the other side of the airport from the Field View site and was approximately 0.8 km northeast of the end of the main runway. This site may be impacted by local road traffic sources as it was located near (0.4–0.55 km) major roadways (average daily road traffic of approximately 36,000) servicing the airport. The Pembroke site was located on the northeast side of the airport, between a residential area and the airport, approximately 0.3 km from the main runway with major roadways further away. A major highway (Interstate-95) with approximately 170,000 vehicles per day is located approximately 2.5 km west of the airport.

One-minute average UFP concentrations were obtained at all sites using water-based condensation particle counters (WCPC Model 3781, TSI). Like other WCPCs, these instruments use a cooled saturator and a heated condenser to make particles into larger water droplets, which are then measured optically. To minimize particle diffusion losses, the aerosol flow rate of this model is set at 0.12 L min^{-1}, with an additional 0.48 L min^{-1} bypass flow at the inlet (TSI, Minneapolis, MN). The minimum detectable particle size of this WCPC is 6 nm. Compared to traditional butanol CPCs, the WCPC has a lower detectable particle size (6 nm versus 10–20 nm) and can run for longer periods of time given the large condensation media reservoir. The water-based and butanol-based instruments are generally concordant with one another, with major deviations expected only for pure hydrophobic aerosols (Franklin et al., 2010).

Along with UFP concentrations, meteorological and airport operations data were collected to allow prediction of the variability in pollutant concentrations over the study period. Meteorological data including temperature, relative humidity, dew point, and precipitation were obtained from the National Weather Service's airport station. High resolution wind data (averaged to 1 min) including wind speed and direction were collected by the Volpe National Transportation Systems Center using sonic anemometers produced by R.M. Young. Data from the anemometers were sampled and reported in either 5 or 10 s averaging times. The data were stored in self-contained data loggers and downloaded daily to a laptop computer. We also obtained from RIAC one-second resolution airport operations data, including arrival and departure times and runway usage, for each individual flight throughout the study period.

While binary flight activity data has been previously associated with near-airport pollutant concentrations (Dodson et al., 2009), emission rates can vary by orders of magnitude across aircraft. To approximate the relative differences in emissions among aircraft, we first identified the types and numbers of the engine of each flight in the LTO database. We then linked that information with a database of fuel consumption by aircraft type (ICAO Engine Exhaust Emissions Data Bank, 2010) which we considered to be a reasonable proxy of UFP emissions. Fuel usage during LTO for each aircraft was calculated as the product of the number of engines and the estimated fuel use during the LTO cycle for each engine.

All data were combined on a minute basis. In a preliminary analysis, we found that replacing the binary flight activity data with the fuel-weighted variable decreased the mean square loss of the model, suggesting a better model fit and justifying its inclusion.

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