Health Impacts of Aviation-Related Air Pollutants

PARTNER Project 11 Final Report

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The Partnership for AiR Transportation Noise and Emissions Reduction — PARTNER — is a cooperative aviation research organization, and an FAA/NASA/Transport Canada-sponsored Center of Excellence. PARTNER fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. The organization's operational headquarters is at the Massachusetts Institute of Technology.

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Project 11: Health Impacts of Aviation-Related Air Pollutants

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Although there is growing interest at FAA and elsewhere in evaluating the health impacts of aviation-related air pollution, previous efforts have had some key limitations. This includes limited understanding of the exposure implications of criteria air pollutant and air toxic emissions, and significant uncertainties associated with the health impacts of exposures to these compounds. In addition, there is broad concern about the degree to which dispersion models can adequately capture spatial patterns of exposure in close proximity to the airport, but it is challenging to determine source contributions from ambient monitoring data.

The primary objective of Project 11 was to better characterize the exposures and health risks associated with aircraft emissions and other airport activities, through the utilization of dispersion modeling and field monitoring studies and the development of updated estimates of toxicity for key air pollutants. Across the duration of the project, we developed and successfully implemented a number of sub-tasks, resulting in 12 peer-reviewed publications, one PARTNER report, and one manuscript currently undergoing peer review. The work under Project 11 is described in full in these 14 documents, which are included as appendices to the final report. Below, we briefly describe key findings across all project tasks, organized across broad thematic areas within Project 11.

Quantification of Aviation-Attributable Air Pollution Concentrations

One of the primary tasks within Project 11 was to develop and apply statistical methods that would allow for the fraction of ambient concentrations attributable to flight activity to be estimated. We led a field study at T.F. Green Airport in Warwick, Rhode Island, linking our monitoring data with measurements collected by the State of Rhode Island

Department of Environmental Management (RIDEM). In the first investigation (Dodson et al. 2009), focusing solely on long-term RIDEM data, we focused on black carbon (BC) concentrations measured at five monitoring sites from July 2005 to August 2006. We used conditional probability functions to ascertain wind direction conditions contributing to elevated concentrations, and constructed generalized additive models looking at the joint effect of wind speed and direction on concentrations. These models were incorporated into linear fixed effects regression models that used flight activity data to predict BC concentrations. Our models identified contributions from the airport, a major highway, and multiple local roads, with aircraft departures and arrivals estimated to contribute to 24-28% of BC concentrations across the monitoring sites.

Building upon this work, we conducted a series of investigations at T.F. Green Airport based on our field measurements, which included large-scale deployment of passive nitrogen dioxide (NO_2) samplers, continuous monitoring at fixed sites, and continuous mobile monitoring. For the NO_2 monitoring (Adamkiewicz et al., 2010), we used land use regression modeling to characterize spatial patterns and determine predictors. We found higher concentrations near the airport terminal, entrance roads to the terminal, and near major roads. In our final regression model, the local influences of highways and arterial/collector roads were statistically significant, as were local traffic density and distance to the airport terminal. This study reinforced the messages from Dodson et al., regarding the contributions of both traffic and aircraft to spatial patterns of air pollution near airports, but within an investigation in which temporal variability was limited.

For our fixed-site monitoring analyses, we focused on ultrafine particulate matter (UFP; Hsu et al. 2012). Statistical techniques were similar to those in Dodson et al. (2009), but we used one-minute average concentrations to better capture time dynamics of contributions, incorporated lag terms for flight activity to give insight about the aspects of landing and take-off (LTO) operations contributing most to concentrations, and used fuel burn weighting to better capture the potential emissions contributions of aircraft. Our results suggested a positive association between UFP concentrations and LTO activities, especially for departures when an aircraft moves near or passes a monitoring site, with a maximal impact one minute prior to take-off. As in previous analyses, we used our regression models to calculate absolute and percent contributions of flight activity by hour, with median aviation contributions of 2-10% across all monitors.

In a follow-up analysis using mobile UFP monitoring data (Hsu et al., 2014), we had a similar objective to determine contributions of both roadways and aircraft to spatial and temporal patterns of air pollutants, but using slightly different statistical techniques to capture data that vary significantly in both space and time (as opposed to the NO_2 data, which vary largely in space, and the fixed-site UFP data, which vary solely in time). We constructed spatially smoothed surfaces and evaluated whether incorporation of predictors changed the patterns within the smoothed surfaces, through examination of residuals from regression models. We found that distance to the nearest Class 2 roadway (highways and connector roads) was inversely associated with UFP concentrations in all neighborhoods. Departures and arrivals on a major runway had a significant influence on UFP concentrations in a neighborhood proximate to the end of the runway, with a limited influence elsewhere.

Although we made significant methodological process in our T.F. Green analyses, demonstrating techniques to calculate source contributions at a mid-sized airport, there were some limitations given the size of the aviation signal. We therefore embarked on a second study at Los Angeles International Airport, using data collected on the airport grounds as part of the Demonstration Project of the Air Quality and Source Apportionment Study (AQSAS). Our first analysis was analogous to our T.F. Green work, in which we examined the influence of flight activity on UFP concentrations (Hsu et al. 2013). Given the proximity of the monitors to the runways and the greater amount of aviation activity, we saw a much larger and clearer signal of flight activity, with the distribution shifting in time and space in a manner consistent with a contribution from departure activity. For example, our calculations of aviation-attributable concentrations indicated median (95th, 99th percentile) percent contribution for all LTO activities of 80.8% (97.9%, 99.4%), 37.8% (73.1%, 82.6%), and 45.6% (67.6%, 74.7%) for the monitor adjacent to the departure runway (SR), one 250 meters downwind (P4), and one 500 meters downwind (P5), respectively. The absolute contribution of LTO activity at the SR monitor had a median (95th, 99th percentile) of approximately 150,000 particles/cm^{3} (2,000,000, 7,100,000), quite large when compared with typical ambient concentrations, although the concentration dropped by an order of magnitude by the airport fenceline.

Our two additional AQSAS investigations extended our monitoring-based work in important directions. In one study (Diez et al., 2012), we examined multiple air pollutants simultaneously using a modified regression modeling approach to determine if there was

a combination of pollutants that could be characterized as an aviation "signature". At the SR monitor, we found a single, prominent peak in CO, CO_2, NOx, and SO_2 and a prominent drop in O_3 approximately 1−2 min following flight departures on the adjacent runway. CO_2 and NOx were the best single predictors of flight activity, but a multi-pollutant combination performed significantly better. In a second investigation (Penn et al., submitted), we compared the performance of our monitoring-based regression models with predictions from the EDMS/AERMOD system. Comparing predictions of both NOx and BC at the SR monitor allowed us to examine the potential for relative biases in the emissions inventory, as AERMOD does not treat these pollutants differently in the near field. We found a stark contrast in regression/dispersion ratios between NOx (0.93) and BC (4.13), indicating that there may be a downward bias in the BC emissions inventory. Comparing predictions of BC across all three monitors (SR, P4, and P5) allows us to determine the strengths and weaknesses of AERMOD and the regression modeling approach at varying distances from sources. Differences in the ratios between SR and the P4 and P5 monitors provides evidence that either AERMOD is overestimating concentrations downwind due to inappropriate treatment of the exhaust plume or that the regression model is underestimating concentrations downwind. Significant differences in diurnal patterns reinforce previously-reported challenges with AERMOD in its treatment of plume buoyancy.

In summary, our studies provided novel statistical techniques that for the first time ascertained source contributions from ambient measurements near airports, looking at an array of pollutants and considering patterns in both time and space. Comparisons with dispersion modeling outputs reinforce the strengths and limitations of multiple approaches for source attribution. More generally, the methods we have developed are applicable to any airport or other monitoring site where aviation contributions need to be quantified.

Estimation of the Public Health Impacts of Aviation Emissions

The second major thematic area under Project 11 involved health risk assessment models to determine the public health implications of aviation emissions. In an early report (Levy et al.., 2008), we focused on three airports (T.F. Green Airport (Rhode Island), Chicago O'Hare International Airport (Illinois), and Hartsfield-Atlanta

International Airport (Georgia)) and conducted preliminary risk assessments to determine the high-priority compounds requiring further study. We summarized the literature for both criteria air pollutants and air toxics, and we used AERMOD and CMAQ outputs and other information to approximate population exposures. Air toxics impacts were two orders of magnitude less than criteria pollutant impacts, which were dominated by fine particulate matter. We therefore used this report to conclude that a significant focus on fine particulate matter would be warranted going forward.

In a follow-up analysis (Arunachalam et al., 2011) in collaboration with Project 16, we modeled health risks from the same three airports and considered the influence of atmospheric chemistry transport model scale and resolution on estimates of the public health impacts from LTO emissions. Although maximum concentrations differed significantly as a function of CMAQ model resolution (36 km vs. 12 km vs. 4 km), total population health risks were largely unaffected by model resolution. In contrast, a larger model scale was extremely important to capture the total public health impacts of an airport, especially for secondarily-formed particulate matter. We extended this modeling work to consider 99 airports across the US, focusing on the influence of time-varying factors (emissions, population, background concentrations) on the public health impacts of LTO emissions (Levy et al., 2012a). Given our defined scenarios, aviation-related health impacts would increase by a factor of 6.1 from 2005 to 2025, with a factor of 2.1 attributable to emissions, a factor of 1.3 attributable to population factors, and a factor of 2.3 attributable to changing non-aviation concentrations which enhance secondary $PM_{2.5}$ formation. The methods that we developed, including the concentration-response functions, approaches for characterizing population data, and strategies for estimating total population exposure per unit emissions, informed public health impact calculations within multiple collaborative PARTNER studies (Barrett et al., 2012; Brunelle-Yeung et al., 2014).

We conducted two additional analyses related to aviation health effects, intended to inform policy models. In the first (Zhou et al., 2009), we focused on the magnitude of air toxics emissions (benzene, 1,3-butadiene, and benzo[a]pyrene) that would be required to exceed 10^{-6} lifetime cancer risks for the maximally exposed individual, and we calculated the resulting total population health risks. The emission thresholds varied by two orders of magnitude across airports, with variability predicted by proximity of populations to the airport and mixing height. At these emission thresholds, the

population risk within 50 km of the airport varied by two orders of magnitude across airports, driven by substantial heterogeneity in total population exposure per unit emissions that is related to population density and uncorrelated with emission thresholds. We therefore concluded that site characteristics could be used to estimate either maximum individual risk or total population risk, but that optimizing on one of these factors would be non-optimal for the other. In the second (Levy et al., 2012b), we developed and applied novel statistical methods to evaluate the likelihood that different particle constituents had differential toxicity, a crucial question for health risk modeling of fine particulate matter. Through a literature survey, we concluded that the methods used to date provided little insight about probabilities of differential impacts per unit concentration change. Using our new statistical methods, posterior probabilities from multi-constituent models provided evidence that some individual constituents were more toxic than others, and posterior parameter estimates coupled with correlations among these estimates provided necessary information for risk assessment.

In summary, our health risk assessment modeling work helped to focus PARTNER efforts on fine particulate matter, provided the functions and databases needed to conduct fine particulate matter health risk assessment, and developed novel insight about potential differential toxicity across particle constituents.

Conclusions

In Project 11, we addressed multiple topics relevant to the evaluation of the health impacts of aviation-related air pollutants. We used a variety of techniques to better understand how aviation activity (especially LTO activity) contributes to ambient concentrations and total population exposures, key inputs for health risk models. We calculated how those changes in concentrations would influence public health impacts, considering an array of issues related to model resolution, model scale, time-varying impacts, and differential toxicity. Collectively, our efforts provided an important foundation for policy models and future investigations of exposures and health effects.

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