Assessing Air Quality Impacts of Airport Emissions from Local to Regional Scales

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• Context of Health Risk due to Aircraft Emissions compared to other Sectors
• Aircraft Emissions – Spatio-temporal Profiles
• Air Quality Studies
  – Regional-Scale Studies at Select Airports
    • Atlanta, Chicago and Providence
  – Future Year Assessment
    • US-wide impacts
  – Airport-Specific Impacts using Sensitivity Modeling
    • NAS-wide vs. Top 99 airports in the U.S.
    • Illustration for NYC Top 3 airports
  – UFP due to Aircraft
  – Local-Scale Dispersion Studies
    • Los Angeles International Source Apportionment Study
• Conclusion
# Health Risks Due to Air Pollution

## Risk Factors by Burden of Disease

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Global</th>
<th>High-income Asia Pacific</th>
<th>Western Europe</th>
<th>Australasia</th>
<th>High-income North America</th>
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<th>Eastern Europe</th>
<th>East Asia</th>
<th>Tropical Latin America</th>
<th>Central Latin America</th>
<th>Southeast Asia</th>
<th>Central Asia</th>
<th>Andean Latin America</th>
<th>North Africa and Middle East</th>
<th>Caribbean</th>
<th>South Asia</th>
<th>Oceania</th>
<th>Southern sub-Saharan Africa</th>
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<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Risk Ranking</th>
<th>Premature Mortalities</th>
<th>Risk Rating</th>
<th>Premature Mortalities</th>
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<tr>
<td>Ambient Ozone</td>
<td>39</td>
<td>152K</td>
<td>34</td>
<td>254K</td>
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<tr>
<td>Ambient PM</td>
<td>9</td>
<td>3.2M</td>
<td>5</td>
<td>4.2M</td>
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Transportation sectors contribution is ~33% for PM$_{2.5}$ and 63% for O$_3$.

Aircraft contribute about 2% for O$_3$ and 1% for PM$_{2.5}$ in the U.S.

**PM$_{2.5}$**
- 200K [95% CI 89K – 367K]

**O$_3$**
- 10.1K [95% CI -1.3K – 3.7K]
Aircraft Exhaust

Adapted from Masiol et al, 2014

Key Air Pollutants: CO, NO₂, SO₂, O₃, Lead, PM₂.₅, UFP, Air Toxics
FAA’s Emissions Model
EDMS -> AEDT

- Only landing and take-off (below 3000 ft) includes climb out, approach, taxi, and idle
- Estimated from Aviation Environmental Design Tool (AEDT) based on the aircraft locations
  - NOx, SO2, VOC, CO + 3 directly emitted components of PM$_{2.5}$

EDMS: Emissions Dispersion Modeling System
AEDT: Aviation Environmental Design Tool

Wilkerson et al, ACP 2010
Baek et al, 2012
PM$_{2.5}$ formed from LTO emissions at 3 U.S. airports
Atlanta, Chicago, Providence

- Focus on Grid-cell containing airport
- Up to 40% of PM$_{2.5}$ is due to secondary contribution

Arunachalam et al, AE 2011
Hybrid Modeling with CMAQ and SCIPUFF (Atlanta Airport)

- Maximum puff conc > 10x grid conc, vary between 6.1 – 42.1 μg/m³
- Use of a subgrid-scale treatment may be less important if one seeks to understand only median impacts, but provides insight in revealing potential max impacts masked by grid-scale modeling
SOA due to Aircraft

- Measured changes in PM mass at different loads (4% idle; 7% taxi, 30% landing and 85% takeoff)
- Traditional SOA model underpredicts total SOA by ~60% at 4% load, and ~40% at 85% load

Miracolo et al, ACP 2011
Non-traditional SOA Contributions to PM$_{2.5}$ at ATL

- NTSA formed from oxidation of S/IVOCs, typically not accounted for in AQMs
- NTSA contributed 1.7 – 7.4% at ATL; ~6x higher than aircraft TSOA
- NTSA comprised up to 30% of aviation-attributable PM$_{2.5}$ downwind of ATL

**Figure 3.4:** Monthly average contributions from aircraft to PM$_{2.5}$ in a) January and b) July, to non-traditional SOA (NTSOA) in c) January and d) July, and NTSOA (＞0.1 ng m$^{-3}$) as a percentage of aircraft-attributable PM$_{2.5}$ in e) January and f) July. Note the differences in scales, that the absolute maximum impacts occur in the grid cell containing ATL but the percentage of aircraft-attributable PM$_{2.5}$ comprised of NTSOA is higher away from the airport, and that the map covers an area of 720 km x 720 km. Circles indicate the location of ATL and 30 km, 54 km, 78 km, and 102 km away from ATL.

To test the impact of OA concentrations on NTSOA concentrations, we conducted a sensitivity analysis using our CMAQbox model. Two test cases were simulated, one using typical ambient OA concentrations (5 µg m$^{-3}$) and the other using mode-specific OA concentrations measured in the smog chamber (6–250 µg m$^{-3}$) during the Miracolo et al. (2011) experiments. Results indicated that when ambient OA concentrations were used, NTSOA and SOA production at the 4% power setting were approximately a factor of six lower compared to the same simulation using smog chamber OA concentrations. This also provides one indication of why the majority of NTSOA contributions were from non-idle aircraft activities, despite the higher potential from idle emissions.

NTSOA/PM$_{2.5}$ *100

Woody et al, ACP 2015
Aviation attributable PM$_{2.5}$ contributions – Current and Future - U.S. Wide activity

- Future year 2025 PM$_{2.5}$ impacts due to aircraft activity growth is 5.5x that of 2005 (using 2005 climate)
- Most of this growth is due to increase in “Free ammonia” in 2025 (8% ↑ in background NH$_3$ and 35% ↓ in background NO$_x$ emissions)
- Incorporating change in climate increases this to 5.9x (~7% additional contribution)

Woody et al, AE 2011
Future Year AQ Impacts of Growth in Aviation from 2005 to 2025

Arunachalam et al, 2015

- Aviation emissions cause a ~6x increase in future year PM$_{2.5}$ impacts, mostly from secondary components
- # Grid-cells exceeding O$_3$ NAAQS (75 ppb) see a 60% ↑ in future year due to change in climate
- Aircraft emissions increase future year NO$_2$ exceedances by 6x in some major urban areas
Primary and Secondary PM$_{2.5}$ Impacts at Downwind Distances of Airport

- Atlanta Airport
- Top 99 U.S. Airports

- Radial analysis of PM$_{2.5}$ from CMAQ-DDM Simulations of 99 U.S. Airports

Boone et al., 2015
Speciated individual airport PM$_{2.5}$ sensitivities at home grid cell

When sensitivity of PM$_{2.5}$ is disaggregated by precursor, the amount of PM$_{2.5}$ species produced by each tagged input can be seen. Airports shown in descending order of home-cell PM$_{2.5}$ sensitivity.

Boone et al, 2015
U.S. airports PM$_{2.5}$ sensitivity by radius

Each ring represents a 50km radius from the airport; airports shown in descending order of average sensitivity.

Boone et al, 2015
Relative contribution at airport grid cell

Boone et al, 2015

- Several airports contribute > 0.1% of total PM$_{2.5}$ in the vicinity of airport
Airport-specific premature mortalities

Penn et al, Environ. Res. 2017
Sensitivities of O$_3$ and PM$_{2.5}$ due to Precursors from NYC airports - EWR, JFK and LGA

**First order Sensitivity of O$_3$ to All**

**First order Sensitivity of PM$_{2.5}$ to All**
Recent studies indicate that number concentrations of ultrafine particle significantly increase due to LTO activity in LAX, BOS, AMST, Rome (Hudda et al., 2016; Hudda and Fruin, 2016; Keuken et al., 2015; Riley et al., 2016; Stafoggia et al., 2016)
Impact of new CMAQ module to treat aircraft emissions using size characteristics from engine measurements

In airport grid-cells, PM$_{2.5}$ mass $\downarrow$ by upto ~25%, whereas particle number concentration (of UFP) by $\uparrow$ upto ~5x at large airports

Huang et al, In Prep
Los Angeles International (LAX) chosen because
- LAX is one of the top 5 airports in the U.S.
- Los Angeles World Airport (LAWA) conducted the Air Quality Source Apportionment Study (AQSAS) Phase III
- Intensive field campaign during two seasons
  - Winter (January 31 – March 13, 2012)
  - Summer (July 18 – August 12, 2012)
- Over 400 compounds measured at 17 locations
- 4 “core”, 4 “satellite” and 9 “gradient”
Aircraft LTO Activity at LAX and monitoring locations

http://www.lawa.org/airQualityStudy.aspx?id=7716
Emissions from Aircraft sources compared to Airport-wide sources at LAX

Aircraft and GSE dominate NO$_x$

Aircraft dominate SO$_x$

PM$_{2.5}$ is from several sources
Mean NO$_x$ during Summer

AERMOD and SCICHEM predicted means are closer to observations, while ADMS and CALPUFF tend to overpredict.

• Health impacts from PM$_{2.5}$ dominate compared to other pollutants ($O_3$, air toxics) (Levy et al., 2008)

• Secondary PM$_{2.5}$ dominates at downwind distances (~200-300 km from airport), while primary components dominate in near field (Arunachalam et al, 2011)

• Future year AQ impacts of aviation growth in U.S. dominated by nitrate aerosol, largely due to increase in background free ammonia (Woody et al, 2011)

• Future year aviation-related health impacts in U.S. would increase by 6.1x from 2005 to 2025 (2.1x due to emissions, 1.3x to population, and 2.3x to background) (Levy et al, 2012)

• Incorporating for change in climate adds another ~7%, which we attribute as “climate penalty” (Arunachalam et al, 2015)

• Hybrid modeling approach assists with assessing local and regional AQ impacts of aviation (Rissman et al, 2013)
Summary Points (2 of 2)

- **NTSOA contributions can be upto ~30% of total PM$_{2.5}$ due to airport emissions (Woody et al, 2015)**
  - Recently gained knowledge on SOA (TSOA + NTSOA) shifts both magnitude and composition of aviation-attributable PM$_{2.5}$

- **Stringent revisions to health-based standards will likely exacerbate aviation-related contributions to exceedances in non-attainment areas**

- **CMAQ-DDM based sensitivity approach provides potentially powerful framework to explore attainment/non-attainment issues**

- **Additional work needed to**
  - Reduce uncertainties in aircraft emissions of nvPM, and precursors of volPM [Stettler et al, 2013; Penn et al, AE 2015]
  - Characterize UFP impacts (Mass vs. Number on a size-resolved basis)
  - Enhance local-scale dispersion models to represent aircraft sources adequately for accurate local-scale impact assessment
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