Supporting Information

Environmental Costs of Leaded Aviation Gasoline

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Aviation Inventory Description

Landing and Takeoff (LTO) lead emissions were taken from the 2008 EPA National Emissions Inventory (NEI). Lead emissions are provided as annual total emissions at nearly 20,000 airport or airfield facilities and were calculated for the 2008 NEI by assuming a fuel lead content of 2.12 g Pb/g and a 5% retention of lead in the engine oil/exhaust system.[1] Emissions outside the continental United States, including 4.8 tons of emissions in Alaska, were discarded as they occur outside the domain of the air quality model. LTO emissions are geo-located by airport center and are averaged over the CMAQ grid-cell containing the airport center. The altitudinal distribution of non-LTO phases of GA flights is heterogeneous and can occur both above and below the mixing height depending on the flight purpose. Non-LTO lead emissions are distributed over all cells in the state of the originating flight, with altitudinal, diurnal, and seasonal distributions applied as described in the main text. The seasonal distribution is applied on a monthly basis nationwide based on the results of the average temporal patterns of General Aviation across the country.[2] This distribution will likely overestimate the seasonality of operations in some regions and underestimate the seasonality of operations in others. Figure S1 shows the national average monthly distribution of operations as applied in this study and compares it to two locations with low and high seasonal heterogeneity.

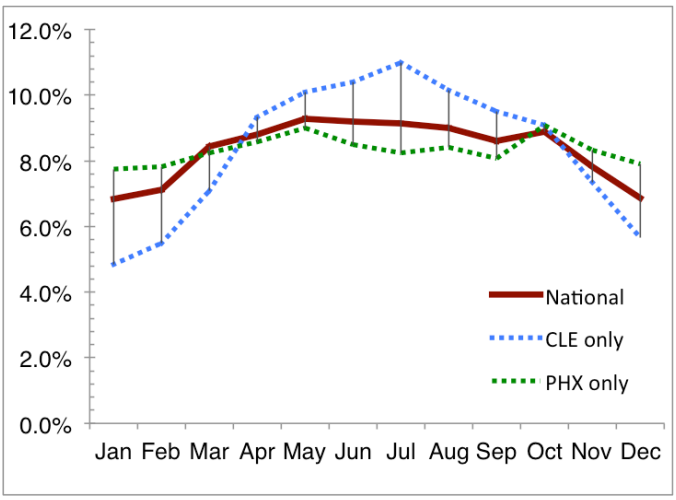

Figure S1. Seasonal distribution of General Aviation operations.

Figure S2 shows the spatial distribution of the yearly total aviation lead emissions (LTO and full-flight emissions). Lead emission totals are the summed annual emissions across all altitude layers and include both LTO and cruise phase emissions.

Figure S2. Map indicating the location of aviation lead emissions across the continental United States.

CMAQ Description

The vertical domain is discretized into 34 layers by pressure levels according to the sigma coordinate system from the surface of the earth up to the 100 millibar pressure level (corresponding to an altitude of approximately 52,000ft or 16km). The vertical grid is terrain-following (i.e. the first grid box is always on the surface). The first 3000ft in altitude are represented by 13 layers with grid box heights ranging between 38-167m.

Table S1. Vertical Layers in the CMAQ modeling domain.

Layer	Sigma Coordinate	Pressure(mb)	Height above ground(m)
34	0.000	100	15668.0
33	0.05	145.6	13664.8
32	0.10	191.3	12080.6
31	0.15	237	10759.7
30	0.20	282.6	9621.2
29	0.25	328.3	8617.3
28	0.30	374	7717.4
27	0.35	419.6	6900.4
26	0.40	465.3	6151.2
25	0.45	511.0	5458.5
24	0.50	556.6	4813.9
23	0.55	602.3	4210.5
22	0.60	647.9	3643.1
21	0.65	693.6	3107.2
20	0.70	739.3	2599.3
19	0.74	775.8	2211.1
18	0.77	803.2	1929.7
17	0.80	830.6	1656.0
16	0.82	848.9	1477.6
15	0.84	867.1	1302.3
14	0.86	885.4	1130.1
13	0.88	903.7	960.7
12	0.90	921.9	794.2
11	0.91	931.0	711.9
10	0.92	940.2	630.3
9	0.93	949.3	549.3
8	0.94	958.4	469.0
7	0.95	967.6	389.3
6	0.96	676.7	310.3
5	0.97	985.8	231.8
4	0.98	995.0	154.0

Layer	Sigma Coordinate	Pressure(mb)	Height above ground(m)
3	0.985	999.5	115.3
2	0.990	1004.1	76.7
1	0.995	1008.7	38.3

CMAQ treats lead as an aerosol phase Hazardous Air Pollutant (HAP), occurring in Aitken, accumulation, and coarse mode. CMAQ computes and tracks aerosol HAPS components within particulate matter; thus, lead emissions are treated as chemically inert but undergo the same microphysical processes and deposition rates determined within the aerosol module. Non-lead emissions contributing to particulate matter concentrations, such as NO_X and SO_X, are not treated as chemically inert by the model. A shortcoming of this approach is that it does not include an aerosol mode representing ultrafine lead particles, which may undergo faster dispersion rates.[1]

Meteorology

Model concentrations are simulated using year 2005 meteorological input data as taken from the Weather Research and Forecasting (WRF) v3.3.1 model.[4] The WRF meteorological data has been compared and validated against monitor data for temperature and wind speed for the CMAQ modeling domain for use in air quality modeling studies.[5,6] Year 2005 meteorology was selected because of the availability of an existing validated data set; and the use of 2005 meteorology has been justified for use in other air quality studies because the presence of summer stagnant air masses and clear skies is conducive to $PM_{2.5}$ and ozone formation.[5]

Year 2005 summer temperatures, particularly in the Northeast and Southwest, and precipitation, particularly in the Southeast and Central Plains, were above average for the United States. Fall temperatures for 2005 were significantly above average for much of the

US.[7] 2008 was on average cooler across the United States than in 2005. Precipitation in 2008 was variable, with periods of excessive rainfall in the Central Plains.[7]

Table S2. Parameterization of atmospheric lead (PbA [μg/m^3]) to blood lead ([PbB (μg/dL)]) Concentration Response Functions (CRFs). The concentration response functions used in this study are taken from literature sources that have differing population demographics, timescales, exposure levels, and geographic scopes. The CRFs are grouped into to functional forms: ln-ln and linear.

Model Form	Model	β	Notes
Ln-ln	Model 1[10]	0.076	Based on NHANES III (1988-1994) national data and annual average TSP from the EPA Air Quality System, for children 1-5 yrs.[27]
	Model 2[10]	0.140	Based on NHANES 9908 (1999-2008) national data and annual average TSP from the EPA Air Quality System, for children 1-5 yrs.[27]
	Model 3[11]	0.3485	Meta-analysis of 18 studies spanning 1970-1982, for a variety of countries, and children's ages. Model based on data for all children.[34]
	Model 4[11]	0.2159	Meta-analysis of 18 studies spanning 1974-1982, for various countries, and children's ages. Model based on data for children with "low" PbB (<20 μg/dL).[34]
	Model 5[12]	0.24	Based on PbB data from Chicago, IL (1968-1988), with quarterly average PbA data from the IL EPA, for children 0.5-6 yrs.[32]
Linear	Model 6[13]	7	Based on PbB data from Trail, British Columbia (1991-2000), with quarterly average PbA data from the smelter company, for children 0.5-6 yrs.[31]
	Model 7[14]	8.6	Based on PbB data from Chicago, IL (1976-1980), with PbA estimated from gasoline usage, for children 0-5 yrs.[33]
	Model 8[15]	3.6	Based on PbB data from Mumbai, India (1984-1996), with 24-hr PbA data collected by the authors at residences of the study population, for children 6-10 yrs.[30]

The two air-to-blood CRF functional form groups behave differently at low concentrations (< 0.02 μg/m^3) and higher concentrations of atmospheric lead. **Figure S3** shows the behavior of the 8 CRFs at low concentrations and **Figure S4** shows the behavior of the same CRFs at higher concentrations.

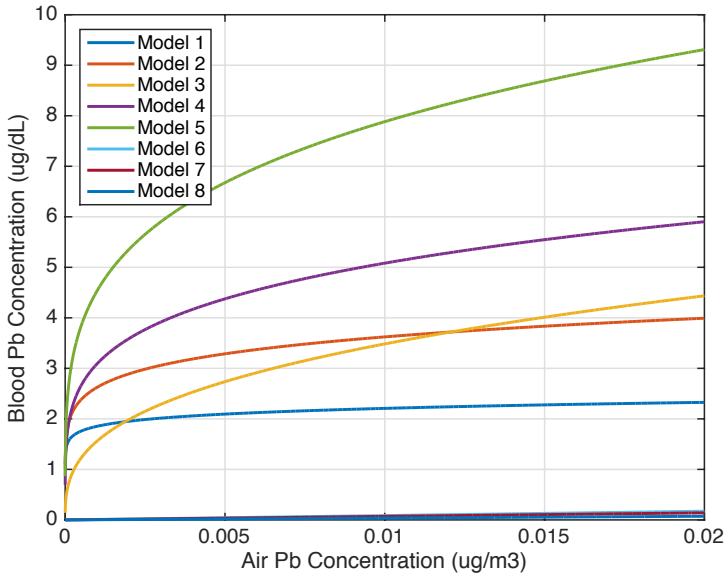

Figure S3. Air-to-blood Concentration Response functions over a range of low air lead concentrations.

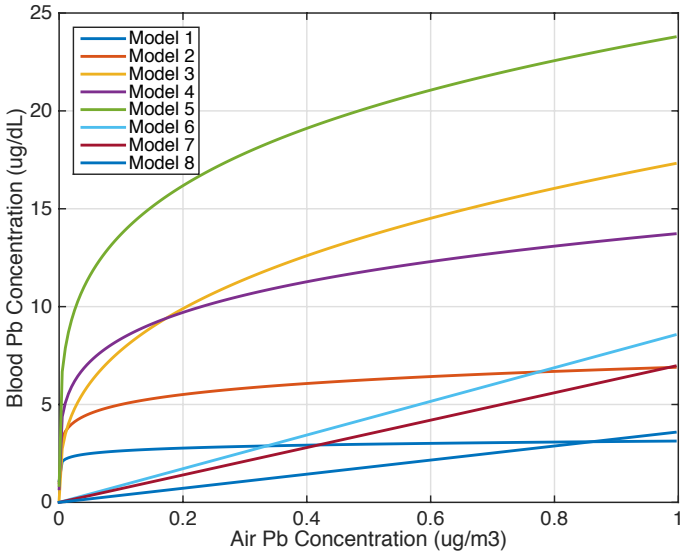

Figure S4. Air-to-blood Concentration Response functions over a larger range of air lead concentrations.

Table S3. Blood lead ([PbB (µg/dL)] to IQ loss concentration response functions.

Model	Model Form	Equation
Model A[16]	**Log-linear with threshold**	*For concurrent PbB > 1 µg/dL* $\Delta IQ = \ln(PbB) \cdot 2.65$ *For concurrent PbB ≤ 1 µg/dL* $\Delta IQ = 0$
Model B[16]	**Log-linear with linearization at low exposure**	*For concurrent PbB > 1 µg/dL* $\Delta IQ = \ln(PbB) \cdot 2.65 + 2.65$ *For concurrent PbB ≤ 1 µg/dL* $\Delta IQ = PbB \cdot 2.65$
Model C[16]	**Dual linear with slope change at 5 µg/dL ("Dual linear – 10")**	*For concurrent PbB > 5 µg/dL* $\Delta IQ = (PbB - 5) \cdot 0.13 + 5 \cdot 0.77$ *For concurrent PbB ≤ 5 µg/dL* $\Delta IQ = PbB \cdot 0.77$
Model D[16]	**Dual linear with slope change at 3.75 µg/dL ("Dual linear – 7.5")**	*For concurrent PbB > 3.75 µg/dL* $\Delta IQ = (PbB - 3.75) \cdot 0.15 + 2.53 \cdot 3.75$ *For concurrent PbB ≤ 3.75 µg/dL* $\Delta IQ = PbB \cdot 2.53$

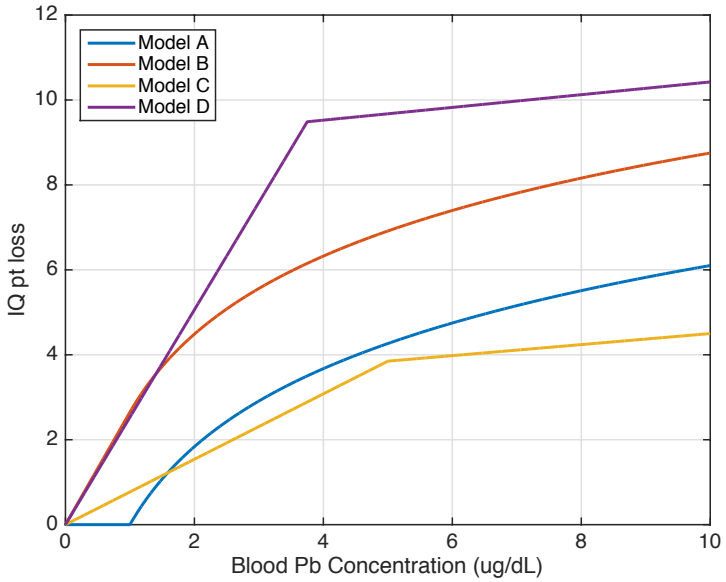

Figure S5. Blood-to-IQ CRFs for a range of blood lead levels.

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