

Boston University and Massachusetts Institute of Technology Report to Congress on the Study on Potential Health and Economic Impacts of Overflight Noise

**FAA Reauthorization Act of 2018
(Pub. L. 115-254)
Section 189**

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1. Introduction

Under the FAA Reauthorization Act of 2018 (Pub. L. 115-254), Section 189, *STUDY ON POTENTIAL HEALTH AND ECONOMIC IMPACTS OF OVERFLIGHT NOISE*, Congress directed the following:

SEC. 189. STUDY ON POTENTIAL HEALTH AND ECONOMIC IMPACTS OF OVERFLIGHT NOISE.

(a) In General – Not later than 180 days after the date of enactment of this Act, the Administrator of the Federal Aviation Administration shall enter into an agreement with an eligible institution of higher education to conduct a study on the health impacts of noise from aircraft flights on residents exposed to a range of noise levels from such flights.

(b) SCOPE OF STUDY. — The study conducted under subsection shall—

(1) include an examination of the incremental health impacts attributable to noise exposure that result from aircraft flights, including sleep disturbance and elevated blood pressure;

(2) be focused on residents in the metropolitan area of--

(A) Boston;

(B) Chicago;

(C) the District of Columbia;

(D) New York;

(E) the Northern California Metroplex;

(F) Phoenix;

(G) the Southern California Metroplex;

(H) Seattle; or

(I) such other area as may be identified by the Administrator;

(3) consider, in particular, the incremental health impacts on residents living partly or wholly underneath flight paths most frequently used by aircraft flying at an altitude lower than 10,000 feet, including during takeoff or landing;

(4) include an assessment of the relationship between a perceived increase in aircraft noise, including as a result of a change in flight paths that increases the visibility of aircraft from a certain location, and an actual increase in aircraft noise, particularly in areas with high or variable levels of nonaircraft-related ambient noise; and

(5) consider the economic harm or benefits to businesses located partly or wholly underneath flight paths most frequently used by aircraft flying at an altitude lower than 10,000 feet, including during takeoff or landing.

In brief, Section 189 was interpreted by the FAA to direct the study to assess impacts of overflight noise referring to noise generated during aircraft flight under 10,000 feet during takeoff and landing. In particular, the study needed to assess health impacts attributable to aircraft overflight noise exposure, including effects on sleep disturbance and elevated blood pressure, in selected metropolitan areas. The study also needed to consider noise perception related to aircraft visibility and the economic harm or benefits to businesses located underneath low-altitude flight paths. In addition, Section 189 also defined specific eligibility criteria for which institutions of higher education may conduct the research. The specific criteria were identified as follows:

(c) ELIGIBILITY. — An institution of higher education is eligible to conduct the study if the institution--

(1) has--

(A) a school of public health that has participated in the Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation of the Federal Aviation Administration; or

(B) a center for environmental health that receives funding from the National Institute of Environmental Health Sciences;

(2) is located in one of the areas identified in subsection (b);

(3) applies to the Administrator in a timely fashion;

(4) demonstrates to the satisfaction of the Administrator that the institution is qualified to conduct the study;

(5) agrees to submit to the Administrator, not later than 3 years after entering into an agreement under subsection (a), the results of the study, including any source materials used; and

(6) meets such other requirements as the Administrator determines necessary.

Consistent with this scope and eligibility criteria, the FAA entered into an agreement with the Boston University School of Public Health (BUSPH) in collaboration with Brigham and Women's Hospital, the Harvard Medical School/Harvard T.H. Chan School of Public Health (HSPH), and Massachusetts Institute of Technology (MIT) to conduct the study and funded the study through the FAA's Center of Excellence for Alternative Jet Fuels and Environment, known as the Aviation Sustainability Center (ASCENT), under Project 3. The information contained within this report summarizes the results of the study on the potential health and economic impacts of aircraft overflight noise in accordance with the requirements of Section 189, and provides links to published articles providing full details. The report provides a summary of key results on aircraft overflight noise and health impacts including the sociodemographic patterns of noise exposure, noise and hypertension, noise and sleep, and noise and cardiovascular disease (CVD) as well as aircraft overflight noise and perception, and aircraft overflight noise and business activity.

Section 2 of this report discusses the background of the study. Section 3 provides an overview of the study methods and data. Section 4 summarizes the study findings and provides links to the published articles. Section 5 provides study conclusions.

2. Background of the Study

Exposure to aircraft overflight noise has been associated with physiological responses and psychological reactions [1,2], including nervousness, annoyance, sleep disturbance, and sleep-disordered breathing [2,3]. However, the extent to which exposure to aircraft overflight noise increases the risk of adverse health outcomes is not well understood. Recent literature, primarily from European studies, provides evidence of a relationship between aircraft overflight

noise and self-reported hypertension [3], increased blood pressure [4-8], antihypertensive medication use [1,9-11] and incidence of hypertension [12,13]. However, it is unclear whether results from international studies would be transferable to U.S.-based populations. More generally, there are few investigations of aircraft overflight noise and health or sleep in large cohorts, which would be needed to distinguish the effects of aviation from other risk factors. Beyond quantifying health impacts, little evidence has been presented on the economic impacts of aircraft overflight noise exposure on businesses located underneath flight paths [14,15].

The study team aimed to use the best available data and techniques to study health and economic impacts and noise perception of aircraft overflights in the U.S. to address gaps in knowledge, fulfill the requirements of Section 189, and support the research goals of the FAA in ASCENT. The BUSPH team met the requirements of Section 189, (c), (1) A and B being a school of public health participating in an FAA Center of Excellence and receiving National Institute of Environmental Health Sciences funding, including related to noise research. All universities met the requirements under (c), (2), (3), and (4), including being located in one of the identified areas (Boston metropolitan area). The BUSPH and HSPH team studied the health impacts and MIT studied the economic impacts.

3. Study Methods and Data

The study team took an *empirical approach* to the charge; that is, the team used noise exposure models and real-world observed health and economic data to identify potential associations between aircraft overflight noise exposure and multiple human health outcomes (including hypertension, cardiovascular disease (CVD) and sleep disturbance), between aircraft overflight noise and perception (particularly aircraft visibility), and between aircraft overflight noise exposure and business activity (e.g., business location). To better inform analyses of health impacts, including identifying underlying factors that might affect the evaluation of the association between noise and health effects, the team also evaluated the sociodemographic patterns of aircraft overflight noise exposure. For all analyses, state-of-the-art methods for data analysis were applied and developed. Data sets covered the metropolitan areas identified in Section 189, (b), (2), including Boston, Chicago, the District of Columbia, New York, the San Francisco Bay Area, Los Angeles and San Diego Metro Areas, Phoenix and Seattle.

Noise analyses were based on noise metrics used in the U.S. regulatory context as well as those thought to also relate to health effects or noise perception. Specifically, noise analyses were conducted using the Day-Night Average Sound Level (DNL) and Nighttime Equivalent Sound Level (L_{night}). DNL is the primary metric used by FAA to determine noise impacts [16] and nighttime noise is a metric potentially more relevant to sleep disturbance that is additionally included in some international noise directives [17]. For the analyses, different DNL thresholds were applied to identify affected areas, with thresholds varying from 45 decibels (dB) to 65 dB. These thresholds were chosen to be consistent with U.S. and global guidelines as well as to

reflect the empirical distribution of noise within the study populations. The underlying dataset, produced by the U.S. Department of Transportation (DOT) Volpe Center (Volpe) under agreement with the FAA, included noise exposure data for DNL and L_{night} surrounding 90 U.S. airports that cover 87% of all passenger enplanements at U.S. airports [18]. Noise data were provided for the period of 1995-2015 in 5-year intervals and included sound levels at 1 dB increments down to 45 dB.

For the business impacts analyses, some of these data were reproduced using Volpe's methods, but with increased spatial and temporal resolution. Specifically, MIT ran high-resolution noise analysis [19] which relies on actual rather than representative flight trajectories. This approach allows for high-fidelity representation of trajectory changes from the introduction of Performance Based Navigation (PBN), including enhanced modeling of dispersion and concentration effects. This high-fidelity representation provides a more accurate measure of the impact on businesses than the data alone. Although the analyses did not specifically test impacts of exposure to flights based on altitude, the thresholds selected included participants and areas with frequent exposure to aircraft overflights resulting from aircraft takeoff and landing below 10,000 feet Above Ground Level (AGL).

Using the methodologies in this section the research team was able to identify the best available datasets to investigate potential associations between aviation noise exposure, health, sleep, and business outcomes. In general, the statistical analyses benefited from large samples and high spatial resolution (i.e., census block and smaller). However, the investigation was challenged by the highly localized nature of aircraft overflight noise exposure. This was especially the case in relation to (1) changes in aircraft overflight noise exposure due to the implementation of PBN procedures, and (2) analyses of health outcomes in relation to a key decision-relevant metric for FAA, given that only a small fraction of the study population (approximately 0.1%) was exposed to aircraft overflight noise more than DNL 65 dB.

3.1. Aircraft Overflight Noise and Health Impacts

To investigate the *impacts of aircraft noise on health*, the team used data from large population cohorts followed over time and applied state-of-the-art epidemiological and statistical approaches to distinguish the effects of aircraft overflight noise from other risk factors. Among participants in the study who were free of health effects at the start of the study, the rates of developing health impacts such as hypertension or cardiovascular disease in those exposed to higher levels of aircraft overflight noise, including noise associated with aircraft overflights below 10,000 feet AGL during takeoff and landing, were compared to the rates in those less exposed. For sleep disturbance, multiple assessments of residents over time were leveraged to look at the relationships with aircraft overflight noise exposure. Aircraft overflight noise data for DNL and L_{night} over multiple years allowed consideration of variation in exposure to noise over time for a 24-hour average period and during nighttime hours, respectively.

For the assessment of the sociodemographic patterns of noise exposure, the team overlaid aircraft noise data with U.S. Census Bureau data to compare exposure to DNL and L_{night} of Census block groups by race/ ethnicity, education, and income at various noise thresholds.

For the epidemiological analysis, to cover multiple geographic regions and include important individual-level data that can predict cardiovascular health, the team chose to utilize geocoded data from the ongoing prospective Nurses' Health Studies (NHS; <https://nurseshealthstudy.org/>), a well-respected data source that includes over 200,000 female nurses living nationwide including in the metropolitan areas specified in Section 189 (b)(2). The participants were assessed biennially over 15-20 years to systematically track health outcomes such as hypertension and CVD as well as sleep. Existing cohort studies such as the NHS offer a wealth of information over the long term that can be leveraged for health impact studies; however, as these studies were not specifically designed to study noise, there were small numbers exposed to aircraft overflight noise, particularly at high levels. This influenced the noise threshold at which the relationship between noise and health outcomes could be assessed and required estimates of noise exposure at high resolution down to fairly low levels.

Aircraft noise data were linked with the geocoded addresses of the NHS participants. Analyses were performed using longitudinal statistical methods to appropriately and fully incorporate multiple years of aircraft noise estimates and participant data (e.g., time-varying proportional hazards).

3.2. Aircraft Overflight Noise and Perception

The correlation between changes in aircraft noise and the visible perception of overflight aircraft below 10,000 ft AGL during takeoff and landing was investigated for a representative metropolitan airport (Boston Logan International Airport (BOS)). BOS was chosen for this analysis because (1) it is located in one of the metropolitan areas explicitly mentioned in Section 189 (b); (2) it experienced localized exposure changes from PBN implementation; (3) the team had access to detailed radar data to model noise exposure at high spatial resolution. A first-principles-based modeling approach for counting the number of visible aircraft was developed. Aircraft flying under 10,000 ft AGL and above a 45-degree angle to the horizon were considered visible.

Recorded flight trajectories were used to model the number of aircraft overflights which were visible from the surface at locations around the airport under idealized conditions, i.e. without additional obstruction in viewing angle such as buildings or weather conditions which reduce visibility. In addition, several noise metrics were calculated for the same locations, including DNL and N60, which is the number of flights which generate a noise level above 60 dB. The analysis was conducted for peak days of operation in 2010 and 2017 to evaluate the impact of change in visibility and surface noise. These dynamics are particularly relevant as they allow us

to disentangle changes in aircraft visibility from changes in noise exposure. We note that the report focused on arrivals from runway 4R and departures from runway 33L because they had the highest amount of community noise sensitivity at BOS and are considered representative runways.

3.3. Aircraft Overflight Noise and Business Impacts

The impacts of aircraft noise on businesses located underneath flight paths were analyzed using noise exposure changes due to large-scale reorganization of departure and arrival flight paths. The analyses were focused on areas surrounding study airports to specifically capture noise exposure changes associated with aircraft flying at lower altitudes during take-off and landing. The study area was therefore designed to capture a radius of approximately 22 miles around a study airport which includes areas where aircraft fly at an altitude lower than 10,000 feet AGL during takeoff and landing.

Reorganizations of arrival and departure paths were the result of: (1) concentration of arrival and departure paths following the introduction of PBN as part of NextGen; and (2) the opening of new runway infrastructure. Since these system-wide changes are unlikely to be driven by the short-term dynamics of the local economy surrounding an airport, contemporaneous responses in business activity, if observed, could be associated with the aircraft overflight noise exposure changes. The team applied statistical methods to explore whether regions with aircraft overflight noise exposure changes show different business dynamics when compared to regions without such noise exposure changes ("difference-in-difference" approach).

For the analysis of business dynamics, business locations from the data analytics firm InfoGroup were collected at the street-address-level between 2010 and 2019, covering millions of businesses nationwide. Such high-resolution data was required to analyze potentially highly local changes in business dynamics. The team focused on (1) retail businesses where changes in noise exposure could have impacts on customer behavior, and (2) the "professional" sector (i.e., professional, scientific, technical, and financial services), where aircraft noise could impact employee productivity. Boston Logan International Airport (BOS) and Chicago O'Hare International Airport (ORD) were chosen for the analysis because (1) they are explicitly mentioned in Section 189 (b); (2) they represent measurable noise exposure changes from new runways and localized exposure changes from PBN implementation; (3) the team had access to detailed radar data to model noise exposure at high spatial resolution; and (4) both airports show significant noise exposure changes over areas with high business density.

4. Study Findings

Based on the available data sources and methods (presented in Section 3: Study Methods and Data), the team was able to report findings in the following areas: (4.1) aircraft noise and health impacts (hypertension and CVD), and aircraft noise and sleep, (4.2) aircraft noise and

perception, (4.3) aircraft noise and business activity, and (4.4) sociodemographic patterns of aircraft noise.

4.1. Aircraft Noise and Health Impacts

4.1.1. *Noise and hypertension*

In the NHS cohorts, the analysis showed suggestive evidence of a positive association between aircraft overflight noise exposure and hypertension. In an analytical model using DNL 55 dB as the threshold and adjusting for key sociodemographic and risk factors (e.g., age, physical activity, smoking, neighborhood-level socioeconomic status), participants exposed to noise levels ≥ 55 dB had a 10% increased risk of hypertension compared to participants exposed to levels < 55 dB, with a 95% confidence interval (CI) of 1% to 19%. The magnitude of the association was similar across a number of sensitivity analyses and controlling for additional risk factors (e.g., family history of hypertension, medication use), with modest attenuation for additional risk factor adjustment ([10.1016/j.envres.2021.112195](https://doi.org/10.1016/j.envres.2021.112195)).^{*} The relative risk reduction associated with reduced overflight noise exposure is similar to the hypertension benefits seen in NHS from higher consumption of whole fruits and vegetables [20], although only ~1% of the study population was exposed to ≥ 55 dB DNL. Our results are consistent with the existing literature, where the majority of studies observed positive associations between aircraft noise exposure and incident hypertension [5,8,12,13,21-25].

4.1.2. *Noise and sleep*

In the NHS cohorts, aircraft overflight noise was associated with short sleep duration (sleep less than 7 hours per day), but not poor sleep quality (difficulty falling or staying asleep at least a good bit of the time during the previous 4 weeks). Specifically, in models controlling for key demographics, behaviors, comorbidities, and ambient factors, exposure to nighttime noise levels ≥ 45 dB was associated with 23% (95% CI: 7%, 40%) increased odds of short sleep duration but not associated with poor sleep quality (9% decreased odds; 95% CI: -30%, 19%). There was an indication of an exposure-response relationship, with higher noise exposure associated with greater odds of short sleep duration. We observed stronger associations with sleep duration among nurses living in the West, near major cargo airports, near water-adjacent airports, and among those reporting no hearing loss (<https://doi.org/10.1289/EHP10959>).[†] Most existing studies have linked aircraft noise with shorter sleep duration, but some have found associations with longer sleep duration along with poorer sleep quality [26-29].

^{*} Kim et al., Long-term aircraft noise exposure and risk of hypertension in the Nurses' Health Studies. *Env Res*, 2021. doi: [10.1016/j.envres.2021.112195](https://doi.org/10.1016/j.envres.2021.112195)

[†] Bozigar et al., Associations between aircraft noise exposure and self-reported sleep in the US-based prospective Nurses' Health Study cohort. *EHP*, 2023. <https://doi.org/10.1289/EHP10959>

4.1.3. Noise and cardiovascular disease (CVD)

In the NHS cohorts, aircraft overflight noise showed no association with CVD. For example, adjusting for key sociodemographic and risk factors, we found no difference in risk of CVD comparing participants exposed to DNL levels ≥ 50 dB compared to participants exposed to levels < 50 dB (95% CI: -11%, 12%)

(https://journals.lww.com/environepidem/fulltext/2023/08000/associations_between_long_term_aircraft_noise.5.aspx).[‡] In the literature, the results related to CVD incidence have been more mixed than for hypertension. Much of the literature has subdivided CVD into different subtypes, as CVD is a broad term that describes multiple cardiac and vascular diseases with different biological mechanisms. In our study, we were already limited in the number of overall CVD cases and could not examine subtypes of CVD [30-32].

4.2. Aircraft Noise and Perception

The analysis found that there is correlation between the number of flights which are visible from the surface and the number of flights which are audible above the 60 dB maximum noise level (N60) for locations and altitudes between approximately 3 to 10 miles away from the airport along the flight track and below 10,000 feet AGL. As a consequence, noise changes based on the N60 metric can provide an initial representation of changes in aircraft visibility. Closer to the airport, the visibility contours will be smaller than the noise contours because aircraft at lower altitudes create higher noise exposure on the ground while being visible from shorter distances only; the number of visible flights (Nvis) are therefore often less than the N60. Conversely, further away from the airport, where aircraft operate at higher altitudes, the visibility areas will be larger than the noise areas and the Nvis would be larger than the N60. For impacts of changes in visibility, it is noted that near the airport, procedures have changed less substantially with introduction of PBN procedures; at high altitudes, where more substantial changes are observed, noise levels are low.[§]

4.3. Aircraft Noise and Business Activity

Wide-spread consensus was identified in the empirical literature that businesses benefit from being located close to an airport and having access to air transportation to reach markets, innovate, and specialize [33]. The exploratory analysis of business data showed no obvious associations between observed changes in aircraft noise exposure surrounding the study airports, including area businesses located under flights of aircraft flying below 10,000 feet AGL during takeoff and landing, and changes in local business dynamics, both for retail and professional business activity. The results were consistent for the spatially more localized

[‡] Grady et al., Associations between long-term aircraft noise exposure, cardiovascular disease, and mortality in US cohorts of female nurses. *Env Epi*, 2023. https://journals.lww.com/environepidem/fulltext/2023/08000/associations_between_long_term_aircraft_noise.5.aspx

[§] Bullock, Aviation effects on local business: Mapping community impact and policy strategies for noise remediation. [S.M. thesis.] <https://hdl.handle.net/1721.1/138966>

effects of flight path concentration around Boston Logan International Airport and the larger-scale noise changes due to runway infrastructure changes around Chicago O'Hare International Airport (<https://hdl.handle.net/1721.1/138966>).**

4.4. A Note on the Sociodemographic Patterns of Aircraft Noise

It is important to understand the sociodemographic patterns of aircraft overflight noise exposure and the potential implications for epidemiological analyses of the populations impacted by overflight noise. The team evaluated the characteristics of the populations around airports with higher odds of being exposed to aircraft overflight noise. This included Census block groups with populations exposed to aircraft overflight noise at multiple DNL noise thresholds—45, 55, and 65 dB— and L_{night} thresholds – 45 and 55 dB in 2010. Although there were substantial differences across airports, areas with a higher proportion of the population self-identifying as Hispanic and with a higher proportion of the population having only a high school education generally were found to have higher odds of being exposed to aircraft overflight noise (<https://doi.org/10.1289/EHP9307>).^{††} In a separate study conducted by BUSPH and HSPH authors in parallel to this Section 189 study, the authors examined racial and ethnic groups exposed to aircraft noise (DNL and L_{night}) over time (1995 to 2015). Hispanic, Black/African American, and Asian populations “experienced higher proportions of exposure [to noise] relative to their subgroup populations compared to non-Hispanic or White populations across all years, indicating ethnic and racial disparities in aircraft noise exposure that persist over time” [34]. These findings reinforced the characteristics of populations exposed to overflight noise and emphasized the importance of additional nationwide studies with appropriate controls for confounders, to ascertain the impact of aircraft noise on populations more likely to be exposed to such noise.

5. Study Conclusions

The study was able to identify suggestive evidence of a relationship between aircraft overflight noise and hypertension and of a positive association between overflight noise and short sleep duration but did not identify an association between overflight noise and cardiovascular disease. While these health studies were conducted among large study populations surrounding 90 airports, an overarching limitation is the fact that the NHS was not originally designed to capture airport noise, resulting in a modest number of study participants with high noise exposures. The study of aircraft visibility did reveal that aircraft visibility trends do not fundamentally diverge from noise exposure trends. On economic impacts, the study did not identify empirical evidence which would support a relationship between aircraft overflight noise exposure and economic activity on the ground. Finally, the study identified

^{††} Simon et al., Sociodemographic Patterns of Exposure to Civil Aircraft Noise in the United States. EHP, 2022. <https://doi.org/10.1289/EHP9307>

sociodemographic patterns of aircraft overflight noise exposure, with elevated exposures across airports most markedly in those self-identifying as Hispanic and those having only a high school education.

The results varied in statistical significance (either statistically significant or not) by outcome. For outcomes that are more prevalent, the likelihood of observing statistical significance is higher, as statistical significance is influenced by the number of exposed cases (i.e., the number of people with the outcome who are also exposed to high levels of aircraft noise). For example, we do see statistical significance in our results for aircraft noise and one of the quantitative sleep outcomes.† For outcomes such as cardiovascular disease, the number of cases is much smaller; therefore, we likely did not have enough power to identify associations if they exist, as the cohorts do not have a great number of participants experiencing aircraft overflight noise exposure. Of note, statistical significance, which relies on an arbitrary cut-off, should be interpreted with caution in favor of the size of the effect estimates and patterns of associations.

This study represents the current state of the knowledge based on available national-scale and airport-specific noise data and connections to existing cohort studies and business databases. They are novel, but consistent with other results from the recent peer-reviewed literature. However, we do not know how results would differ in populations that are more diverse and highly exposed, where participants are specifically enrolled to analyze the impacts of noise, or where there is higher resolution economic data.

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