# Project 003 Cardiovascular Disease and Aircraft Noise Exposure

## Boston University

## Project Lead Investigator

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## University Participants

**Boston University (BU)**

- PI(s): Prof. Jonathan Levy (University PI), Prof. Junenette Peters (Project PI)
- FAA Award Number: 13-C-AJFE-BU-016
- Period of Performance: June 14, 2019 to September 30, 2019

**Massachusetts Institute of Technology (MIT)**

- Sub-PI and Co-I: Prof. R. John Hansman, Dr. Florian Allroggen

**Tasks** (Performance Period)

*Related to 2018 FAA Reauthorization, Section 189, Tasks 1–3*

1. Generate preliminary results from analyses of aircraft noise (day–night average sound level [DNL] and equivalent sound level [Leq] Night) and hypertension
2. Generate preliminary results of supporting analyses
    a. Trends of aircraft noise exposure
    b. Sociodemographic patterning of aircraft noise exposure
3. Assess suitability of existing cohort data on sleep quality and potential approaches for noise–sleep analysis

*Related to 2018 FAA Reauthorization, Section 189, Task 4*

4. Review existing scientific literature to identify potential economic impacts of aviation

## Project Funding Level

Total Funding (3-year funding): $1,729,286
Matching: $1,729,286
Source of Matching: Nonfederal donors to the Nurses’ Health Study (NHS), Health Professional Follow-up Study (HPFS), and Women’s Health Initiative (WHI) cohorts

## Investigation Team

**Junenette Peters, PI, Boston University**
Dr. Peters is responsible for directing all aspects of the proposed study, including study coordination, design and analysis plans, and co-investigator meetings.

**Jonathan Levy, Boston University**
Dr. Levy will participate in noise exposure assessment and provide expertise in the area of predictive modeling and air pollution.

**Francine Laden, Jaime Hart, and Susan Redline, Harvard Medical School/Brigham and Women's Hospital**
Dr. Laden is our NHS and HPFS sponsor for this ancillary study. Dr. Hart will assign aircraft noise exposures to the geocoded address history coordinates of each cohort member. Dr. Laden and Dr. Hart will also assist in documenting data from the NHS and HPFS based on their previous experience in air pollution and chronic disease outcome research in these cohorts and in appropriate analyses of hypertension and cardiovascular outcomes. Dr. Redline will lead efforts related to noise and sleep disturbance in the NHS and WHI.

**John Hansman and Florian Allroggen, Massachusetts Institute of Technology**
Dr. Hansman will participate in the economic impact assessment and will provide expertise on analytical approaches for quantifying noise. Dr. Allroggen will perform an economic impact assessment based on his expertise in analyzing the societal costs and benefits of aviation.

## Project Overview

Exposure to aircraft noise is considered the most significant perceived environmental impact of aviation in communities surrounding airports (Wolfe et al., 2014). Exposure to aircraft noise has been associated with physiological responses and psychological reactions (Bluhm & Eriksson, 2011; Hatfield et al., 2001), including sleep disturbances, sleep-disordered breathing, nervousness, and annoyance (Hatfield et al., 2001; Rosenlund et al., 2001). Recent literature, primarily from European studies, provides evidence of a relationship between aircraft noise and self-reported hypertension (Rosenlund et al., 2001), increased blood pressure (Evrard et al., 2017; Haralabidis et al., 2008; Haralabidis et al., 2011; Jarup et al., 2008; Matsui et al., 2004), antihypertensive medication use (Bluhm & Eriksson, 2011; Floud et al., 2011; Franssen et al., 2004; Greiser et al., 2007) and incidence of hypertension (Dimakopoulou et al., 2017; Eriksson et al., 2010). However, the extent to which aircraft noise exposure increases the risk of adverse health outcomes is not well understood. Impacts related to annoyance have been empirically studied using the stated preference approach (Bristow et al., 2015) and the revealed preference approach, which often relies on analyses of house prices (Almer et al., 2017; Kopsch, 2016; Wadud, 2013). Although the impacts of aircraft noise on individuals are well understood, little evidence has been presented on the impact of aircraft noise exposure on companies located beneath flight paths. Section 189 of the 2018 FAA Authorization has called for a study on the potential health and economic impacts attributable to aircraft overflight noise.

The goal of this ongoing project is to examine the potential health impacts attributable to noise exposure resulting from aircraft flights, and this project will leverage ongoing work within ASCENT to respond to Section 189. This study aims to assess the potential association between aircraft noise exposure and outcomes such as sleep disturbance and elevated blood pressure. The study will leverage existing collaborations with well-recognized and respected studies that have followed over 250,000 participants through the course of their lives to understand factors that affect health. These studies include the NHS and HPFS. Furthermore, this work is aligned with an ongoing National Institutes of Health (NIH)-funded effort to examine these associations in the WHI. The research team will leverage aircraft noise data for 90 U.S. airports from 1995–2015, as generated using the Aviation Environmental Design Tool (AEDT); these data will then be linked to demographic, lifestyle, and health data for the participants of long-term health studies. These studies provide considerable geographic coverage of the United States, including all of the geographic areas specified in Section 189.

This work will also respond to the aspect of Section 189 calling for the study of economic harm or benefits for businesses located underneath regular flight paths. The study will involve a first-of-its-kind empirical assessment of the economic impacts on businesses located beneath flight paths at selected U.S. airports. Such impacts are expected to be driven by (a) potential positive economic impacts related to the airport and its connectivity and (b) environmental impacts such as noise, which may reduce the revenue and productivity of businesses beneath flight paths. The team will evaluate whether such impacts can be empirically identified while considering economic outcome metrics such as the gross domestic product (GDP), employment, and revenue.

The overall aims for the three-year project are as follows:

- Perform Tasks 1–3 [*Sec. 189. (b)(1–3)*]: Potential health impacts attributable to aircraft overflight noise
  - Investigate the relationship between aircraft noise exposure and the incidence of hypertension in the NHS and HPFS, accounting for other individual- and area-level risk factors
  - Investigate the relationship between aircraft noise exposure and the incidence of cardiovascular disease (CVD) in the NHS and HPFS cohorts and determine whether sufficient data exist to prove a causal relationship

- Determine whether a relationship exists between annual average aircraft noise exposure and general sleep length and quality in the NHS and the Growing Up Today Study (GUTS) and report whether sufficient data exist to prove a causal relationship
    - Evaluate the potential relationship between residing under a flight path and measures of disturbed sleep in the WHI WHISPER sub-study
- Perform Task 4 [*Sec. 189. (b)(5)*]: Potential economic impacts attributable to aircraft overflight noise
    - Model noise exposure before and after the introduction of area navigation (RNAV) procedures on the basis of FAA flight trajectory data
    - Combine noise data with yearly county-level data from the Bureau of Economic Analysis (BEA) (e.g., GDP, employment) and with city-level statistics for the years 2007, 2012, and 2017 from the Economic Census (e.g., revenue, employment)
    - Compare economic outcomes using state-of-the-art econometric approaches while controlling for regional and national economic trends
    - Evaluate whether the spatial resolution of the available data can significantly impact the study results.

# Task 1- Generate Preliminary Results from Analyses of Aircraft Noise and Hypertension

Boston University

## Objective

To generate preliminary results from analyses of aircraft noise (DNL and Leq Night) and hypertension.

## Research Approach

We will intersect modeled noise exposure surfaces for 1995, 2000, 2005, 2010, and 2015 with geocoded addresses of the participants over the follow-up period. We will select a large set of a priori variables to be examined as confounders and/or effect modifiers and will use time-varying Cox proportional hazards models to estimate hypertension or CVD risks associated with time-varying aircraft noise exposure, while adjusting for both fixed and time-varying covariates. We will also perform a sensitivity analysis to address potential biases.

## Milestone

Generate results from analyses of aircraft noise (DNL and Leq Night) and hypertension – January 2020.

## Major Accomplishments

- Intersected modeled exposure surfaces for DNL with the participants' geocoded addresses over the follow-up period
- Determined the number of people free of hypertension at baseline
- Determined noise exposure distribution of those without hypertension at baseline in two cohorts (NHS and NHS II) for the follow-up period (Table 1)
- Selected a large set of a priori variables, including age, alcohol use (g/day), body mass index (BMI), calendar year, comorbidities (diabetes, hearing loss, hypercholesterolemia), smoking status, diet (dietary approaches to stop hypertension [DASH] score), hearing problems, family history of hypertension, individual-level socioeconomic status (SES) variables (educational attainment, marital status, and partner's educational attainment), medication use (current statin and non-narcotic analgesic drug use), menopausal status, physical activity (metabolic equivalent hours per week), and race, as well as region, latitude, area-level SES variables (census-tract median income and house value), and air pollution ($PM_{2.5}$ and $PM_{2.5\text{-}10}$).
- Used time-varying Cox proportional hazards models to estimate hypertension risks associated with time-varying aircraft noise exposure, while adjusting for both fixed and time-varying covariates
    - Performed analysis for each cohort separately (Figures 1 and 2 for NHS and NHS II, respectively)
    - Performed meta-analysis to combine the results found for each cohort – NHS and NHS II (Figure 3)
    - Performed the following sensitivity analyses (assessing the sensitivity of each primary analysis to underlying issues)
        - Restricted participants to those living close to one of the 90 modeled airports (≥45 dB) to address potential exposure errors, for example, to exclude those living near an airport that is not included in

the 90 airports and to minimize the impact of potential differences in populations living close to airports versus those living farther away

- Analyzed the potential effect of noise abatement programs for DNLs higher than 65 dB to address possible exposure errors related to noise abatement programs among those with noise exposure above the FAA threshold (>65 dB).
- Adjusted for air pollution and area-level SES, which is available for only a portion of the time period.

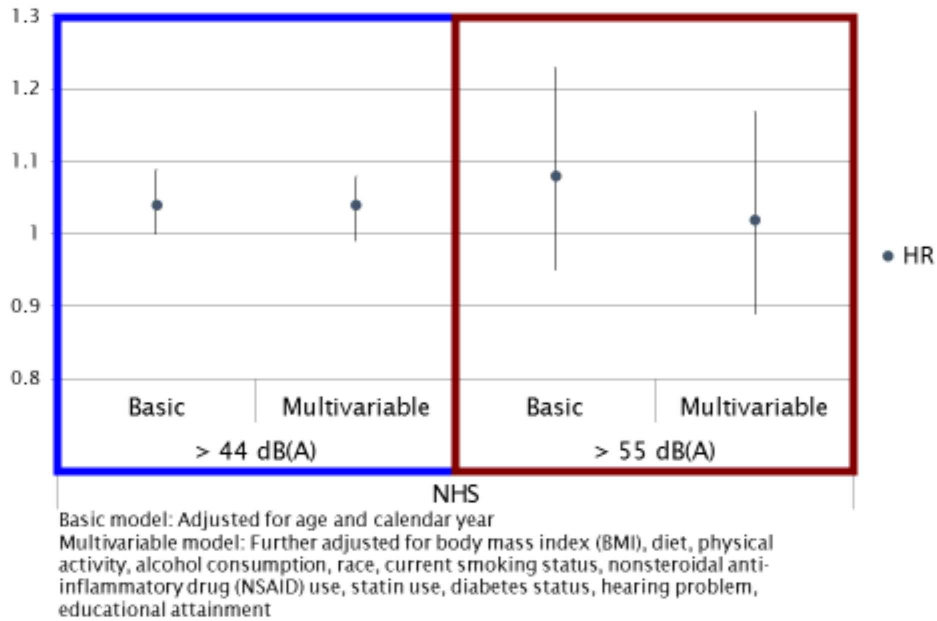



**Figure 1.** Hazard ratios (95% confidence intervals [CIs]) for hypertension associated with aircraft noise in the NHS, comparing results for >44 dB with those for ≤44 dB and comparing results for >55 dB with those for ≤55 dB.

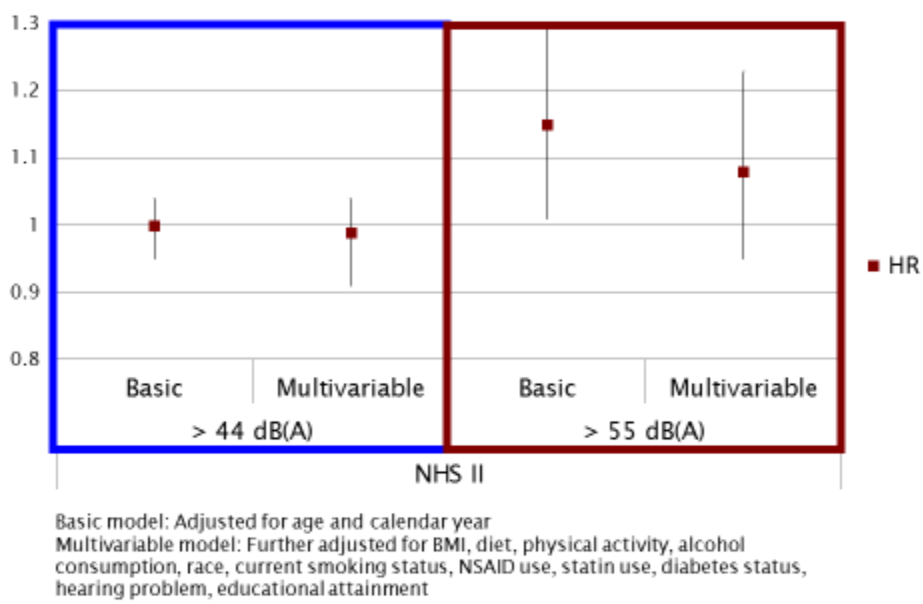



**Figure 2.** Hazard ratios (95% CIs) for hypertension associated with aircraft noise in NHS II, comparing results for >44 dB with those for ≤44 dB and comparing results for >55 dB with those for ≤55 dB.

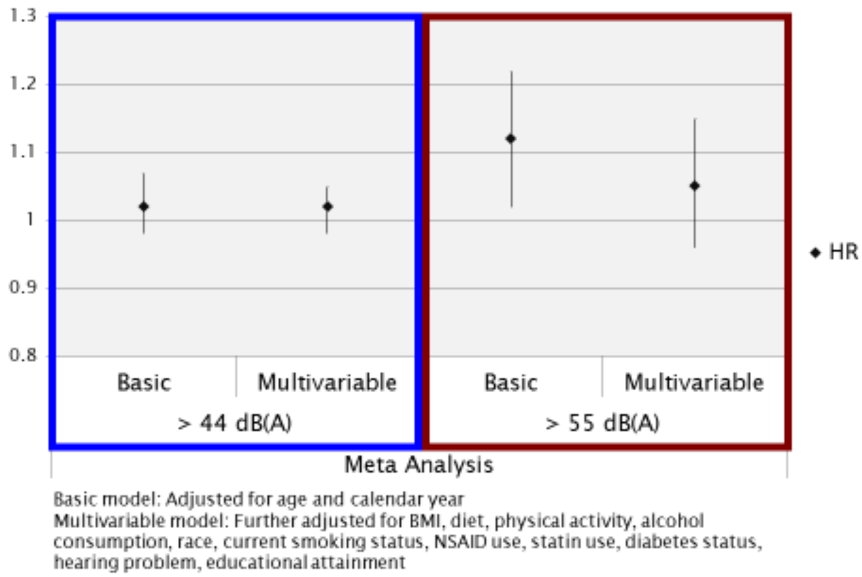



**Figure 3.** Hazard ratios (95% CIs) for hypertension associated with aircraft noise in a meta-analysis (combined results for NHS and NHS II), comparing results for >44 dB with those for ≤44 dB and comparing results for >55 dB with those for ≤55 dB.

The results indicate an increased risk for incident hypertension associated with higher aircraft noise exposure in both NHS and NHS II (Figures 1 and 2). A meta-analysis across both cohorts (Figure 3) gave a hazard ratio (HR) of 1.02 (95% CI: 0.98, 1.07) and 1.08 (95% CI: 0.98, 1.18) for the multivariable model with cut-points of 45 and 55 dB, respectively. The HRs were relatively stable across the sensitivity analyses.

## Task 2 - Generate Preliminary Results from Supporting Analyses: (a) Trends in Aircraft Noise Exposure and (b) Sociodemographic Patterning of Aircraft Noise Exposure

Boston University

### Objective

To understand changes in exposure that will facilitate our interpretation of time-varying exposure measures in noise-health analyses and to understand sociodemographic patterning of noise exposure that may confound or modify potential associations of noise and health.

### Research Approach

For (a, Noise Trend), we will overlay noise contours for 2000, 2005, 2010, and 2015 and census block data from the U.S. Census Bureau and American Community Surveys for 2000, 2010, and 2015 in a geographic information system to estimate population changes within noise levels. We will utilize linear fixed-effects models to estimate changes in the sizes of exposure areas based on U.S. census regions/divisions with DNL values ≥65 dB or ≥55 dB. For (b, Sociodemographic Patterning), we will describe the characteristics of populations exposed to aviation noise by race/ethnicity and income/education using the U.S. Census Bureau and American Community Survey for 2010 and will perform univariate and multivariable hierarchical analyses.

### Milestone

Perform supporting analyses characterizing aircraft noise trends and sociodemographic patterns of exposure to aviation noise - N/A.

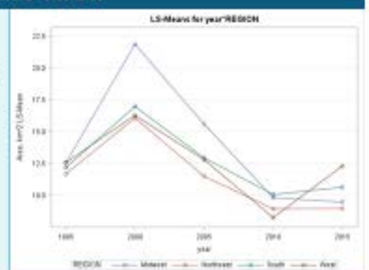
## Major Accomplishments

- Overlaid noise contours for 2000, 2005, 2010, and 2015 and census block data from the U.S. Census Bureau and American Community Surveys for 2000, 2010, and 2015
- Excluded areal hydrography (water bodies) using the Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) data set and national, state, and local parks using ESRI and TomTom
- Determined the exposure area and number of people exposed to aircraft noise using data over time (2000–2015); preliminary results are presented in Figure 4
- Determined and implemented an optimal approach for assigning the exposed and unexposed census blocks
- Determined social patterning of aircraft noise exposure by race/ethnicity and income/education for 2010 using univariate and multivariable analysis; preliminary results are presented in Figure 5

**Exposure Area**

Found non-monotonic trends in mean exposed areas for ≥55 and ≥65 dB DNL over time that peaked in 2000.

- Exposed areas largest in the Midwest region from 2000 to 2005.
- Only West region increased from 2010 to 2015.




**Exposed Population**

| * per thousand | DNL 55 dBA | | | DNL 65 dBA | | |
|---|---|---|---|---|---|---|
| | Population in 2000 | Population in 2010 | Δ | Population in 2000 | Population in 2010 | Δ |
| All | 8352 | 4595 | -45% | 731 | 309 | -58% |
| Region | | | | | | |
| Midwest | 2040 | 892 | -56% | 160 | 51 | -68% |
| Northeast | 2493 | 1381 | -45% | 198 | 86 | -56% |
| South | 2164 | 1359 | -37% | 191 | 68 | -64% |
| West | 1655 | 963 | -42% | 182 | 103 | -43% |

**Figure 4.** Preliminary results for noise trends based on exposure area and number of people exposed.

**Race/Ethnicity Patterning - Univariate**


- Exposure patterns vary by airport.
- Low economic status and minorities tend to have higher aircraft noise exposure.

**Overall Sociodemographic Patterning - Multivariate**

| DNL | 55-dB Threshold | |
|---|---|---|
| Variable | Odds Ratio | 95% CI |
| % Black | 1.003 | (1.002, 1.005) |
| % Asian | 1.006 | (1.003, 1.009) |
| % Hispanic | 1.006 | (1.004, 1.008) |
| % Other | 0.993 | (0.985, 1.001) |
| Distance to Airport (km) | 0.781 | (0.772, 0.790) |
| % <9thGrade | 1.016 | (1.011, 1.022) |
| % 9th-<College Degree | 1.007 | (1.004, 1.010) |
| % HH <$25k | 0.988 | (0.985, 0.992) |
| % HH $25k-$100k | 0.994 | (0.991, 0.998) |
| Region (ref: NE) | | |
| Midwest | 1.539 | (1.376, 1.720) |
| South | 1.073 | (0.972, 1.184) |
| West | 0.828 | (0.744, 0.920) |

**Figure 5.** Preliminary results for sociodemographic patterning in aircraft noise exposure based on univariate analysis for race/ethnicity and multivariable analysis.

## Task 3 - Assess Suitability of Data on Sleep Quality and Potential Approaches for Noise–Sleep Analysis

Boston University

### Objective

To identify sleep measures that may be used to evaluate potential associations between noise and sleep outcomes.

### Research Approach

We will review the available measures of sleep quality for the NHS to determine their timing and frequency and their relationship to the timing of the noise exposure data. We will also determine which measures, if any, are relevant to the average exposure measures.

### Milestone

Assess potential analysis approaches and suitability of sleep quality data from the NHS – January 2020.

### Major Accomplishments

A BWH Research Fellow in sleep medicine with experience with the NHS has joined our team, been approved to work on the project by the Institutional Review Board, and met with team members to establish a timeline for this project. This task in on track to be completed on schedule.

## Task 4 - Review Existing Scientific Literature to Identify Potential Economic Impacts of Aviation

Massachusetts Institute of Technology

### Objective

To evaluate the literature to structure potential pathways through which the aviation sector can impact economic activity.

### Research Approach

We will analyze the literature to structure the potential pathways through which the aviation sector can impact economic activity.

### Milestone

Assess potential empirical approaches, data sources, and economic outcomes to be analyzed – December 2019.

### Major Accomplishments

We have compiled a preliminary review of studies that analyze the economic impacts of the aviation sector in the United States. Preliminary results from the literature review, including potential empirical approaches and economic outcomes, are shown in Figure 6.

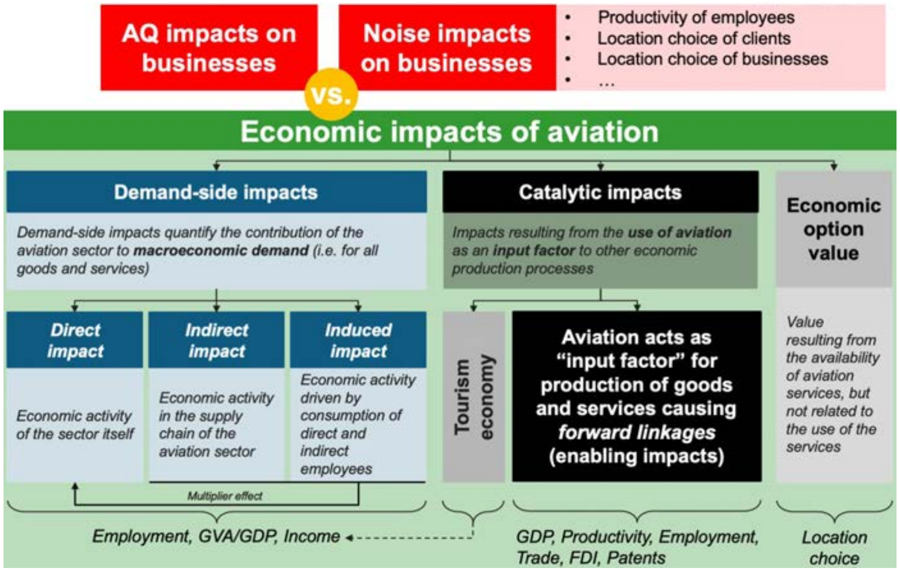



**Figure 6.** Preliminary structure outlining the economic impacts of the aviation sector.

The results show that the aviation sector can increase economic activity through three major pathways:

1. **Demand-side impacts:** The aviation sector can increase economic activity through its impact on macroeconomic demand. These impacts can be justified on the basis of Keynesian demand-side economics, including direct impacts in the sector, indirect impacts in the supply chain of the aviation sector, and induced impacts caused by increased demand due to income associated with direct and indirect impacts. Notably, these demand-side impacts can only be fully allocated to the aviation sector under the assumption of an underutilization of resources (e.g., labor) and production capacity.
2. **Catalytic impacts:** These impacts exist if the use of aviation services constitutes a benefit to an economic system. Such effects can include the establishment of a tourism economy that relies on air transport connections, potential forward linkages, and enabling effects (Lakshmanan, 2011). The latter impacts, which are often considered to increase the productivity of economic systems, have been demonstrated as significant in empirical studies, including, for example, reports by Brueckner (2003), Allroggen and Malina (2014), and Campante and Yanagizawa-Drott (2018).
3. **Economic option value of aviation:** This value can be observed if companies move closer to airports or other hotspots of the aviation industry, without currently being a regular user of air transportation or interacting with the air transport industry. While these effects do not immediately result in global economic benefits, they can benefit regions in the proximity of airports or other hotspots of the aviation industry.

## Publications
N/A

## Outreach Efforts
An outline of this project, preliminary results on the health impacts of aviation, and a first approach towards structuring the economic impacts of aviation were presented at the Fall 2019 ASCENT Advisory Committee Meeting.

## Awards
None.

## Student Involvement
The dissertation of Chloe Kim (doctoral candidate, BU) includes the development and implementation of statistical analyses on the noise and hypertension risk. Chloe Kim graduated in the fall of 2019 and is currently working for the Environmental Science, Policy, and Research Institute.

The dissertation of Daniel Nguyen (doctoral candidate, BU) includes a characterization of the temporal trends in aviation noise surrounding U.S. airports.

The research rotation of Stephanie Grady (doctoral student, BU) includes the development of statistical analyses on noise and cardiovascular event risk.

Carson Bullock (master's student, MIT) is supporting the literature review.

## Plans for Next Period

(October 1, 2019 to September 30, 2020)

*Related to 2018 FAA Reauthorization, Section 189, Tasks 1–3*

- Assign noise exposure estimates to participants for Leq Day and Leq Night metrics and explore the value of assigning estimates for Time Above metrics
- Complete models estimating the risk of hypertension associated with aircraft noise exposure and finalize a manuscript for publication in a peer-reviewed journal
    - Perform analysis using Leq Night for NHS and NHS II
    - Perform a meta-analysis combining Leq Night results for the two cohorts
    - Update current draft of the manuscript
    - Submit manuscript for FAA review and to a professional journal
- Replicate noise and hypertension results in an all-male HPFS cohort
- Develop and execute models for estimating the risk of CVD events associated with aircraft noise exposure
- Develop a plan for analyzing the relationship between noise and sleep
- Develop abstracts for presentations at professional conferences

*Related to 2018 FAA Reauthorization, Section 189, Task 4*

- Finalize an overview of the literature analyzing the economic impacts of aviation
- Outline the empirical approach (including experimental design), potential data sources (including the airport sample), and economic outcomes to be analyzed
- Collect data on airport samples, experimental settings, and noise contours
- Perform empirical implementation and preliminary analysis using county-level BEA data

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