ReACh: Resuspension Emissions Based on Aerodynamic Characteristics

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Research Needs

Resuspension emissions (RE) are non-exhaust emissions produced by vehicles aerosolizing and/or suspending road debris into the environment; these represent a major concern for environmental and human health [1]. Higher concentrations of particulate matter (PM), both course (PM_{10}) and fine ($PM_{2.5}$), are linked with respiratory and cardiovascular diseases and increased mortality [2]. Further, RE is a significant source of airborne PM, especially in areas with elevated traffic (i.e., urban environments) [3], where RE can be responsible for up to 60% of non-exhaust emissions [4], although the specific proportions vary based on environmental factors including average humidity, precipitation, and temperature [1]. In addition, these adverse effects are likely exacerbated in areas with higher proportions of unpaved roads (e.g., rural communities) and poor pavement conditions (e.g., lower income communities).

Regulations and technological advancement have significantly lowered exhaust emissions in recent years, increasing the interest in RE as a pollutant pathway and spawning many studies. However, most of these studies focus on characterizing the components of RE and large-scale spatio-temporal dynamics (e.g., seasonality, fleet-averages, and regionality) [1]. There is further concern that electric vehicles (EVs), which are thought to produce more RE than internal combustion engine vehicles (ICEVs) by virtue of their increased weight [5], might face restrictive regulations to mitigate RE. However, there are few studies that focus on the characteristics of specific vehicles that affect RE [1], [4], meaning there is minimal evidence to inform vehicle-specific regulations to mitigate RE.

This project aims to understand the connection between specific vehicle characteristics, including ride height, rear bumper overhang, undercarriage area, and resuspension emissions. Understanding how these characteristics exacerbate or mitigate RE will both inform our understanding of resuspension pathways, and facilitate vehicle regulations and/or modifications to reduce RE.

Research Objectives

The main objective of this research is to understand resuspension as a function of vehicle characteristics including undercarriage area, ride height, and rear bumper overhang. Whereas past studies focused on fleet/roadway averages or the contributions from weight-delineated generic vehicle classes, we propose to study the individual vehicle characteristics that contribute to resuspension, on the basis that vehicle-induced turbulence is a significant contributor to resuspension [6]. Understanding the contributions of different aerodynamic characteristics to a vehicle's resuspension emissions on various roadway surfaces can inform both empirical models to predict the resuspension emissions of new vehicles and policy recommendations for vehicle designs. This project will also serve as a basis for future research to understand and mitigate resuspension emissions.

Research Methods

There are several widely-used and sophisticated testing methodologies that were developed to study resuspension emissions in the field, including TRAKER [7], SNIFFER [8], and SCAMPER [9]. However, these methods were designed to study the composition and traffic-

averaged volume of RE (SCAMPER), and/or the contributions of road-tire wear to RE (TRAKER, SNIFFER), and all rely on sophisticated mobile laboratories [1].

While we will borrow aspects of these methods (e.g., detector placement, analysis protocols), studying individual vehicles necessitates an alternative approach. In contrast to other studies, we will incorporate both static (curbside) and dynamic (vehicle-leading and vehicle-trailing) measurements of RE on a closed course (CSU's Christman airfield) before conducting tests on naturalistic roadways. We will employ low-cost air quality monitors (AQMs) to develop a more repeatable process less reliant on expensive sensing and testing equipment. Further, we will use both personal and CSU-owned vehicles to study a wide variety of vehicles during the closed environment testing.

Relevance to Strategic Goals

This project aligns with the USDOT Strategic Goals of Safety, Equity, and Climate and Sustainability. Understanding RE has direct impacts on air quality and associated health outcomes, which relate to **safety**. We are particularly interested in the effects of roadway surface conditions on RE, motivated by the often disparate surface conditions in rural communities; where this research aims to highlight **equity** in [re-]pavement projects. Lastly, EVs are considered to offer a more **sustainable** option over ICEVs, and this project seeks to quantitively compare RE as a function of vehicle characteristics beyond the traditionally assumed variable of vehicle weight, which results in EVs likely being incorrectly attributed to higher RE.

Educational Benefits

This project will help fund one MS student and serve as the topic of their master's thesis. This student is expected to lead, under the guidance of the PI and co-PIs, the experimental design, data collection, data analysis, and report writing. As a result, this student will gain experience in air quality, vehicle aerodynamics, experimental design, data analytics, and technical writing. Since the funding for this project is for 18-months, and a typical MS thesis takes 24-months to complete, this student will also be funded through a graduate teaching assistantship (GTA) for 6-months, which will further their educational training and development. Further, the data collected in this study will be used for in-class exercises in co-PI Gallegos' ENGR 478 (Applied Engineering Data Analytics) and SYSE 541 (Engineering Data Design and Visualization).

Outputs through Technology Transfer

This research will be disseminated to researchers and practitioners through a research white paper, suitable for submission to an academic journal, that details the process, results, and policy implications of the research. This research will be further be translated into a preliminary policy statement that will recommend a regulatory strategy appropriate to mitigating RE. We will leverage opportunities to present this work to a wider audience through presentations to relevant academic conferences (e.g., TRB Annual Meeting), the CSU System Engineering department's *Friday Talk* series, and/or local *Science on Tap* events.
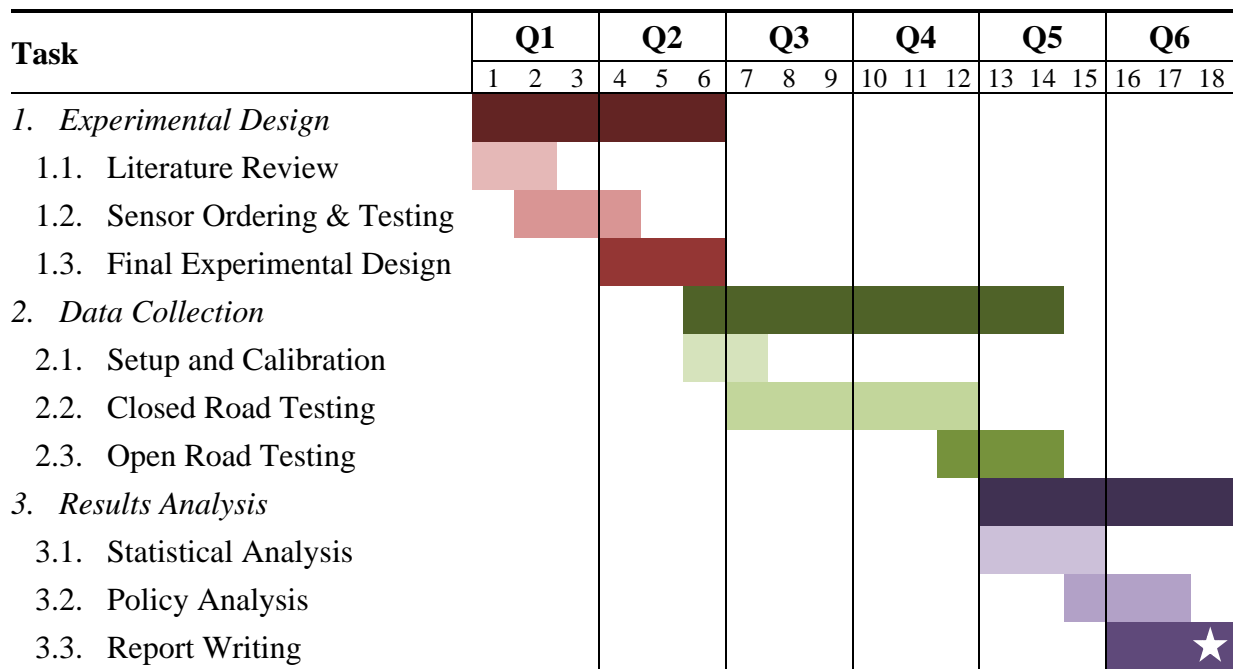
Expected Outcomes and Impacts

We expect to find that there are correlations between the volume of RE produced by vehicles and their aerodynamic characteristics. Due to their effect on the presence of turbulent flow along the

undercarriage and in the vehicle wake, we expect that ride height, rear bumper overhang, and undercarriage area will have significant impacts on RE production. As this study will be among the first to investigate vehicle-specific characteristics for the effect on RE, we anticipate building a predictive model for the RE produced by individual vehicles with more explanatory power than is provided by vehicle weight and road-tire interactions alone. By testing on various roadways (asphalt, concrete, gravel), we will also be able to quantify a multiplier effect on RE based on roadway surface.

The impact of this work will therefore be both academic and pragmatic. Academically, this work will address technical gaps in our current understanding of RE production by determining the vehicle characteristics that contribute to or mitigate RE. Further, this work provides a basis for more in-depth analyses of individual vehicles to design systems that can mitigate RE production. Pragmatically, this work will greatly inform our ability to create reasonable, meaningful regulations to mitigate RE. Previous studies on RE focused on fleet/city averages and/or RE composition, or isolated vehicle weight and road-tire interactions as causal factors for RE. However, the results of these studies are not specific to vehicle designs, and are thus likely insufficient as a basis for effective regulation of vehicles. We expect that studying the aerodynamic characteristics of specific vehicles will allow us to create more effective vehicle regulations.

Work Plan

This project is expected to take 18-months to complete, and is delineated into three tasks: experimental design, data collection, and results analysis. The Gantt chart below details the expected timeline and subtasks for each phase of the study.

Task	Q1			Q2			Q3			Q4			Q5			Q6		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. *Experimental Design*	█	█	█	█	█	█												
1.1. Literature Review	█	█																
1.2. Sensor Ordering & Testing		█	█	█														
1.3. Final Experimental Design				█	█	█												
2. *Data Collection*							█	█	█	█	█	█	█	█	█			
2.1. Setup and Calibration							█	█										
2.2. Closed Road Testing								█	█	█	█	█						
2.3. Open Road Testing												█	█					
3. *Results Analysis*													█	█	█	█	█	█
3.1. Statistical Analysis													█	█	█			
3.2. Policy Analysis															█	█	█	
3.3. Report Writing																	█	★

The first task of the project, *Experimental Design*, will first conduct a more thorough literature review to ensure that the researchers have an appropriate grasp of the relevant background information and previous studies performed in this area. The literature review will determine any other vehicle characteristics to study, inform on sensor placement for monitoring RE, and the optimal environmental conditions for testing. This will be followed by ordering and testing the AQMs that will form the bulk of the testing equipment, and finally determining a final experimental design for closed-environment testing at the CSU Christman Airfield.

The second task in this project will be to calibrate the experimental setup (e.g., placing sensors, measuring the average silt loading rate on the airfield surface, and planning testing days). Following this, data will be collected first under the "closed road environment" of the CSU airfield, where traffic patterns will not influence the results and the road conditions can be known precisely. Secondary data collection will be conducted on public roads around Fort Collins, to both understand how traffic influences the RE produced by individual vehicles, and monitor RE on different road surfaces (asphalt, concrete, gravel).

The last task for this research is to analyze and disseminate the results. The results will be analyzed to understand the principal causal factors for RE from individual vehicles, which will then inform a preliminary policy statement outlining regulatory strategies that could reduce RE contributions from individual vehicles. This task will culminate with the writing of the final report, a white paper suitable for publication in a peer-reviewed journal, and targeted for presentation at the TRB annual meeting, denoted on the Gantt chart by a white star.

Project Cost

Total Project Costs: $120,000
CTIPS Funds Requested: $ 60,000
Matching Funds: $ 60,000
Source of Matching Funds: Colorado State University

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