Design of a Fan-Powered Face Mask with Advanced Filtration Capability
(Technical Paper)

Obesity as the Catalyst for Change: How a Societal Trend Can Impact Car Restraint Design
(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Introduction

Despite the National Highway Traffic Safety Association (NHTSA) reporting a decrease in roadway fatalities for the second year in a row, the numbers behind how cars protect all passengers does not tell the whole story (NHTSA, 2019). Modern research shows that factors such as age, gender, and body mass index introduce an added variability in motor vehicle crashes that results in a higher risk of severe injury and fatality (Carter, 2014). New societal norms, such as an increase in the prevalence of obesity (CDC, 2019), seem to be shifting car design to focus more on protecting less represented anthropometries, or body types, in an effort to equally protect all drivers on the road, but to what extent is this change occurring in this field? The final STS deliverable, a research paper, will examine the injury biomechanics field through various methods and frameworks to determine how societal norms, specifically obesity, are impacting the development of vehicles.

On a different note of protecting the general population, proper mask filtration technology can help contain the spread of COVID-19. Current mask technology that filters inhalation and exhalation air, like an N95 respirator, is uncomfortable to breathe in for long periods of time (Mayo Clinic Staff, 2020). Fan powered systems, such as a Powered Air Purifying Respirator (PAPR), can be worn for extended periods, but fail to filter exhalation air (CDC, 2020). The final technical deliverable, a powered mask that filters inhalation and exhalation air, aims to address the issues with both designs to provide a comfortable breathing experience while also protecting the user and individuals in their environment.

Technical Topic

With the worldwide death toll due to COVID-19 recently surpassing one million, the need to create solutions that protect the general public is more pressing than ever (Johns Hopkins, 2020). Current mask technology has two main designs: non-powered systems and fan powered systems. When properly designed, non-powered systems consist of filter material that covers the nose and mouth to prevent aerosols that contain viruses from entering the body through inhalation, and exiting the body from exhalation. Properly filtering both inhalation and exhalation is crucial to protect both the user and those in the same environment. This technology, such as an N95 respirator, is effective but uncomfortable to breathe in for long periods of time (Mayo Clinic Staff, 2020). On the contrary, fan powered designs force air through a filtration system and provide constant airflow across the face. This method, such as a Powered Air Purifying Respirator (PAPR), can be worn for extended periods, but fails to filter exhalation air due to the constant positive pressure within the system (CDC, 2020). Ideally, combining the capability to filter inhalation and exhalation air in non-powered systems with the ease of breathing in fan powered systems would create the ideal user experience, while protecting individuals in the surrounding environment.

The final technical deliverable produced by the research team will be a powered mask system that filters both inhalation and exhalation. Research on current standards associated with powered systems will help inform design requirements and initial prototype designs (Berry Ann, 2020). Metrics such as air flow rate, component sizing, filtration rating, and system pressure will be considered in initial designs. Current mask designs, such as a half-face respirator or a continuous positive airway pressure (CPAP) mask used for sleep apnea, go through exhaustive design and approval processes (NIOSH, et al., 2018). The research team will repurpose these designs to ensure that the final product's fit on the face meets current standards and can be utilized by a wide range of facial structures. This preexisting mask design will be combined with a 3D printed housing that will contain a fan, filter material, and potentially a battery unit. Figure 1 below displays the Gantt Chart for the project with each design objective timeline being showed. The project team will conduct design and write the technical report detailing the process over one semester, with a target end date of November 24, 2020.

Date	9/28 - 10/4	10/5 - 10/11	10/12 - 10/18	10/19 - 10/25	10/26 - 11/1	11/2 - 11/8	11/9 - 11/15	11/16 - 11/24
Task								
Component Sizing	■	■						
Fan Design		■	■					
Mask Body Design		■	■	■	■			
Battery & Microcontroller Design			■	■				
Risk & Safety Analysis					■	■	■	■
Testing and Iteration					■	■	■	■

Figure 1: Gantt Chart of project

The final deliverable will be assessed by the group with three metrics: computational fluid dynamics (CFD) analysis, testing ease of breathing through putting the mask on, and a mock fit test that is used for current mask systems. CFD analysis is a capability of various 3D modeling software, such as SolidWorks, that can display how fluid will interact with a given object. Information such as airflow pathways, pressure differences, and vortex regions can be seen with the proper application of CFD. The project team will use this to assess the overall airflow throughout the system and help to determine if a proper amount of air and pressure is being supplied to the user. As CFD is not an exact representation of real-world application, the team will assess ease of breathing through a qualitative comparison between the final deliverable and an N95 respirator. Finally, a mock fit test will be performed to determine if the final system properly filters inhalation and exhalation air. This fit test will consist of spraying a bitter solution, Bitrex, within an enclosed environment. If the user cannot smell the solution, then the mask functions properly and effectively filters air (OSHA, 2020). The final deliverable will create the ideal user experience, while stunting the spread of COVID-19.

STS Topic

As drivers across the United States traverse an estimated 3.3 trillion miles every year, researchers must continue to investigate how restraint systems, such as airbags and seat belts, can be improved to protect them (Office of Highway Policy Information, 2019). Since the 1970s, researchers have proposed many different ways to model how the human body reacts to the harsh conditions of a motor vehicle crash (Viano, 1989). Crandall, et al. discusses the five surrogate types (cadavers, volunteers, anthropometric test devices (ATDs), animals, and computational models) that have been used to analyze this complex interaction. Every surrogate, while not equally effective as the next, has the same disadvantage: not being able to model the body's response with 100 percent accuracy (Crandall, et al., 2011). Despite that disadvantage, the research field has amassed an extensive library of studies utilizing all five surrogates and achieved the ability to characterize a wide variety of motion in motor vehicle crashes (Forman, et al., 2015). Even though this library exists, it lacks a focus on the diversity of the drivers it aims to protect (Feigenoff, 2018).

In the past, researchers have focused their efforts on the 50^{th} percentile male anthropometry. This field-wide research focus has given experts the ability to describe how the 50^{th} percentile male anthropometry interacts with restraint systems in great detail as seen in Kent and Forman's *Restraint System Biomechanics*. While incredibly helpful in saving lives, these descriptions do not provide an explanation of how factors such as body mass index, gender, and age impact body kinematics, or motion, in motor vehicle crashes. In 2014, Carter, et al. found that these factors correlate to a higher risk of severe injury and fatality by analyzing crash data from 2000-2010. Other researchers have confirmed this correlation by conducting math modeling and matched cadaver testing (Forman, et al., 2009; Viano, et al., 2008). Dummy technology development has also lagged behind when addressing the changing demographics in the general population. The complex approval process associated with dummy creation has made it difficult to create new dummies that more accurately describe the kinematics associated with the obese population (Xu, et al., 2018). Although this issue has been identified, Jason Kerrigan, the deputy director at UVA's Center for Applied Biomechanics, said that experts "still do not understand enough about the nature of obesity to know why it makes the situation worse" (Feigenoff, 2018). This gap in research has led to car restraint systems not effectively protecting drivers and dummy technology from accurately reflecting the general public. In recent years, research has transitioned from focusing on creating industry standards for testing and dummy technology to addressing underrepresented demographics, such as obese individuals (Feigenoff, 2018).

Thomas Kuhn's paradigm shift will help reveal how the prevalence of obesity in society is changing the efforts of researchers. The Kuhn Cycle is a concept used to describe how new scientific paradigms take root. Kuhn's theory describes how new scientific discoveries found in Normal Science, or the regular work of scientists theorizing, can introduce anomalies in current paradigms to cause Model Drift. As more anomalies arise, Model Crisis occurs, causing current paradigms to be questioned and tested. Finally, Model Resolution determines if the new scientific theory is either accepted, resulting in Paradigm Change, or rejected (Kuhn, 2015). Kuhn's theory has many criticisms including the following: a failure to explain additional factors that impact scientific development, and an inability to be applied to every field of science (Adams, 2017). Kuhn's Paradigm Shift assumes that scientific development is only subject to influence from within its community, but many factors impact scientific discoveries. For example, exterior forces, such as prejudice, ethics, etc., that suppress certain research can impact the path a given field takes when pushing the limits of what is known. I plan to use this gap in Kuhn's theory to help identify these factors and how they have impacted this crucial scientific advancement from occurring sooner. Kuhn's theory also cannot be effectively applied to every field due to many not being "paradigm-like." Certain research areas are built on the accumulation of scientific knowledge over time, while others work to generate and iterate on paradigms. There is significant evidence that the injury biomechanics field follows this "paradigm-like" nature, as specific standards and practices are prevalent in various research papers. The paradigm of current design and research standards is now coming into question as anomalies associated with gender, body mass index, and other factors are becoming more prevalent in car design. I plan to use this framework to analyze how the field of injury biomechanics is changing and to help shed light on what gaps need to be filled in order to allow this emerging paradigm to take hold.

Research Question and Methods

Research Question: How are new societal norms, such as obesity, impacting the research and development of automobile safety systems?

To answer this research question, Document Research Methods and Interview methodologies will be used. The injury biomechanics field has applications that span across many areas due to the human body being susceptible to injury in a wide variety of scenarios.

Document Research Methods will help to comb this wide database of research papers to help focus the narrative of the paper on this specific sector of the research field. Keywords that will be used in this method will be “obesity,” “body kinematics,” “car restraint systems,” “dummy technology,” and “safety standards”. Although many researchers have investigated how obesity impacts individuals with various surrogate methods, there are still many unknowns surrounding this condition in motor vehicle crashes (Forman, et al., 2009; Viano, et al., 2008). Through this methodology, I will display how the field of injury biomechanics lacks a deep understanding of how obesity impacts the kinematics of the body under a motor vehicle crash. Research will also provide an overview of the research field and help shine light on how it is adapting to address this issue in current times.

The Interview methodology will be used to support and supplement the Document Research Methods discussed above. Interviews will be conducted with various experts in the field. These experts will help to provide insight into how the research field has reacted to societal norms that have become prevalent in recent times. During the interview, experts will be asked about the difference in the past and present focus of the research field. Questions will also pertain to why the focus of the research field has shifted, and what factors contributed to a shift. Lastly, interview questions that address current research efforts to accommodate for the obese population will also be asked. I will use these interviews to confirm trends found through Document Research Methods and also supplement this methodology with research efforts that are happening in real time.

Conclusion

This proposal covers the design of a powered mask system that filters inhalation and exhalation air as well as an investigation of how car restraint design is adapting to protect the growing obese population. The research team will develop a powered mask design that aims to protect the user and other individuals in their environment, with a target end date of November 24, 2020. We expect the final design to pass a mock fit test modeled after standardized fit tests created by the Occupational Safety and Health Administration (OSHA) while being comfortable to breathe in for extended periods of time. We are also aiming to create a compact and aesthetically pleasing design that will be likely to be worn by the public. This design effort will aim to create a new technology that will aid in stunting the spread of COVID-19.

In relation to public safety, this proposal also discusses an investigation of current car restraint development and how the field is changing to accommodate for underrepresented demographics, such as the obese population. As obesity becomes more prevalent in society, car design is being presented with new challenges when trying to protect drivers and passengers on the road. This investigation will assess how old paradigms in the injury biomechanics field are being challenged and adapted through current research. By using this lens, gaps in current research can be identified to help usher a necessary change in current car restraint design. Another outcome of this research would be an increased amount of awareness for the underrepresentation of the obese population in car design and how it impacts their safety on the road.

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