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Project Title

Crash Modeling of High-Profile Moving Vehicles under Strong Crosswinds Based on Computational Fluid Dynamics

University

Colorado State University

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Research Needs

Extreme wind conditions can prove to be a formidable foe to both highway and driver safety. Strong gusts increase the likelihood of wind-induced vehicle accidents especially over highway structures such as bridges and road embankments/cuttings (Baker and Reynolds, 1992, Chen and Chen, 2010, Hou et al., 2019, Zhu et al., 2012). In particular, high-profile vehicles are vulnerable to single-vehicle crashes (SVC) subjected to strong crosswinds, such as rollover and sideslip. To model and assess the risk of SVC under high crosswind conditions is a challenging task which is strongly dependent on the accuracy of the wind loads acting on moving vehicles. Much of our current understanding on wind loads on vehicles have been obtained primarily from wind tunnel tests along with some recent contributions from CFD studies. However, limitations due to scaling issues of wind tunnel results (e.g. low Reynolds numbers), movement of the vehicle and ignoring the group effects of other vehicles, have constrained the understanding on the nature/uncertainties of the extreme load distributions associated under high lateral wind conditions.

Research Objectives

The overall goal of this research study is to provide new insights and develop preliminary guidelines on improved vehicular safety performances under strong crosswind conditions. Specifically, this overall goal includes the following objectives:

1. Provide a comprehensive assessment of different hazardous scenarios due to crosswinds that are likely to occur in different highway settings (urban and rural).
2. Provide preliminary modeling of SVC occurrence based on the modeled wind loads from CFD.
3. Evaluate the effect of grouping of vehicles under strong crosswinds.

Research Methods

The proposed work will consist of CFD simulations to determine the aerodynamic forces on a vehicle under different scenarios. The output of the wind loads from the CFD model will be used to model SVC.

The thrust of the CFD studies will revolve around a parametric study that will take into account the wind forcing (speed and angle of attack), vehicle characteristics (profile and motion) to determine the aerodynamic forces on the vehicle passing over different highway structures (e.g. bridge, cutting/embankment). Given the computational effort to carry out such a task, the CFD modeling effort will focus on using primarily the Reynolds-Averaged Navier-Stokes (RANS) simulation approach to get turbulence-averaged aerodynamic forces on a high-profile road vehicle. We will test and evaluate the sensitivity of different turbulence closure models such as the widely used k-ε model to the more successful SST k-ω model (e.g. Menter 2009). Comparisons between loads for stationary and moving vehicles will be performed to highlight the effect of the vehicle motion on the flow field and resulting loads. We will also perform preliminary large-eddy simulations (which resolve the large eddies in the flow field and thus computationally intensive) to determine the variance in the loads obtained from the RANS simulations. All the proposed CFD simulations will be carried out using the open-source CFD package "OpenFOAM" (Open Field Operation and Manipulation). The governing fluid flow differential equations will be solved using the finite-volume method for unstructured meshes and is highly parallelizable through the message passing interface (MPI) (OpenCFD, 2012, Wilson et al., 2014).

Once we have developed an envelope of the aerodynamics load from the CFD simulations, preliminary modeling of SVC will be performed to determine susceptible conditions to rollover (overturn), sideslip and yawing of vehicles. Advanced simulation-based SVC model will be applied with the improved wind loads on vehicles to simulate the possible vehicle crashes, followed by parametric studies to further identify critical variables and vulnerable scenarios.

Expected Outcomes

We envisage this proposed study will lead to new insights that will give us the impetus to undertake a comprehensive study using an integrated approach involving CFD and field data collection, leading to robust guidelines for improved transportation safety performance under hazardous driving conditions. Specific outcomes of this work are 1) preliminary guidance on appropriate level of CFD model sophistication required for obtaining wind loads (magnitude and distribution) on vehicles, 2) preliminary modeling of SVC occurrence based on wind loads from CFD, and 3) suggestions on safety preventive measures which may lower the associated safety risks.

Relevance to Strategic Goals

The proposed study specifically addresses primarily USDOT strategic goal: Safety. A related secondary strategic goal would be: Economic Competitiveness.

This study will help towards improved safety assessment and development of guidelines for management of traffic movement under extreme meteorological conditions. It will also in a broader context inform policy decision making that can mitigate negative (e.g. high economic costs) impacts associated with vehicular accidents.

Educational Benefits

This proposed work will have strong educational impacts in a number of ways. Foremost, it would enable the training of a graduate student who will be funded through this project to work on an interdisciplinary project that involves the use numerical simulations of fluid flow and vehicle mechanics to inform traffic safety. Second, findings of these research pertaining to both fluid modeling and vehicle dynamics (and their interactions) will be leveraged to challenge and excite students in both of the PIs graduate courses in Computational Fluid Dynamics (Venayagamoorthy) and Traffic Engineering (Chen).

Technology Transfer

We envisage that technology transfer will happen through a number of avenues. This would primarily be through journal and conferences papers in aerodynamics and transportation safety related journals and professional meetings. Results will also be reported on website and news articles and shared with interested stakeholders.

Work Plan

The major tasks associated with this research are as follows:

1. A comprehensive literature review of the state-of-art for modeling wind loads on moving vehicles and crash simulation under extreme meteorological conditions will be conducted. This will inform our both our CFD modeling and vehicle crash modeling efforts.
2. Conduct parametric CFD study to obtain wind-induced loads on stationary and moving vehicles under different scenarios to overcome the limitations from wind tunnel tests.
3. Provide preliminary modeling of SVC occurrence based on the modeled wind loads from CFD.
4. Provide preliminary safety suggestions to mitigate crash risks of vulnerable vehicles.
5. Disseminate the results through a peer-reviewed journal publication, conference talk and graduate student thesis, and a final project report.

Both PIs will jointly supervise the graduate student that will be recruited to work on this project. We envisage this project to be completed 24 months from initial start date.

Project Cost

Total Project Costs:	$123,000
MPC Funds Requested:	$ 60,000
Matching Funds:	$ 63,000
Source of Matching Funds:	Colorado State University, in-kind support

References

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