Investigation of Ground Level Wind Forces and Blowing Snow Conditions

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Introduction

Wyoming has always faced problems with snow and wind. This came to the forefront after I-80 opened in October 1970; not long after it was opened it was closed due to blowing snow. In response to this, the first stretch of snow fence was installed in 1971 (WYDOT, 2009). Since then, Wyoming Department of Transportation has developed one of the most extensive snow fence programs in the country with the Winter Research Services leading the way since 2004. Wind also creates problems for roadway operations when the wind forces become strong enough to blow over vehicles, particularly large profile semi-trucks, causing roadway closures, property damage and on occasion, injury and fatal crashes.

While wind forces and blowing snow create recognizable hazards, there are many unknowns about the mechanisms behind these hazards. Much of what we know about wind forces and blowing snow relates to atmospheric wind conditions and not the conditions down at the road surface. The purpose of the research proposed is to investigate ground level wind conditions (between 0 and 30 feet with a focus on 0 to 15 feet) and apply what is learned to better prediction of blowing snow conditions and the overturning crash risk associated with high winds.

Relationship to WYDOT Strategic Goals

The proposed research has strong ties to the following WYDOT strategic goals:

- Keep people safe on the state transportation system.
- Serve our customers.

High wind and blowing snow conditions create some of the most hazardous conditions faced by travelers in Wyoming. Better prediction of these conditions and better quantification of the risks would inherently improve the safety of the system. Direct benefits from the research are in the form of fewer crashes and reduced road closures (frequency and duration).

Regarding the serving of the WYDOT customers, the output of this research would lead to improved traveler information for users of the transportation system. In particular, the freight users of the system would benefit from improved advanced predictions of hazardous conditions and a better understanding of the relationship between a vehicle's profile, configuration, and weight with respect to turnover crash risk in high wind conditions.

Background

The background section is divided into previous research and issues associated with High Wind Related Crashes and with Blowing Snow.

High-Wind Related Crashes

The proposed research is a related to earlier efforts at the University of Wyoming that investigated the operation of roadway segments in high wind conditions. In 2005, a project looked at truck movements and safety for the entire state (Young et al., 2005). This initial work lead to research that focused on the overturning truck crashes in high wind conditions (Liesman, 2005; Young & Liesman, 2007a). This follow-up research determined that there was a relationship between the crash occurrences and the measured wind speed at nearby weather stations. Prior to this work it was unknown if weather station wind speeds were an adequate predictor of crashes since wind forces are known to be highly localized. Results from this work provide the foundation for utilizing weather station data for making roadway operational decisions. A later paper set out a framework for utilizing different ITS technologies for operating the roadways subject to frequent high wind conditions (Young & Liesman, 2007b). The most recent research effort developed guidelines for the WYDOT Traffic Management Center in operating the Bordeaux corridor during high wind conditions (Young et al., 2010). While the past research efforts found that the road weather information system (RWIS) data was correlated to crash occurrence it was unable to quantify the actual risk to particular trucks traveling the corridor.

What is needed by the freight logistics companies is the relationship between crash risk and wind conditions given the freight vehicle configuration (i.e. trailer size, length, height) and weight. The previous research identified wind speed thresholds when the risk increased but it was observed that many trucks, even lightly loaded and unloaded, were able to pass through the corridor during hazardous conditions with no issues until an unexplained condition occurred and then several trucks were blown over. The likelihood that overturning crashes occurred to multiple vehicles in a short period of time was quite high and in many cases more likely than a single overturning crash. This unexplained condition is not captured in RWIS data and is likely the reason that theoretical models for overturning truck crashes using wind forces on vehicles are not good predictors of the crashes WYDOT has historically seen on its roadways (Young et al., 2010).

Because truck drivers have a history of traveling through the corridors during hazardous high wind conditions without incident it leads to disregard of traveler warnings. Identification of this additional wind condition is necessary in order to both provide more reliable high wind warnings and to develop risk equations that relate to truck configuration and weight. This research team believes there are two likely causes of the unidentified condition not being captured in RWIS data.

1. Differences between wind conditions at the RWIS station and at ground level.
2. Wind conditions not fully characterized by the wind speed, wind gust speed, and wind direction variables measured by the RWIS.

Blowing Snow

Blowing snow is a condition common to Wyoming, which has led to extensive research for over 40 years in the state. Most notable is work of Dr. Ron Tabler, who developed an international reputation as one of the founding fathers of snow fence research and blowing snow through his research work in Wyoming (Tabler, 1988; 1991a; 1991b; 1994; 2003). More recent research efforts by Tabler focused on the blowing snow conditions associated with near snow issues (Tabler, 2006; 2009). Tabler's work has been incorporated into WYDOT's road design practices and snow fence design and implementation and has led to reduced crashes and road closures (Tabler & Meena, 2006).

A research group from the Civil Engineering Research Institute for Cold Regions in Japan has also done considerable research related to blowing snow mitigation measures (Kaneko et al, 2012). Another interesting aspect of their recent research has been to look at driver reaction to reduced visibility conditions due to snow (Matsuzawa et al, 2008; 2009).

While considerable research has been done on blowing snow, snow fence design, and blowing snow visibility there is still many unknowns in this area. The research proposed in this document will add to the area of blowing snow in two significant ways:

1. Develop better understanding of wind speeds and forces at the ground level in order to better predict hazardous blowing snow conditions.
2. Develop better understanding of blowing snow related visibility conditions at the ground level.

The first research contribution listed above is related to the high wind crash risk research described in the previous section. The data collected for the high wind hazard purpose also has benefits in further quantifying the blowing snow prediction models originally developed by Tabler. Modeling of ground level wind, snow depth, snow structure, topography, and ground surface conditions can be used to improve prediction of blowing snow.

The second research contribution is related to visibility and blowing snow. Currently WYDOT visibility is based on RWIS visibility sensors, web cameras, and reports by personnel traveling the roadway. The last of these is likely most reliable but is limited by the need for personnel to be on the roadway and the qualitative reporting of the conditions (i.e. exact visibility measurement can only be estimated). Web cameras are also only qualitative in nature and have the further disadvantage of being located well above the roadway surface so the viewed conditions could be quite different than what the drivers are observing. Ongoing research on the Variable Speed Limit Corridors has led to concerns about the RWIS visibility sensors. It is believed that the location of these sensors is not adequate for detecting surface level blowing snow. Conversations with the ITS Program and maintenance indicates that it is infeasible to locate the sensors at a more desired location due to clear zone requirements and maintenance of the sensors if they are located closer to the snow plow operations. Given these concerns it is felt that a different method for incorporating visibility into both variable speed limit operations and traveler information systems would be beneficial (Buddemeyer et. al, 2010; Young et al., 2013).

One of the challenges associated with visibility is not just the difference in visibility as observed at the RWIS or web camera level and the road environment but the differences in visibility between passenger vehicle drivers and drivers of larger vehicles such as snow plows and freight vehicles. The proposed research would collect data from three roadside visibility sensors located at the driver's eye height for passenger cars, the driver's eye height for larger vehicles, and one below the passenger driver's eye height to represent visibility of the road surface.

Study Benefits

The ultimate benefit of this study will be to give WYDOT the necessary information to better predict hazardous blowing snow and high wind conditions. Specifically the deliverables from this project will be:

- Improved risk-based traveler information for vehicles during high wind conditions based on current or forecasted wind conditions and vehicle characteristics.
- Better prediction of blowing snow conditions.
- Relationship between wind conditions, snow characteristics, and predicted visibility for inclusion in traveler information and variable speed limit systems.

Work Plan

The objectives of this research are to:

1. Correlate wind speed at a location remote from a road and at an elevation far above a road (typical RWIS location) to a wind speed profile at the road.
2. Model the relationship between this remote wind speed (RWIS location) and the road-level wind profile using computational fluid dynamics (CFD).
3. Model the relationship between road-level wind profile and pressure distribution on a tractor-trailer profile using CFD.
4. Correlate wind speed at a location remote from a road and at an elevation far above a road to visibility at road-level.
5. Correlate blowing snow visibility to snow quality based on the snow modeling and monitoring.

The first phase will focus on designing and constructing the wind-measuring tractor-trailer profile. The second phase will focus on correlating the wind speed to wind speed profile, wind pressure profile, and blowing snow visibility.

Project Tasks

The methods for meeting the research objective are broken down into tasks within the two phases below. More details about the proposed field instrumentation and modeling associated with the tasks are provided in the sections following.

1. Install wind speed sensors, snow depth, air temperature, humidity, radiation, precipitation, wind speed, wind direction, and blowing snow visibility sensors.
2. Monitor remote wind speed, road-level wind profile, and snow visibility.
3. Create CFD model of terrain for wind study.
4. Create CFD model of tractor-trailer or Ahmed body (standard shape used for CFD problems involving vehicles) for wind study.
5. Set up snow model for surface snow density estimation.
6. Continue data collection.
7. Correlate remote wind speed to road-level wind speed profile.
8. Correlate remote wind speed to road-level snow visibility.

9. Correlate the estimated snow density to road-level snow visibility.
10. Refine CFD model of terrain.
11. Refine CFD model of tractor-trailer or Ahmed body (standard shape used for CFD problems involving vehicles).
12. Review data with WYDOT Winter Research Services.
13. Develop draft report and deliver to all stakeholders.
14. Produce final report incorporating feedback from stakeholders.
15. Present findings at WES 2015.
16. Present findings at TRB 2015.
17. Prepare manuscript(s) for refereed journal.

PI Mukai and the graduate student will work on all tasks. PI Young will assist on wind measurement and risk analysis. PI Ohara will conduct all snow modeling.

CFD Modeling

Computational Fluid Dynamics (CFD) will be used to construct two models: 1) a model of the terrain between the RWIS wind-speed monitor and the road-level wind speed and pressure sensors and 2) a model of a vehicle subjected to the road-level wind profile. The CFD modeling will be done in COMSOL, commercial multi-physics software. The COMSOL CFD module has been verified against the standard vehicle CFD problem, flow around the Ahmed body (Figure 1). Figure 1 shows the wind forces in line with the vehicle but given the problem of overturning trucks the problem modeled in this research would be for perpendicular wind forces. The Ahmed body is used to validate the model prior to the modeling of vehicle dimensions more typical to Wyoming.

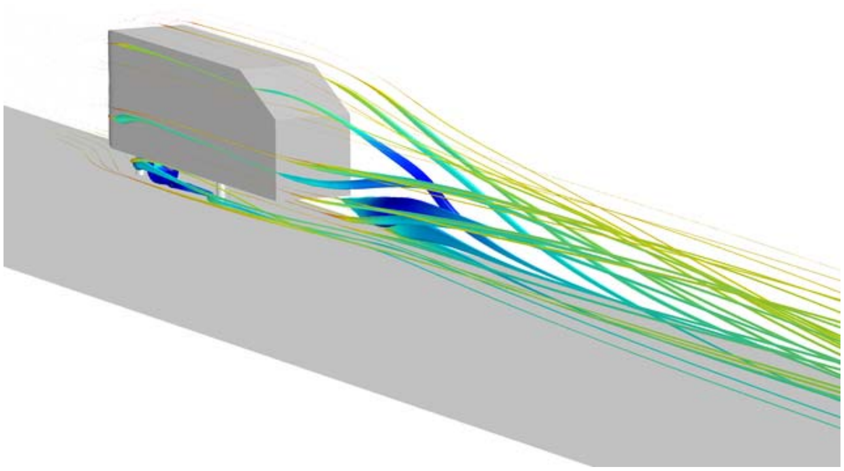

Figure 1. Ahmed body problem solved with COMSOL.

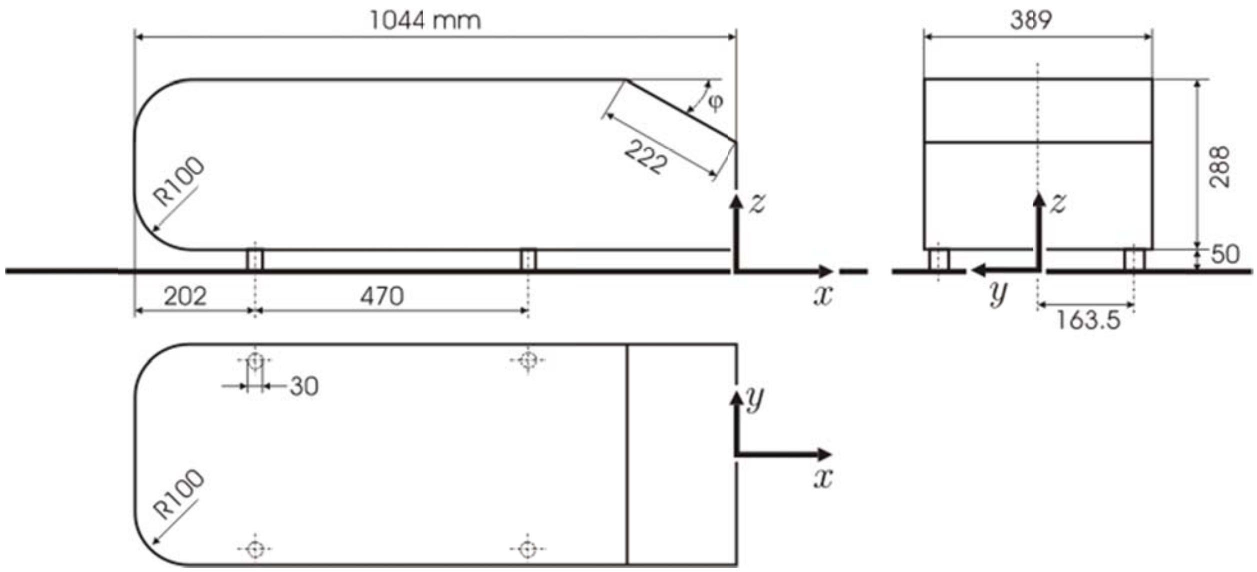

Figure 2. Ahmed body dimensions.

Visibility and Snow Monitoring

Snow monitoring tower will be installed at the place where snow is likely to be captured and stored depending on the local topography of the site (Figure 3). The tower will measure snow depth, air temperature, humidity, radiation, precipitation, wind speed, and wind direction. These variables will be used for snow storage and surface snow density estimations by a snow model. Meanwhile, the three visibility sensors at different heights will be installed at the road side. The lower one will measure the snow transportation due to snow saltation, and the other two will measure the visibility at a typical driver's sight level passenger vehicles and freight vehicles or snow plows due to snow suspension.

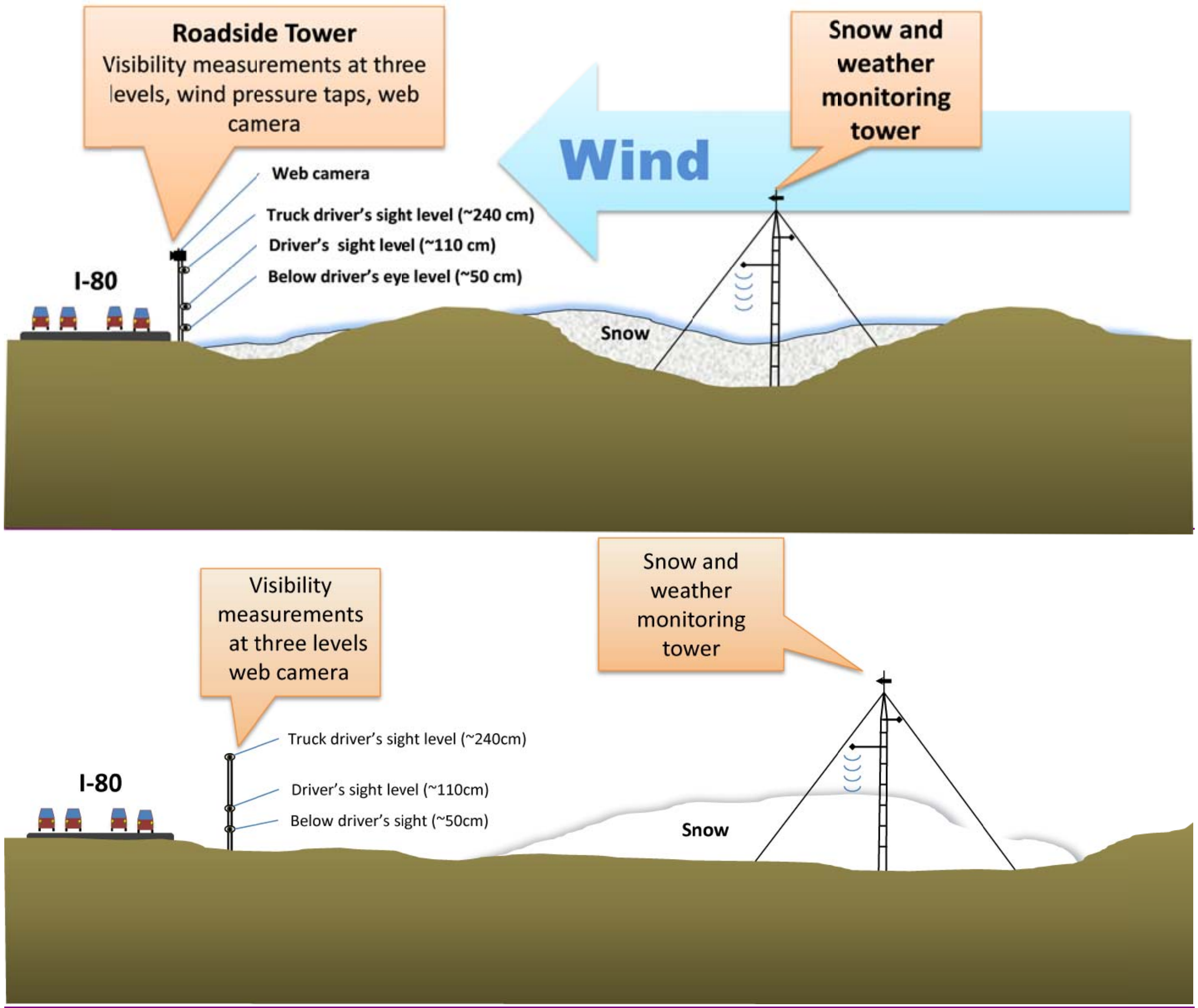

Figure 3. Schematic of the proposed field monitoring setup

Snow Model for Surface Snow Density Estimation

Direct measurement of snow mobility is difficult to perform without snow surface disturbance. In this work, a physically-based snow model developed by PI Ohara (Ohara and Kavvas, 2006) will be used to estimate the surface snow density or erodibility and to extrapolate the snow surface condition of the surrounding area. This model computes snow depth, surface snow temperature, snowmelt, snow density, and snow wetness by the energy balance over the snowpack. The snow monitoring tower will provide the atmospheric information for the snow model. This model will quantify the snowmelt amount, snow accumulation due to precipitation, and snow redistribution. The estimated surface snow density will be correlated to the blowing snow visibility on the road.

Work Schedule

The project is scheduled for 14 months, beginning in November of 2013 and ending in December of 2014. See "Project Tasks" section for more details about each of the phases.

Estimate

The total cost estimate for the tasks outlined in this proposal is ***$105,803*** which includes two years of graduate student support. The cost estimate also includes ***$28,500*** in monitoring equipment. A detailed budget is included at the end of this proposal.

Technology Transfer

Technology transfer will be done through dialog with the Wyoming Department of Transportation and other stakeholders throughout the entire project. Results will be disseminated through a final report, peer-reviewed publication(s), and technical presentations at national conferences such as the annual meeting of the Transportation Research Board. The results will be transferable to other agencies operating roads subject to high wind conditions.

References

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PROJECT TITLE: Investigation of Ground Level Wind Forces and Blowing Snow Conditions

Research Agency:	University of Wyoming Department of Civil and Architectural Engineering 1000 E. University Avenue, Dept. 3295 Laramie, WY 82071		
Budget Period:	November 1, 2013 – December 31, 2014		
Contract Period:	14 Months		
A. Senior Personnel			
1. Noriaki Ohara	1 month	$	8,300
2. David Mukai	0.5 month	$	4,470
3. Rhonda Young	0.5 month	$	4,678
	(A) Total Senior Personnel	**$**	**17,448**
B. Other Personnel			
1. One (1) Graduate Student	14 months	$	18,885
2. Student Worker	500 hours at $10/hr	$	5,000
	(B) Total Other Personnel	**$**	**23,885**
C. Fringe Benefits			
1. Senior Personnel * 45.56%		$	7,950
	(C) Total Fringe Benefits	**$**	**7,950**
D. Operating Expenses			
1. Computer Usage and Service		$	1,200
2. Communication		$	300
3. Office Supplies		$	200
	(D) Total Operating Expenses	**$**	**1,700**
E. Technology Transfer			
1. Presentations at Meetings, Conferences and Workshops		$	2,500
2. Travel to Project Sites		$	1,500
3. Final Report		$	600
	(E) Total Technology Transfer	**$**	**4,600**
F. Equipment			
1. Wind Anemometers	4 anemometers and support for 3 sites	$	3,000
2. Power and Communications		$	2,000
3. Visibility Sensors	3 road-side visibility sensors	$	15,000
4. Snow sensor	1 Snow sensor	$	6,000
5. Tower	1 Tower	$	2,500
	(F) Total Equipment	**$**	**28,500**
G. Total Direct Costs (A through F)		**$**	**84,083**
H. Indirect Costs (Specify Rate and Base)			
1. Indirect Costs	20% of Total Direct Costs	$	22,817
	(H) Total Indirect Costs	**$**	**16,817**
I. Tuition and Fees			
1. Tuition and Fees	No indirect costs	$	4,903
	(I) Total Tuition and Fees	**$**	**4,903**
J. Total Direct and Indirect Costs (G+H+I)		**$**	**105,803**