UAB SCHOOL OF ENGINEERING

Development of Trailer Underride Preventive Measures

A Proposal for Designing and Testing Design Concepts

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1. Introduction

Standards that regulate the construction of underride guards on semi-tractor trailers have had a tumultuous history, dating back to the 1970s. Standards have invariably called for limits on allowable ground clearance and offset from the end of the trailer to the guard. More recent requirements have mandated that the guard be able to carry high static loads, but eventually deform. However, these standards vary all over the world, with some of the most stringent standards found outside the United States. Some studies have indicated that the current U.S. standards have no real tangible effect on safety. As such, the need for a paradigm shift in the design of trailer underride guards is clear, especially to the more than 300 people who are killed in rear-end truck underride collisions each year.

Relative risk is a measure of the danger of a particular type of crash. In the roadside safety industry, relative risk can be measured for each hardware device on the side of the road in terms of the number of fatal and severe-injury (K+A) crashes divided by the total number of crashes, including all injury levels and property-damage-only (PDO) crashes. Roadside safety engineers often strive to reduce relative risk to 3% or less. For collisions in which a light vehicle rear ends a tractor-trailer, the relative risk sores to around 80%. This extraordinarily high number is reflective of the implementations of standards that require all new trailers to come equipped with guards. The relative risk was likely much worse before.

However, standards in and of themselves do not necessarily reflect the necessary design constraints. For example, the current standards, FMVSS 223/224, primarily restrict clearance gaps. The bottom of the guard can be no more than 22 inches from the ground level, and the face of the guard can be no more than 12 inches offset from the end of the trailer. However, researchers from Transport Canada built and crash tested underride guards that adhered to this standard, and showed that even at only 30 mph, small cars could easily underride the trailer and cause severe injuries or death to the occupants. However, those researchers were also able to demonstrate that if the guard could absorb energy, then the 22-in ground clearance parameter could be met while still providing adequate safety.

The problem is that the impact conditions observed in reality are difficult to discern. Therefore, the initial phase of this research will be to clearly define the problem in terms of impact energy that must be managed in a rear-end underride impact. After the problem is defined, a research and development path will be undertaken to design a light-weight energy-absorbing guard system to mount underneath trailers that, at a minimum, adheres to FMVSS 223/224.

2. Phase I – Defining the Problem

Fortunately, large-truck underride statistics have been collected for quite some time. Recently, the National Highway Traffic Safety Administration (NHTSA) released a report titled “Heavy-Vehicle Crash Data Collection and Analysis to Characterize Rear and Side Underride and Front Override in Fatal Truck Crashes” (March 2013). This document contains information on the type of secondary vehicle collided with the truck, the amount of underride, if any, that the secondary vehicle experience, and estimated impact speeds based on crash reconstruction techniques.

In order to replicate and improve upon the statistics in NHTSA's report, thousands of man-hours would be required to collect the data and analyze it to the level necessary to identify defining trends. Because of this, and because the NHTSA report has substantive detail, their report will be studied to identify an impact condition that is reflective of the most possible scenarios while disallowing for highly extreme conditions. Design constraints cannot support rear end impact velocities of 100 mph, for example. Therefore, the forces that the guard must withstand will be derived from a representative vehicle mass, orientation, and velocity taken from the NHTSA report. A comprehensive review of this document will require one month for a research engineer to complete, including a written summary of the findings. This review will be assisted by an outside consultant at an estimated cost of $5,000.

3. Phase II – Solving the Problem

Full product development would require numerous full-scale crash tests, and extensive design formulation and revision. And even then, a working design may not even be possible under the impact conditions identified in Phase I. Therefore, this phase will provide a proof of concept, namely, that a vehicle can be safely stopped by an underride guard system.

The impacting kinetic energy that must be absorbed will come from Phase I. However, there is an additional design constraint: weight. The final weight of the design must be minimized as much as possible to reduce costs associated with transporting the under-ride guards.

With the problem fully defined, concepts will be developed through brainstorming sessions and initial first principles analyses. These first principles analyses will serve to highlight energy dissipation characteristics of the brainstormed ideas as well as the required stroke of the system to arrest a vehicle safely. A target deceleration of 20 g's (20 times the force of gravity) will be used to approximate the required stroke, or distance traveled by the vehicle through the impact event. As an example, from 60 to 0 mph, with an average deceleration of 20 g's, the vehicle would travel 6 feet. Therefore, in this example, the new guard would have to apply the force to obtain a 20-g loading while dissipating the car's energy in only 6 feet, which must be traversed without crushing the occupant compartment. Phase I will provide a true impact speed, which will govern the stroke limit, and mass, which will govern the energy management characteristics of the design.

Numerous design concepts will be generated and evaluated using first principles analysis. The most promising design concepts will be explored using one of the following two approaches (1) construct and crash test at the Barber Laboratory for Advanced Safety Education and Research (BLASER) in Leeds, AL; or (2) multiple concepts will be modeled with LS-DYNA without any crash testing.

Crash Testing

A semi-trailer will be purchased and used as a stationary target for crash testing. On the trailer, the best design concept will be built and set up for testing at BLASER. Two crash tests will be conducted, one with a small car, near the 5th percentile from the Phase I results, and a large SUV, near the 95th percentile from the Phase I results. The small car test will be used primarily to demonstrate that the deceleration rate and occupant compartment crush are survivable. The SUV test will be used to measure the structural capacity of the device to ensure that it can absorb the higher energy level without bottoming out. This test will also be evaluated for safe levels of deceleration and occupant compartment deformation. The cost associated with acquiring two used vehicles, a semi-trailer, and lab space time at BLASER were approximated at $40,000, which includes a $1,000 daily charge for 5 day of construction and testing. In addition to this equipment cost, one month of time for a research engineer, two months of time for a fabricator, and three weeks of time for a faculty member will be used in the brainstorming, analyzing, and testing portions of this phase.

Computer Modeling

An alternative path to completing the proof-of-concept is to use only computer simulation, rather than the more expensive crash testing. An explicit finite element analysis tool known as LS-DYNA will be used in this endeavor to accurately capture the complex arrangement of geometry, material characteristics, and stress wave propagation inherent in impact problems. LS-DYNA has been used in the field of energy management since its inception in the early 1980s. It is by far the most common simulation tool used in the automotive industry when evaluating a vehicle’s safety performance. It has also become extraordinarily popular among roadside safety engineers to study energy management in impact conditions between cars and roadside objects. The research team at UAB has extensive knowledge of the use of LS-DYNA and access to licenses of the program through the Cheaha supercomputer at UAB.

With a reasonable degree of engineering certainty, although less certain than full-scale crash testing, the use of computer simulation can provide a close estimate to the levels of deceleration and occupant compartment crush for a selective group of vehicles. Unfortunately, the cost to develop a vehicle model is hundreds of thousands of dollars. As such, currently available vehicle models, such as those on the NCAC model archive website, will have to be used. The selection of the vehicle model will be as close as possible to the identified vehicles in Phase I.

4. Summary and Conclusion

Parameters of the problem must be fully defined before a design effort can be undertaken. Statistics have been compiled and analyzed by NHTSA and reported on in a publicly available document. That document will be review to specifically identify impact conditions to be used in the design of a new underride guard. With this approach, all impact conditions of less severity would be less critical and more survivable.

After the problem is defined, a proof-of-concept will be carried out to show that a vehicle can be safely stopped by a new underride guard. This can be done in one of two ways: full-scale crash testing or LS-DYNA modeling. Full-scale crash testing would be more accurate but more expensive.

Based on the results of either crash testing or computer modeling, a recommendation for the direction of full product development will be provided. The findings of this proof-of-concept could show that the identified impact conditions cannot be survived regardless of the design of the guard. However, UAB researchers do not believe this to be true. It is more likely that design optimization recommendations will be made to improve the performance of the proof-of-concept prototype.

Full-scale crash testing, complete with costs for time, equipment, fringe benefits, and overhead, will cost $138,040 This cost would cover two months for a research engineer (Kevin Schrum) to identify impact conditions and develop design concepts, two months for a fabricator (Steve Thompson) to construct the test prototype, and three weeks for a faculty member (Dean Sicking) to oversee the project and develop design concepts. In addition, consulting services outside of UAB are expected to cost $5,000 and equipment for crash testing is expected to cost $40,000.

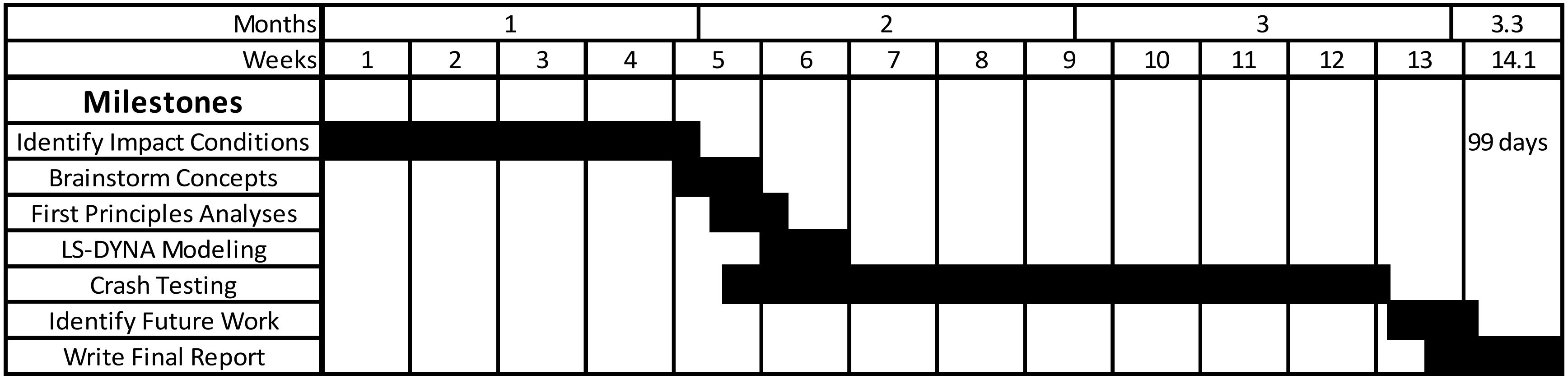
Alternatively, full-scale crash testing can be supplanted with computer simulation only, although the accuracy of the results may not be as robust as the physical testing. This approach is expected to cost $61,048. This cost would include 2.5 months for a research engineer (Kevin Schrum) to identify impact conditions and develop/model design concepts and three weeks for a faculty member (Dean Sicking) to oversee the project and develop design concepts. In addition, consulting services outside of UAB are expected to cost $5,000. The budgets for each method are shown on the following page.

5. Research Team

Dean Sicking has a Ph.D. in Civil Engineering from the Texas A&M University. He was the director of the Midwest Roadside Safety Facility (MwRSF) at the University of Nebraska-Lincoln (UNL) between 1992 and 2012, where he also achieved tenure as a professor in the School and Engineering and emeritus status before leaving for the University of Alabama at Birmingham (UAB) in 2012. Dr. Sicking has led the development of numerous roadside hardware devices that have save the lives of thousands of motorists. Additionally, he has written crash test standards that have led to paradigm shifts in safety performance across the entire industry. While at MwRSF, he led the development team that created the SAFER barrier used by NASCAR and Indy Racing League on high-speed race tracks. Prior to the implementation of this barrier, it was common for 1 or 2 drivers to be killed in any given year. Since its implementation, almost 10 years ago, no one has been killed in a crash involving the wall. Dr. Sicking's combined experience in writing standards, developing products, and managing energy dissipation uniquely qualify him to lead the development of a new truck underride guard system.

Kevin Schrum has a Ph.D. in Engineering from the University of Nebraska-Lincoln, where he studied under the direction of Dr. Dean Sicking. While at UNL, Dr. Schrum compiled and analyzed crash statistics related to roadside slopes in order to provide guidance to the sponsor for selecting a grade for the roadside that was cost-effective while maintaining an acceptable level of safety. He also worked on modeling the fracture behavior of steel under dynamic loading, accounting for high levels of localized strain energy density. Upon graduating, he joined Dr. Sicking at UAB as a research engineer where he primarily works on new product development.

Table 1. Timeline Based on Full-Scale Crash Testing



Months	1				2				3					3.3
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14.1
Milestones														
Identify Impact Conditions	■	■	■	■	■									99 days
Brainstorm Concepts					■									
First Principles Analyses					■	■								
LS-DYNA Modeling						■								
Crash Testing					■	■	■	■	■	■	■	■	■	
Identify Future Work													■	■
Write Final Report													■	■

Table 2. Budget Based on Full-Scale Crash Testing

Item Description	Title	Monthly Salary	Hourly Salary	Hours	%Effort	Cost
Labor						
Sicking, Dean Leo	Professor/PI	$ 20,416.67	117.79	130	6%	$ 15,313
Schrum, Kevin	Research Engineer	$ 5,000.00	28.85	347	17%	$ 10,010
Thompson, Steve	Field Manager	$ 5,833.33	33.65	347	17%	$ 11,678
CFB						
Faculty			28.6%			$ 4,379
Staff			34.7%			$ 7,526
Subcontract		$ 5,000.00				$ 5,000
Supplies		$ 35,000.00				$ 35,000
Services	BLASER Facility (5 days of Testing)	$ 1,000.00				$ 5,000
Subtotal						$ 93,905
IDC			47.0%			$ 44,135
Total						**$ 138,040**

Table 3. Timeline Based on LS-DYNA Modeling

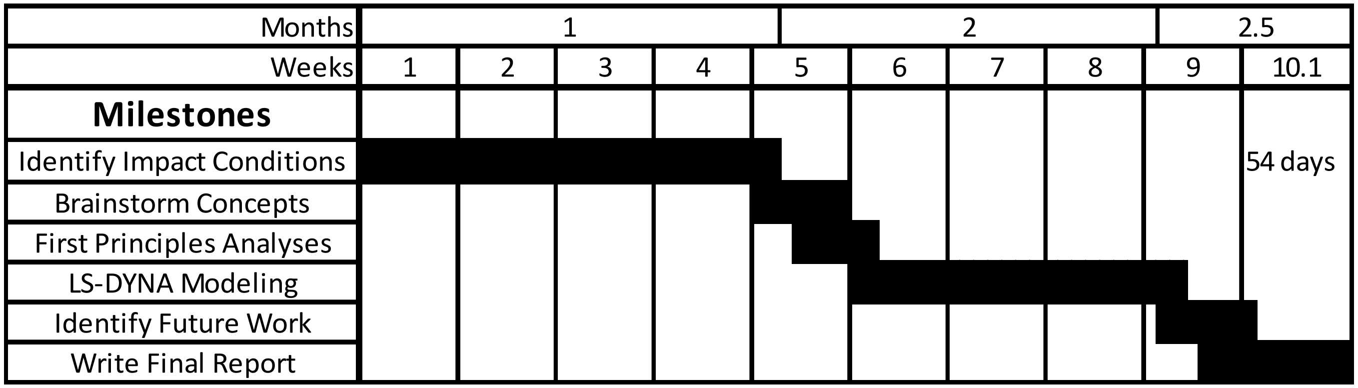


Table 4. Budget Based on LS-DYNA Modeling

Item Description	Title	Monthly salary	Hourly Salary	Hours	% Effort	Cost
Labor						
Sicking, Dean Leo	Professor/PI	$ 20,416.67	$ 117.79	130	6%	$ 15,313
Schrum, Kevin	Research Engineer	$ 5,000.00	$ 28.85	433	21%	$ 12,500
Steve Thompson	Field Mangager	$ 5,833.33	$ 32.69	0	0%	$ -
CFB						
Faculty			28.60%			$ 4,379
Staff			34.70%			$ 4,338
Subcontract		$ 5,000.00				$ 5,000
Subtotal						**$ 41,529**
IDC			**47.00%**			**$ 19,519**
Total						**$ 61,048**