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# **SPE-185674-MS Improving Rollover Crashworthiness of Heavy Trucks Equipped with Towers and Booms Overhanging the Cab**

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## **Abstract**

Many purchasers and operators of heavy trucks may be unaware of the potential added danger to occupants from equipment overhanging the cab under rollover conditions. This study examines US and EU regulations for heavy truck occupant protection and the options for minimizing injuries with aftermarket equipment. US and EU government regulations regarding occupant protection in heavy trucks were reviewed and their shortcomings with regard to vehicles modified with a boom structure are highlighted. A finite element model of a truck and boom were created. Baseline performance was verified against real world data and simulations run for rollover impacts. Significant intrusion into the occupant compartment due to the loading of the overhead boom was observed. Overhead booms can deform during contact with the ground, with longer overhanging associated with greater intrusion into the cab under rollover impact conditions. The effect of these structures on heavy truck crashworthiness, especially with regard to low strength OEM cabs, must be considered during up-fitting. A simulation was run with an aftermarket device and conclusions are presented.

**Keywords:** Heavy Trucks, Roof Strength Requirements, Overhead Equipment, Rollover Occupant Protection, Frontal Occupant Protection

## **Introduction**

Many companies in the Industrial Sector rely on aftermarket heavy equipment devices to do the “heavy lifting” of their work environments. Heavy equipment boom structures of various types are retrofitted to light and heavy duty trucks. These boom structures can be lifts, cranes or drills and are used in everyday work by all sorts of occupations. There are governmental regulations that cover some of these vehicles in both the US and Europe that must met in order for the vehicles to sold and used in those countries. In the US, trucks are regulated by the National Highway Transportation Safety Administration, (NHTSA) and the Federal Motor Carrier Safety Administration (FMCSA) under the US Department of Transportation Federal Motor Vehicle Safety Standards (FMVSS). These standards lay out the minimum requirements that must be met by Original Equipment Manufacturers (OEM), to the extent that they are applicable to the vehicle type being built. [1]

In Europe, The United Nations Economic Commission for Europe (ECE) implemented Regulation 29, in 1974 and with subsequent revisions, lays out uniform provisions for commercial vehicles, including heavy trucks [2].

In May of 2015, NHTSA presented the results of their research finding to US Congress, called, "The Need for Additional Heavy Truck Crashworthiness Standards". [3] The report stated that in 2012 there were 697 fatalities, the majority of which were drivers. Further, the study found that approximately three events made up 89 percent of crashes that resulted in a fatality or severe injury to truck drivers. The most harmful events are rollovers (41%), collisions with other vehicles (33%) or collision with a hard-fixed object (15%). Vehicle rollover presents the greatest risk to heavy truck occupants with ejection of the occupants highly correlated to vehicle rollover. They go on to say that "the review found that a majority of these fatal crashes had severe deformation of the cab or intrusion significantly compromising the cab's occupant space. Specifically, fatal rollover events typically involved more than a single quarter turn, resulting in severe cab deformation." [3]

The US FMVSS 216 is the standard for roof strength for vehicles up to 6000lbs GVWR (2268Kg). Among its requirements is a static roof strength test, with a pass at a measured strength-to-weight ratio (SWR) of 3. The Insurance Institute for Highway Safety has defined the required SWR as 4 to be considered Good. Generally, there are no roof strength requirements for vehicles over 4536 kg Gross Vehicle Weight (GVW) (10000 lbs) and only minimal requirements, (SWR >1.5) for those greater than 2722kg (6000 lbs) up to 4536 kg (10000 lbs) GVW. However, heavier vehicles do not have any regulatory requirements associated with roof strength, and are only guided by industry defined test procedures in the US.

None of the regulations address real world loading conditions and none of them consider the effects of structures overhanging the occupant compartment.

There are many crash modes and crash circumstances that these tests and regulations do not address and without significant and/or specific regulations for additional roof strength requirements with the addition of overhead structures to vehicles, the purchasers of these vehicles have little idea of the enhanced risk from these boom structures to their vehicle occupants. Many trucks originally sold as incomplete vehicles to third party vendors ultimately have structures protruding over the top of the cab. Examples include crane booms, drill booms, cherry picker booms, used for example in support of power line maintenance, construction, heavy lifting, installation activities, and well drilling activities, shown in Figure 1.



Figure 1. Examples of trucks with booms overhanging the cab

These vehicles are involved in rollovers and other crash configurations while in the service. During these impacts, the boom type structures have the potential to intrude into the occupant space often with fatal consequences as shown in Figures 2 and 3.



Figure 2. Example rollover crash with overhead boom



Figure 3. Example cab deformation with tower in stowed position

Next, we look at an example of what can occur and what can be done to protect occupants from fatal consequences and the associated evaluation methods. Examining an aftermarket attachable structure to help address such hazards is considered. A virtual representation of an existing aftermarket structure system was created and mounted on an existing production vehicle structure. An example boom structure observed in a real-world crash was added to the vehicle model and allowed to intrude into the occupant space during a rollover event. Virtual rollover tests were then conducted to examine the effects of the retrofitable rollover protection design approach compared with baseline conditions.

## Method

A finite element model of a truck and boom were created for use with LS-DYNA 971 as illustrated in Figure 4. The baseline roof performance was validated against available test data as shown in Figure 5.

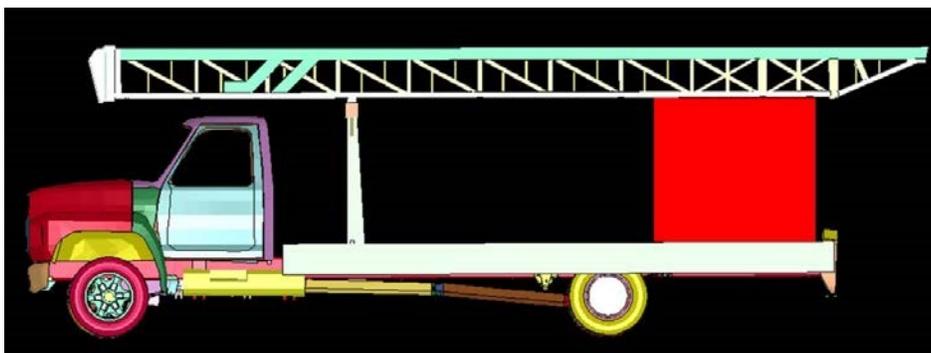


Figure 4. Finite element model of vehicle and boom

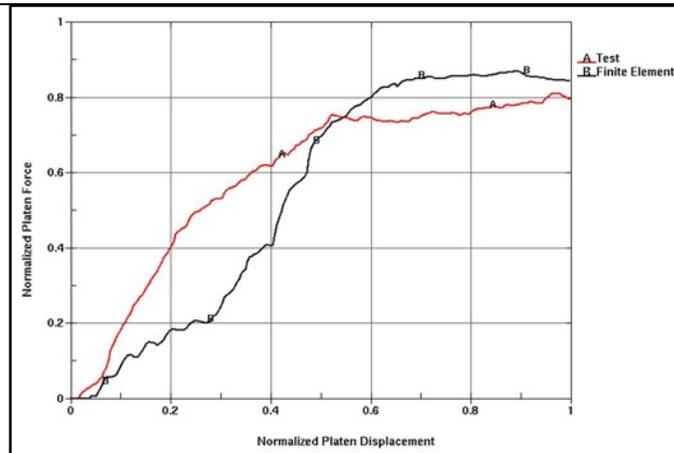


Figure 5. Comparison of FE model roof strength with test data for subject vehicle

A three-dimensional model of the terrain was created from a laser scan of the scene shown in Figure 6.



Figure 6. 3-D model of terrain

At the start of the simulation, the truck is rolled to 120 degrees, and moving over the terrain at 17.5 m/s with a sideslip angle of 30 degrees, and an initial roll rate of 2.0 rad/s (Figure 7).

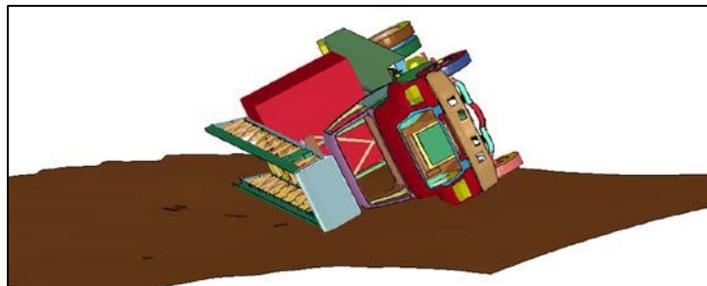


Figure 7. Baseline design impact conditions

Rollover impact conditions were selected that created significant intrusion into the driver compartment of the baseline truck (Figure 8).

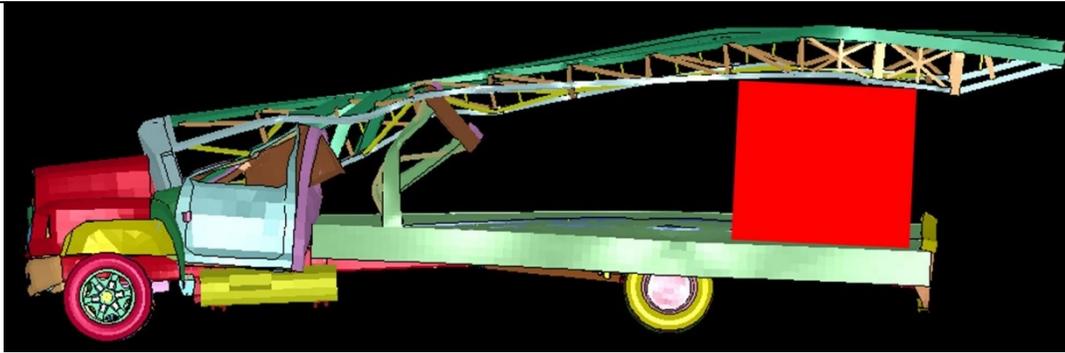


Figure 8. Baseline roof performance

A model of a retrofitable rollover protection design approach was then created as shown in Figure 9. The unoptimized retrofit design increased the overall weight of the truck by less than 1%.

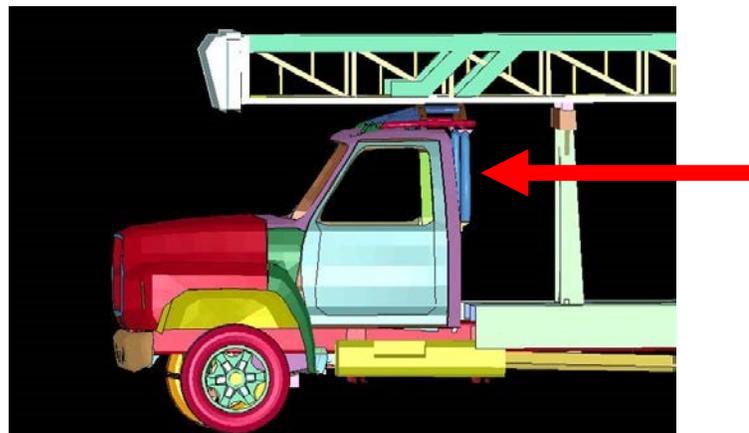


Figure 9. Model with retrofitable rollover protection design approach fitted to cab

The performance of the retrofit design approach was then evaluated under these same conditions and compared with the baseline results.

## Results

The impact conditions for the baseline vehicle produced the deformation shown in Figure 10. There was significant intrusion into the occupant compartment due to the loading of the overhead boom. This intrusion would likely be fatal to the restrained driver of the truck. The finite element model of the alternative design with the retrofitable rollover protection was then virtually tested under the same impact conditions. The resulting intrusion is illustrated in Figure 11.

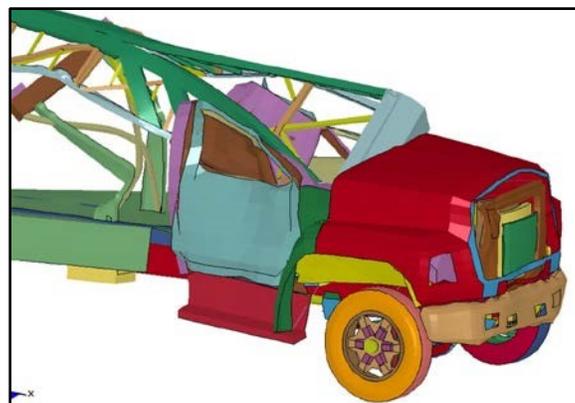


Figure 10. Baseline cab crush resulting from rollover

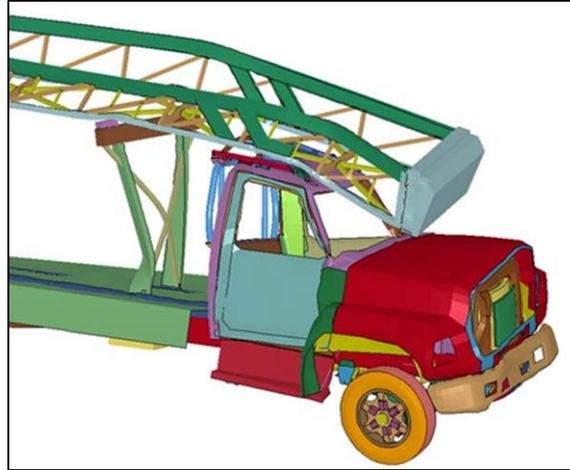


Figure 11. Alternative design cab deformation under same rollover conditions

A comparison of the relative intrusion amounts over the driver seat position are shown in Figure 12. The reduction in intrusion with the retrofit would have enabled the driver to survive this crash. It should be noted that in the baseline configuration, the boom support rack deformed extensively downward and rearward due to loading. An effectively designed boom support rack placed close to the back of the cab may also reduce the crush of the compartment during the rollover.



Figure 12. Comparison of intrusion over driver seat position

## Discussion

The results show that the retrofit design approach provided effective protection against the intrusion of the overhead boom. Similar retrofit systems have been installed in over a thousand vehicles around the world, typically in mining and pipeline construction applications, providing pickups, vans and SUV's with improved protection in rollover crashes. Here, it has been shown to provide protection to occupants of larger trucks against the threat represented by booms that have been installed on the vehicle and overhang the cab structure.

Because these boom structures are installed typically as part of the incomplete vehicle finishing process, there is a clear opportunity to incorporate aftermarket countermeasure designs to provide improved

protection to the operators of the vehicles after completion. For example, the installation of an effectively designed support rack would assist in mitigating interaction between the overhanging boom and cab structure.

The intermediate or final stage manufacturers have the opportunity to evaluate the threats that booms installed on an incomplete vehicle represent. The evaluation can be done across a broad range of impact conditions under which the incomplete vehicle has not necessarily been evaluated.

The overhanging boom structures represent a threat to occupants in rollover impacts as well as frontal impacts. In frontal impacts if the vehicle design does not have the ability to handle the moments and loads introduced, the cab can be crushed from the rear during pitching motion of the boom structure.

The incomplete vehicle manufacturers have an opportunity to support the intermediate and final stage manufacturers by providing guidance on the incorporation of added components that may introduce excessive threats to the occupants. Additionally, after-sales support could be provided to help assess the threats represented by the proposed additions to the vehicle prior to final sale.

## Conclusions

Given that the US and Europe regulations do not sufficiently cover heavy trucks, there is a need for the purchasers of these vehicles to be aware of the potential hazards to occupants with the addition of overhead boom structures. Incomplete vehicle designs, to which a variety of booms are added that overhang the cab structure, represent an important opportunity for the introduction of rollover and roof intrusion protection designs.

The threats being introduced with booms and related type structures that overhang vocational vehicle cabs can be addressed through the use of virtual testing methods at low cost to manufacturers.

Overhead booms typically can deform during contact with the ground, and the longer the overhang the more likely the intrusion into the cab under rollover impact conditions. It is important that these impact loading conditions be considered before adding structures to incomplete vehicles.

## References

- 1 NHTSA, 49 CFR Parts 571 and 585, Federal Motor Vehicle Safety Standards; Roof Crush Resistance; Phase In Reporting Requirements; Final Rule. May 12, 2009.
2. Intereurope E.C.E- Truck Safety Cabs, Regulations No. 29, March 15, 1974.
3. NHTSA Congressional Report, The Need for Additional Heavy Truck Crashworthiness Standards, May 2015