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Finite element analysis of occupant head injuries: Parametric effects of the side curtain airbag deployment interaction with a dummy head in a side impact crash

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ABSTRACT

In this study, we investigated and assessed the dependence of dummy head injury mitigation on the side curtain airbag and occupant distance under a side impact of a Dodge Neon. Full-scale finite element vehicle simulations of a Dodge Neon with a side curtain airbag were performed to simulate the side impact. Owing to the wide range of parameters, an optimal matrix of finite element calculations was generated using the design method of experiments (DOE); the DOE method was performed to independently screen the finite element results and yield the desired parametric influences as outputs. Also, analysis of variance (ANOVA) techniques were used to analyze the finite element results data. The results clearly show that the influence of moving deformable barrier (MDB) strike velocity was the strongest influence parameter on both cases for the head injury criteria (HIC36) and the peak head acceleration, followed by the initial airbag inlet temperature. Interestingly, the initial airbag inlet temperature was only a ∼30% smaller influence than the MDB velocity; also, the trigger time was a ∼54% smaller influence than the MDB velocity when considering the peak head accelerations. Considering the wide range in MDB velocities used in this study, results of the study present an opportunity for design optimization using the different parameters to help mitigate occupant injury. As such, the initial airbag inlet temperature, the trigger time, and the airbag pressure should be incorporated into vehicular design process when optimizing for the head injury criteria.

1. Introduction

Improving occupant safety remains among the most important and challenging design considerations in the automotive industry. Statistics from the National High-Way Traffic Safety Administrations (NHTSA) shows that five million vehicle crashes occurred in the United States in the year 2009, which injured more than two million people and claimed more than 33,808 lives (NHTSA, 2009). Among the injured or killed, head injury is the most common cause of death during worst-case side impact scenarios, and the head is the most likely injured body region, even among occupants using a three-point restraint system. Also, prior analyses demonstrate that some occupant restraint devices, such as airbags and seatbelts, contribute to reduce the risk of head injury and enhance occupant safety during impact crashes (Gabauer and Gabler, 2010). They are typically installed as thorax-or torso-only airbags, torso-head airbags (combination airbags), or separate torso and head airbags (curtain or inflatable tubular structures). Although federal regulations do not exist in the United Stated for side airbags, such systems are gaining popularity, because of public awareness for safety and their potential injury mitigation characteristics (Fujiyama et al., 2011; Dix et al., 2011).

Nonetheless, there is still a controversy about serious occupant injuries caused by airbag deployment, mainly attributed to the airbag interacting with the occupant position. Moreover, as the number of cars equipped with airbags increases, more data is becoming available and more reports of injuries caused by deployed airbags have appeared in the literature (Christy et al., 1998; Jeon and Park, 2006; Audrey et al., 2011; Potula, 2012). For example, McGwin et al. (2003) investigated the associations between a side airbag and risk of injury in motor vehicle collisions under side

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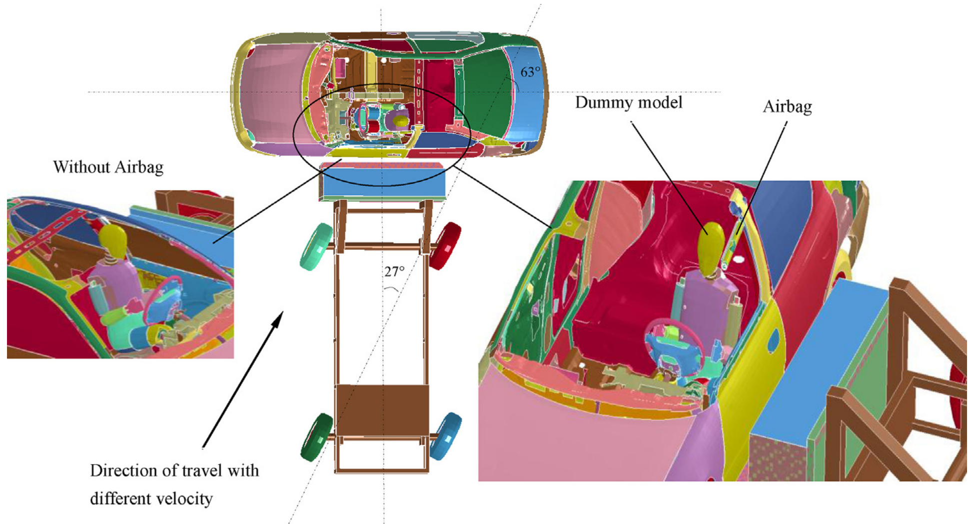

Fig. 1. Two kinds of side impact finite element (FE) simulations were used for the side impact of a Dodge Neon using a dummy in order to investigate the effect of airbag parameters on head injury: one *with* the airbag and one *without* the airbag.

impact using the United States national automotive sampling system (NASS) databases for the years 1997–2000; they concluded that front seat occupants of vehicles with side airbags had a risk of head injury similar to that of occupants of vehicles without side airbags. Recently, Potula et al. (2012) investigated occupant injuries and safety through simulating the interaction between side curtain airbag deployment and an out-of-position occupant and found that the airbag significantly affects occupant injury/safety. As such, studies to assess the mechanisms of head injury associated with airbag deployment are being conducted to determine the parameters of the airbag and the position of the drivers in relation to the airbag (Kiuchi, 1998; Iyota, 2003; Fang et al., 2005a,b).

Although the aforementioned studies confirm that the airbag-head separation distance, the airbag deployment, and the airbag variables all have a significant effect on the occupant injury, very few studies to date have focused on the side curtain airbag and its relationship to head injuries (Ref. Potula, 2012 and Potula et al., 2012). In this study, we seek to obtain the influences of five parameters on two responses, namely, the peak head acceleration and the head injury criterion measured over a 36 ms time period (HIC36). Because we are considering five parameters, the design-of-experiments (DOE) technique (Fisher, 1935a,b) was used to evaluate the effect of each parameter in an efficient manner. Popularized by Taguchi (1987) in the field of quality engineering, the DOE approach used herein has been previously utilized in various contexts of mechanics problems and design by Horstemeyer et al. (1999, 2009). By doing so, the crash performance of the side curtain airbag and the effect of the airbag variables on the occupant injuries were comparatively investigated and assessed. The airbag parameters considered were the following:

(1) The airbag-head separation distance,
(2) a moving deformable barrier (MDB) strike velocity,
(3) different trigger times between when the MDB started to strike the car and the time when the bag started to inflate,
(4) initial airbag inlet temperature airbag, and
(5) the number of computational particles employed representing the amount of air in the airbag.

Hence, the objective of this study was to delineate the relationship between crash severity, head injury of a dummy, and airbag-head separation distance for different parameters of a side curtain airbag using finite element (FE) simulations.

The outline of this paper is as follows. Section 2 introduces the simulation models and presents details of the simulation set-up. Section 3 presents a brief overview of the DOE methodology including the parameters, the parameter values used, and the response variables. Section 4 presents the simulation results and the analysis of those results using the DOE methodology. Finally, Section 4 presents conclusions and the implications of this study towards vehicular design of side curtain airbags.

2. Methods

2.1. Side impact simulation

In this section, the full-scale FE model of the Dodge Neon with a side curtain airbag used in the side impact crash simulations is introduced; the FE model was originally developed and validated at the National Crash Analysis Center (NCAC) of the United States for a full frontal impact, and the FE model was modified and validated for use in simulations of side impacts by the Center For Advanced Vehicular System (CAVS), Mississippi State University (Solanki et al., 2004; Fang et al., 2004a,b, 2005a,b; Yildiz and Solanki, 2011; Potula, 2012). One kind of side impact meshes with airbag is illustrated in Fig. 1. Fig. 2 illustrates the different airbag parameters considered in this study. Both side impact simulations were performed using a MDB.

As illustrated in Fig. 1, the side-impact simulations were achieved using an MDB, which impacted the vehicle at different closing speeds at an angle of 63° with the longitudinal center-line of the test vehicle. The wheels of the MDB were "crabbed" 27° toward the rear of the test vehicle to ensure that the front of the MDB was parallel to the side of the test vehicle at the moment of impact. The MDB FE model had a total mass of 1388 kg comprised of two honeycomb sections, the front face, and the main block. The front face of the barrier had eight components. Both honeycomb blocks were covered by shell elements, and null materials were used in defining a contact interface. The previous work on FE model development includes those of Solanki et al. (2004), Fang et al., 2004a,b, 2005a,b, Yildiz and Solanki (2011), and Potula (2012).

In addition, the dummy injury criteria used in the simulations were the head injury criteria, head acceleration, and the peak