Conceptual design modification for reducing aortic strain in a left-lateral impact: A Design of Computer Experiments Study

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Introduction

Aortic Injury (AI) leading to disruption of the aorta is an uncommon but highly lethal consequence of trauma in modern society. Estimates of the incidence of this injury vary, but the most recent estimates range from 7500 to 8000 cases per year from a variety of causes (Hunt et al. 1996). However, motor vehicle crashes (MVCs) are the most common incident leading to this injury, representing 81% of the clinical cases of AI (Fabian et al. 1997). While recent advances involving the use of endovascular stent grafts have resulted in major improvements in the survival of patients with AI who reach the hospital alive (Demetriades et al. 2008), the fact remains that more than 60% of motor vehicle AI victims are dead at the scene and between 31% and 57% of the crash survivors have been reported to die either in the emergency room or in the operation room after admission. Hence it is evident that **effective means of substantially improving the outcome of MVC-induced AIs is by preventing the injury in the first place**.

Methods

An analysis of the National Automotive Sampling System Crashworthiness Data System (NASS–CDS) database was performed from survey years 1993 through 2008 to estimate the number of thoracic aortic injuries and primary vehicular structures coded as being responsible for the injury. All data were taken post 1993 because it was the first year that the then newly established AIS 90 coding system was required by NASS and these data were useful in pinpointing the exact location of the injury within the occupant's body. We performed this database survey in an attempt to understand a possible pattern of thoracic aortic injury. The non-weighted data cannot be used directly to ascertain a specific injury source but are helpful in confirming a possible trend.

Interior hardware, followed by armrest and B-pillar intrusion are the top three notable injury sources coded as being responsible for aortic injuries due to left lateral impacts (Figure 1).

To demonstrate the usefulness of Design of Computer Experiments (DOCE) in studying preventative strategies, a lateral impact AI case, obtained from the Crash Injury Research and Engineering Network (CIREN) database was selected as a test case.

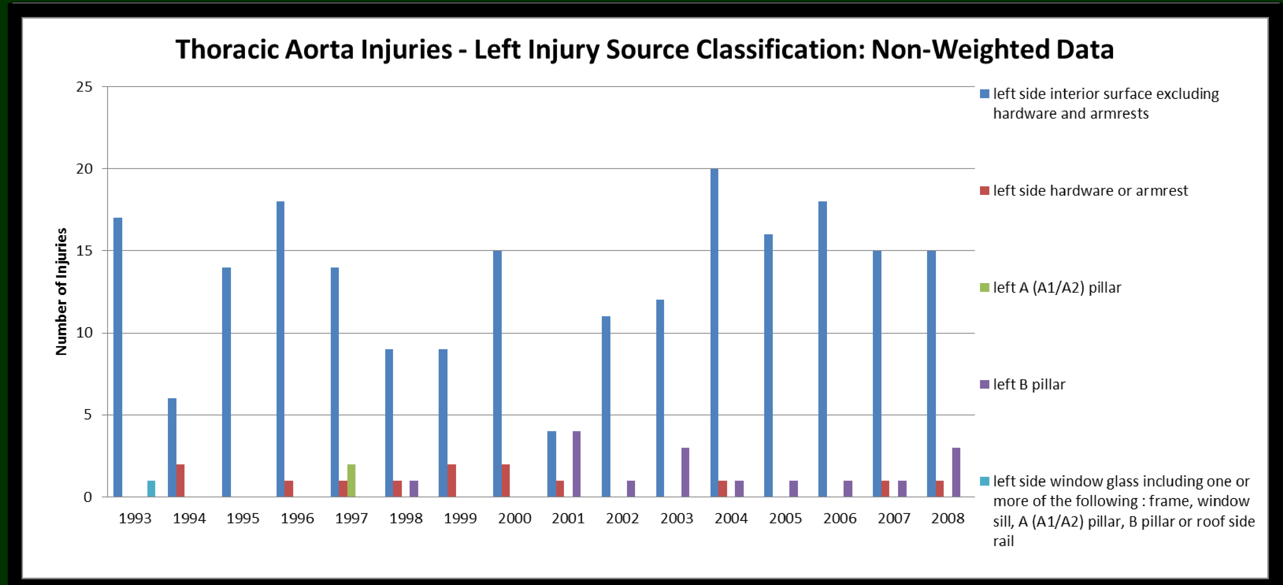

Figure 1: Thoracic Aorta Injury Source, NASS-CDS Database

Based on the incident report, kinematics of the bullet and target vehicles were reconstructed using finite element models of the vehicles involved. The relative position of the two vehicle models were then adjusted until the model-predicted deformations matched the measured data (Stage I – Figure 2).

Figure 2: Vehicle deformation patterns of the actual case vehicle and that of the FE simulation using the scaled FE vehicle model

A total of 18 DOCE simulations were carried out on six design factors based on a Latin Square sampling algorithm using modeFRONTIER 4.1 (ESTECO North America, Novi, MI). These factors include an increase in the stiffness of the B-pillar beam, addition of a cross-beam within the door, variations of the thickness of the sheet metal structures in the left side door, and the use of a higher yield strength of 300 MPa. Further, we used a conceptual single-inflator overall airbag to cover the entire left side door. It was deployed at 6 ms after initial contact. Deformation time histories of the left side door structures, including the B-pillar, were used as input to the Wayne State Human Body FE Model (Stage II – Figure 3). The maximum principal strain at the aortic isthmus, maximum pressure within the aorta, and compartmental intrusion were used as response variables. A main effects analysis was carried out using Minitab 15 (Minitab Inc., State Park, PA) on these response variables to estimate the effectiveness of each design factor.

Results

Table 1 lists the 18 DOCE matrixes with six design factors as inputs and three response outputs.

Table 1: Maximum Isthmus Principal Strain (%), Maximum Pressure (kPa) in the aorta and B-pillar Intrusion (mm) for each run

Run #	Design Factors						Responses		
	B-pillar Beam (Mild Steel)	B-pillar Beam Dimensions (mm)	Cross-Beam (Mild Steel)	Side 'Overall' Airbag	Thickness factor	Yield Strength (MPa)	Isthmus Maximum Principal Strain (%)	Maximum Aortic Pressure (kPa)	B-Pillar Intrusion (mm)
I	0	10 by 60	0	1	2	300	17.2	126.4	225
II	0		1	1	4		17.6	128.5	165
III	0		1	0	1		25.2	127.2	278
IV	0		0	1	1		20.1	132.7	212
V	1		1	0	2		19.8	120.8	63
VI	1		1	1	4		13.8	113.3	81
VII	1		0	0	4		15.5	113.7	289
VIII	1		1	1	1		20.1	135.1	213
IX	1		1	1	2		19.2	123.2	227
X	1	20 by 60	1	1	4		14.4	117.5	85
XI	0		0	1	1		15.8	128.7	250
XII	1		1	0	1		17.2	126.7	319
XIII	1		1	1	1		19.9	124.9	319
XIV	1		1	0	1	400	19.4	127.8	314
XV	1		1	0	1	500	18.6	126.8	298
XVI	1		1	1	1	400	18.5	133.4	314
XVII	1		1	1	1	500	17.5	133.7	298
XVIII	1		1	1	4	600	12.5	111.2	78

Discussion

From the main effects analysis shown in Figure 4, addition of a cross-beam increased the maximum principal strain of the aorta while the other five factors decreased the aortic strain. It was also found that the pressure in the aorta decreased with addition of a B-pillar beam and an increase in the thickness of the door structures. The addition of a crossbeam, side airbag, 4X thickness factor, and change in the yield strength reduced intrusion of the side structure.

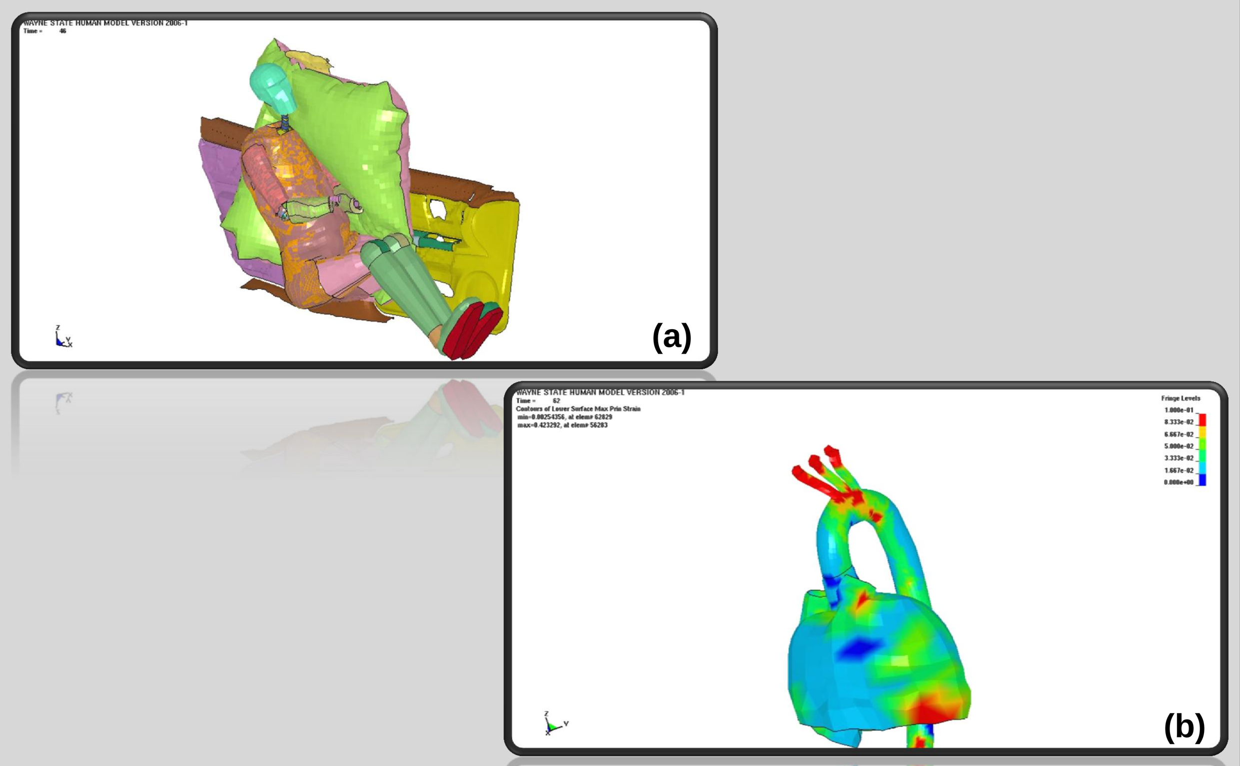

Figure 3: (a) Occupant kinematics and (b) Maximum principal strain pattern at the time of maximum vehicle deformation

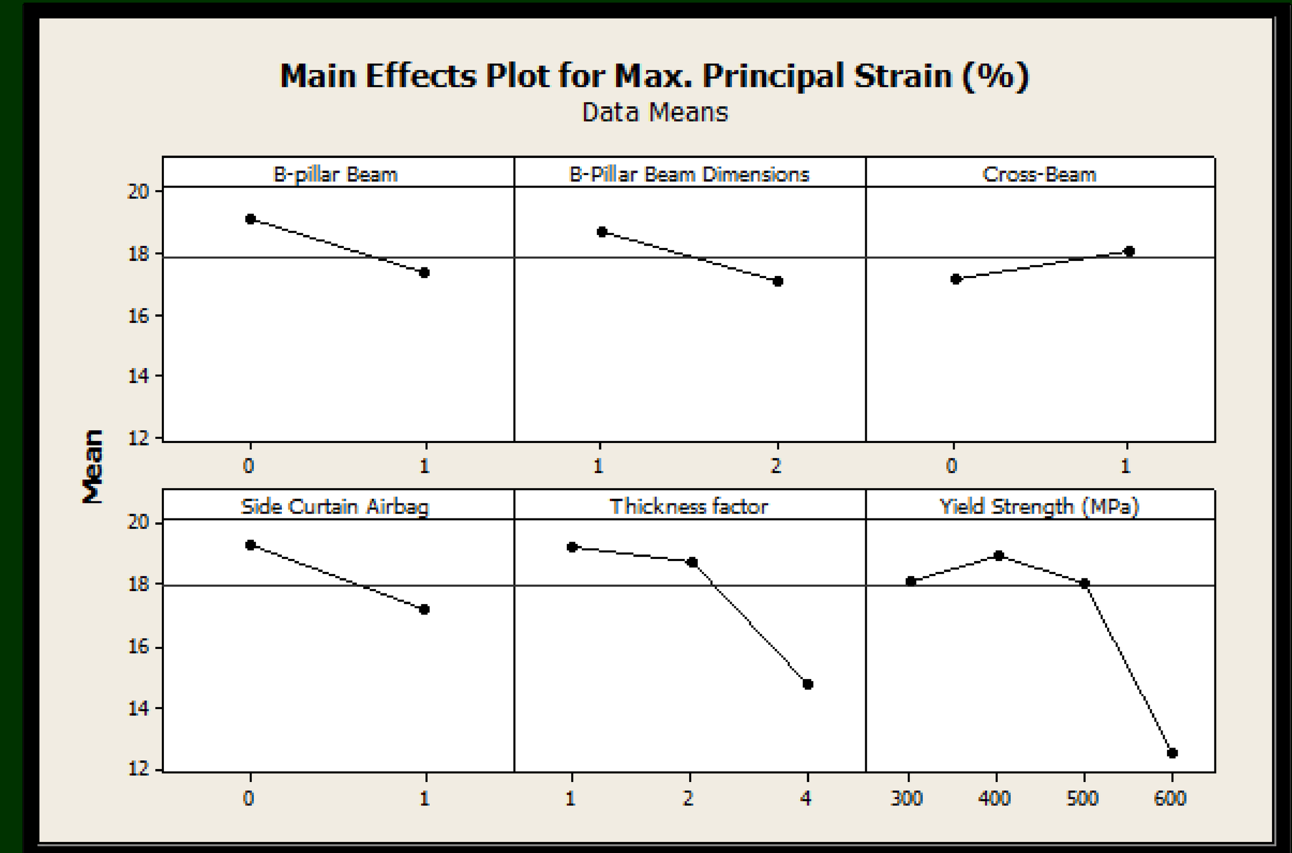

Figure 4: Main effects analysis plot - Maximum Principal Strain (%)

Conclusions

Comparing data from actual scene photographs (CIREN data), NASS-CDS database survey, and the FE simulation data, it is evident that the B-Pillar is the site most likely to be the major causative factor in initiating maximum aortic strain and chest forces. From DOCE simulations we can reduce aortic strain and compartmental intrusion by altering the structural stiffness and by adding a large overall side airbag. However, the study neither considered the effect of weight increase, manufacturability of the conceptual overall airbag, nor its effect on fuel efficiency of the vehicle.

Stiffening the side structure by adding a B-pillar beam and increasing sheet metal thickness is likely to reduce overall intrusion. Strategic placement of an airbag, which covered from the car from the seat pan to the roof to buffer head and chest contact with the B-Pillar, can have a protective effect by softening the blow of the side structure on the torso. Combining these two countermeasures can lead to a reduction in aortic strain and thus substantially reduce aorta-induced mortality due to lateral impacts. More research is needed to determine if the same conclusion can be reached for other impact scenarios involving different types of vehicles.

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