Analysis of a Real-World Crash Using Finite Element Modeling to Examine Traumatic Rupture of the Aorta

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Background

- Blunt Aortic Injury (BAI) or Traumatic rupture of the Aorta (TRA) is the second most common cause of death associated with motor vehicle crashes (MVCs), second only to traumatic brain injury (Sauaia et al. 1995)
- Approximately 7500 to 8000 deaths result from BAI in the United States every year (Mattox 1989)

Background

Laboratory experiments have yielded limited success in producing aortic injury

Retrospective studies have established a statistical link between BAI and various crash parameters

Various injury mechanisms have been proposed for BAI, but still there is limited understanding of this injury

Background

- There is no consensus regarding the mechanisms actually involved in BAI resulting from MVCs
- It is difficult to develop an injury criteria designed to prevent BAI
- Determining the *in-vitro* response of intra-thoracic organs, including the aorta, is difficult

Why Finite Element (FE) Models ?

- Recently FE has emerged as companion tool to experimental efforts in the laboratory
- Finite element modeling provides a bridge between laboratory experiments and real-world crashes to better understand injuries to the occupant
- Very few studies have used FE models to simulate the real-world crash environment

Difficulties with FE Modeling

Initial conditions influence results significantly

- Angle and point of initial vehicle impact
- Occupant seating position and posture
- Restraint configuration

Availability of validation data

Material models and structural approximations

Need many simulations to reasonably match available crash-investigation data

Objective

To develop and verify a relatively inexpensive method to investigate BAI using FE modeling of real-world crash scenarios

Case Selection and Details

Case obtained from the William Lehman Injury Research Center (WLIRC) – CIREN

Vehicles:

- 1990 Lexus ES-250 (case vehicle)
- 1983 Oldsmobile Cutlass (principal other vehicle, POV)

PDoF = 290 (CDC code: 10-LYAW-3) approximately a left-side impact

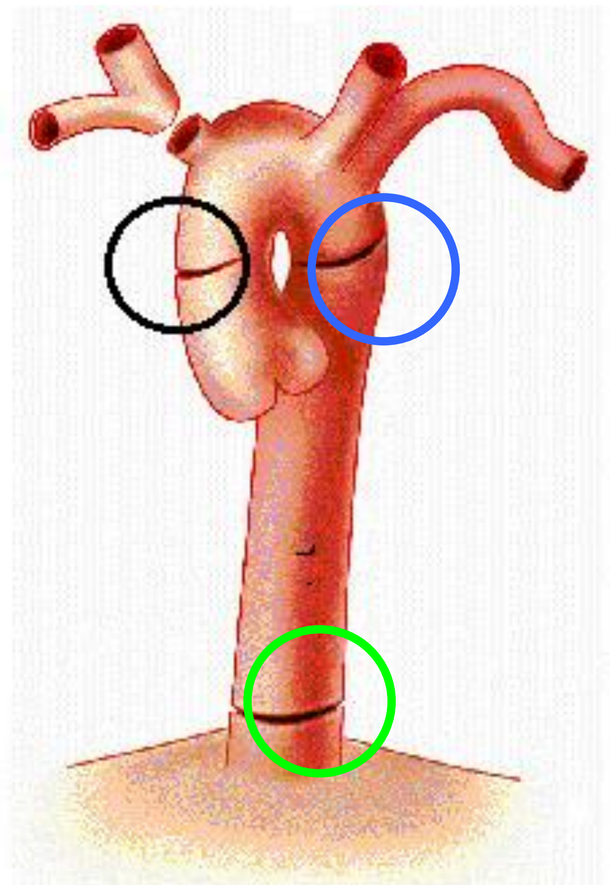
Total ΔV = 6.2 m/s (SMASH missing vehicle algorithm)

Case Selection and Details

Case vehicle occupant:

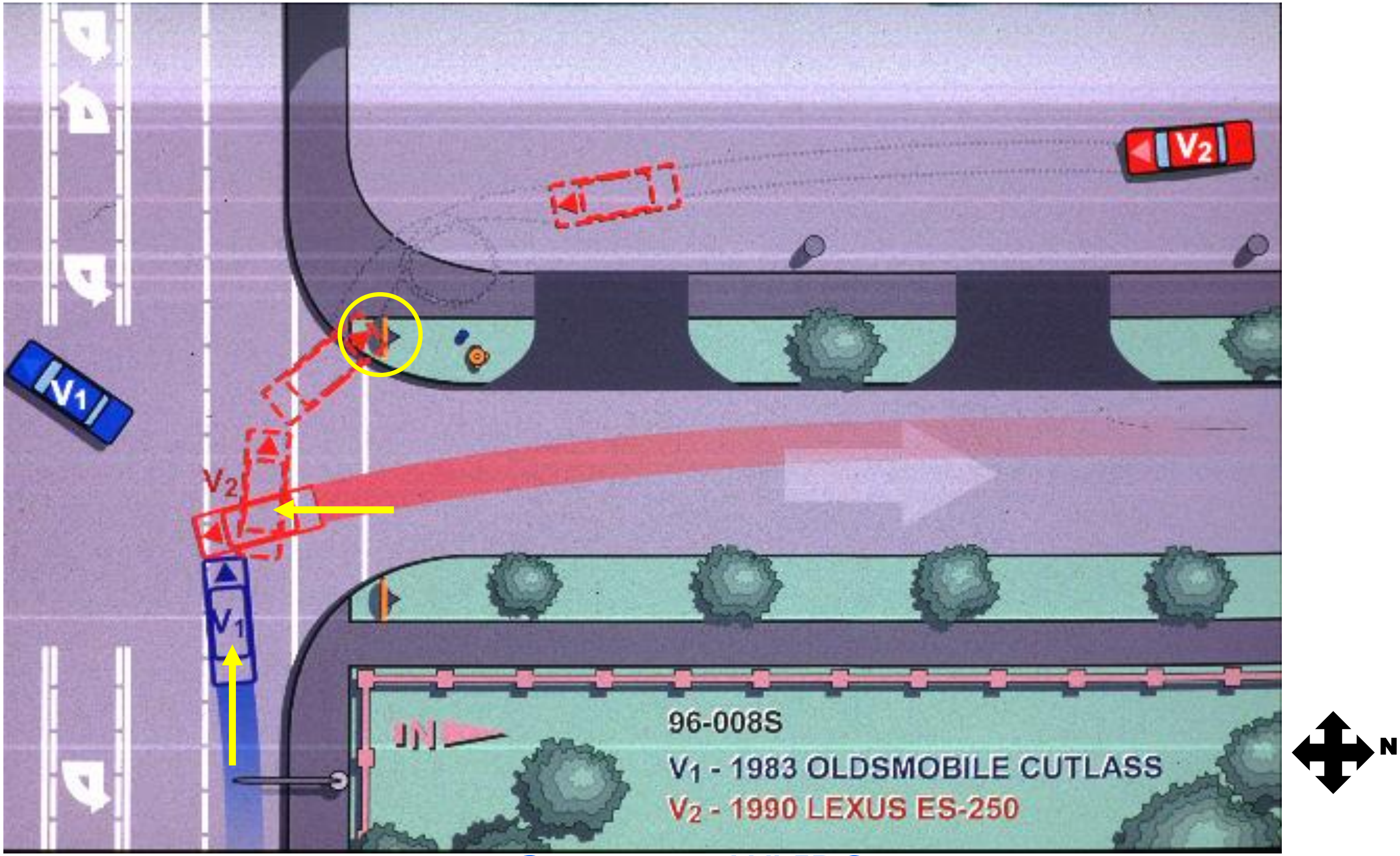
- 62-year old mid-sized male
- 1.73 m (68 in) height and 79 kg (174 lbs) weight (close to 50th-percentile male)
- The occupant was wearing a 3-point belt and the frontal airbag deployed during the crash
- The occupant sustained multiple rib fractures, right ventricle, and ascending, isthmus, and descending thoracic aorta lacerations among other injuries

Case Subject Aortic Injuries



Courtesy: WLIRC

Accident Scene Diagram



Courtesy: WLIRC

Simulation Setup

Two phases:

Phase 1

- Car-to-car crash numerical reconstruction

Phase 2

- Sub-modeled case vehicle:
  door structure-to-whole-body human FE simulation

Methods

Sub-modeling approach:

Phase 1 matched the available intrusion and deformation data for the case vehicle without the occupant model

The deformation data for the side structures of the case vehicle from the Phase 1 simulation was used as input to the Phase 2 simulation

Phase 2 involved the occupant model and only structures of the case vehicle considered crucial to the occupant injuries

Advantages

The approach overcomes the difficulties related to initial conditions by facilitating many simulations to match known conditions

Simplifies conduct of parametric studies by reducing the number of variables for each simulation phase

Fosters a better understanding of the effects of variables on the simulation results

CPU time and cost reduction

Simulation Setup – Phase 1

Two FE vehicle models obtained from National Crash Analysis Center (NCAC) public FE model archive

Two model files were changed to LS- Dyna keyword format

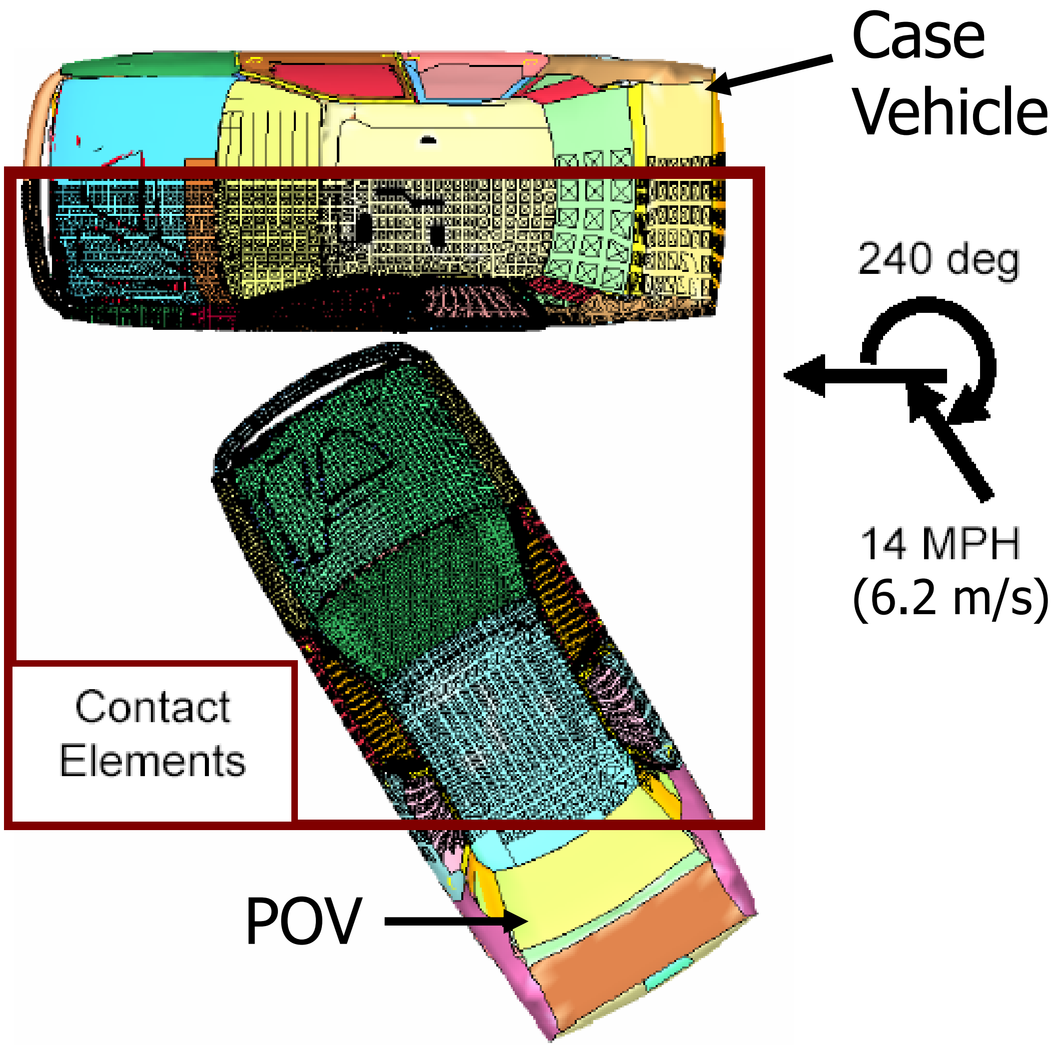
Unit system converted to mm, ms and kg to match occupant model for Phase 2

Total simulation time 200 ms

Simulation Setup – Phase 1

	Case vehicle	POV
Real crash	1990 Lexus ES-250	1983 Oldsmobile Cutlass
Substituted FE reconstruction	Ford Taurus (side impact model)	Ford Taurus (frontal impact model)
Adjusted Gross vehicle weight (kgs)	1457.78	1544
Occupant weight (kgs)	77.3 (driver)	76.5 (driver)

Simulation Setup – Phase 1

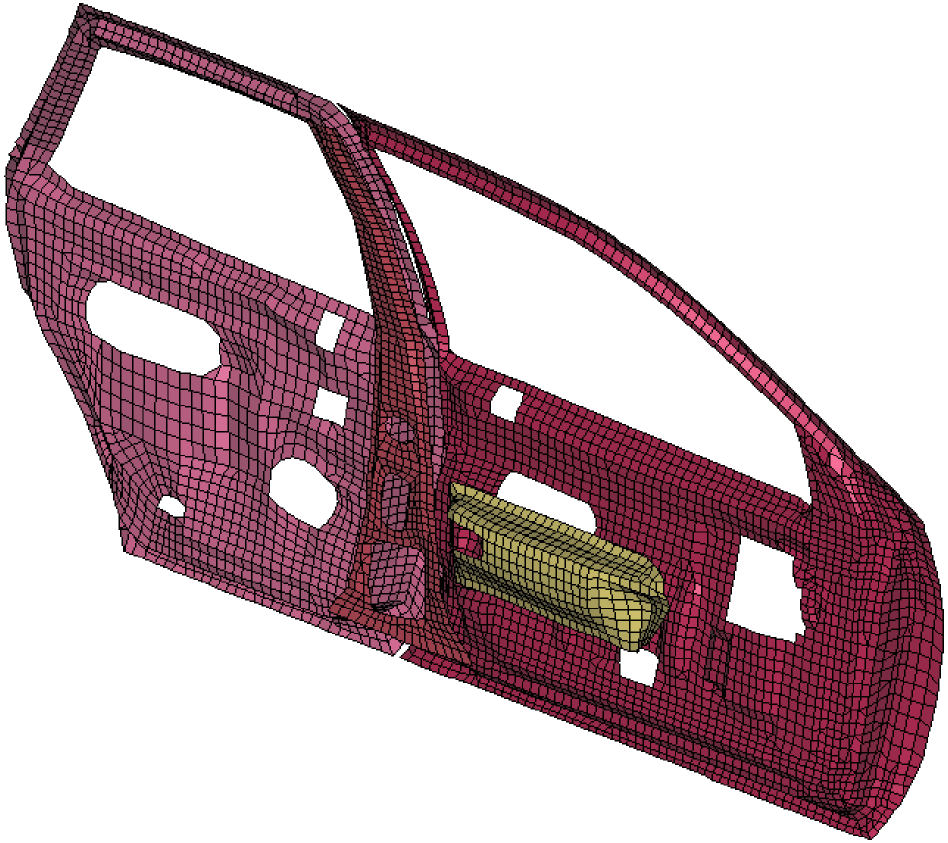


Simulation Setup – Phase 1

- The angle of impact was different from the actual crash
- A series of simulations was performed with an initial impact angle from 210 to 330 degrees
- The purpose was to match the intrusion and deformation pattern of the model case vehicle with the actual crash information
- Matching intrusion was more important than matching the velocity change and impact angle for this low-velocity crash

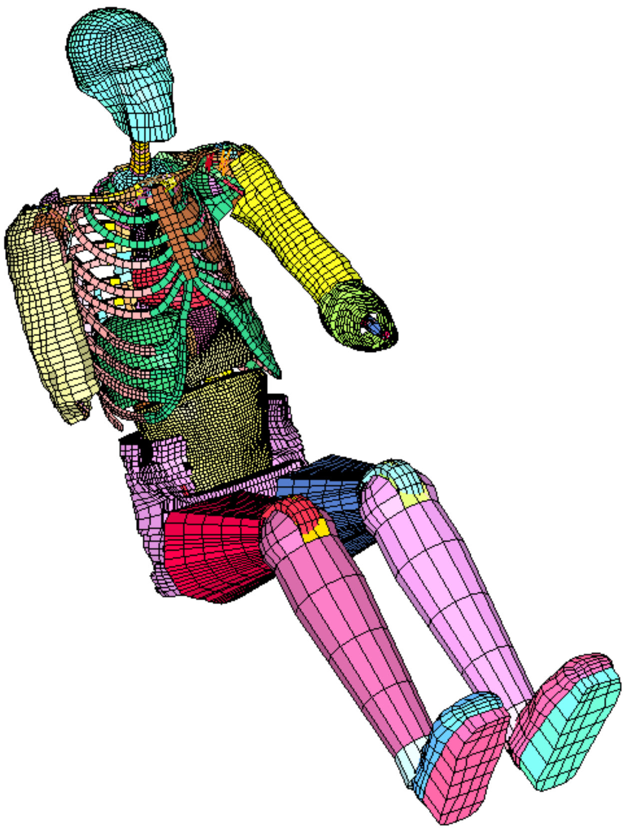
Simulation Setup – Phase 1

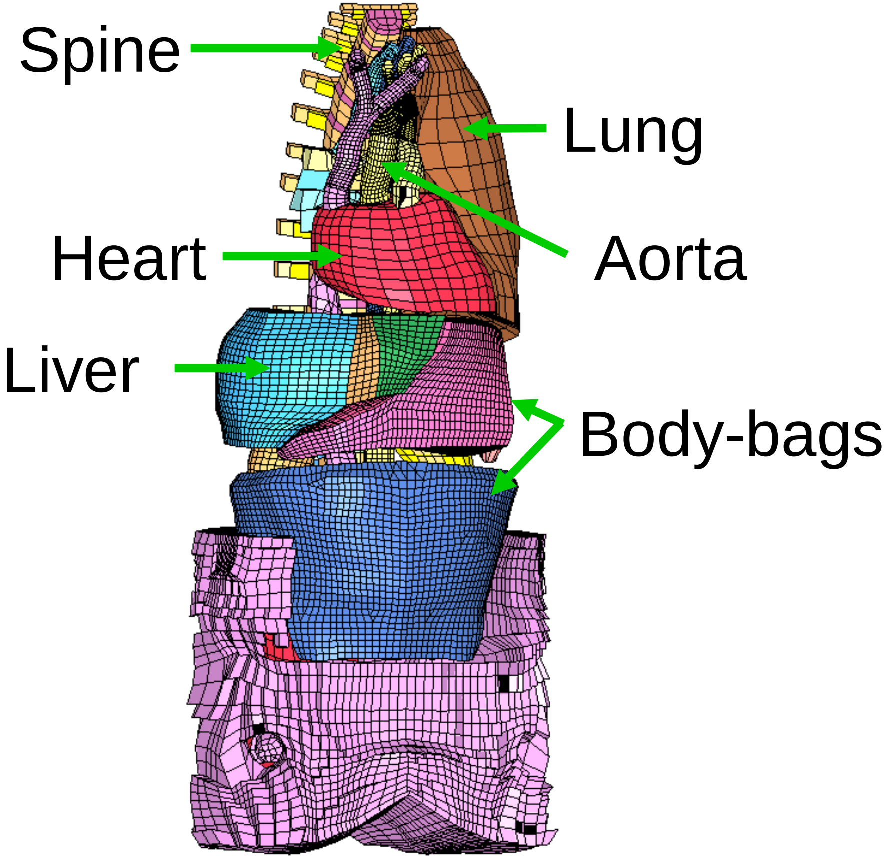
Deformation data for the case vehicle door side structure was recorded (interface file) and used for the Phase 2 simulation



Simulation Setup – Phase 2

FE occupant model (Shah et al. 2004)
Detailed thorax, abdomen, and shoulder

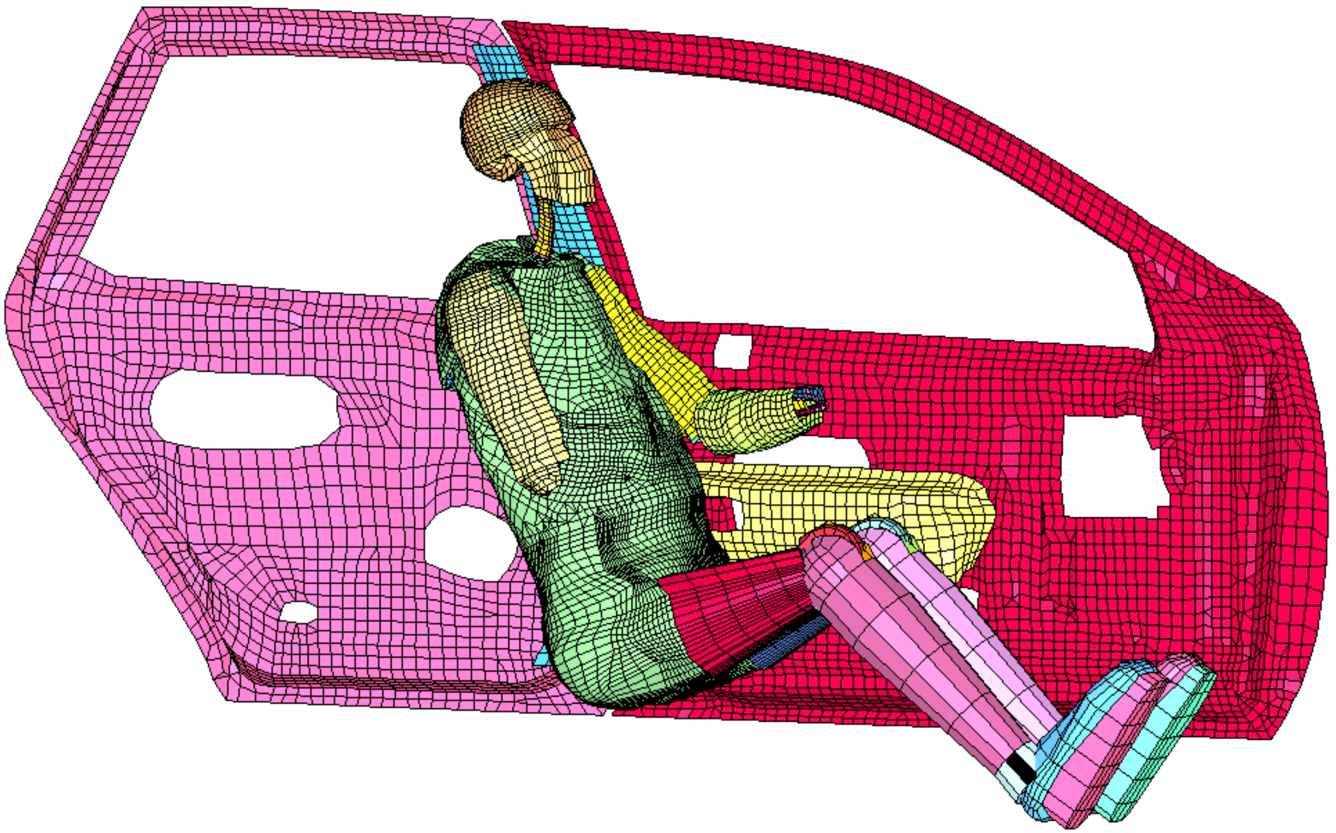




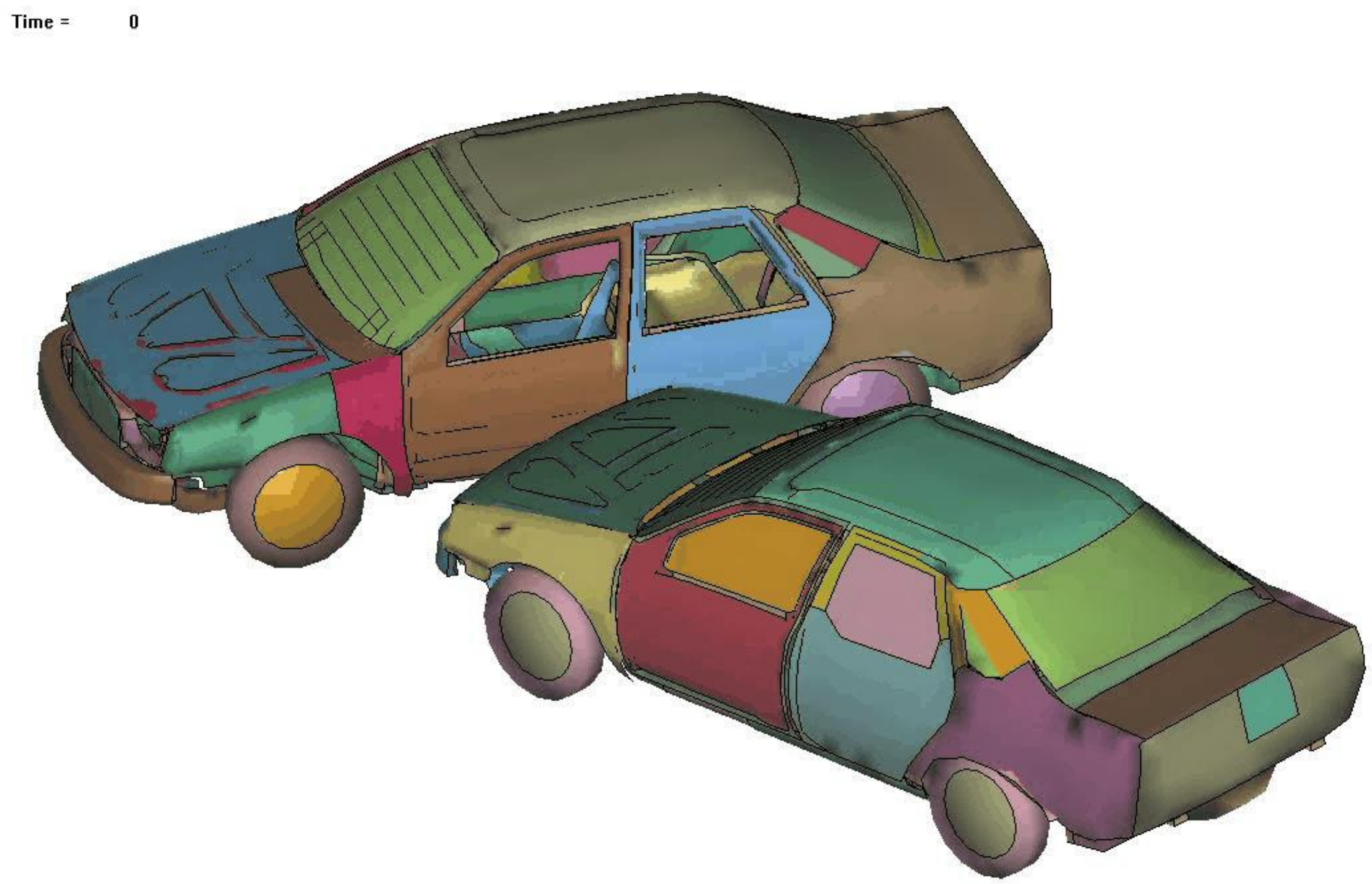
Simulation Setup – Phase 2

- The FE occupant model was imported into the Phase 1 simulation input file and positioned in a seated posture based on the post-crash photographs
- Except for the side structures of the case vehicle and the FE occupant model, which were exported to new file, all structures were deleted
- Only the deformation data for side structures of the case vehicle obtained in Phase 1 simulations were used as input to this new file
- Thee simulation time was 80 ms (time of peak intrusion obtained in Phase 1)

Simulation Setup – Phase 2

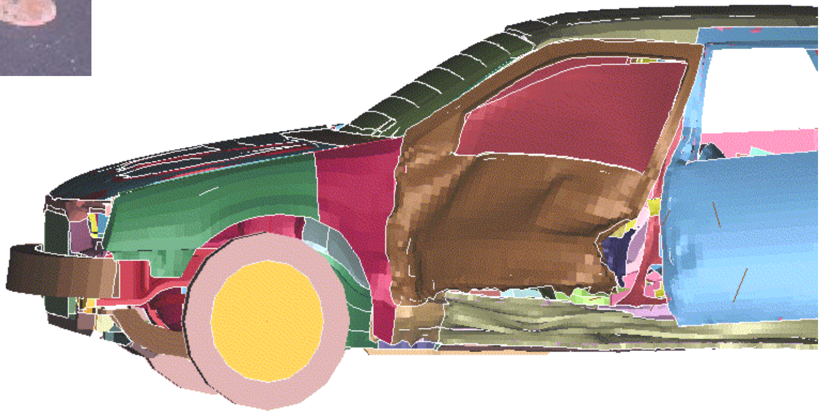


Results – Phase 1



Results – Phase 1

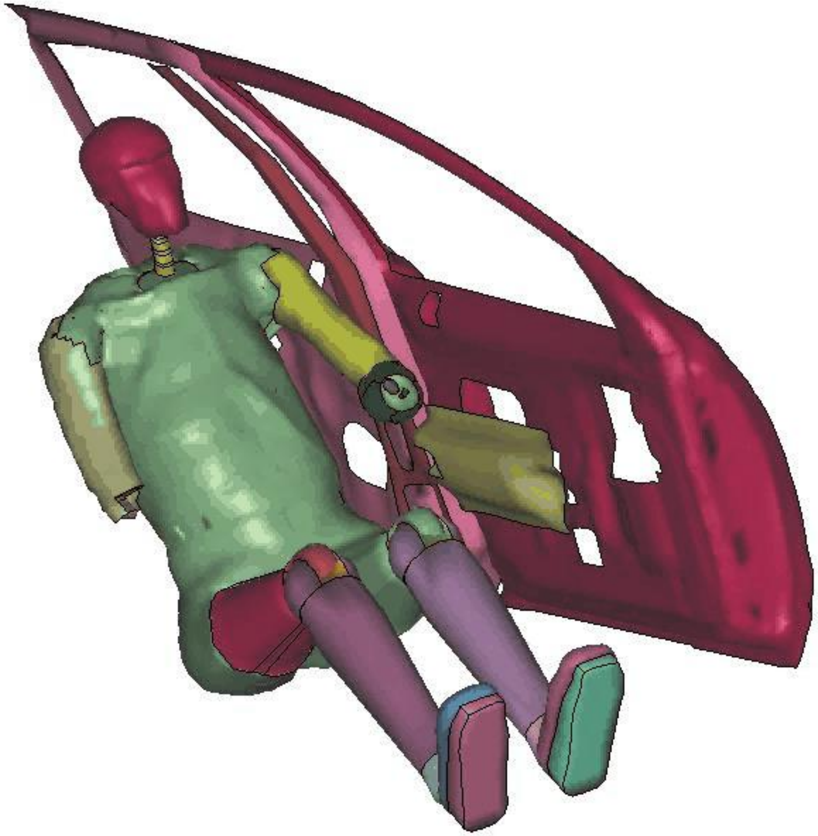
Courtesy: WLIRC



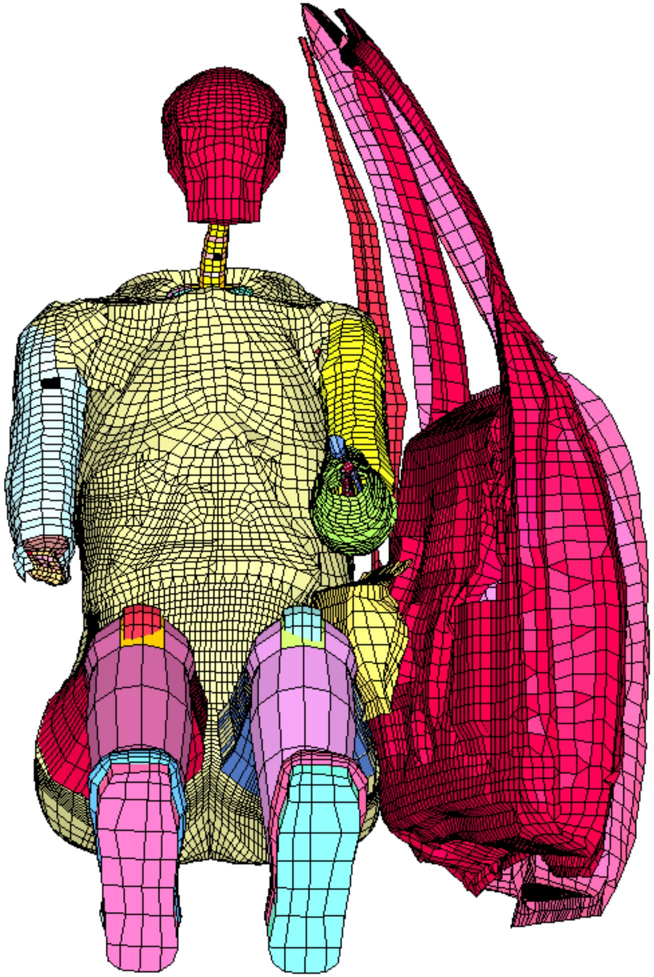
Results – Phase 1

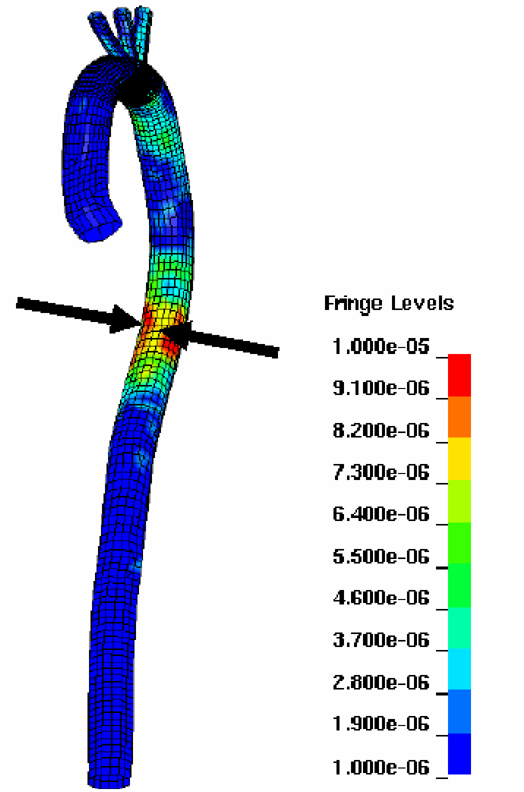
	Real crash deformation (mm)	Simulation results of Phase 1	
		FE Deformation (mm)	% Difference
B-pillar intrusion	140	131	-6.4
Left front door intrusion	210	241	+14.7
Left front door crush	330	303	-8.1

Results – Phase 2



Results – Phase 2





Time = 80 ms

Results – Phase 2

- Aortic stress patterns – should be considered for illustration purposes only
- Autopsy of the occupant revealed laceration of ascending, periisthmic, and descending regions of the aorta
- It was beyond scope of this study to investigate the detailed kinematics of the aorta
- It is premature to propose any mechanism
- Many more simulations are needed to examine kinematics and possible injury mechanisms

Discussion

Limitations related to unknown information:

- Car deformation was available only at three locations
- Quantitative occupant kinematics data are unavailable
- The seating position and posture are unknown

Discussion

Modeling limitations:

- The car models were of the same class as the crash vehicles, but of different make and model (geometric and structural differences)
- The 3-point belt and frontal airbag were excluded, under the assumption of their having minimal effect in side impact
- No local (only global) validation of the occupant FE model is available

Future Work

- Examination of the effects of restraint system use
- Sensitivity analyses of seating position and posture
- Parametric studies for Phase 2 simulations
- Detailed kinematics study of the aorta and its surrounding anatomical structures
- If available, use same make and model for FE vehicle models as involved in real crash

Conclusions

A sub-modeling approach was demonstrated, and can be used for injury biomechanics applications

Simulations of car-to-car impact and of the interaction of the occupant with the interior of the struck vehicle were conducted successfully

This study can be considered as a additional step toward bridging laboratory experiments with the real-world crash environment

Acknowledgment

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Thank you for your attention