Pregnant Driver Injury Investigations in Oblique Crashes

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Abstract - Kinetics and kinematics of an oblique impact are different when compared to frontal collisions. The objective of this research is to simulate various oblique crash scenarios that pregnant drivers may experience by using the computational pregnant occupant model, '*Expecting*' and investigate potential injuries that pregnant drivers may suffer. Half-sine acceleration pulses representing crash speeds 15kph to 45kph are used in the simulations. Oblique impact simulations are conducted both from the nearside and the farside (offside) of the vehicle. The placental abruption and hence fetus mortality risks during oblique crashes are compared with the full-frontal impact cases.

Keywords: pregnant driver, oblique impact, placental abruption, injury criteria

NOTATION

Δt	impact duration of the pulse
ΔV	change in velocity
ATD	Anthropomorphic Test Device
UPI	Uteroplacental interface

INTRODUCTION

Motor vehicle crashes are statistically the major cause of traumatic injuries for pregnant women and their fetuses [1]. Research shows that the number of pregnant women as vehicle occupants is increasing each year [2]. Women are likely to be vehicle drivers or passengers during their pregnancy and according to the most recent UK statistics, there are approximately 800,000 new maternities each year [3-5]. Various factors such as increased employment by young women also result in an increase in average number of annual vehicle miles driven by women of a reproductive age [6]. In the light of all these facts, investigating road traffic collisions involving pregnant women, focusing on the fetus' and woman's well-being, is an important area of research.

It is not viable to investigate the safety and the risk of injury of pregnant occupants in automobile collisions via cadaver experiments and human volunteer tests due to ethical issues. Real world crash data on pregnant occupant injuries is also scarce. One way of investigating pregnant occupant involvement in automobile accidents is to employ physical models, namely Anthropomorphic Test Devices (ATDs). The Hybrid III small female ATD is integrated with a pregnancy insert in order to convert the dummy into a physical pregnant woman model [7]. The second generation pregnant ATD, 'MAMA2B' has a water filled bladder, equivalent to the size of a 30th week pregnant uterus, and a neoprene 'skin' jacket [8]. No placenta or fetus are included in the model, however pressure in the bladder is measured and used in calculating fetal injury risk.

The other way of effectively investigating pregnant safety in crashes is to use computational human body models, which offer cost-effective and rapid solutions with a greater level of anatomical detail, potentially resulting in an improved biofidelic response over ATDs. The model by Moorcroft *et al* [9], integrates an FE uterus representing around the 30th week of pregnancy into an existing 5th percentile female occupant. However, the model does not include a fetus.

In this study, the dynamic response of pregnant women during full-frontal and oblique accident simulations are conducted with '*Expecting*'. The three dimensional computational model '*Expecting*', which includes a detailed multi-body model of a 38-week old fetus in a finite element model of a uterus with a placenta, was developed by Acar and van Lopik at Loughborough University [10].

Previous research reveal that a high percentage, more than 70%, of all frontal impacts are not full-frontal collisions; they are predominantly oblique or offset [11-13]. In oblique impact situations, the kinetics and kinematics of the occupant differ significantly from the uniaxial impacts, such as the full-frontal impact. In an oblique impact situation, the components of the acceleration pulse act in two principal directions as longitudinal and lateral, which result in a combined response of the occupant. The design of the 3-point seat belt is also considered to be of vital importance in terms of the impact direction. The shoulder portion passes along the torso diagonally from one shoulder on one side of the occupant towards the hip below on the opposite side. Therefore, the direction of the oblique impact may potentially affect the protection provided by the seat belt. This study aims to shed light on pregnant occupant safety during frontal automotive crashes by investigating oblique impacts and comparing results with those from full-frontal crashes.

METHODOLOGY

'*Expecting*', the computational pregnant occupant model, is used to simulate the kinematics of pregnant driver in oblique crashes from both sides of the automobile up to 45 degrees of impact.

The pregnant occupant model: '*Expecting*'

Expecting tackles the complexity of a pregnant woman's anatomy by integrating a detailed multi-body representation of a fetus within a finite element uterus model, both of which are supported with an existing 5th percentile female model modified to incorporate pregnant anthropometry [10]. The model is built in the multi-body/finite-element software package MADYMO. The multi-body fetus model representing 38th week of pregnancy, comprises 15 rigid bodies representing various anatomical regions of the fetus interconnected by kinematic joints with a total fetal mass of 3.3kg. The overall model sitting in a car interior is shown in Figure 1.

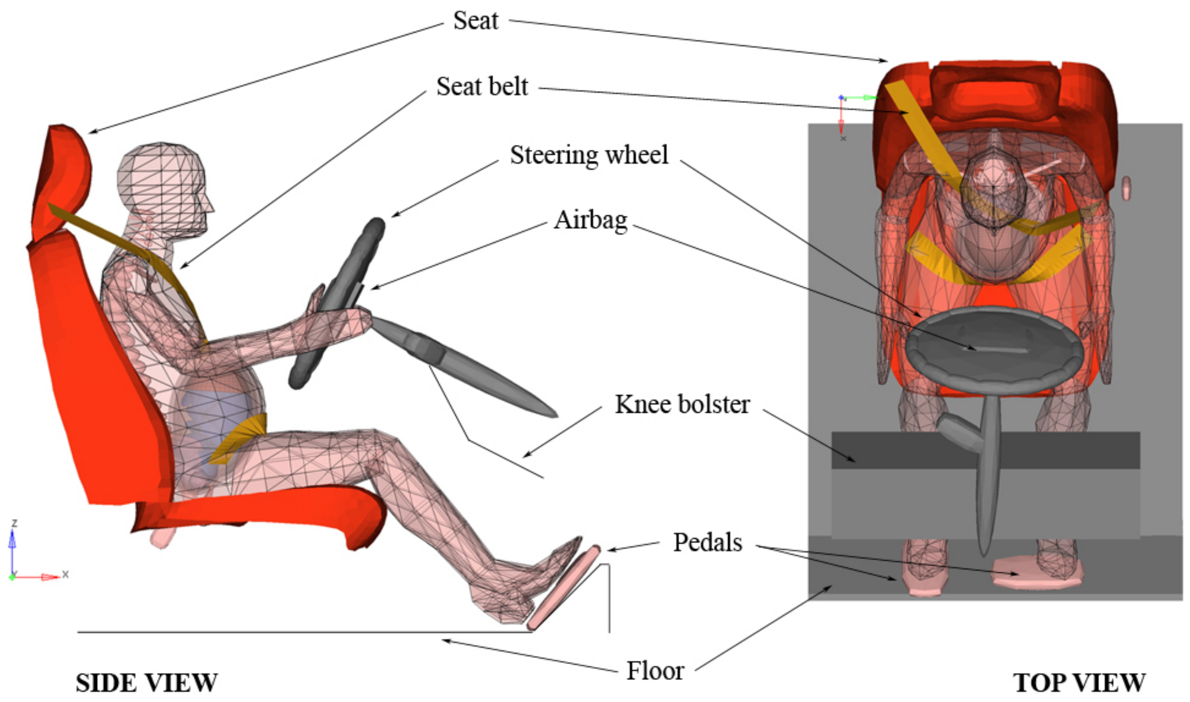

Figure 1. '*Expecting*'

The finite element uterus model is developed in conjunction with the multi-body fetus model with the fetal dimensions and configuration controlling the dimensions of the uterus to give a snug fit around the fetus as shown in Figure 2. A layer of fat is meshed around the outer surface of the uterus. The resulting total mass of the uterus with placenta is 1.29kg. The placenta and uterus in the model share a common finite element interface, elements completely connected at nodes, but with different material properties. The pregnant occupant model is validated against rigid-bar impact and belt loading tests [10].

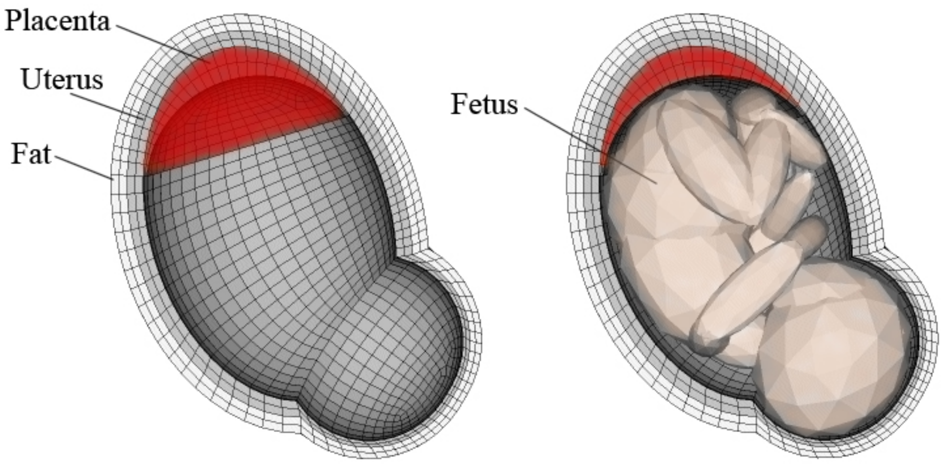

Figure 2. The uterus, placenta and fetus in '*Expecting'*

Simulation settings

Oblique crash simulations are conducted to investigate the response of the pregnant occupant model 'Expecting' as the vehicle driver. The model incorporates a standard 3-point seat belt and a driver's airbag. Any other safety features such as the curtain airbags are not included in the model.

In MADYMO applications, Finite Element (FE) driver airbag model with Computational Fluid Dynamics (CFD) gas flow module is generated for in- and out-of-position simulations [14]. *Expecting* is based on the in-position 5th percentile pregnant female driver, seated in an optimal seating position with the assumption of making a proper use of the safety seat belt. The airbag is folded and placed in a box at the centre of the steering wheel. It is meshed with linear triangular 3-node membrane (MEM3) elements, which do not possess hourglass modes and potentially describe the geometry of the components better. The element strains and stresses are calculated with the GREEN formulation in order to handle large deformations [14].

Four groups of simulations are conducted and compared with the previously simulated full-frontal impact case [10]; oblique impacts from the *nearside* of the vehicle with impact angles of 30° and 45°, and oblique impacts from the *farside (offside)* of the vehicle with impact angles of 30° and 45°, as illustrated in Figure 3. *Nearside* is defined as the passenger side and *farside (offside)* is the driver side.

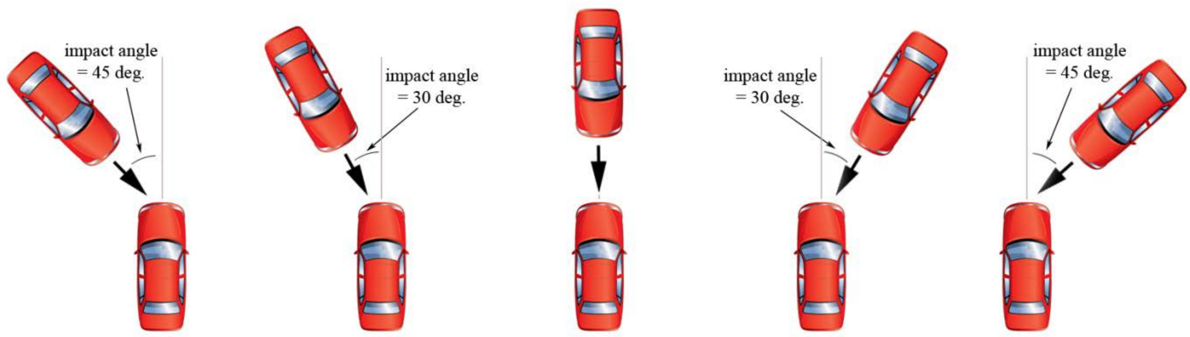

Figure 3. Impact directions and angles

For each group, simulations are run with crash speeds of 15 kph to 45 kph with 5 kph increments. Half-sine wave acceleration pulses with 120 ms duration are applied to the model as depicted in Figure 4.

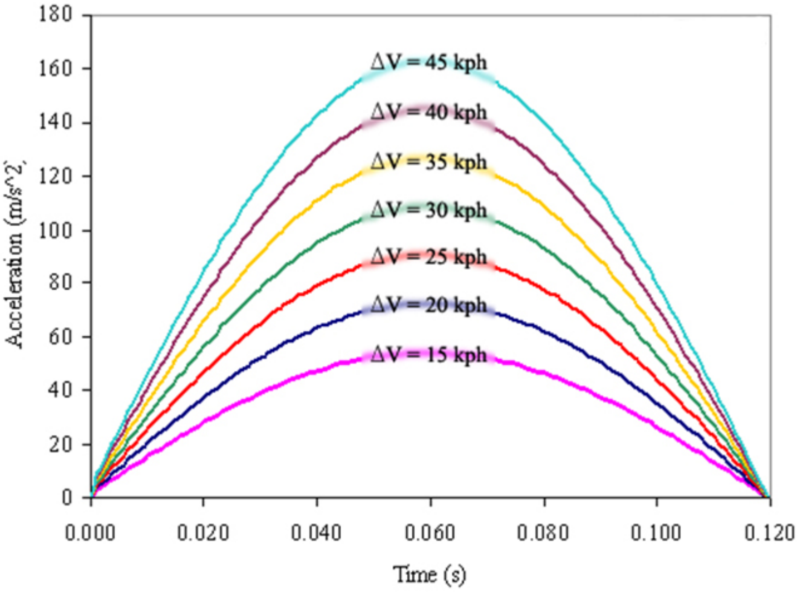

Figure 4. Half-sine acceleration pulses used as input for the crash simulations.

Injury criterion

Maximum von Mises equivalent strain levels in uterus at placental location and *in overall uterus* are collected from the model simulations to predict the placental abruption, which leads to fetal and occasionally maternal death. The threshold strain value for the occurrence of placental abruption is widely accepted to be 0.60 at the UPI [8].

RESULTS

Maximum strains at UPI (Utero-Placental Interface), maximum overall strains in uterus and are computed to investigate the risk to the fetus. The results are illustrated for the four groups of oblique impact cases, and compared with the full-frontal impact predictions. Figure 5 depicts typical simulation results for all five cases showing the model kinematics from front, side and top views; all for 35 kph impact velocity at 100 ms of impact instant.

Maximum von Mises strains occurring in uterus at placental location, namely at the uteroplacental interface (UPI), and maximum von Mises strains anywhere in the uterus are presented in Figures 6 and 7 for all cases respectively. Any values above 0.60 indicate serious risk of placental abruption potentially leading to fetal death. Figure 6 shows a similar trend, increasing from 15kph to 45kph for all cases.

Full-Frontal Impact and Oblique-farside 30° Impacts result in strains below 0.60 threshold for all impact severities considered. *Oblique-farside 45° and Oblique-Nearside 30°* demonstrate a similar behavior, strain levels reaching 0.60 at 30kph *ΔV*. *Oblique-Nearside 45°* shows a very sharp rise in strain level at and beyond 35kph *ΔV*.

Maximum Von Mises strains anywhere in the uterus show similar behavior to the UPI strains but generally with higher strain levels.

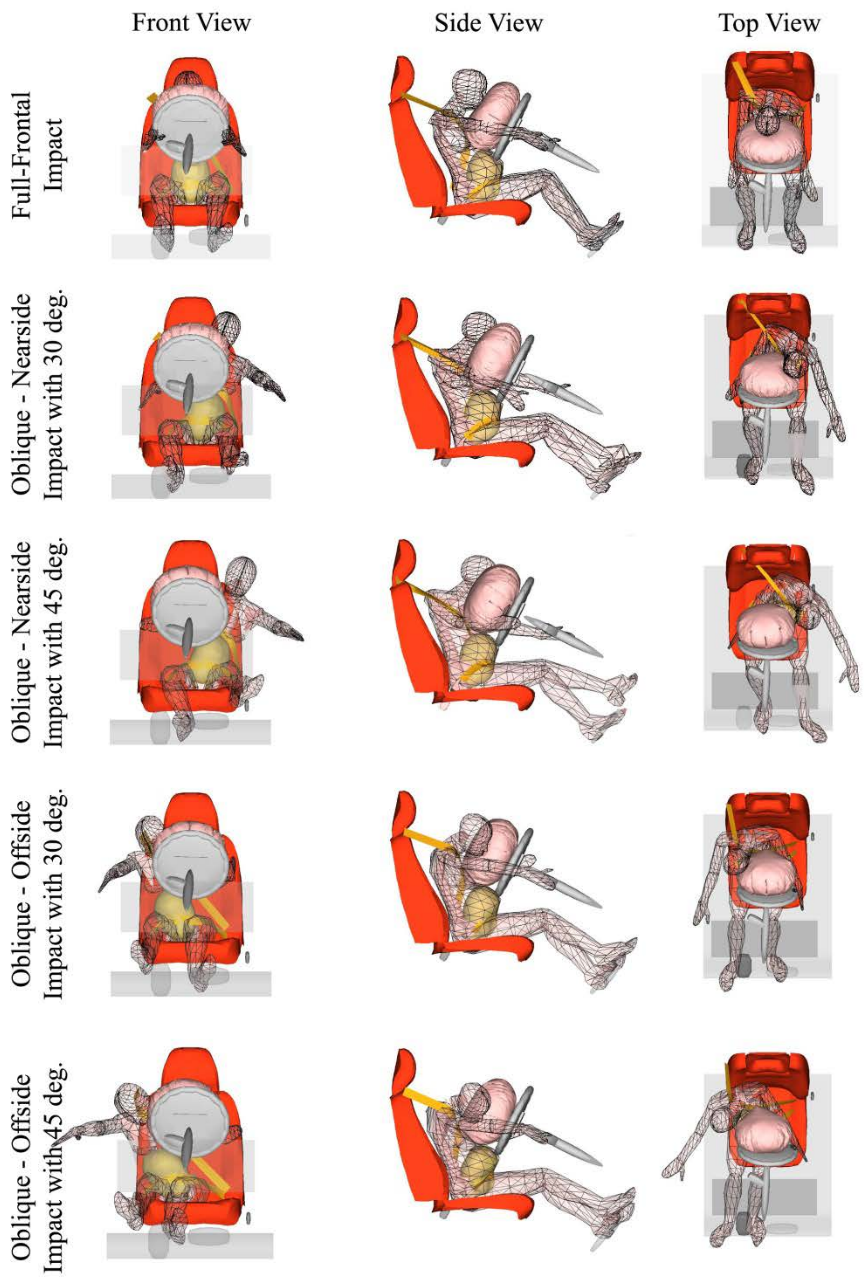

Figure 5. Views from accident simulations for 35 kph crash at 100ms of impact

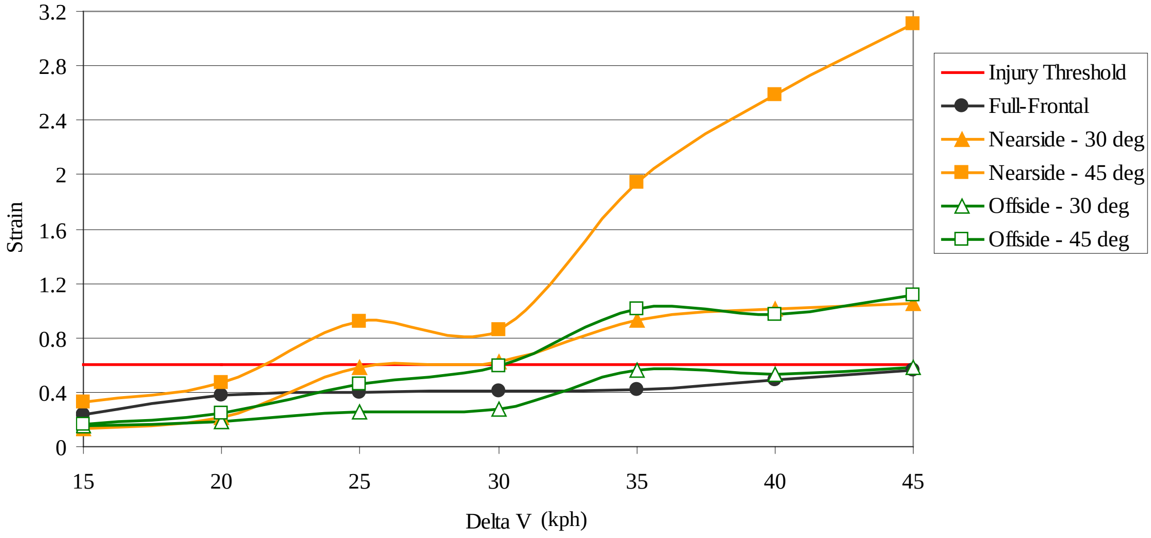

Figure 6. Maximum von Mises strains at the uteroplacental interface (UPI) vs *ΔV* (kph)

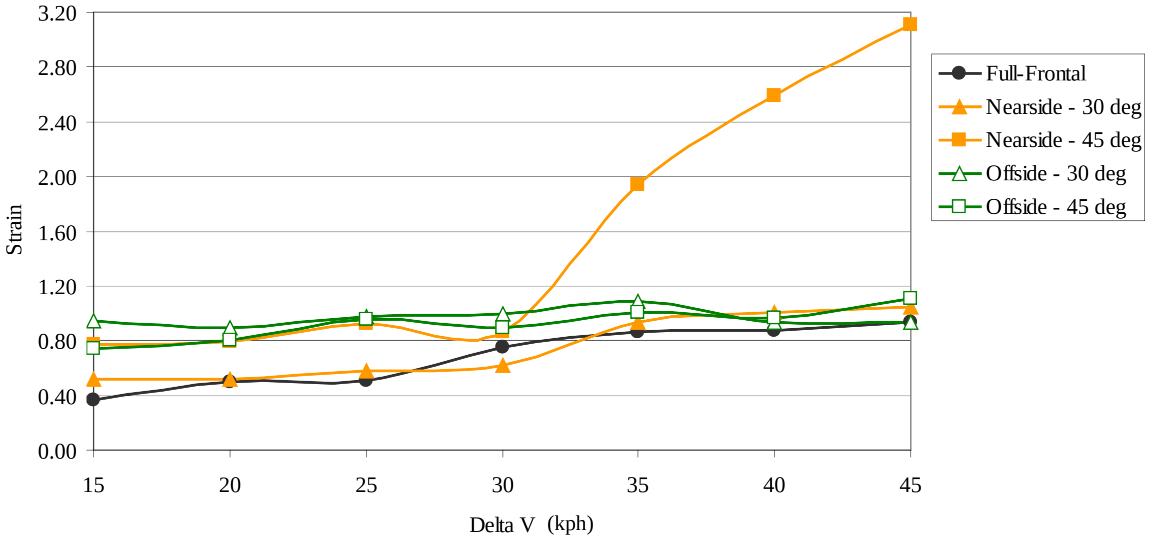

Figure 7. Maximum von Mises strains in overall uterus vs *ΔV* (kph)

DISCUSSION AND CONCLUSIONS

The computational model '*Expecting*' which also incorporates a fetus is shown to be a useful tool in the investigations of pregnant drivers' safety in oblique crashes. The simulations have provided an insight into a wider range of impact scenarios in addition to full-frontal collisions.

The results demonstrate that oblique impacts cause generally higher strain levels in the uterus when compared with the full frontal impacts. *Oblique-Nearside 30°* values yield results very similar to those of *Oblique-farside 45°* impact. *Oblique-Nearside* crashes cause greater strain levels than *Oblique-*

farside crashes. This is attributed to the 3-point seat belt configuration. As the seat belt system is not symmetric; it therefore affects the pregnant driver's response differently against impacts coming from different directions. The shoulder portion of the 3-point seat belt for the driver runs from the farside shoulder towards the nearside hip below. During a *Nearside* impact, the torso of the driver is not restrained by the shoulder belt and moves relatively freely out of the shoulder portion, whereas during an *farside* impact, the shoulder portion restrains the torso from further displacement towards vehicle interior as seen in Figure 5. In *Nearside* crashes the lower portion of the shoulder belt exerts pressure on the abdomen, in turn giving rise to strain levels. A combination of the lap belt restriction and the lack of shoulder belt restriction, and the compression between the torso and the thighs, cause the fetus move more freely and at the same time is forced towards the placenta. This movement of the fetus during impact explains very high strain values at the utero-placental interface (UPI) for both *Nearside* cases.

It should be noted that there is no widely accepted injury criteria for the overall strains in uterus, unlike the commonly accepted injury threshold of 0.60 for the strains in UPI region in uterus. In general high strains are not desirable in any part of the uterus, which may eventually cause tears, bleeding or discomfort.

In the oblique impact cases investigated in this study, steering wheel loading appears to be minimal whereas in full-frontal impacts, the risk associated with the placental abruption is mostly due to steering wheel loading on uterus at the UPI.

This research suggests that during oblique crashes, the strain values at the placental location of the uterus are greater than the threshold value for placental abruption especially at higher speed collisions and collisions with large oblique impact angles. *Oblique Nearside* crashes appear to be more hazardous than *Oblique farside* crashes for the fetus.

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