Research of Vehicle Airbag Non-deployment Cases

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Abstract. In this paper, the conditions, criteria and the algorithms controlling the deployment of vehicle airbags are analysed. The sequence of the algorithm and specific thresholds used in airbags control are analysed as well. The means are provided for airbags testing to ensure their reliability and proper functioning. The types of road accidents including specific cases are described in terms of possible airbag non-deployment. The computer simulations of critical impact scenarios with a finite element model of light vehicle are done in LS DYNA software. The analysis of achieved impact force results show that even relatively small speed (30 and 50 km/h) causes different conditions for airbag deployment.

Keywords: Airbag deployment · Frontal impact · Vehicle collision · Passive safety

1 Introduction

The World Health Organization announces about 1.35 mln. road deaths and from 20 to 30 mln. injuries every year [1]. The 21% reduction of fatal road accidents was estimated in Europe Union (EU) during last eight-year period [2]; however, road accidents is still a relevant problem worldwide.

Airbags are one of the most important and complicated system of vehicle passive safety and the engineers are responsible for its relevant design and safety performance during road accident. According to U.S. National Highway Traffic Safety Administration (NHTSA) 2,790 lives were saved just because of front airbags in 2017 and more that fifty thousand lives since 1978 when the front airbags became widely used in road vehicles [3]. The front airbags reduce the risk of death for drivers by 29%, and by 32% for front passengers over 13 years of age [4]. According to NHTSA, the combination of front airbag and seatbelt reduces the severity of death during frontal impact by 61% comparing with 50% using only a seatbelt. Side airbags protects only mainly a head, but still reduce the severity of by 37% during side impact, and the side airbags that protect only the torso area reduce the severity of by 26% [5]. However, the cases of non-deployed airbags during road accident are also possible and sometimes unfortunately happens causing deaths or injuries.

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The objective of this research is to analyse the causes and algorithms of airbag deployment, and to do a computer simulation of vehicle-obstacle impact in different moving cases with the purpose of estimating the deployment capabilities of car airbags.

2 Conditions, Criteria and Algorithms for Airbag Deployment

Vehicle airbag systems must function properly and be reliable; therefore, various analyses including different impact cases of computer simulations using Madymo, LS DYNA and other software are performed [6, 7]. A real driving tests of different vehicle driving modes also tests in test benches are organized for development of airbag systems.

The deployment of vehicle airbags during the impact depends on few thresholds. For some vehicles, the airbags are designed to deploy during a frontal collision with an undeformed wall when the speed of the vehicle is at least 23 km/h. Airbag deployment limits are generally governed by various vehicle design regulations, for example, U.S. law requires airbags to deploy at a speed of at least 22.5 km/h in the event of a frontal collision [8]. According to the NHTSA, the front airbags must deploy during a frontal or near-frontal impact with an undeformed wall at a speed of 12.8 to 22.5 km/h what is equivalent to a collision with a stationary vehicle at a speed of 26–45 km/h [3]. Seatbelts are usually sufficient to protect the driver and passengers at low collision speeds and the deployment of the airbags is unnecessary; however, at higher collision speeds, only the combination of seat belts and airbags can effectively protect [9].

The initial technologies of the airbags have been designed to deploy in all cases where certain thresholds were exceeded during a collision, which is not applied for now. It's been a while as the deployment of the airbags is adapted to the nature of the collision, its severity, the size and weight of the occupant, as well as the use of the belts and the position of the occupant in relation to the airbag. Vehicle body sensors transmit the signals to the airbag control unit, which determines in which mode the airbags must be deployed and whether they need to be deployed at all [8].

Advanced airbags have a dual-level inflation system which regulates the force of the deployment depending on the severity of the collision. This is necessary because passengers move forward at different speeds and for different periods of time; therefore, it is important that the airbag inflates at the right time and with the right force. All airbag systems are designed so that they do not deploy during sharp braking or when driving on uneven and potholed roads. The accelerations during these driving cases do not reach the thresholds of airbags deployment [10]. Also the deactivation of front airbag in cases of children is possible [8].

The airbag control unit receives a continuous signal from each sensor or MEMS (micro-electro-mechanical systems) and records data for a period of time after a specific event fixed [11]. The function of the vehicle's airbag system is to record the data about an event close to the deployment of the airbags which is also defined as Event Data Recorder (EDR). In the case of an airbag deployment, the collision data is permanently stored in the control unit. The data can be erased after 250 vehicle start cycles or when another event occurs close to the deployment of the airbags. The airbag control unit records data about 5 s before the collision and shortly after the collision [12].

The collision algorithmic process is performed in sequence shown in Fig. 1. Initially, the acceleration signals received from the sensors are processed by a signal filter and if the initial condition is met, the algorithm is excited. Normally, the algorithm does not work continuously, when the signal is received, the algorithm is excited within 4–5 ms. Then, if the results of the algorithmic solutions meet the various set thresholds, the airbags are deployed [13]. The algorithm usually has a very short time to process the received signal and make airbag deployment decisions; usually around 10–50 ms depending on collision type. Algorithms have to perform two main tasks: i) evaluate the received information and perform calculations based on airbag deployment, ii) determine the appropriate time for the airbags to deploy [9].

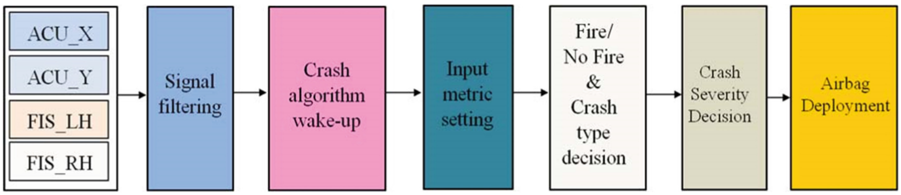


Fig. 1. Crash algorithm block diagram [13].

The control unit uses the appropriate algorithm to determine the severity of the collision by estimating one or more of the variables listed in Table 1 [11].

Table 1. Variables used in algorithms of airbag system [11].

Variable	Expression
Acceleration	$a = \frac{dv}{dt}$
Velocity	$v = \int adt = \frac{dx}{dt}$
Displacement	$x = \int vdt = \iint adtdt$
Energy density	$e = \int_{x_0}^{x} adx = \int_{v_0}^{v} vdv = \frac{1}{2} \cdot (v^2 - v_0^2)$
Energy	$E = \frac{1}{2} \cdot m(v^2 - v_0^2)$
Power	$\overline{p} = \frac{dE}{dt} = mva$
Power density	$p = \frac{\overline{p}}{m} = va$
Power rate density	$p' = \frac{dp}{dt} = vj + a^2$
Jerk	$j = \frac{da}{dt}$

Almost all algorithms used today are based on certain set thresholds where the acceleration is used mostly and the other variables are calculated from it [9]. Each airbag control unit has variable value limits against which algorithms estimate the need for airbag deployment. For a frontal collision, the longitudinal acceleration limits required to activate the airbags may be different: the lower acceleration limit varies between 4.7–7.5 g, and the upper acceleration limit value varies between 8.2–13.2 g [11]. An example of an algorithm scheme is shown in Fig. 2.

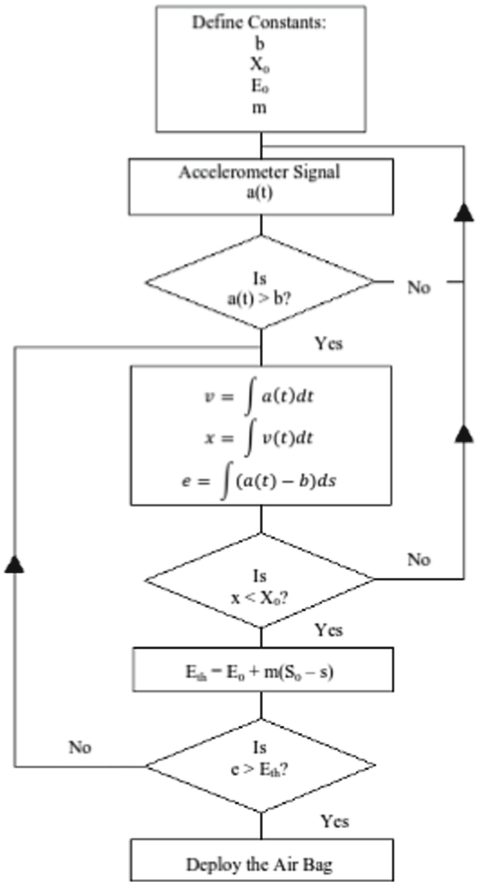


Fig. 2. An algorithm scheme for airbag deployment [11].

The presented algorithm estimates the acceleration (*a*), velocity (*v*), displacement (*x*) and energy density (*e*). If the acceleration (*a*) does not exceed a certain acceleration limit (*b*) during the collision, the algorithm is returned to its initial state. If the limit is exceeded, further calculations are performed (*v, x, e*). If the displacement (*x*) is less than the set limit, the limit energy density (E_{th}) is calculated. If the calculated energy density (*e*) is higher than the calculated limit value (E_{th}), the airbags are deployed, otherwise not deployed.

Airbag deployment schemes vary widely in different patents where the variables of acceleration and its jerk are used while new systems also perform an estimation of the presence of passengers and the position of the passenger in relation to the air bag.

New airbag systems are currently being widely developed to make the decision about the type of the vehicle collision before it happens. The system evaluates information before and during the collision, utilizing vehicle surrounding and impact sensing correspondingly. In this type of algorithm, the control unit independently uses the interface of the two main algorithms between pre-collision and collision cases (Fig. 3) [13].

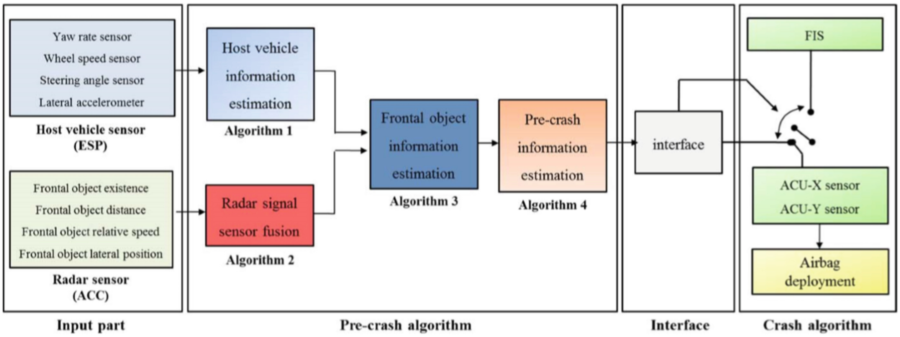


Fig. 3. Block scheme of an algorithm based on pre-collision information [13].

The input data used in the algorithms is derived from vehicle stability control sensors, radar and acceleration sensors. This algorithm is based on obtaining information from a pre-collision algorithm, the purpose of which is to predict the probability of a collision, the time before the collision, information about the type of collision and possible collision scenarios. Based on the information obtained, the airbags can be deployed so that their deployment corresponds to a particular defined collision configuration; however, the interface between the collision algorithm and the pre-collision algorithm is very important in this case. If the performance of the pre-collision algorithm fails, the overall performance of both algorithms deteriorates, unlike using only one, simple collision algorithm [13].

3 Critical Road Accidents Conditions for Airbag Deployment

Real traffic accidents are not regular collisions to steep solid obstacles at a certain set angle as it is evaluated during vehicle safety assessment tests; therefore, it is necessary to analyze cases where the deployment of the airbag is not fully ensured [11]. The deployment of vehicle airbags depends on the type of the collision. Statistically, the most common collisions occur in the front of the vehicle or in the front corner while the impact with the rear is least common (Fig. 4).

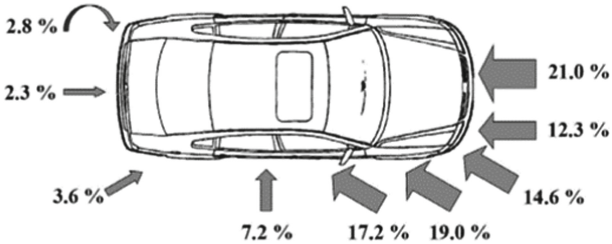


Fig. 4. Statistically based vehicle impact directions [14].

The airbags may not inflate when only one narrow area of the vehicle is deformed, such as in a collision with a pole. In addition, the airbags may not inflate when the vehicle underrides an object, such as a truck because at this case the impact duration is longer. The airbags may not deploy during a collision when the relative stiffness of the objects is very different, such as when the front of a vehicle collides with the side of another vehicle. Collisions that occur at an inclined angle do not always result in the deployment of the airbag, as in this case the deceleration does not occur in a direction parallel to the sensor [11]. These and similar cases are also described by manufacturers. As an example, Fig. 5 shows the cases in the Mazda CX-3 manual that do not allow the airbags to deploy.

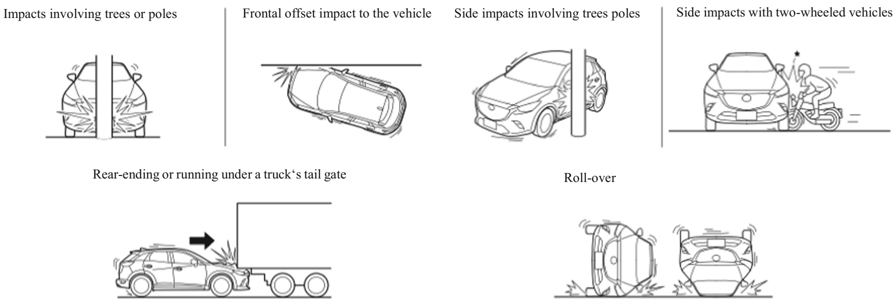
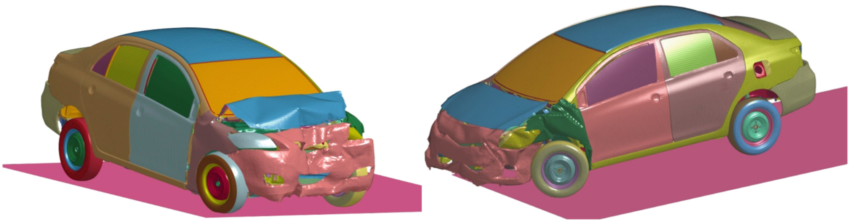


Fig. 5. Cases when the deployment of the airbags is not ensured [15].

Thus, the nature of the collision during an accident is an important factor on which the deployment of the airbags depends. As the main purpose of the airbags is to protect the occupants and the driver, a great attention must be paid to the design of the airbag systems and the arrangement of the system elements avoiding the cases of non-deployed airbags when it can mitigate the consequences of road accident.

4 Computer Simulation of Airbag Deployment

The finite element model of light vehicle Toyota Yaris is used for computer simulations. This model is created in Center for Collision Safety and Analysis of George Mason University (U.S.) with the purpose of various vehicle impact analysis into LS DYNA software (Fig. 6). The model was validated according to frontal impact performed by NHTSA [16]. The model is free available (https://www.ccsa.gmu.edu/models/2010-toyota-yaris/).



a) b)

Fig. 6. The view of Toyota Yaris vehicle after the impact with a rigid wall at 50 km/h: a) with 50% overlap; b) at an angle of 25°.

The finite element model of Toyota Yaris consists of 378,376 elements and 393,165 nodes. The construction of vehicle body, chassis and interior elements with their physical and mechanical properties are detail designed in this model.

Determining whether the airbags will deploy in a given collision requires having set of previously described acceleration limits. According [11], Toyota uses 5.8–10.2 g acceleration limits for airbag deployment during frontal impact. If the recorded maximum acceleration is over 10.2 g the airbag must deploy; however, the deployment of the airbags is likely if the acceleration is within the specified values.

At this research vehicle speed of 30 km/h and 50 km/h are used for collisions with rigid wall. The duration of computer simulation in LS DYNA was 150 ms. The cases of these impacts is analysed further: i) the impact with full overlap, ii) the impact with 50% overlap, iii) the impact with 25% overlap, iv) the impact at an angle of 45°, v) the impact at an angle of 25°.

5 Results and Discussion

The Toyota Yaris crash simulations provided the forces achieved during the impact by an obstacle collision (Fig. 7 and Fig. 8). These forces causes vehicle body deformations and previously described accelerations.

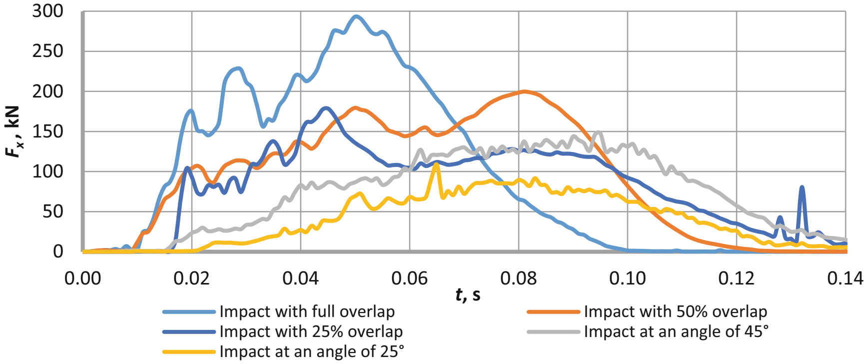


Fig. 7. Forces during the impact at a speed of 30 km/h.

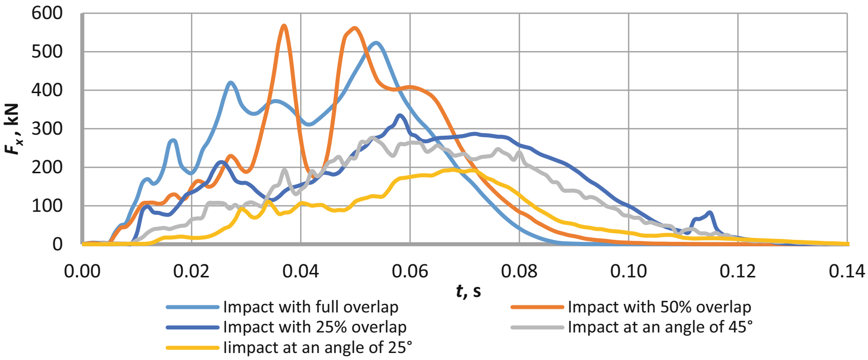


Fig. 8. Forces acting during the impact at a speed of 50 km/h.

The graphs show that the forces generated during a collision depend on the speed of the vehicle and the configuration of the collision. Table 2 presents the maximum values of the forces for simulation of each impact.

Table 2. The maximum values of the forces for simulation of each impact.

The case of impact	Speed before the impact, km/h	Maximum force, kN
The impact with full overlap	30	293.4
	50	522.5
The impact with 50% overlap	30	199.8
	50	561.3
The impact with 25% overlap	30	178.6
	50	334.5
The impact at an angle of 45°	30	147.6
	50	276.6
The impact at an angle of 25°	30	108.5
	50	193.5

It is recognised from the data table, that the maximum force is reached for vehicle impact with 50% overlap at 50 km/h speed, while the lowest force occurs for an impact of 25° angle at 30 km/h speed.

During the simulation of frontal impact with a rigid wall with 50% overlap at 30 km/h and 50 km/h speeds the longitudinal acceleration of 18.8 g was found for 30 km/h speed and it was reached after 0.083 s from the beginning of the impact. For simulation of 50 km/h the maximum acceleration was 58.5 g and it was reached after 0.041 s. At these cases the airbag deployment cause was exceeded (acceleration window 5.8–10.2 g), therefore airbags should be deployed for both analysed speeds. The upper acceleration limit for airbag deployment was reached after 0.0140 s at 30 km/h speed and after 0.0085 s at 50 km/h. It was also recognised a negative vehicle speed values just after the impact. This is because of the vehicle was blown back.

During the simulation of frontal impact with of a rigid wall at an angle of 25° at 30 km/h, the maximum longitudinal acceleration of 10.0 g was reached after 0.084 s from the beginning of the impact. For 50 km/h the maximum acceleration is 19.1 g and it was reached after 0.066 s. The limits of longitudinal acceleration for airbag deployment (5.8–10.2 g) is reached for 50 km/h case. For 30 km/h only the lower limit for airbag deployment was reaches; however, the upper limit was not reached. So the deployment of vehicle front airbag is guaranteed only for 50 km/h, and for 30 km/h the deployment is possible, but not guaranteed. The lower acceleration limit for airbag deployment was reached after 0.0565 s at 30 km/h speed and after 0.0439 s at 50 km/h. At this case the vehicle interacts with the obstacle (barrier) by sliding contact therefore vehicle's movement duration is longer.

The graphs also show that the force changes significantly during the impact duration. This is because of different shapes and stiffness of vehicle body. The highest forces was estimated when the impact reached front bumper beam, engine, front chassis legs.

6 Conclusions

After the research of vehicle airbag deployment, its related issues and performed computer simulations, the following conclusions are made:

1. The main variable for control of vehicle airbag is acceleration which activation thresholds varies between 4.7–13.2 g. The values of longitudinal acceleration used for airbags deployment analysis in computer simulation with light vehicle is between 5.8–10.2 g.
2. After computer simulation with software LS DYNA using Toyota Yaris finite element model, the largest longitudinal acceleration (58.5 g) was found during the impact with rigid wall with 50% overlap at 50 km/h speed. Changing the overlap of vehicle's collision with an obstacle from 50% to 100%, the longitudinal acceleration at a speed of 30 km/h increased 1.3 times. However, the largest increase (1.68 times) was found changing the overlap of vehicle's collision with an obstacle from 25% to 50% at 50 km/h speed.

3. Changing the angle of vehicle's impact with the obstacle from 25° to 45°, the longitudinal acceleration increased 1.4 times at both 30 km/h and 50 km/h speeds.
4. During the impact with rigid wall at an angle of 25° at a speed of 30 km/h, the resulting longitudinal acceleration (10.0 g) is within the limits of the airbag activation, in which case the deployment of the airbags is likely, but not mandatory. In all other simulated cases, the deployment of the airbags is mandatory because the longitudinal acceleration values obtained exceed the specified longitudinal acceleration limits.

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