

# PEDESTRIAN AIRBAG TECHNOLOGY – A PRODUCTION SYSTEM

**Lotta Jakobsson**  
**Thomas Broberg**  
**Henrik Karlsson**  
**Anders Fredriksson**  
**Niklas Gråberg**  
**Christina Gullander**  
**Magdalena Lindman**

Volvo Car Corporation  
Sweden

Paper Number 13-0447

## ABSTRACT

Pedestrians in conflict with passenger cars represent an important portion of all road user fatalities.

This paper presents the world-first pedestrian airbag technology offered in a production vehicle, being one way of addressing pedestrian protection, focusing on trying to help further cushion the impact for a pedestrian and also enable a sleek styling of the vehicle in question.

A description of the technology is provided as well as examples of tests for evaluating technical performance, head impact characteristics and overall technology performance.

Sensors in the bumper provide input to the pedestrian airbag control unit that determines if the system should be activated. The hood hinges are released and the pedestrian airbag deploys helping both to elevate the hood itself as well as helping to cushion a potential impact. The lift height is controlled and limited.

Numerous tests of the components and the system are performed in various situations, including different weather conditions, verified the technical performance and validated the complete chain of events from detection of a pedestrian leg to the final state of deployment.

Using head impactor tests, the head impact protection capabilities showed overall good performance. Impact towards the pedestrian airbag reduces the acceleration level as compared to without the airbag.

Overall performance of the complete technology, including head impact timing, airbag coverage and overall occupant kinematics was verified using a pedestrian prototype crash test dummy and four different pedestrian FE human models.

The pedestrian airbag technology as being one possible solution to cushion an impact helps to protect pedestrians in certain situations when struck by the vehicles front end with a consequent impact to the hood and the area around the windscreen wiper recess and A-pillar.

## INTRODUCTION

According to IRTAD (2011), out of all reported road user fatalities in 2009, pedestrians represent 13% in the US, 14% in Germany and 12% in Sweden.

Passenger cars are reported as the most frequent (74%) collision opponent in fatal pedestrian accidents (Gravila et al. 2003). In 75% of recent Volvo car-pedestrian crashes the car is moving forward and in more than 85% of these, the collision takes place at speeds up to 40 km/h (Lindman et al. 2011). Further, the most frequent AIS2+ injured body parts are the lower extremities followed by the head, upper extremities, chest, pelvis, spine, face and abdomen (in the order of presentation).

Fredriksson et al (2010) reported in a study based on The German In-Depth Accident Study (GIDAS) database that with regard to AIS3+ injuries, the most frequent injury mechanisms were leg-to-front end, head-to-windscreen area, chest-to-hood area, and chest-to-windscreen area. Also, for surviving pedestrians, it was estimated that the head was the dominating body region to sustain a severe permanent medical impairment.

Public domain testing for the car-pedestrian scenario was first introduced in 1997 by EuroNCAP and the first regulatory requirement came into effect in 2005 in EU and Japan. The methods used are physical component tests simulating frontal impacts with pedestrians, aiming at reducing pedestrian injury.

To meet the safety rating and regulatory targets, protective functionalities are introduced by car manufacturers. For example, in a study by Kühn et al (2005), different concepts of car front structure, uplifting hood and uplifting hood with airbag are discussed.

Strandroth et al, (2011) found a significant correlation between Euro NCAP pedestrian score and injury outcome in real-life crashes, suggesting that this is an effect of more pedestrian friendly car design. Further

developments are continuously presented and updates of test methods are expected the next years. These will also include car safety technology aiming at avoiding or mitigating the car to pedestrian accidents, such as Pedestrian detection with auto brake functionality (Lindman et al. 2010).

The aim of this study is to present a production airbag technology focusing pedestrian head impacts. A special focus is given to the technical challenges.

## PEDESTRIAN AIRBAG TECHNOLOGY

The Pedestrian Airbag Technology consists of a number of components integrated into the vehicle as a complete system. The technology was first introduced in the Volvo V40 in 2012, Figure 1.



Figure 1. Deployed Pedestrian Airbag Technology in a Volvo V40.

### Main components

Figure 2 displays the main components of the Pedestrian Airbag Technology; pedestrian airbag control unit, pedestrian airbag module, hood lift limiter, hood hinge release mechanism, hood hinges and sensors.

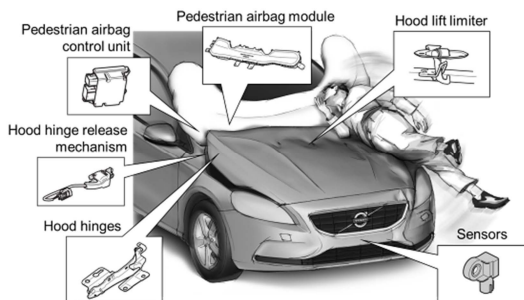


Figure 2. Main components of the pedestrian airbag technology integrated in the vehicle

The system's activation range is between 20 and 50 km/h. Sensors embedded in the front of the car (bumper) transmit signals to the pedestrian airbag control unit. When the car comes into contact with an object, the signals change. The control unit evaluates the signals and if it registers what it interprets as a human-like leg the pedestrian airbag technology is activated.

When a decision to trigger the pedestrian airbag technology is made, trigger signals are simultaneously sent to the two pyrotechnical

hood hinge release mechanism and the airbag inflator. Each hood hinge release mechanism pulls out a pin and releases a second pivot point which makes it possible for the rear of the hood to lift. At the same time, the airbag starts filling with gas and opens the lid of the pedestrian airbag module cover. During the inflation and positioning sequence the airbag raises the back of the hood to an extent of approximately ten centimeters. The lift height is controlled and limited. The principle sequence is illustrated in Figure 3.

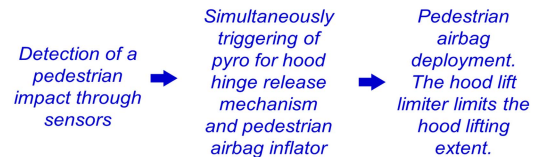


Figure 3. Principle sequence of deployment

### Hood lift limiter

To limit the hood lifting it is equipped with a lift limiter consisting of a hook in the hood and a loop in the strut tower bar (see Figure 4). The hook is designed to hitch into the loop only when the back of the hood is lifted by the pedestrian airbag. Hence, when the hood is lifted in the front, e.g. during service, the hook will not hitch into the loop.

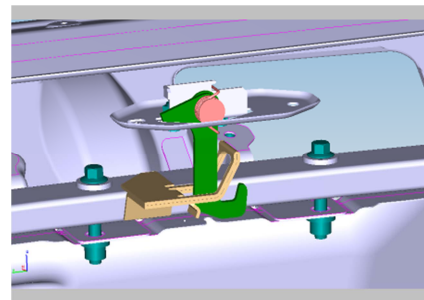


Figure 4. Lift limiter hook mounted on the hood and loop mounted on the strut tower bar

### Pedestrian airbag module

In contrary to most vehicle airbags, the pedestrian airbag is located on the outside of the vehicle. Some adaptations were made to this environment. Except for the airbag size, the general concept is the same as of interior airbags, comprising a cover, a hybrid inflator, and an airbag. Upon activation, the airbag is filled with gas within a few milliseconds and stays fully inflated for about 300 milliseconds. The entire sequence from activation of the system to full inflation takes less than hundred milliseconds.

When the airbag is completely deployed it covers the part of the A-pillars and lower part of the windscreen. This corresponds to approximately one third of the windscreen.

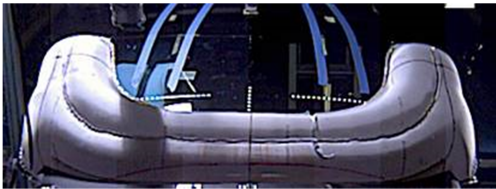


Figure 5. Pedestrian airbag completely deployed.

### TESTING / EVALUATION

During the development work, the technology was evaluated using several different types of testing. Head impact tests, Computer Aided Engineering (CAE) as well as physical test, were used to show the benefits of the pedestrian airbag and hood functionality. Overall dynamic performance was evaluated using a pedestrian prototype crash test dummy and four different sized pedestrian FE human models. Also, the sensor functionality when interacting with different objects was evaluated.

#### Technical performance evaluation

Extensive testing has been made during the development phase of the pedestrian airbag technology. Numerous tests were performed in various situations, including different weather conditions and loading conditions for the evaluation of the technical performance.

Component tests were performed on the hood hinges, hood hinge release mechanisms, lift limiter, hood and pedestrian airbag module for durability and functionality testing. Hundreds of airbag tests have been performed to get the optimal deploying performance and timing.

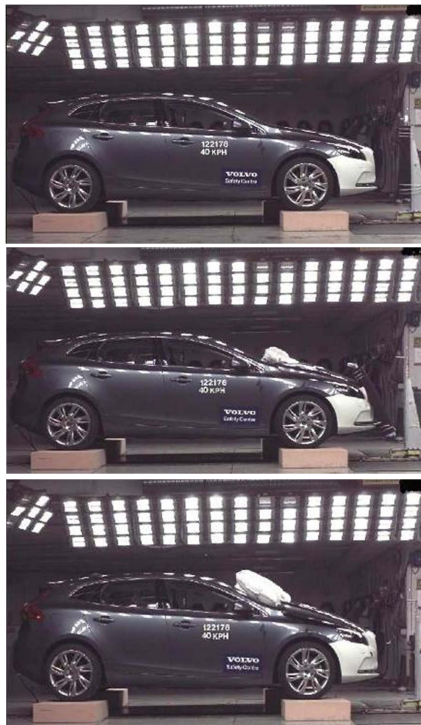


Figure 6. One example of system testing, using a leg impactor, three time sequences

System tests were performed to validate the complete chain from detection of a pedestrian to complete airbag deployment. A great number of development tests were run with different types of impactors, in several environmental situations, as well as in different configurations to simulate humans for activation, as exemplified in Figure 6.

The system was also tested during varying environmental conditions such as snow, ice, dirt, different temperatures and also after ageing and durability tests. Figure 7 shows a climate chamber that is used to test the system in different temperatures. Figure 8 shows activation test with a car packed with snow in the area above the pedestrian airbag module area. The technology shows good performance in all evaluated configurations, meeting the internal targets.



Figure 7. Photo of a climate chamber for testing at different temperatures.



Figure 8. Activation test in a car packed with snow in the area of the pedestrian airbag module.

#### Head impact performance

Head impact tests were performed according to the Euro-NCAP test protocol (Ver 5.3.1. Nov 2011), using the pedestrian rig at Volvo Cars Safety Centre, Figure 9. A child head impactor and an adult head impactor were used and launched towards impact areas defined in the protocol as relevant for the different pedestrian

sizes. Used impact speed was 11.1 m/s. The airbag was triggered so the impactor hit the airbag with timing corresponding to that of a car to pedestrian impact.

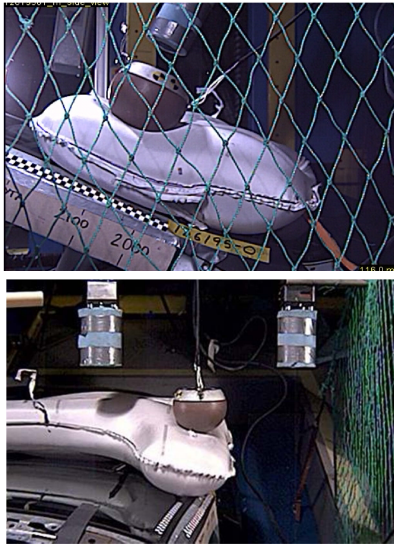


Figure 9. Head impact test. Top: view from the right hand side of the car. Bottom: view from the roof of the car.

The injury criterion evaluated is HIC (Head Injury Criterion) based on the accelerometer signal from the head impactors.

One summary of the head impactor responses was presented by EuroNCAP for the Volvo V40 (EuroNCAP, 2013), Figure 10. EuroNCAP grades the responses in the different impact points in scores of GOOD, ADEQUATE and MARGINAL.

As can be seen in Figure 10, the Pedestrian Airbag Technology integrated in the Volvo V40 shows an overall GOOD performance and achieved the maximum score of 24 points for the head impact tests. The total pedestrian protection score was 88%, which was the highest score yet achieved in this part of the assessment in 2012.

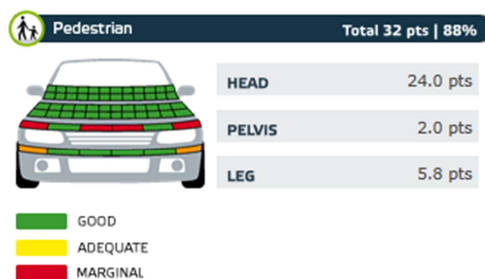


Figure 10. EuroNCAP results of Volvo V40 pedestrian evaluation (EuroNCAP, 2013)

An example of acceleration vs time signal for an impact point at the area of the pedestrian airbag is shown in Figure 11. A comparison is made in the same impact point with and without an

airbag. It can be seen that the pedestrian airbag substantially reduces the acceleration level and thus the HIC value.

The increased distance to the underlying structure due to the lifted hood, also provide further improvements regarding head impact performance compared to the hood in its normal position.

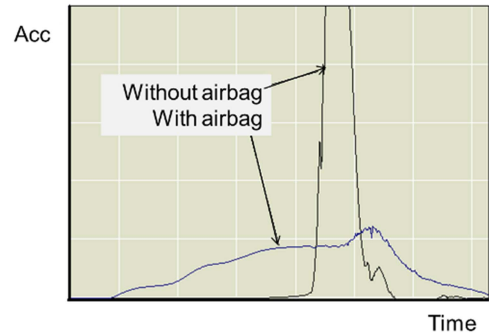


Figure 11. An example of head impacts responses (acceleration vs time) comparing with and without the pedestrian airbag at one specific location.

### Complete technology performance

**CAE.** Numerous Computer Aided Engineering (CAE) simulations were run using human FE pedestrian models and a vehicle model of the Volvo V40 using the LS-Dyna software. The purpose was to evaluate the performance of the complete technology, including head impact timing, airbag coverage and overall occupant kinematics. The human FE pedestrian models were in different sizes; 6 years old child, 5%-ile female, 50%-ile male and 95%-ile male sizes, Figure 12.

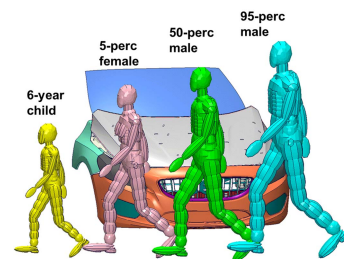


Figure 12. The four different human FE pedestrian models.

For robustness evaluation, the pedestrian stances as well as the vehicle impact points and vehicle speeds were varied. Some of the test setups are displayed in Figures 13 and 14.

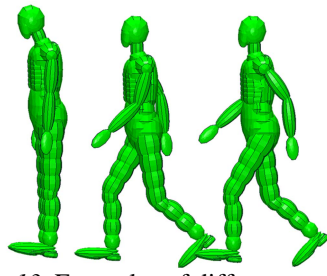


Figure 13. Examples of different evaluated pedestrian stances.

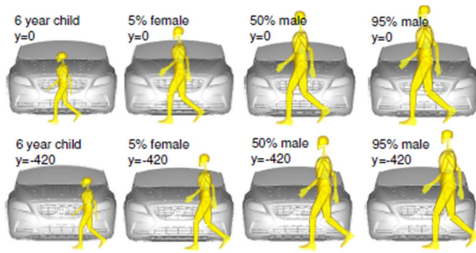


Figure 14. Examples of vehicle impact point setups.

For the different combinations of vehicle pedestrian interactions, the kinematics of the pedestrian, different timing aspects and head impact points were evaluated and used for setting the timing in deployment and for evaluation of complete technology performance. The timings required for optimum performance were evaluated and met. The head impact points were compared to the head impact tests and considered relevant from a complete technology performance perspective.

As an example, Figure 15 presents the pedestrian trajectories for the 50%-ile male FE pedestrian model, in a walking stance, impacted at left vehicle front in 40 km/h.

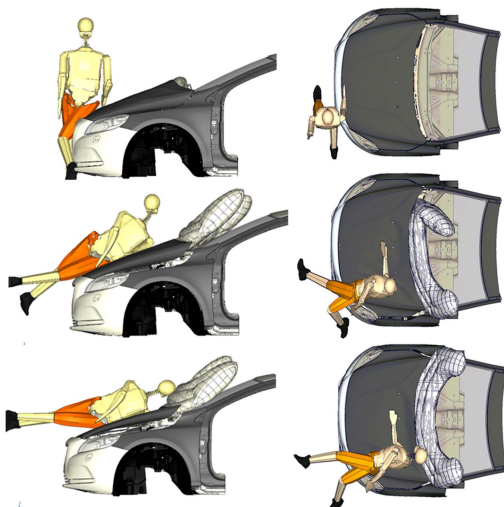


Figure 15. Kinematics of 50% male FE pedestrian model.

**Physical testing.** As a complement to the CAE simulations, a number of full vehicle testing using a 50%-ile male size prototype pedestrian dummy (Fredriksson et al. 2011) were performed. The tests were run at different speeds, dummy positions and vehicle impact points to evaluate the complete vehicle performance. Since a prototype pedestrian dummy was used, overall kinematics rather than specific body region injury criteria were considered. Figures 16 and 17 illustrate two tests with different dummy positions prior to impact. The main purpose was to compare to the human FE pedestrian tests, which showed similar kinematics. The physical tests added valuable input to the robustness evaluation of the complete technology performance.



Figure 16. Full vehicle testing at speed 40 km/h impacting a 50%-ile male size prototype pedestrian dummy standing sidewise.



Figure 17. Full vehicle testing at speed 40 km/h impacting a 50%-ile male size prototype pedestrian dummy facing the vehicle.

## DISCUSSION

The pedestrian airbag technology as the first of its kind in a production vehicle consists of a number of components all working together enabling the complete technology performance. During the development process numerous challenges were mastered both on component and complete system level. The technology presented is a first unique step in using airbag technology to address collisions with pedestrians.

The regions of the A-pillar and windscreen are important structural load paths in crash scenarios like to the front and side and are exposed to potential head impact in a pedestrian crash. Especially the A-pillar and windscreen wiper recess areas are challenging to design addressing

pedestrian head impacts while maintaining the strength needed in combination with styling aspects. Although challenging in itself the technology presented in this study is one possible solution addressing the issue by providing a built-in cushioning effect for a pedestrian upon impact in certain situations.

A technical aspect was to take the knowledge from interior airbag technology and apply that to an airbag which is located on the outside of the car. Specific adaptations to this challenging environment were made. Also, a new test method, including a climate chamber was developed for testing the technology performance at different environmental conditions.

The required location of the airbag unit itself in the plenum area and its size in combination with the engineering aspects to enable mounting outside the car made the airbag module challenging also from a packaging perspective. To make the engineering challenge even greater the same airbag module is used for both left and right hand drive cars.

Further, adaptations were needed to surrounding components and several new inventions were required to get the essential overall performance of the complete system. One example being the lift limiter and tailor-made hood-hinges which may be perceived as minor parts but actually have a high contribution to the overall performance of the technology.

More so, during the inflation phase, the pedestrian airbag has to open a lid, push the hood upwards and deploy itself over an uneven surface and position on the windscreen and the A-pillars. This needs to be done in fractions of a second. In comparison to a conventional interior passenger airbag which primarily opens a lid and position itself this process is much more complex and puts high demands on the design and folding of the airbag.

This first generation of the pedestrian airbag technology is designed to operate in a vehicle speed interval of 20-50 km/h. This is a logical first step as this addresses a speed interval where a significant number of pedestrian collisions involving serious injuries occur. More so, setting up these boundaries helped in making this unique technology feasible at this point of time.

This paper describes the overall functionality of the technology from a pedestrian protection point of view. However, the challenge in the design of this new unique technology also included studies evaluating aspects of daily usage and operation of the vehicle, including misuse cases and studies of driver reactions.

The evaluation of the Pedestrian airbag technology comprises several different methods providing a solid ground for evaluating the technical performance. Pedestrian dummies are

still under development and thus provided a limitation in possibility for complete system evaluation including dummy criteria. However, the usage of a combination of different existing validated tests and CAE methods together with some new tests both on sub- and complete system level gave high confidence as to the overall performance of the pedestrian airbag technology.

Partly due to lack of different sizes of pedestrian dummies and in order to cover a more wide impact area, head impact performance was evaluated using the head impactor test. As shown in Figure 11, head impact towards the pedestrian airbag results in substantially lower head impact severity compared to the same impact point without a pedestrian airbag on this specific vehicle.

The pedestrian airbag technology, comprising a pedestrian airbag together with a hood lifting functionality mainly addresses improved protection to the pedestrian's upper body regions. Protection is also provided in the vehicle front by focusing pedestrian leg impact protection when interaction in this area. Hence, the pedestrian crash protection of the complete vehicle is more than the pedestrian airbag technology as presented in this study.

In 2010, Volvo Cars introduced an avoidance and mitigation technology detecting pedestrians that shows high potential (Lindman et al. 2010). This technology provides a warning to the driver and auto brake the car if the driver does not take any action trying to avoid a likely collision with a pedestrian. With this in combination with the pedestrian airbag technology, the pedestrian will be impacted at reduced speed, if not the crash is avoided as such.

Pedestrians are not the only type of Vulnerable Road Users (VRU) that may be impacted by the front end of a car. Even if the pedestrian airbag technology has been designed focusing the impact between a car and pedestrian, there may be situations where the technology might have a cushioning effect also in relation to other types of VRUs. This, however, was not part of this study.

## CONCLUSIONS

The pedestrian airbag technology being a world-first pedestrian airbag technology offered in a production vehicle is one way of addressing pedestrian protection, especially when car size and styling aspects are setting the borders.

The pedestrian airbag technology helps to protect pedestrians in certain situations when struck by the vehicles front-end with a consequent impact to the hood and the area around the windscreen wiper recess and A-pillar, where there may be a risk of head impacts.

## ACKNOWLEDGEMENT

The development of the Pedestrian Airbag Technology is a team work. The authors would like to acknowledge all of those who have participated, especially highlighting;

The creativity and support by team leader, material coordinator and testing staff at Safety Centre Testing Laboratory.

The enthusiasm and support by Sven-Gunnar Johansson, Mats Erlingfors, Gunnar Hallnéus, Eddy Bergenheim, Venti Saslecov, Mats Bjureblad, Daniel Bodebratt, Tommy Zippert, Christer Björnerud, Anders Dahlén, Emil Lidström, Anders Carlsson, Håkan Önal, Stefan Larsson and Thomas Boberg at Volvo Cars

Further, Rikard Fredriksson at Autoliv Research and Dan Bergman, Björn Widerholm, Stéphane Prétot at Autoliv Sverige AB are greatly appreciated for their professional co-operation.

## REFERENCES

- EuroNCAP, Test results for Volvo V40, Pedestrian, downloaded February 2013; <http://www.euroncap.com/results/volvo/v40/485.aspx>
- IRTAD [International Traffic Safety Data and Analysis Group] IRTAD Annual Report 2009. Joint OECD/ITF Transport Research Centre, Paris, 2011
- Gavila DM, Marchal P, Meinecke M-M. SAVE-U Deliverable 1-A: Vulnerable Road User Scenario Analysis APVRU, 2003
- Fredriksson R, Håland Y, Yang J. Evaluation of a New Pedestrian Head Injury Protection System with a Sensor in the Bumper and Lifting of the Bonnet's Rear Edge, ESV Conference, Paper No. 131, 2001
- Fredriksson R, Rosen E, Kullgren A. Priorities of Pedestrian Protection—A Real-Life Study of Severe Injuries and Car Sources. *Accident Analysis and Prevention*, 42, 2010: 1672–1681.
- Kühn M, Fröming K, Schindler V. Further Development of Pedestrian Related Component Tests, *ATZ worldwide*, 7-8, Volume 107, ISSN 0001-2785/10810, 2005.
- Lindman M, Ödblom A, Bergwall E, Eidehall A, Svanberg B, Lukaszewicz T. Benefit Estimation Model for Pedestrian Auto Brake Functionality. *ESAR Conference*, Hanover, Germany, 2010.
- Lindman M, Jakobsson L, Jonsson S. Pedestrian Interacting with a Passenger car; a Study of Real World Accidents. *Ircobi Conference*, Krakow Poland, 2011
- Strandroth J, Rizzi M, Sternlund S, Lie A, Tingvall C. The Correlation between

Pedestrian Injury Severity in Real-Life Crashes and Euro NCAP Pedestrian Test Results. *ESV Conference*, Paper No. 11-0188, 2011