LATERAL IMPACT CRASH TESTS FOR POWERED TWO-WHEELERS

Simona Roka, Genís Mensa, Victor Garcia
IDIADA Automotive Technology
Spain

Niccolò Baldanzini
UNIFI
Italy

Marco Pieve
PIAGGIO
Italy

Simone Di Piazza
DUCATI
Italy

Paper Number 23-0259

ABSTRACT

Protection of the Powered Two-Wheelers (PTW) is a major concern due to the increase of this mode of transportation in the accident statistics during the last years. In fact, nowadays, more than 12 riders die on European roads every day and more than 100 are severely injured. In that scenario, IDIADA has promoted and coordinated the European project PIONEERS within the H2020 EU funding programme. This project aimed to reduce the number of PTW fatalities and severely injured by increasing the safety performance, comfort, and usage rate of Personal Protective Equipment (PPE) and the development of new on-board vehicle safety devices. To be able to evaluate the effectiveness of the on-board vehicle safety devices, a lateral testing protocol has been developed considering specifications of the sensor mounting, fixing of the PTW into the test rig, etc. to ensure the repetitiveness of the tests. Four lateral barrier (AE-MDB Euro NCAP) impact tests with two different on-board systems have been performed within the scope of the PIONEERS project according to the impact protocol defined. A Motorcycle Anthropomorphic Test Device (MATD) has been attached to the upper part of a standard Hybrid III dummy from IDIADA to perform the crash tests. Simulations have been performed by UNIFI and compared with the physical tests performed in the laboratory. Results show significant differences between the use of lateral airbag and safety leg cover. The differences are observed not only in the biomechanical values of the MATD but also in the kinematics of the PTW and dummy and in the final relative position of both. By developing new test protocols, more realistic and robust test methodologies will provide better physical data for PTW manufacturers, as well as for on-board protective equipment OEMs (Original Equipment Manufacturers) and PPE suppliers. The data from the tests can be considered as a baseline for further development of the injury assessment for PTWs and it's believed that this data will help to develop more sophisticated testing devices. This paper covers the preparation of testing protocols and execution of PTW lateral safety testing activities performed in IDIADA.

INTRODUCTION

Today, Powered Two Wheelers (PTW) are regarded as one of the most dangerous modes of road transport. PTW accidents have suffered a very low reduction in fatalities in the recent years. In the EU, between 2006-2015, accidents decreased in general by 57%, while in the recent years, PTW accidents just decreased by 28%. PTW accidents made up 18% of road accident fatalities in 2015 in the EU.

This project aims to reduce the number of PTW fatalities and severely injured by increasing the safety performance, comfort and usage rate of Personal Protective Equipment (PPE) and the development of new on-board safety devices. As part of its role, IDIADA designed new full-scale crash test protocols for lateral motorcyclist safety.

Results from previous study done in PIONEERS project D1.1 revealed that the most common AS (Accident Scenario) in this context are AS3 and AS6. AS3 refers to accidents between an L3 (A two-wheeled vehicle with an engine cylinder capacity in the case of a thermic engine exceeding 50 cm3) vehicle and a passenger car/taxi, whilst AS6 refers to single L3 vehicle accidents. Moreover, the most frequently reported first collision contact point is the centre front for the PTW (28.9% of all cases), and the left side for the Opponent Vehicle (OV) (21.9% of all cases). In fact, urban two-participant crashes at intersections are a prevalent cause of serious injuries to PTW riders in all countries. Therefore, in this study a lateral left-side test between an L3 vehicle and a car has been considered to represent AS3.[1]

TEST DESCRIPTION

As outlined in D1.1, in AS3 cases, the PTW impact speed was often higher than the OV impact speed. L3 vehicles more frequently crashed with a speed ranging between 25-35 km/h and 45-60 km/h, while OVs more frequently crashed with a speed ranging between 10-25 km/h. In AS6 crashes, 60.2% of PTWs were between 40-80 km/h.

The most common demographics of PTW riders injured in crashes in Europe were young males (16-35 years old) with a height of 161-180 cm. Thus, a male dummy will be chosen to perform the two different crash tests in Task 3.5 of the PIONEERS project.

Regarding target injuries, the analysis from D1.1 highlighted four body regions: Thorax & Thoracic Spine (TTS), Head & Face (HF), Upper Extremities (UE), and Lower Extremities (LE). At least moderate injuries (AIS 2+) were most frequently found in the thorax (rib cage, lung, and haemothorax) and the brain. Also, abrasions of severity AIS 1 were most frequently found in the LE, followed by the UE.

Accident conditions were selected, including target accident scenarios and main injuries, with special attention to this accidentology data.

Two full-scale crash test protocols to validate the two different on-board systems developed have been defined. The selected test conditions were based on the most suitable impact configuration and have been validated with several simulations to ensure the desired dynamics and the requirements of repeatability and reproducibility.

Each of the tests consisted in two crashes (in total there were 4 crashes). Those were side impacts, trying to simulate as much as possible the most common AS3 accident scenario. The tests consisted in a side impact, using an AE-MDB barrier of 1400kg, crashing with an angle of 90º into the side of the motorcycles, a Ducati Multistrada and a Piaggio MP3. The barrier impacted at speeds of 30 km/h for the Ducati tests and at 15km/h for the Piaggio tests. Both motorcycles crashed at a speed of 30 km/h.[1]

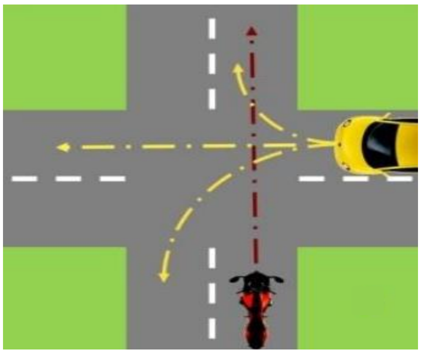


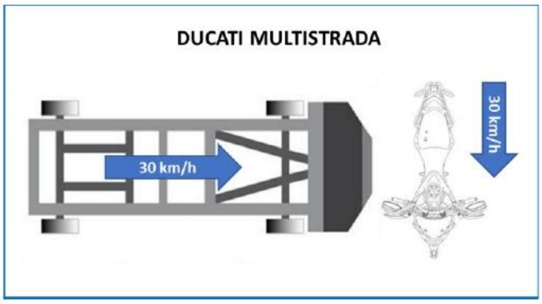
Figure 1. Representation of the AS3 that has been tested, from PIONEERS project D1.1

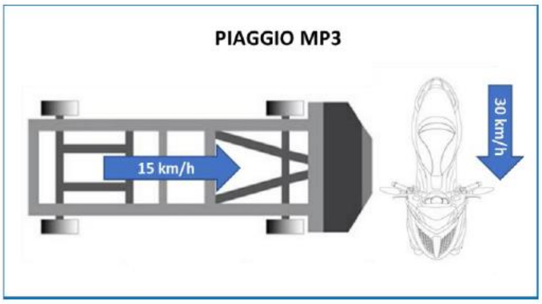
Test environment
These two crash modes were designed with the objective to validate two novel on-board safety systems that were developed in the PIONEERS project with the objective to reduce the severity of motorcycle rider leg injuries. These safety systems were, namely, a lateral airbag system from DUCATI and a safety leg cover designed by PIAGGIO. By developing new test protocols, the PIONEERS consortium hoped to achieve a more realistic and robust test methodology providing better physical data for PTW OEMs (Original Equipment Manufacturers), as well as for on-board protective equipment and PPE suppliers.

As a result of the work conducted in PIONEERS T3.3, the two side impact test protocols shown below in Figures 2 and 3, were defined. Figure 2 represents the crash configuration for the test to evaluate the effectiveness of the Lateral airbags, whilst Figure 3 shows the test protocol defined to assess the PIAGGIO safety leg cover. In both cases, the tests were designed to use a specialized Motorcyclist dummy (MATD) as motorcycle rider or, alternatively, a combination of a Hybrid III 50th percentile upper body and a MATD lower body.

This paper explains the details of the test protocol definition for the two studied lateral impact cases in the framework of PIONEERS. It is important to note that, the two crash configurations indicated above were also chosen considering the design parameters of each of the on-board safety systems and motorbikes.

The Piaggio’s range of speed is considered to be more urban (lower speed) and therefore a suitable on-board safety system, lower leg cover, was chosen. On the contrary, DUCATI motorbike is considered to be used on highways or with elevated speed and so an adequate on-board safety system such as lateral airbag was used.





Figures 2 (left) and 3 (right); 1: Ducati test protocol; 2: Piaggio test protocol.

Four full-vehicle crash tests were conducted at IDIADA. Two tests were performed using a DUCATI Multistrada and the other two tests were performed using a PIAGGIO MP3 500.

For each vehicle model, one crash test was conducted where no countermeasure was included (baseline) and the other crash test did include an on-board safety system. The on-board safety systems considered for this project were, respectively, the DUCATI on-board side airbags and the PIAGGIO safety leg cover. The overall test matrix used in this test series is shown in Table 1.

	Test number		Vehicle		Test date	Test type	Barrier		
Test	IDIADA	Customer	Brand	Set-up			Trolley	Def. element	Serial no.
1	A210409COEC	WP3.5_1	Ducati	W/ AIRBAG	1/28/2021	Side barrier AE-MDB	Lateral Europe 1400 kg (+/- 20 kg)	Cellbond AE-MDB Side impact barrier Part.no. 70AEMDB05L	208318
2	A210410COEC	WP3.5_2	Ducati	W/O AIRBAG	1/28/2021				208429
3	A210415COEC	WP3.5_3	Piaggio	W/O safety leg cover	1/29/2021				208317
4	A210505COEC	WP3.5_4	Piaggio	W/safety leg cover	2/2/2021				208427

Table 1. Test matrix showing the four side barrier tests performed

Test vehicle

The overall vehicle specifications, including the manufacturer, body type, Vehicle Identification Number (VIN) number and test weight (both by axles and in total) is shown in Table 2.

	Test number		Vehicle			Test weight (kg)		
Test	IDIADA	Customer	Manufacturer	Body type	VIN	Front	Rear	Total
1	A210409COEC	WP3.5_1	DUCATI	Multistrada	ZDM12BWW2GB000042	144	190	334
2	A210410COEC	WP3.5_2	DUCATI	Multistrada	ZDMAA07AAJB019225	142	188	330
3	A210415COEC	WP3.5_3	PIAGGIO	MP3	ZAPTA120200001007	168	196	364
4	A210505COEC	WP3.5_4	PIAGGIO	MP3	ZAPTA10W3K5000163	168	197	365

Table 2. Vehicle specifications for each of the four tests

The pre-crash pictures showing the vehicle configuration for all four crash tests may be found in Figure 4.

Test 1

Test 2

Test 3

Test 4

Figure 4. Images showing the vehicle configuration before each test

- Test 1: Without fuel and all other liquids, without chain, with dummy, with instrumentation, data acquisition system located in Top Case and with two lateral knee airbag modules mounted on the right side of the vehicle.
- Test 2: Without fuel and all other liquids, without chain, with dummy, with instrumentation and data acquisition system located in Top Case.
- Test 3: Without fuel and all other liquids, without chain, with dummy, with instrumentation, data acquisition system located in the Helmet box under the saddle and with safety leg cover mounted on the frontal part of the vehicle.
- Test 4: Without fuel and all other liquids, without chain, with dummy, with instrumentation and data acquisition system located in the Helmet box under the saddle.

Vehicle instrumentation

The tested motorcycles were instrumented with triaxial accelerometer sensors in order to obtain information for the post-crash in-depth analysis. Table 3 summarizes the vehicle instrumentation that was included in both tests.

		DUCATI		PIAGGIO	
	Magnitude	Direction	Channels	Direction	Channels
Frame attachment rear dumper	Acceleration	X, Y, Z	3	X, Y, Z	3
Frame under saddle	Acceleration	X, Y, Z	3	X, Y, Z	3
Frame left side of footrest	Acceleration	X, Y, Z	3	X, Y, Z	3
Steering head middle	Acceleration	X, Y, Z	3	X, Y, Z	3
Front right suspension up	Acceleration	-	-	X, Y, Z	3
	Total		12		15

Table 3. Vehicle instrumentation for both vehicles DUCATI and PIAGGIO

Dummy instrumentation

The dummy was composed of HIII 50th percentile male dummy head, neck, torso, and arms and Motorcycle Anthropomorphic Test Device (MATD) abdomen, pelvis and legs with the instrumentation found in Table 4:

Sensor location		Magnitude	Dir.	Channels
Head		Acceleration	X, Y, Z	3
		Angular Velocity	X, Y, Z	3
Neck Upper		Force	X, Y, Z	3
		Moment	X, Y, Z	3
Chest		Acceleration	X, Y, Z	3
		Deflection	X	1
		Angular Velocity	X, Y, Z	3
Lumbar Spine		Force	X, Y, Z	3
		Moment	X, Y, Z	3
Femur	Left Upper	Force	Z	1
		Moment	X, Y, Z	3
	Right Upper	Force	Z	1
		Moment	X, Y, Z	3
			Total	**33**

Table 4. Dummy instrumentation for all the tests executed

Dummy positioning

The dummy was positioned according to D3.1 (1) in order to reproduce as much as possible, the natural human riding position for 50% male rider's dummy. In addition, in order to stabilize the dummy torso, a foam block was used to support the dummy and avoid him leaning backwards when the motorcycle movement was initiated. An example of the position of this block in the PIAGGIO tests may be found below in Figure 5. This was also done in the DUCATI tests where the foam block rested against the top case.

Figure 5. Foam block used to increase stability during the crash

Camera locations and views

At least 6 high-speed cameras that work at a sampling rate of 1000 fps must be used to record the test, filming from -15 ms to +1500 ms, including 1 real time film recorded with a normal or GoPro type camera.

Test tool, ATD

Vehicle sled

For vehicle propulsion and guidance, a special adaptable sled has been designed and manufactured by IDIADA. It is a modular tool that allows to fit different types and sizes of motorcycle to be impacted in a full-vehicle crash test. The vehicle sled can be adjusted to different motorcycle tyre widths and number of wheels.

The main goal is to control the forward movement of the motorcycle and ensuring the stability of the vehicle at every moment, especially at the crash moment.

The rear support of the sled is used to maintain the correct inclination of the motorcycle and to support the dummy to avoid the unwanted lateral movements. System of rollers has been developed in order to maintain the rolling of the wheels during the pre-crash acceleration.

The sled test setup designed within this project enables any type of motorbikes to be tested. As can be seen on Figure 6, the sled test can perform a test with a motorbike with one or two front wheels. The vehicle sled has two plates on the rear side that will impact to a couple of aluminium tubes installed in the crash area. This will allow the vehicle sled to gradually brake while releasing the motorbike at the desired speed to be impacted by the barrier.

Figure 6. Images of the vehicle sled fitting the two types of motorcycle before the test

Simulation environment

Virtual simulations of full-vehicle crash tests were performed for both on-board safety systems (DUCATI on-board side airbag and PIAGGIO safety leg cover).

First, a simulation environment was set up with FE models and impact conditions aimed to reproduce the test conditions. The complete simulation environment can be seen in Figure 7.

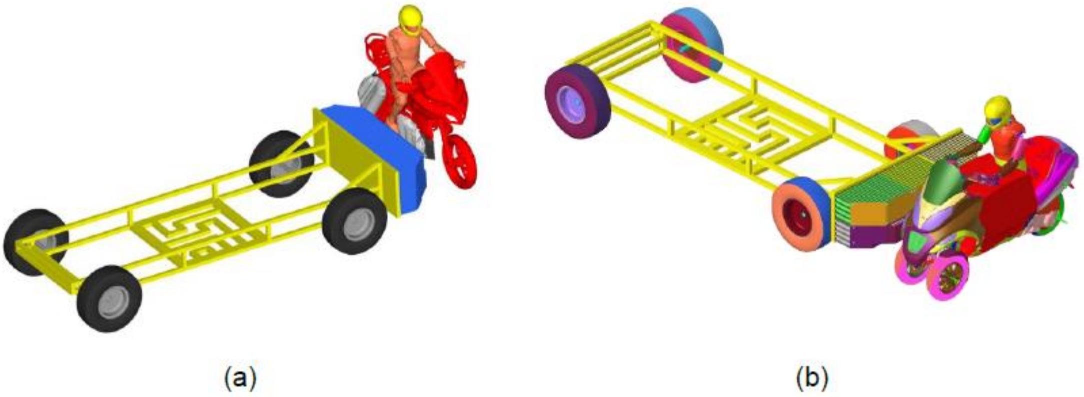


Figure 7. Full simulation environment for the airbags on Ducati Multistrada (a) and safety leg cover on Piaggio MP3 (B)

The simulation environment consist of finite element models of:

1. The main vehicle models used in the finite element simulation activities of Task 5.4 “Lateral Impact Mitigation” equipped with on-board safety systems
2. Test dummy (Figure 8).
3. Deformable barrier

Virtual sensors were created at the same locations, where IDIADA installed the sensors for the experimental tests, and the same orientation was implemented.

1. Main vehicle models

The motorcycle was modelled as a rigid body, as in the development phase of the airbags the primary concern was on leg protection and avoidance of its crushing between the car and the motorcycle. Since the motorcycle components that interact with the leg are much stiffer than the leg itself, the rigid body approximation was acceptable.

The simulation environment has two limitations which need consideration for a proper interpretation of the results: The rigid body approximation allows to have a correct representation of the inertia matrix of the vehicle, but the disadvantage is that front and rear suspensions are rigid (1st limitation) and the steering degree of freedom of the handlebar is suppressed (2nd limitation). The latter approximations may influence the kinematics of the motorcycle.

1a. Motorcycle with on-board side airbag

As shown in Figure 8, a Ducati Multistrada FE model was used, with a Hybrid III 50th percentile adult male dummy sitting on it.

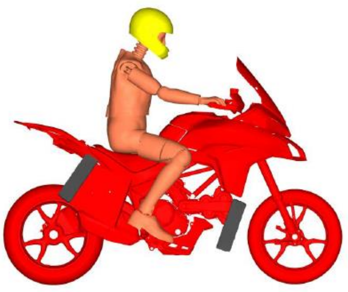


Figure 8. FE model of the Ducati Multistrada, with sitting Hybrid III and airbags (grey boxes)

The environment was complemented by FE models developed by ZF, i.e., two airbags of the same type and model (Figure 9 and Figure 10) and the Advanced European Movable Deformable Barrier (AE-MDB), Version 1.0 specification, released on 26.02.2013.

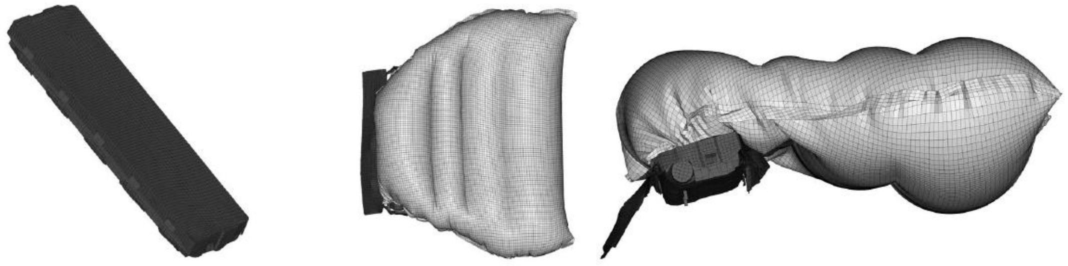


Figure 9 (left). FE model of the airbag in closed configuration; Figure 10 (right). FE model of airbag in open configuration (overhead view – left – and lateral view – right)

Since it was not possible to produce prototypes of the airbags developed in Task 5.4 the tests were performed using two knee airbags, designed for car applications. The airbags and their finite element models were provided by ZF to Ducati, and the models were integrated by UNIFI in the virtual environment on the basis of information provided by Ducati and IDIADA

1b. Scooter with safety leg cover

In Figure 10, the Piaggio MP3 500 FE model is shown, with Hybrid III dummy. Vehicle FE model is equipped with the final version of the safety leg cover which was designed and developed in Task 5.4 (Figure 11).

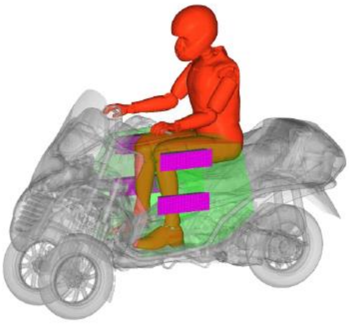


Figure 10. FE model of the MP3 scooter, with sitting Hybrid III and safety leg cover

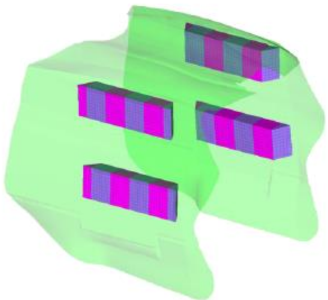


Figure 11. FE model of the safety leg cover: foam blocks of the protecting bars highlighted in alternated colours

2. Test dummy
Hybrid III dummy was selected for the simulations since there was no numerical finite element model of the MATD (7). As MATD has frangible bones (femur and tibia) and in literature (8) it is reported that different rider kinematics was observed after a bone fracture (bone fractures affect the rider's kinematics), the analysis of results has to factor these previous findings.

3. Deformable barrier
A model of the Advanced European Movable Deformable Barrier (AE-MDB) Version 1.0 specification, released on 26.02.2013 was used in the simulations.

TEST RESULTS

Actual vs. target test conditions

The four crash tests were successful from a testing point of view. The vehicle and barrier speeds were inside the target tolerance (specified based on IDIADA's testing experience) in all cases, as shown in Table 5.

	Test number		Vehicle speed (km/h)		Barrier speed (km/h)		Lab condition		
Test	IDIADA	Customer	Target	Actual	Target	Actual	Temperature (°C)	Humidity (%)	Pressure (mBar)
1	A210409COEC	WP3.5_1	30 (+/- 1)	29,68	30 (+/- 1)	29,68	21,3	48	1005
2	A210410COEC	WP3.5_2	30 (+/- 1)	29,8	30 (+/- 1)	29,8	19	70	1005
3	A210415COEC	WP3.5_3	30 (+/- 1)	30,63	15 (+/- 1)	15,31	21	47	1001
4	A210505COEC	WP3.5_4	30 (+/- 1)	30,4	15 (+/- 1)	15,18	20,3	42	1000

Table 5. Target and actual vehicle and barrier speeds and lab conditions during test

Main test findings

Overall, the crash tests were successful from a test execution point of view and were useful to confirm the behaviour predicted by means of virtual simulations. This made the tests themselves comparable and repeatable.
The test results from the DUCATI crash tests conducted led to believe that the use of on-board motorcycle lateral airbags has a potential to improve rider safety in the event of a motorcycle being impacted laterally by a passenger vehicle.

It has been seen that the overall deformation of the AE-MDB deformable barrier (representing the passenger vehicle's front-end) is significantly reduced when the lateral airbags are used. Thus, the airbags have a cushioning effect, acting as energy absorbers between the passenger vehicle and the motorcycle, reducing the severity of the impact and delaying the barrier response. On the other hand, a slight reduction in injury measurements from the dummy sensors has also been found, together with a significant reduction in the dummy's excursion/free flight after the impact (Figure 12).

In the specific case of the PIAGGIO tests, the vehicle kinematic differences were significantly affected by the usual uncontrolled degrees of freedom of motorcycles (at least roll and steering). These kinematic differences are completely independent of the use (or lack thereof) of the safety leg cover. Therefore, no considerations about the post-crash motion of the rider and its related consequences from an injury perspective can be clearly drawn.
The Piaggio's range of speed is considered to be more urban (lower speed) and therefore a suitable on-board safety system, lower leg cover, was chosen (Figure 13).

The use of the safety leg cover did not show any significant changes (neither positive nor negative) of the leg extremity results (both from an injury metrics perspective and from a frangible bone fracture perspective); as the leg sensor response was similar between tests and the frangible tibias and femurs did not break in any of the two tests. [13]

Figure 12. Post-crash, DUCATI with airbags

Figure 13. Post-crash, PIAGGIO with leg cover

Virtual simulations results

The airbag test renderings were performed at 32 / 74 / 112 / 152ms to align with the comparison of both tests. The limited size of the airbags doesn't influence massively the kinematic compared to the crash without the protection system. In the latter configuration, at 112 ms, the dummy is separating from the motorcycle and its movement is slightly anticipated compared to the configuration with the airbags.

The post-crash analysis of the barrier reveals that without airbags the leg of the dummy had a more direct impact with the barrier and the shape of the leg is visible in the deformed configuration. When the airbags were present, the barrier deformation was more uniform, and the load was partitioned between the airbags and the leg.

The leg cover test renderings were performed at 55 / 115 / 165 / 225ms to align with the comparison of both tests. The simulations without and with the safety leg cover were compared to assess a possible influence of the cover on the rider kinematics. The comparison shows only minor differences between the two series: only at 225ms in the simulation with the leg cover, the rider is closer to the scooter, as a result of an interaction of its movements with the leg cover. In the safety leg cover simulations the AE-MDB performed differently, and the speed reduction was higher in the configuration with the leg cover installed. The dummy response is very close in the two simulations until approximately 100 ms. Onwards there are differences in the load of the right leg (impact side) and the simulation with the leg cover shows lower load. The femur axial force of the left leg shows differences after 225 ms. Head and chest acceleration are similar, while higher rotation rate is reported in the configuration without leg cover after approximately 115 ms.

Conclusions on the experimental vs. virtual test comparison

The virtual environment has proved the capability to capture the main trends of the interaction of the barrier with the motorcycles (the curves of the COG acceleration and velocity are close). Also, the motorcycle acceleration at the footrest is on satisfying agreement between experimental and simulated data. The dummy sensor data at the legs show that there is agreement between simulations and experiments only in the initial part of the acquisitions. The main hypothesis is that differences amplify after the rupture of the tibia. The tilting movement during the experimental tests influenced the kinematics of the dummy and thus the comparison of the experimental and simulation activities. The dummy head and chest kinematics are in line with the respective video analysis, thus the hypothesis of a satisfactory agreement between experimental and simulated kinematics, in case of equal tilting, seems plausible but needs further verification. Such tests could further validate that Hybrid III dummy is appropriate to reproduce the rider kinematics if there are no bone fractures.

The results confirm the potential of the virtual environment as design tool for the lateral airbags, but the following improvements are necessary to have a better correlation with the experimental data:

1. Refinement of the motorcycle model, introducing at least the steering degree of freedom,
2. Development of a model of the lower limbs, reproducing the characteristics of the MATD.

Figure 14. Impact with airbags: front view at 74ms

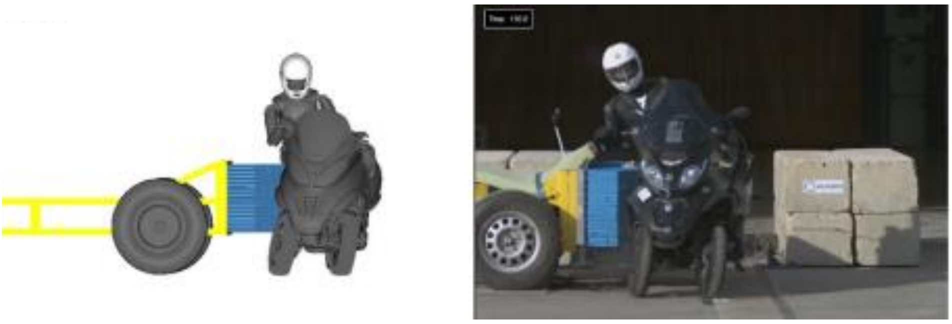


Figure 15. Impact with leg protector: front view at 115 ms

LIMITATIONS

There were some limitations encountered when preparing and conducting the tests:

- There was no tracking of the dummies in the physical tests as it was not in the scope of the PIONEERS project.
- Only 4 tests were conducted. More motorcycles and barriers would have been needed to perform extra tests in order to obtain more precise results.
- Dummy combination of HIII and MATD: Unfortunately, due to the MATD's lower leg characteristics, it was not possible to assess the exact level of injury suffered in the tibias as the tibia load cells were not compatible with the use of the frangible bones. Because, of this, further research would be required in order to be able to quantify this injury and fully evaluate the potential of the on-board side airbag implementation in the DUCATI Multistrada.
- No instrumentation of the tibias: For the same reason as before, the tibias on the Ducati tests had no instrumentation.
- As explained earlier, the airbags were already inflated due to the problems / delays due to COVID. The used airbags were knee airbags, adapted to the tests.

CONCLUSIONS

This document describes the procedures and environment for the tests carried out within the PIONEERS project. The goal of the tests was validation and evaluation of two protective innovations of new equipment for enhanced rider safety. Those systems consisted of a leg cover and a lateral airbag, as countermeasures proposed in case of lateral impact.

In order to execute those tests a new test method was developed using an AE-MDB deformable barrier used for lateral impact passenger car evaluation. Indeed, motorcycles do not have a safety regulation that covers crash tests and are not as extensively tested as other types of motorized vehicles under those conditions. Therefore, this new test method consists of a series of physical full-vehicle crash tests that were conducted and also reproduced in simulation environment by means of detailed FE models of the vehicles.

The full-vehicle crash test results were used to validate virtual simulations and to confirm them as a reliable design tool; moreover, they served to study the feasibility of passive safety devices for lateral impact mitigation. While there were certain limitations due to the context, those tests were executed, and the results proved the validity of the test method proposed.

ACKNOWLEDGEMENTS

The authors would like to thank the European Commission for funding the PIONEERS project and therefore the development of these new side crash test protocols for PTW, through Horizon 2020 research and innovation programme under Grant Agreement No. 769054.

REFERENCES

1. **Soriano, Enric, et al.** *Test procedures for PPE, helmet and full vehicle.* s.l.: PIONEERS D3.1, 2020.

2. *Characterizing the performance of a single-layer fabric system through a heat and mass transfer model – Part II: Thermal and evaporative resistances.* **Ding, Din, et al.** 2011, Vol. Textile Research Journal.

3. *Glass Transition Temperature of Nylon 6***. Forster, Michael. 38-5,** 1968, Vol. Textile Research Journal.

4. *The Glass Transition of Nylon 6***. Greco, L. et al.** 1976, Vols. Macromolecules 9-4.

5. *Effect of Splitting on the Tensile Strength of Leather.* **Wilson, John Arthur et al.** 1926, Vol. Ind. Eng. Chem.

6. *Behavior of leather as a protective heat barrier and fire-resistant material.* **Bacardit, Anna et al.** 105-2, 2010, Vol. Journal of the American Leather Chemists Association.

7. **Maffè, Francesco, et al.** *Demonstrators of lateral impact mitigation system. D5.3 PIONEERS. 2020.*

8. *A Standardized Motorcyclist Impact Dummy for Protective Device Research.* **J.W. Zellner, K.D. Wiley, N.L. Broen, J.A. Newman.** 1996. 15th International Technical Conference on the Enhanced Safety of Vehicle. Paper Number 96-S10-W-21.

9. **SAE International.** *Surface Vehicle Recommended Practice. (R) Instrumentation for Impact Test - Part 1 - Electronic Instrumentation*. 2014. SAE J211-1 /1_2014-03.

10. *Application of crash pulse on the car crashworthiness design.* **Tso-Liang Teng, Peng-Hsiang Chang, Cho-Chung Liang and Da-AnFung. s.l.: Journals Sage,** 2017, Vols. Advances in Mechanical Engineering. Vol. 9 (9) 1-8. DOI 10.1177/168781 4017700096.

11. **EuroNCAP.** *AE-MDB Specification, Technical Bulletin TB014. 2013.*

12. *Powered Two-Wheelers – Road Traffic Accident Scenarios and Common Injuries.* **Wisch, Marcus. Breunig, Sandra. et al.** *PIONEERS PROJECT D1.1,* 2019.

13. *Test results.* **Di Piazza, Simone. et al.** *PIONEERS PROJECT D3.3,* 2021.