Full Scale Motorcycle Crash and Fall Physical Simulations Using a Modular Launching Catapult

Nicola Petrone, Giuseppe Zullo, Alberto Foltran, Tommaso Morandin

Abstract The safety of powered two-wheeler users remains a global concern, with high rates of fatalities and injuries. To advance the development and accessibility of protective technologies like electronically activated airbags, this paper presents a modular, cost-effective catapult system for simulating full-scale crash and fall tests. Designed to launch vehicles up to 350 kg at speeds up to 50 km/h, the system utilizes bungee cords and modular aluminum lattice trusses to recreate various impact and fall scenarios. It supports crash simulations involving motorcycles, bicycles, and skiers, including frontal collisions, jump landings, and high or low side falls. The carriage mechanism accommodates rider dummies equipped with data acquisition systems to assess airbag trigger performance and injury metrics. The modularity, portability, and use of commercial components make the system adaptable for diverse testing needs without requiring permanent infrastructure. This setup facilitates more affordable testing, enabling broader industry participation in the development and validation of advanced safety technologies and supporting the extension of safety standards for electronically triggered airbags.

Keywords catapult, crash physical simulation, fall physical simulation, motorcycle.

I. INTRODUCTION

Safety of powered two-wheelers users is a serious concern around the world where the number of fatalities and severe injuries is alarming [1]. Demand for increased usage and availability of protective devices such as airbag technologies is challenging manufacturers and researchers: electronic activated airbags are expected to spread from power two-wheelers to bicycle users, from track to street and to off-road, as well as even to skiers. The functional evaluation of airbag technology requires performing crash and fall tests to quantify the time of activation associated to most risky situations such as crashes against vehicles or obstacles, high and low side falls and other conditions such as jumps or sand impacts in the case of off-road applications. Non-collision accidents count for about the 56% of single vehicle accidents [2], and lowside represents the most frequent, followed by highside and over-the-bar accidents. When collisions occur with fixed obstacles or vehicles, the most frequent posture is the upright posture and the thorax is the most injured region [3]. As recent experiences confirm [4], the significance and complexity of full scale tests justify the high cost per test, independently on the adoption of ATDs or PMHSs [5-6]. The possibility of performing full scale fall simulation tests rather than waiting for falls to happen in the track, as well as the potential of producing crash tests at sustainable costs will both facilitate the development of affordable airbag technologies and their diffusion. Aims of the present work are (i) to present a modular launching catapult suitable for full scale crash & fall tests on motorcycles up to 350 kg mass and 50 km/h speed, and (ii) to discuss the feasibility of full scale physical simulation of complex motorcycle crash and fall configurations.

II. METHODS

The catapult was designed to launch a two/three wheeled vehicle/rider assembly against fixed obstacles or safety barriers, as well as to reproduce different fall types. The catapult structure consists in two lattice trusses of 12m length (3 modules of 4m) suspended at the two extremities by two columns fixed on the ground, acting as guides for a carriage sliding over them and pushing the vehicle/dummy assembly during the acceleration phase. The carriage/vehicle acceleration is obtained by a couple of bungee cords pretensioned by means of winches to the desired value measured by load cells applied at the extremities. The carriage is equipped with beams contacting the motorcycle vehicle from the handlebar and the rear axle as well as supporting the rider with

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back/shoulder supports. The carriage release occurs via electromagnetic anchors actuated from remote: carriage braking is obtained by a set of climbing dynamic ropes connected to the rear fixed portion of the catapult. The different systems composing the catapult will be described in further detail in the following paragraphs.

Catapult guides

The catapult launching guides consists of two main lattice trusses of 12m length (8 m for bicycle and ski crashes) obtained by the combination of 3 (or 2 in the case of bicycle and ski) modules each of LITEC QX30SA400 connected in series. Lattice trusses have 300 mm side square section obtained by the welding of inclined tie-rod tubes to four main 50 mm diameter aluminum tubes and of two ending plates presenting housing for modular connection ogives and pins. The main beams axes are suspended at 0.866 m from the ground as they are connected via suitable T elements to two columns fixed on the ground by short elements and base plates. Additional cables reinforce the horizontal stability of the columns to the ground. Main guides support a carriage that has approximately a free movement of 11 m (7 m). The guides are open at the launching side to release the vehicle under testing and are connected by a transverse suitable lattice truss in the rear portion, where the preloading winch and the release magnets are fixed (Fig. 1).

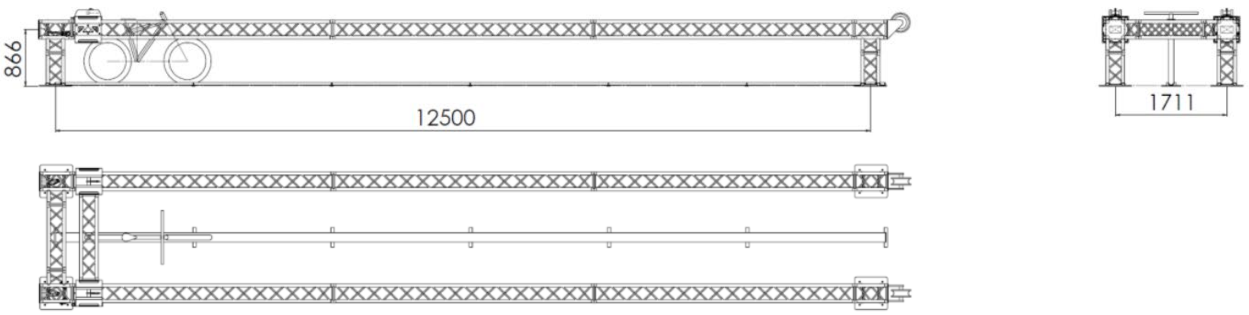

Fig. 1. The catapult overall structure and dimensions: two main lattice trusses suspended from the ground connect at the extremities with four columns and guide the free movement of the vehicle launching carriage.

Launching carriage and vehicle/dummy support system

The launching carriage is composed by two trolleys LITEC TLU30S compatible with guiding trusses, connected by a transverse cruciform truss element enabling the vehicle propulsion and support. Motorcycle and bicycle are riding on the ground on their own wheels: two beams are in contact with the motorcycle at the handlebar extremities and two more beams can push the rear wheel axle with ball socket unidirectional contact joints. A couple of beams can be adjusted to support the dummy rider at the armpit and to support his back as a backrest (Fig. 2). The total mass of the carriage can range from 50 kg in the lightest version (bicycle, ski) to 90 kg in the case of large motorcycle tests.

Fig. 2. The carriage launching and support system.

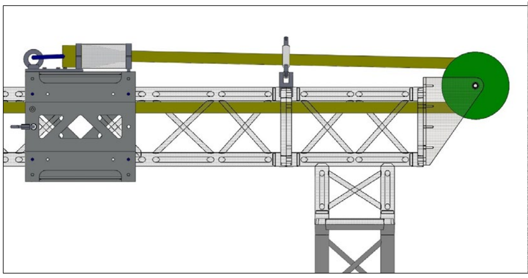

Fig. 3. The bungee acceleration cord around the front tip pulley.

Fig. 4. Bungee rear pretension winch and control load cell.

Carriage/vehicle acceleration system

After placing the vehicle and dummy in the carriage, with the bungee in released conditions, the carriage is pulled back to the rear portal transverse truss where it will be hold by electromagnetic anchors. The carriage can be accelerated by means of two bungee cords of 7.5 m (5.0 m for bicycle) that are connected on the top of each carriage side, run across two large pulleys applied at the front extremities of the guide trusses and return towards the back of the catapult to the preloading system, inside the guide trusses (Fig. 3). The two bungee cords can be pretensioned by means of two independent winches that can pretension the cords to the desired value measured by load cells applied at the posterior extremity of the guide trusses (Fig. 4). Repeatability of the setup depends on bungee elements preloading and energy release. The motorcycle/dummy launching speed is tuned by controlling the load cells connected to the preloading winch. A proprietary tuning algorithm has been developed to predict the preloading force given the target exit speed, the overall mass of the carriage+vehicle+dummy mass, and the available acceleration distance. Variability of repeated tests at a given preset launching speed resulted to be not larger than 5%, as worst case, depending on the adoption af motorcycles not always identical.

Accelerations applied to the carriage/vehicle/dummy assembly depend on the target exit speed and the available acceleration distance, namely 11 m in the case of long catapult or 7 m in the case of short catapult. In such a short speeding up distance, longitudinal acceleration can reach considerably high values, such as 8-9 g. The launching acceleration are verified with the manufacturer of the device under testing, to exclude any risk of undesired activation during the launching phase.

Carriage Release & stopping system

The carriage launch can occur after the carriage has been equipped with the vehicle and the dummy in safe unloaded conditions: a central recall winch can bring the carriage/vehicle complex in contact with the rear transverse truss where two electromagnetic anchors can be activated (Fig. 5) to sustain the carriage until the bungee are preloaded at the desired value. Remote control of the preloading winch and of a recall latch ensure the execution of the launch in safe conditions for the operators. From a remote bench control unit, once the desired preload is reached the anchors can be deactivated and the carriage is instantaneously released for the acceleration phase. The carriage is stopped 1 m before the end of the guide truss by the intervention of a set dynamic climbing ropes, of known stiffness and suitable length, connecting the back of the catapult to each carriage lower side (Fig.6). Stopping ropes ensure a smooth release of the vehicle/dummy assembly: after about ten launches ropes need to be substituted due to the permanent stretch that can be accumulated.

Fig. 5. Catapult rear beam with central recall winch and two electromagnetic anchors.

Fig. 6. Catapult ready for the high side fall simulation launch: motorcycle/dummy on the carriage, bungee pretensioned, stopping ropes connected.

Crash simulation tests

The Catapult design allows launching several combinations of vehicle/dummy total mass and exit speeds. With the 12 m setup and longest bungee, mass-speed combination may range from 90 kg at 100 km/h (a skier) to 350 kg at 75 km/h (large motorcycle + 50th percentile male dummy) (Fig. 7). The crashes that can be simulated are moving motorcycle with seated or standing rider against a rigid obstacle, a car/van at different impact locations (Fig.6-9), a pothole or low height obstacle, and a sand pile. The introduction of a ramp allows also the simulation of jump landing crashes on sand piles (Fig. 8). Intervention time is evaluated from the wheel first contact t0 (fork accelerometer) to the trigger activation instant t1, obtained by an airbag output signal connected to a DTS SLICEnano datalogger.

Fig. 7. Catapult ready for a launch: motorcycle/dummy on the carriage, upright posture, bungee pretensioned.

Fig. 8. Setup for jump landing crash simulations with ramp and landing sand pile.

Fall simulation tests

In addition to crash tests, high side and low side falls simulation methods were developed. High side and Low side falls are reproduced by the appropriate introduction of wheels stopping elements or handlebar destabilizing cables, with fall kinematics that are compared with available track recoded falls data.

High side falls are obtained by launching the motorcycles in a yawed configuration (Fig. 6 & Fig. 9): after the motorcycle release, a set of cables produces a sudden stop of front and rear wheels, releasing a pre-compressed rear damper and ejecting the rider from the saddle. Low side falls are obtained by inducing a sudden steering of the front wheel on a slippery surface (Fig. 10), causing the rider fall at the same side of the motorcycle fall.

For the evaluation of high side and low side physical simulations feasibility, video of racing track high side falls and low side falls were collected by airbag manufacturers that kindly shared also the kinematic data coming from the sensor units embedded in the back protector. Three high side falls and three low side falls were analysed after realignment of sensor accelerometer and gyro meter data with the dummy trunk sensor reference system presented in Fig.11. Comparison between the track signal HS and LS falls data and simulated falls in the catapult were performed in terms of overall trend of the three acceleration components and their resultant values.

Fig. 9. High side fall launching setup.

Fig. 10. Low side fall destabilizing handlebar cable.

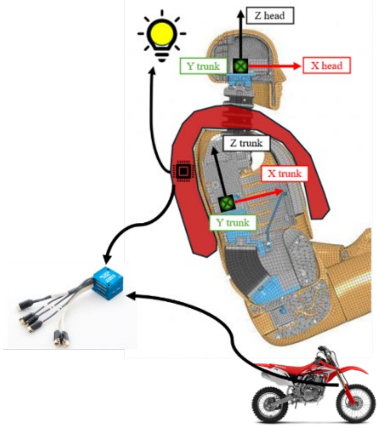

Fig. 11. Sensors and data logger setup

Sensors and data logging

In-dummy data logging solution was adopted in order to avoid umbilical cables in such complex crash and fall physical simulations. As well, data logger placed in the rear trunk were avoided to leave the motorcycle inertial properties unchanged. A DTS Slice nano data logging system is embedded in a Hybrid III ATD collecting data at 10 kHz per channel. The dummy is equipped with a DTS 6DX-PRO/A sensor at the head COM and a triad of DTS A64C and DTS ARS3 PRO at the trunk. The chest deflection sensor is also recorded. When the airbag trigger signal is available from the airbag control unit, the instant of activation (t1) is also collected synchronously with the dummy signals, as well as the fork accelerometer detecting the wheel impact (t0) and a saddle switch detecting the off-saddle instant (t0) for high side intervention time evaluation.

A set of high visibility flash leds is applied to the helmet or to the jacket shoulder in order to visualize also in high-speed video recording the instant of activation of the airbag. (Fig. 12)

III. RESULTS

Crash physical simulation tests results

The Catapult is successfully used to perform motorcycle crash tests, with speed ranging from 25 to 90 km/h, motorcycle ranging from motocross (130 kg mass) to fully equipped endure/touring (260 kg mass): obstacles range from cars to fixed block obstacles, deep holes and inclined curbstones. The catapult can launch motorcycles equipped with a H-III 50th percentile instrumented dummy against fixed barriers (Fig. 12), logs and sand piles (Fig. 13), as well as it can produce jump landing crashes on sand piles (Fig. 14).

Fig. 12. Front seated crash on a rigid obstacle


Fig. 13. Front standing crash on a sand pile obstacle.


Fig. 14. Jump landing crash on sand pile.

Examples of information that can be retrieved from such tests are reported in Fig. 15 and Fig. 16, respectively for a standing crash against a rigid block and of a landing crash from jump. Resultant acceleration at the head (blue), the trunk (red) and the front fork (yellow) are presented: following the terminology introduced in EN TC 162 WG9 groups for airbag standardization, the activation time period can be evaluated as time interval between the wheel contact instant t0 (orange) and the trigger activation instant t1 (black).

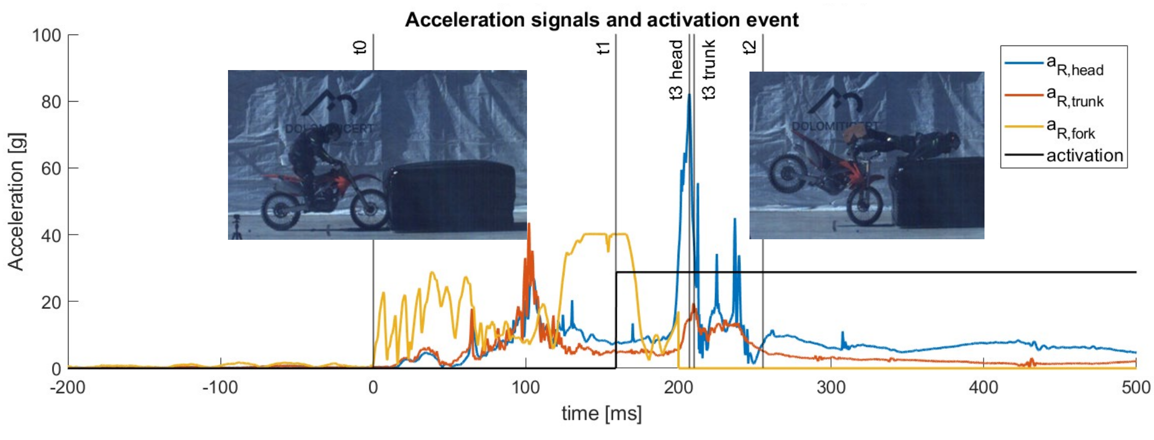

Fig. 15. Example of standing rider crash against a rigid block. Activation time period can be evaluated from the wheel contact t0 (orange) to the trigger activation instant t1 (black), connected to the DTS datalogger.

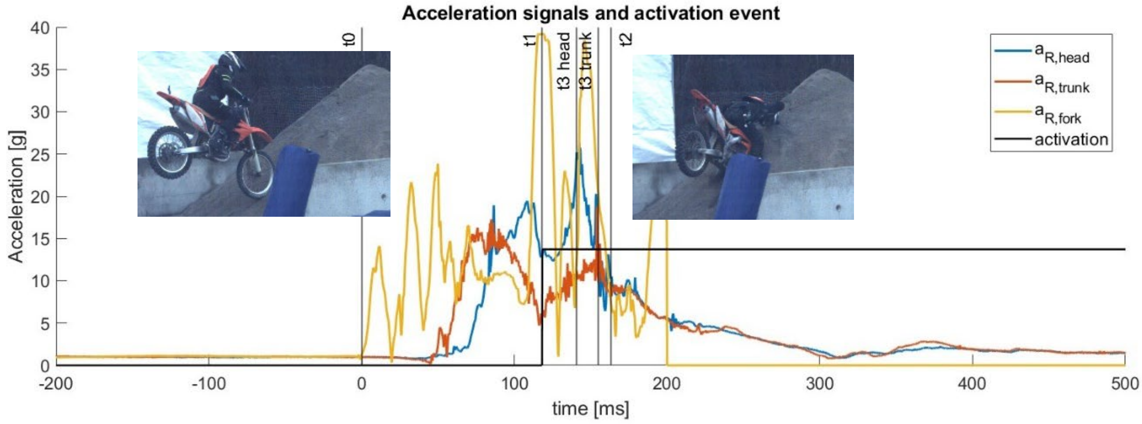

Fig. 16. Example of crash from jump landing test: after a jump of about 10 m flight against a sand pile, activation time period is evaluated from the wheel contact t0 (orange) to the trigger activation instant t1 (black), connected to the DTS datalogger.

Falls physical simulation tests results

The solution adopted for the simulation of high side and low side falls in the catapult allowed the collection of simulated falls that can be compared visually and quantitatively with the track available data. In Fig. 16 and 17 the stroboscopic sequence of frames obtained during respectively a high side and a low side simulated fall are reported.

Fig. 17. High side fall physical simulation test example, exit speed 50 km/h.

Fig. 18. Low side fall physical simulation test example, exit speed 48 km/h.

Having stated that all track falls are different in motorcycling, the comparison between track falls and catapult simulated falls can be achieved with attention to the three acceleration and gyro components of the dummy trunk signals during rider's loss of control, that is between the beginning of the event and the irreversible loss of control of the vehicle, leading to the possible airbag triggering and the unavoidable trunk with the ground. The signals recorded during the track high side fall TRACK 3 are reported in Figure 19, whereas signals recorded during catapult simulation CSIM 2 are reported in Figure 20.

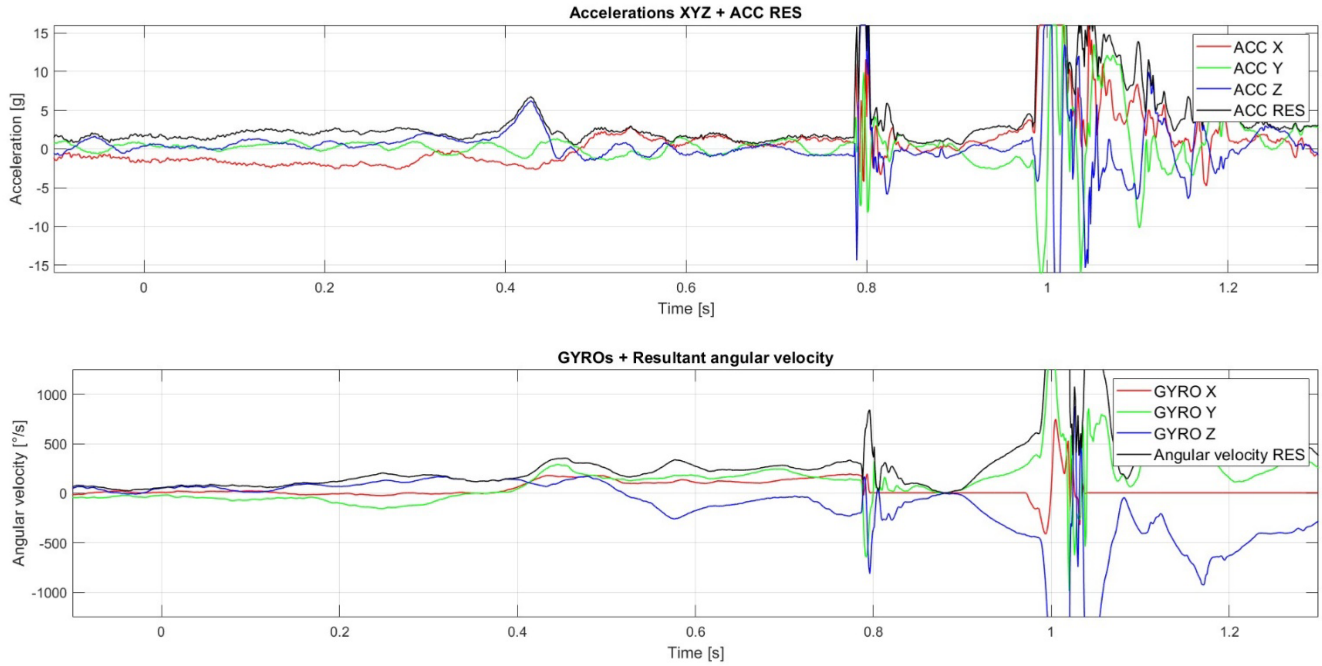

Fig. 19. Track recorded High side fall (HS Track 1) .

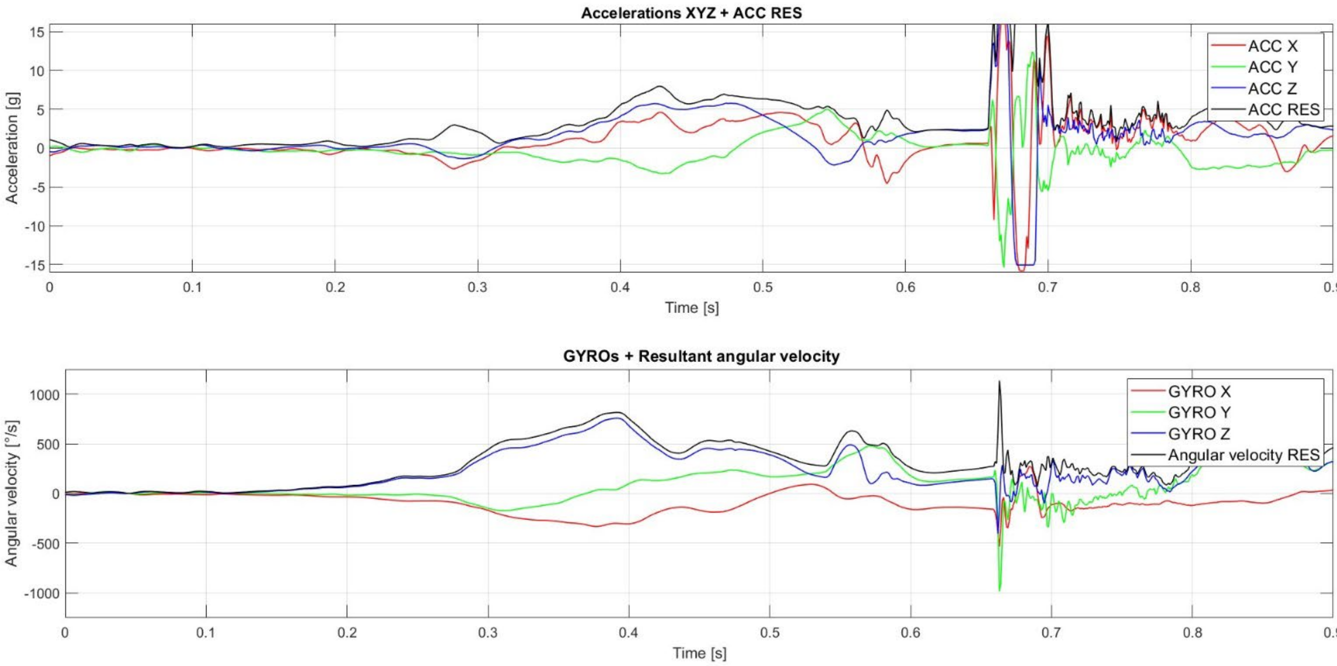

Fig. 20. High side fall physical simulation test example, exit speed 50 km/h. (HS_CSIM_2)

Attention payed to the combined cross plot of resultant values of acceleration (aRES) and angular velocity (ωRES) can support the validation of the adopted simulation methods with respect to real track falls in terms of intensity and movement combinations (Fig. 21). As it can be seen from these Figures, simulated HS tests named CSIM 1 and CSIM2 are overlapping with three track HS falls. From a risk management point of view, this means that an electronic airbag undergoing the simulated HS test like CSIM2 is subjected to representative kinematic conditions, therefore its activation performance is significant and expected. Similarly, simulated LS tests named CSIM 1 and CSIM2 are representative of the three track LS falls as they kinematic patterns are overlapping with two out of three LS track falls. LS Track 3 fall is challenging the classification between HS (high values of aRES and ωRES) and LS. In this case, LS Track 3 video analysis reveals that it is associated with a fall from an almost vertical vehicle orientation, rather than a fall from high leaning angle as LS Track 1 and 2.

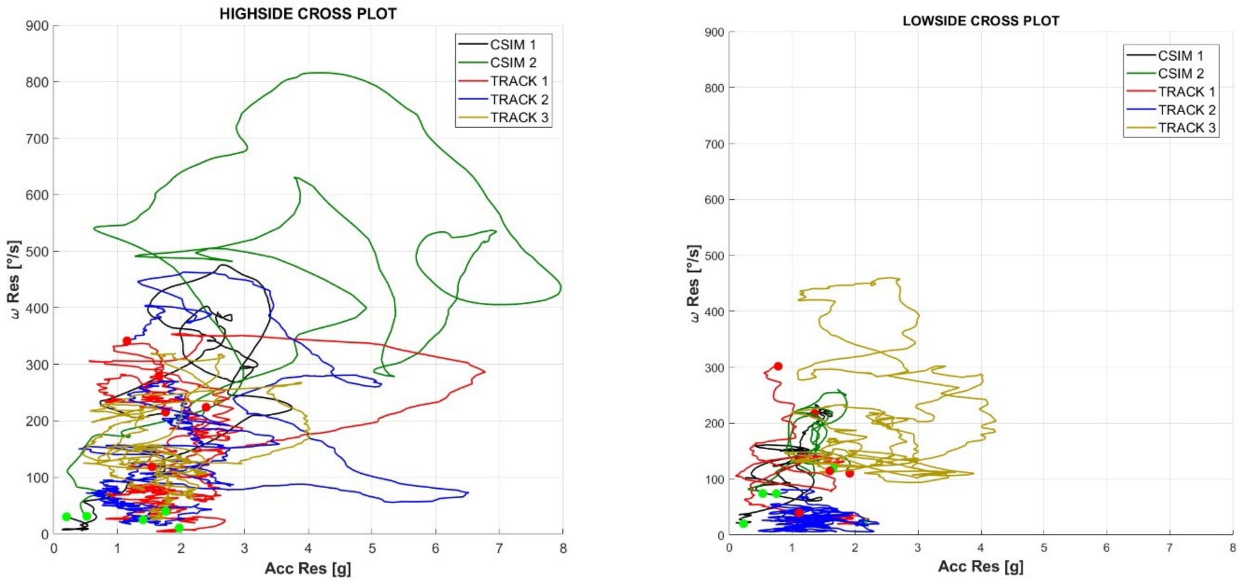

Fig. 21. Cross-plots of ω RES vs aRES, for High side falls (left) and low side fall (right), from Track and catapult simulated tests (CSIM). Patterns and peak values of the two kinematic resultants can be reproduced by the physical simulated test methods adopted.

IV. DISCUSSION

The first aim of the work was the presentation of the launching catapult developed for motorcycle crash and fall simulation tests. The presented Catapult is a modular system that can be used in indoor and outdoor scenarios for vehicles ranging from 90 kg (dummy skier) to 450 kg (heavy motorcycles+rider) mass: the adoption of commercial components and the absence of underground guiding or stopping elements allows the installation on any surface of sufficient area (15 m for the catapult installation and 25-30 m for the impact/fall area), reducing the construction and maintenance costs. Crash tests test of moving motorcycle against stationary car can be performed in established crash test centers, typically equipped for full scale car crash accidents, with launching cable running under the testing ground, carriages moved in speed control by large electric/hydraulic motors. The present system, due to the absence of foundation costs and the adoption of passive elastic system for acceleration reduces the construction, conduction and maintenance costs. Crash tests can be performed at comparably reduced costs, depending on deals among manufacturers and test lab. Additional positive features of the catapult are that it is modular, removable, adjustable, transferrable, and suitable for indoor tests. This favors the certification of electronically activated devices, therefore supporting manufacturers and customers towards the diffusion of airbag safety technologies".

Second aim was the analysis of the feasibility to reproduce complex kinematics of crash and fall accidents by means of simulated accidents. From the available data retrieved by airbag manufacturers involved in racing track data collection, the kinematic pattern reproduced by the catapult simulated high side and low side falls are comparable with the track available data. The Catapult is then, to our knowledge, an unique device that allows the experimental validation of triggering algorithms for protection against high side and low side falls, without the need of collection of hundreds of hours of racing track data collection, waiting for falls to happen. This allows manufacturers without long racing equipment experience to enter the market, again at affordable investments in terms of costs and development time.

These methods are supporting the extension of EN safety standards [8] to electronically activated airbag for street and possibly track use. The catapult has also been adapted to perform crash and fall tests on bicycles equipped with dummies and also on dummy skiers equipped with skis & boots: this confirms the setup flexibility and versatility of applications of the catapult.

V. CONCLUSIONS

The Catapult is a versatile flexible installation enabling the reproduction of crash and falls of motorcycle in realistic conditions without requiring permanent indoor or outdoor complex foundations and infrastructures, being modular, self-contained, adjustable and transferrable from one location to another. The system allows the simulation of complex fall mechanisms for the quantitative evaluation of electronic airbag trigger algorithms. This results extremely useful in the case when data from real street and track data may not yet be available in the early stages of a product development.

VI. ACKNOWLEDGEMENTS

Authors would like to thank all technicians in Certottica Scarl and Master Students involved in the crash and fall simulation tests. Acknowledgements also to Dainese and Alpinestars companies for sharing the track falls videos and sensor data.

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