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PRELIMINARY INVESTIGATION ON THE DYNAMICS OF MOTORCYCLE FALL BEHAVIOR: INFLUENCE OF A SIMPLE AIRBAG JACKET SYSTEM ON RIDER SAFETY

ABSTRACT

Airbag technology, predominantly developed for cars, is still in its first stages for motorcycles. Up to now, research has mainly followed the successful path already traced for cars, mainly focused on collisions between the vehicle and some obstruction. On the contrary, motorcyclists are more likely to experience falls due to front slippage, rear slippage or high-side phenomena, especially on tracks. The dynamic behavior of the motorcycle-rider system under different fall conditions is very complex, and the development of a rider protection safety system under such conditions is to be considered a challenge. It is necessary to identify an algorithm capable of predicting the fall, to test its robustness against misuse, and finally to design a proper airbag restraint for protecting the rider.

In this paper an exploratory study on the dynamics of motorcycle fall behavior is carried out. First, an example of data recorded during an actual fall due to wheel slippage is presented, and experimental data recorded for both rider and motorcycle are analyzed. Some other typical falls are then simulated using MADYMO and the dynamic behavior of the motorcycle and the rider are analyzed. Both experimental and simulated falls are used for testing a fall-predictive algorithm, which is still under development. In the end, the effect of a simple airbag system, fitted on the rider and triggered by the aforementioned algorithm, is simulated and its influence on rider safety is discussed.

1. INTRODUCTION

The challenge for motorcycle safety is beginning to chase new solutions for enhancing the passive safety. Recent studies [1] [2] demonstrates that motorcycle users are exposed to injuries, moreover solo accidents can account for about one quarter of the total cause of injuries and death; in particular in not build-up areas. A specific characteristic of motorcycle accidents is the prevalence and severity of cases in which the motorcycle is the only vehicle involved. These kind of events can account for more than one third of the total fatalities. It must be underlined that even when colliding with cars (which is the most common source for impacts), there is still 20% of all cases in which the impact happens after the motorcycle has already capsized. Moving the focus to injured body parts, the most frequent are: lower extremities, head and neck, torso and upper extremities. Even if lower extremities injuries are the most frequent, the severity is not always high, while head and thorax injuries in many cases can prove fatal. Efforts for enhancing the passive safety of the rider should, therefore, focus on augmenting the protection of the upper part of the body. Since most deadly or invalidating impacts happen at low speeds, it would still be possible to provide protection; but it is very difficult to reduce arm and upper torso injuries only with the limited protection offered by protective clothing. For that reason since 1973 there have been hints of airbag tests being carried out for motorcycles, but only recently have these systems started to appear and been implemented in real production vehicles. Up to now only TRL, DEKRA and Honda have realized airbag prototypes for motorcycles, and only the latter developed a commercial system on a large touring bike [3] [4] and is currently also developing a scooter system [5]. In trying to realize an airbag for motorcycles, the complexity involved in the two wheeled vehicle dynamics, arises, and augments the problem of the out of position airbag inflation, adding a great deal of complexity to an already difficult problem [5].

This paper proposes a different approach to improving motorcycle passive safety, no longer centered on the vehicle but on the rider. Changing the placement of the airbag from the vehicle to the rider could get rid of the unpredictability of the contact point of the rider with a fixed airbag, underlined by P. Rüker [6]. Being that the airbag is already “in position” inside the jacket, possible harms for improper firings of the bag should also be avoided, improving the risk/benefits factor.

For realizing a working system, different steps will be needed. The first step, is to identify a coming fall with a proper algorithm. Typical falls are low-side and high-side falls [7] [8]; in both cases, first the driver loses control of the vehicle, and then eventually hit a barrier, an obstacle or the ground. Activation time triggering is critical for inflating the airbag before a collision occurs. Robustness to misuse is also essential for avoiding unnecessary deployments. A second task is realizing an adequate airbag restraint system, able to protect the rider in different conditions. Bag dimension and inflation pressure must be chosen correctly. Finally it's necessary to evaluate the effectiveness in real conditions considering all the aspects together: it must deploy on time; it must be robust to misuse, and be able to reduce injuries to the rider. If it were to fulfill all these requirements, it would be possible to reduce damage from both primary (with the ground) and secondary (with other objects) impacts.

This article wants to focus on motorcycle fall and tilting movements, to better understand the first instants of a fall. In addition it attemps to offer some preliminary insight into the dimensioning of a proper airbag.

Dainese s.p.a. and the University of Padova are studying the fall behavior of motorcycles to realize a "fall predictive" algorithm, with the hope of providing a better degree of protection for motorcycle riders in the coming future.

2. RECORDED REAL FALL DATA ANALYSIS

In order to understand the behavior of the motorcycle and the rider during the fall events, some racing motorcycles were instrumented. Each motorcycle was equipped with an inertial platform (made up of 3 gyrometers and 3 extensimetric accelerometers), speed sensors on both wheels and linear potentiometers on the suspensions. The rider was also equipped with a full inertial platform (3 gyrometers, 3 accelerometers and GPS sensor). The hardware, realized by 2D GmbH, is very compact and light. The two units are completely stand-alone and may be easily installed on the rider hump and motorcycle tail, as shown in Fig. 1.

As an example of a low-side fall we may consider the one which occurred at the Jerez Circuit during a 2005 European Championship race. The rider, Robin Lasser of the team KTM junior 125, asserted that the tire lost grip and this caused the motorcycle to crash. Fortunately he suffered no injuries.

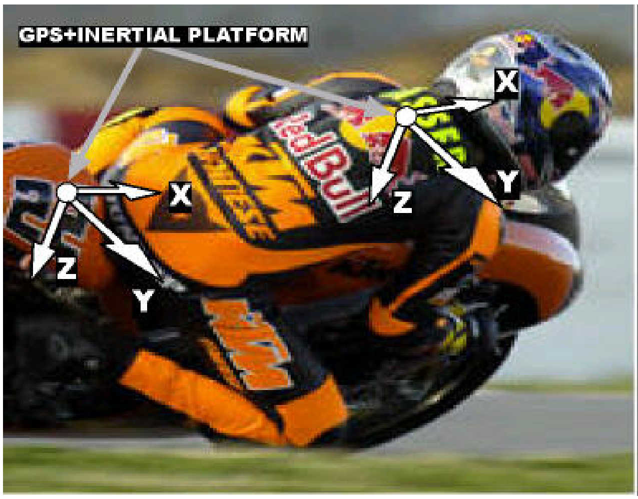


Fig. 1 - Location of measurement units on the motorcycle and rider.

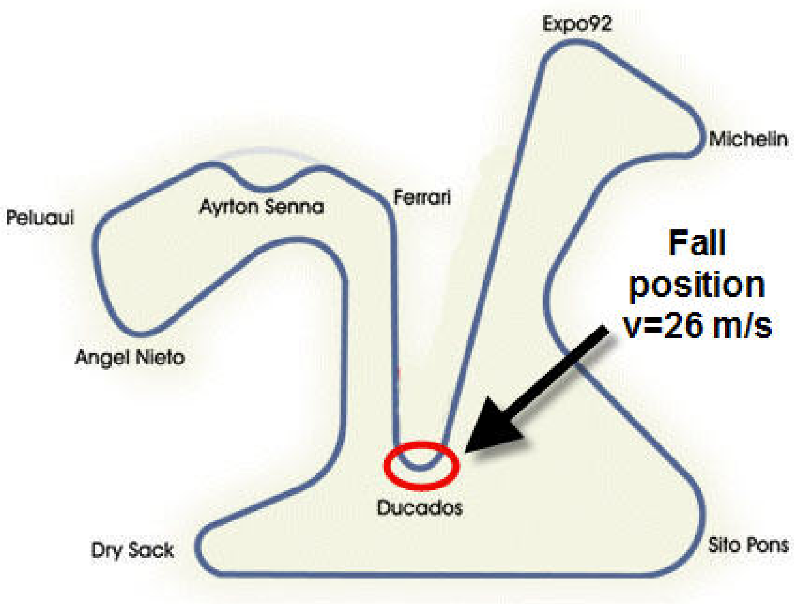


Fig. 2 - Fall position in Jerez circuit.

Fig. 3 shows the front wheel spin rate and the rider speed for the crash event: it is evident that the front wheel stopped after the fall, while the rider continued his forward movement. Unfortunately, the speed discrepancy is evident when the motorcycle has already fallen, i.e. too late for any preventive action.

In Fig. 4 and Fig. 5, accelerations and angular rates relative to the motorcycle and the rider are shown in the regular lap, compared with that measured in the crash lap. The time interval which elapsed between the fall start and the fall end is highlighted by the gray band. Fall start is assessed when signals of the normal lap and signal of the crash lap differ significantly. Fall end is assessed looking at the suspensions signals (not reported): when one of the wheel suspensions remains fully extended it means that the motorcycle has lost contact with the ground and can be considered fallen.

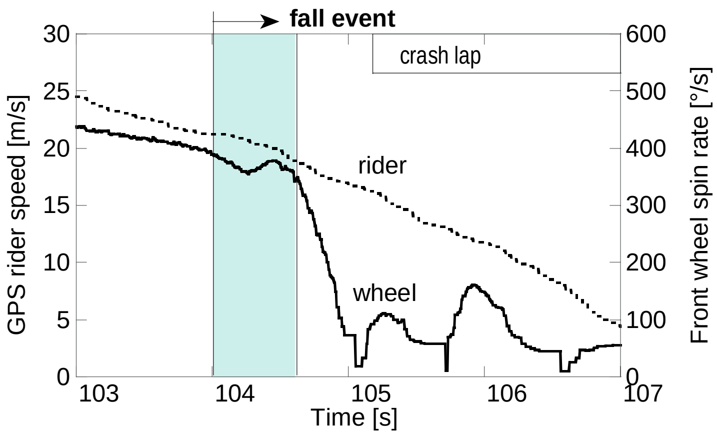


Fig. 3 - Recorded speeds of the rider and front wheel on crash.

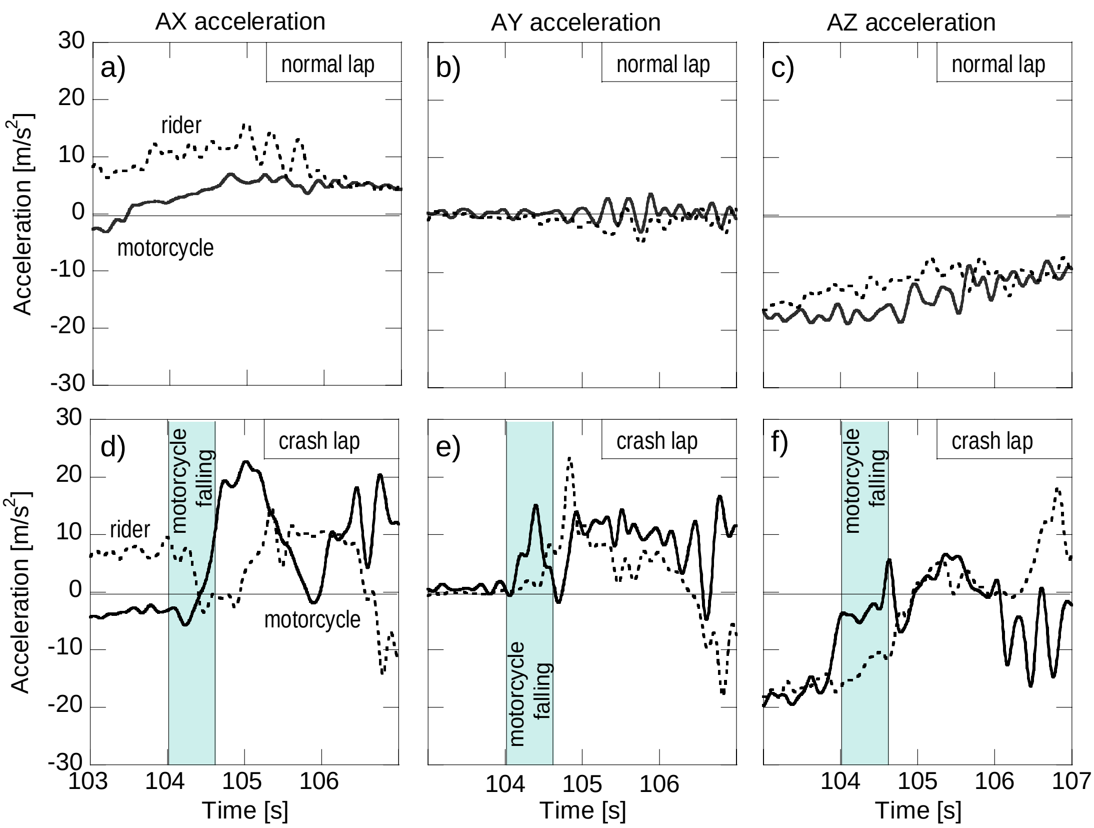


Fig. 4 - Accelerations of motorcycle and rider recorded during a normal and the crash lap.

Accelerations and rotations are expressed in the reference triad reported in Fig. 1 The accelerations of the rider and the motorcycle in Fig. 4d, 4e, 4f give additional information about the state of the system. Accelerometers are extensimetric, so they are sensitive to low frequency acceleration and in particular to gravity [9]. The AX acceleration of the rider (Fig. 4a, 4d) so does not start from zero because of the relative inclination of the rider measurement triad with respect to the motorcycle. The rider's hump is pointing upward with an angle of about 30° and registers contribution of the gravity. AX acceleration of the motorcycle (Fig. 4d) has a peak probably due to the rotation of the tail where the sensor is mounted, during the slippage of the rear tire. AX of the rider instead starts to decrease because of the tilting motion. Simultaneously AY acceleration of the bike (Fig. 4e) changes from nearly zero to 9.8m/s^2 of acceleration, as a result of the 90° tilting rotation of the motorcycle. AY of the rider also shows a peak after contact with ground occurs. The AZ accelerations of both motorcycle and rider, besides a peak, drop to a zero value in opposition to the -9.8m/s^2 value normally registered in straight motion.

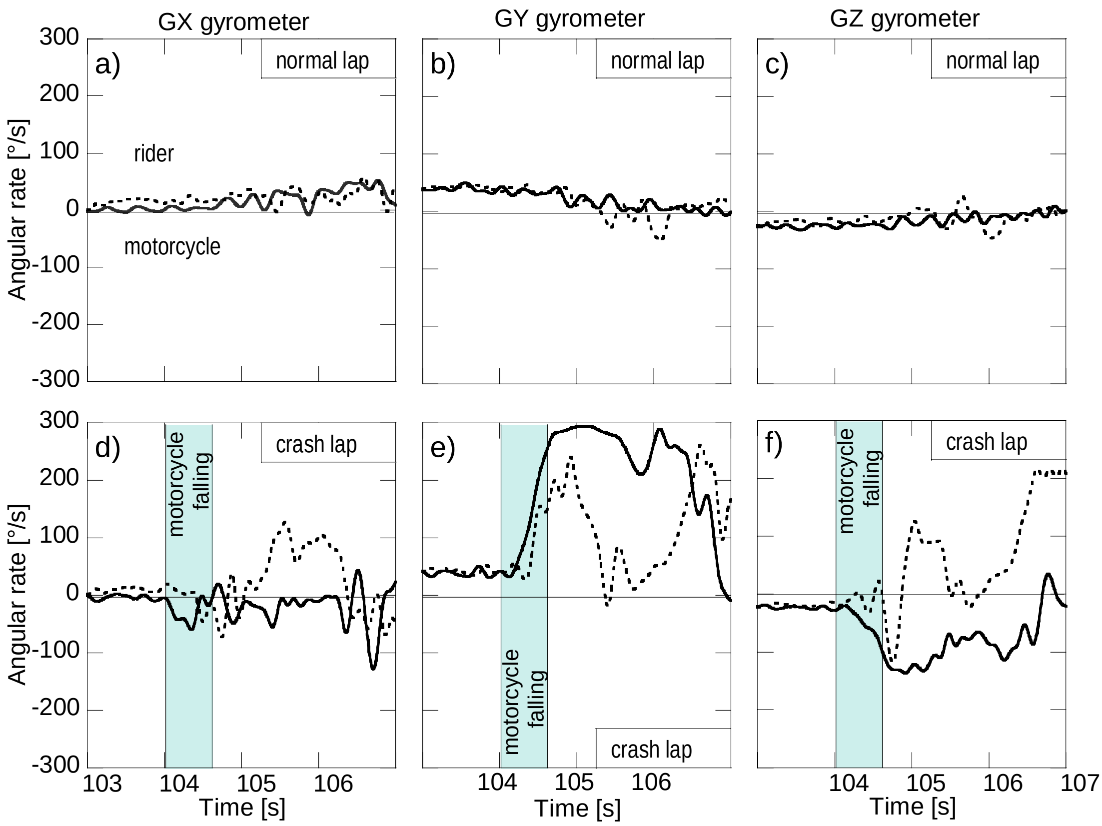


Fig. 5 - Angular rates of motorcycle and rider recorded during a normal and the crash lap.

Moving the attention to Fig. 5d, 5e, 5f gyrometer data recorded during regular driving does not particularly differ between motorcycle and rider. Looking at data recorded during the crash lap, it is clear instead that a critical event occurs to both the motorcycle and the rider. Indeed the pitch and yaw gyrometers during the fall, register angular rates which are much higher than those experienced during the previous race laps. For almost two seconds, angular rates GY and GZ exceed 180°/s leading, in about 2s, to almost a complete rotation of the motorcycle. The roll gyrometer signal absolute value, is not very high considering that the motorcycle tilting movement is mainly a roll movement. This suggests that the rider being in the center of a curve and with the kneepad touching the ground, in some way blocks the tilting motion of the motorcycle or at least delays it. In brief, the gyrometer analysis, suggests that the motorcycle in its left curve entering is violently over-steering, leading to a complete rotation of the motorcycle.

To better understand the meaning of the measurements presented, the following formula (which neglects the pitch motion) should be taken into consideration:

$$\dot{\psi}_{fix} = GZ \cdot \cos(\varphi) + GY \cdot \sin(\varphi)$$

This formula points out the relationship that connects the yaw gyrometer and the pitch gyrometer measurements of the motorcycle with an actual yaw motion in a SAE triad.

3. EXPERIMENTAL-SIMULATION DATA COMPARISON

Now that it has been possible to analyze what happens during a real fall, the following step could be that of trying to extend the analysis to other types of fall. To realize this, other experimental data are needed, but this is not particularly feasible because the main source of data are competitions. Driver style and rider maneuvers cause only certain types of fall events to be probable. Moreover experimental acquisition of fall events, inside or outside the race context, is seriously hazardous and definitely not easily realizable. For this reason, missing information could be obtained by simulating this and other types of falls using a multi-body code like MADYMO [10]. The advantage is the possibility of experimenting very different types of fall, extremely difficult and dangerous to be acquired experimentally. Building a realistic multi-body model of the motorcycle it also offers the possibility to simulate almost any dangerous condition, with a minimum computational effort.

Of course, it is very difficult to obtain a perfect match between experimental and simulated data, because many conditions necessary to develop the model cannot be obtained. The mass, inertia of the vehicle and rider parts, tire data and rider behavior [11] [12] [13], were all unknowns and have to be estimated. Also the slight repeatability of fall events makes it difficult to interpret the behavior of the motorcycle especially after ground collision. Road unevenness, different grip conditions, and road contacts, generate conditions that are not easily controllable. Nevertheless simulated measurements should not be too far from reality, and definitely useful for a basic interpretation.

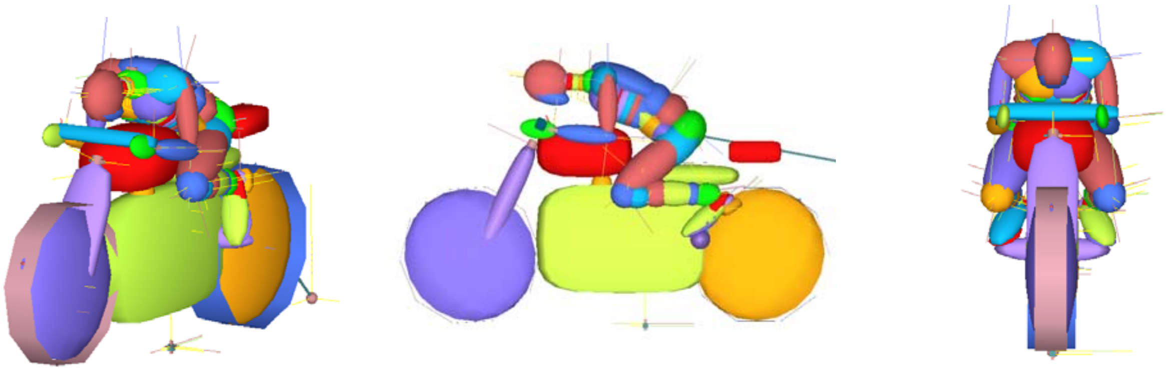


Fig. 6 - MADYMO model: rider and motorcycle.

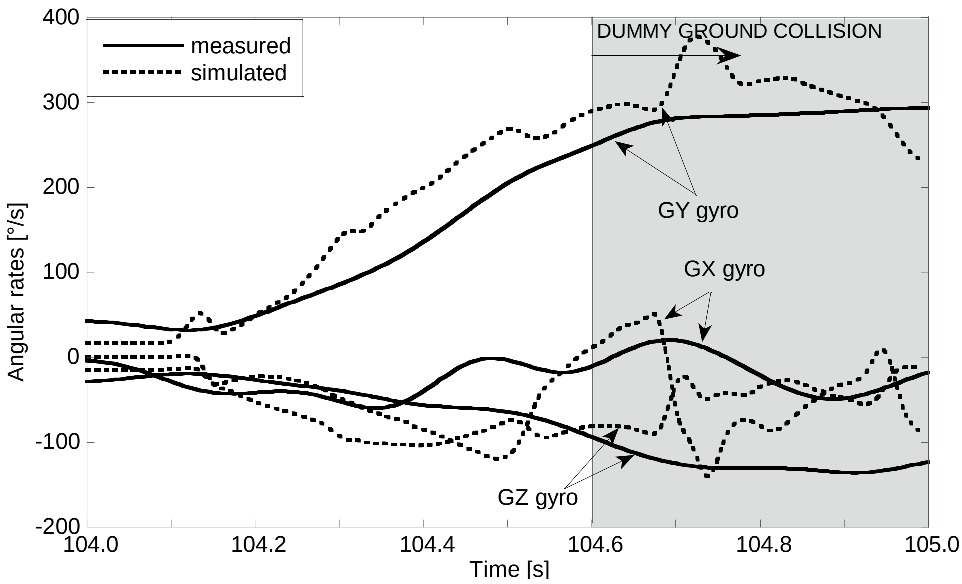


Fig. 7 - Comparison of real data with simulation during a fall event.

In Fig. 7, a preliminary simulation with MADYMO is reported. This case study simulates a motorcycle fall in conditions similar to the real case reported at the beginning of this paper. Of course, a perfect match between model and reality is far from being reached. Since our interest to prevent falling, the most important part for studying the dynamics of the fall, is the initial part, i.e. before contact with ground. In this phase the behavior of the motorcycle is still not influenced by ground contact, apart from the tires, and for this reason can be correctly understood.

4. DATA ANALYSIS OF FALL SIMULATIONS

In the following pages an additional three types of fall are simulated using MADYMO: a fall due to rear tire slippage, a fall due to the front tire slippage and a fall due to the highside phenomena. For all cases presented, three angular rates and three accelerations components of both the motorcycle and the rider are reported in the same way as they were recorded for the real case fall. For a quick reference, acceleration and gyrometers measurements will be referred as AX, AY, AZ and GX, GY, GZ. As for the real case the contribution of gravity to acceleration was taken into account by measuring accelerations.

4.1 SIMULATION OF A REAR LOW-SIDE FALL

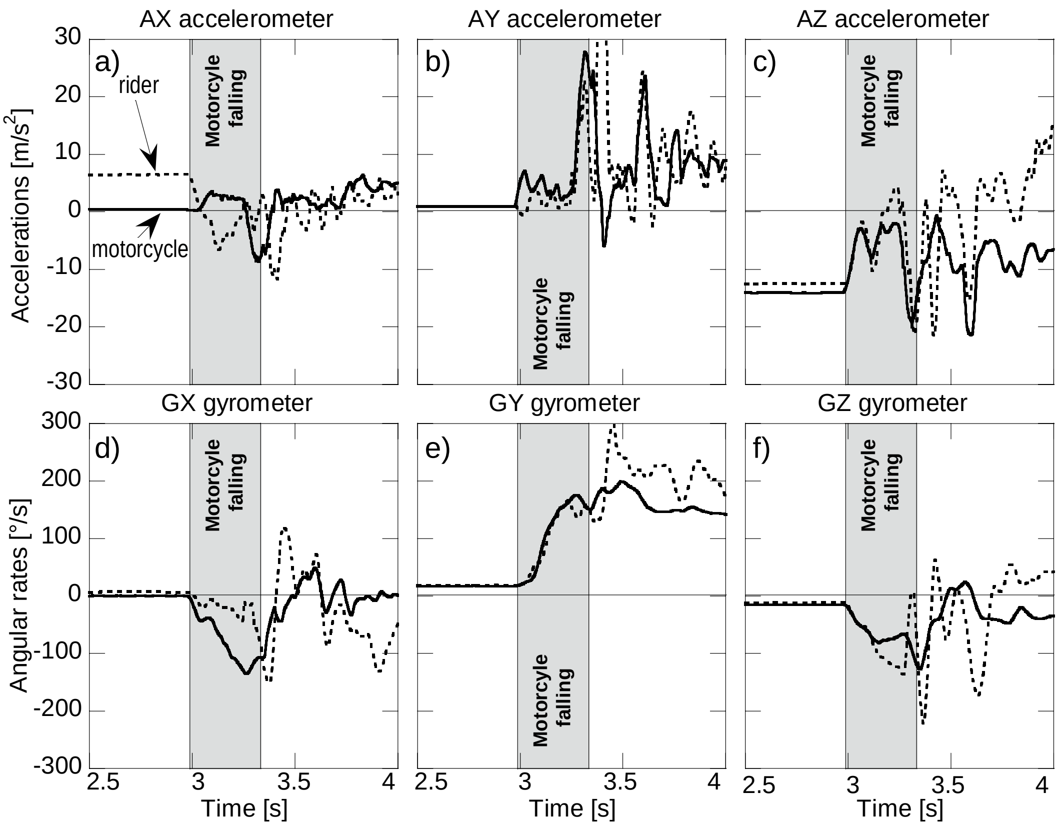


Fig. 8 - Accelerations and angular rates experienced by motorcycle and rider during a rear low-side fall.

The particular rear low-side presented in Fig. 8 starts when the vehicle is performing a counter clockwise curve at a speed of 26m/s and a roll inclination of about 50°. At time 3s the rear tire loses adherence. This is an extreme event and should be regarded as a worst case scenario for a rear low-side. The acceleration AX before the motorcycle fall starts from $0m/s^2$. The AX of the rider instead does not start from zero because of the relative inclination of the rider measurement triad with respect to the motorcycle. The rider's hump is pointing upward with an angle of about 30° and registers the contribution of gravity. Then acceleration AX of the rider towards the end of the fall movement starts to decrease, because of the tilting motion experienced by the rider. The sudden tilting movement of the motorcycle brings the rider down and because of the extreme lean angle he touches the ground with the knee. AY, for this reason shows lateral accelerations caused by contact of the rider's kneepad with the ground leading to values of up to $20m/s^2$. At the beginning acceleration AZ of both motorcycle and rider show the contribution of gravity but are also influenced by the centrifugal term due to the curve which moves its values up to $15m/s^2$. Then AZ accelerations besides oscillations due to ground contact change their value to zero within the fall interval because of the tilting movement. Moving the attention to the gyrometers, it is visible that rider and motorcycle values are quite aligned at least before contact with the ground. GX signals, after fall start, show high negative values attributable to the tilting motion that affects both motorcycle and rider. GY gyrometers of both motorcycle and rider show larger signal values with respect to GX. GZ values are lower, because of the high value of roll inclination of the motorcycle. Gyrometer values can all be explained with the main rotation experienced by the motorcycle about the yaw axis of the fixed triad $\dot{\psi}_{fix}$.

4.2 SIMULATION OF A FRONT LOW-SIDE FALL

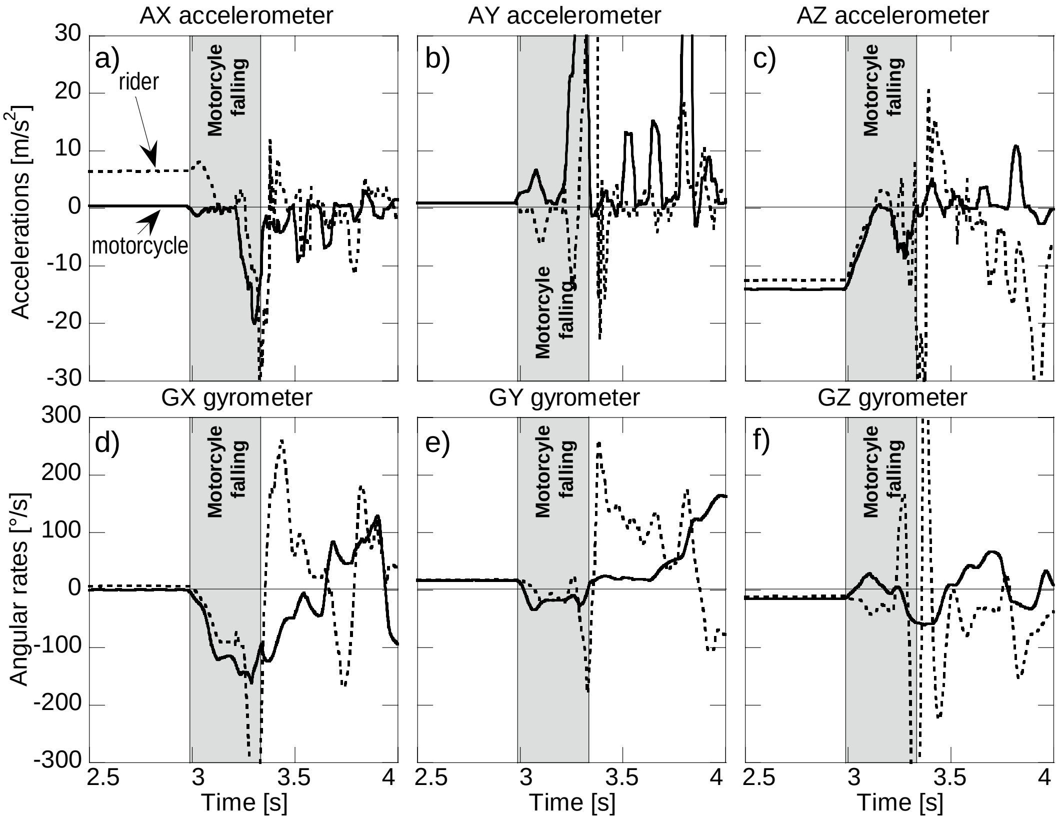


Fig. 9 - Accelerations and angular rates experienced by motorcycle and rider during a front low-side fall.

The front low-side presented in Fig. 9 starts when the vehicle is performing a counter clockwise curve at a speed of 26m/s and a roll inclination of about 50°. At time 3s the front tire loses adherence. This is an extreme event and should be regarded as a worst case scenario for a front low-side. In this case the fall is extremely rapid. In Fig. 9a, 9b, 9c for accelerations AX, AY and AZ of the rider and the motorcycle are valid the same considerations expressed in the preceding case. When the upper part of the dummy hits the terrain, the peak acceleration registered reaches 200m/s^2. It should be noted that accelerations are however difficult to interpret because even small contacts can generate significant measurements.

Gyrometer signals of the motorcycle and rider, instead, are similar, showing differences, only in the last parts of the fall. GX signals in Fig. 9d rapidly reach high values meaning that the motorcycle tilt movement is sudden. GY in Fig. 9e show small negative values, meaning that the rider closely follows the motorcycle in its pitch motion. This suggests that in this type of fall there is no sudden separation between rider and motorcycle, and that the parting happens only after contact with ground. Positive GZ values suggest an under-steering movement of the motorcycle.

4.3 SIMULATION OF A HIGH-SIDE FALL

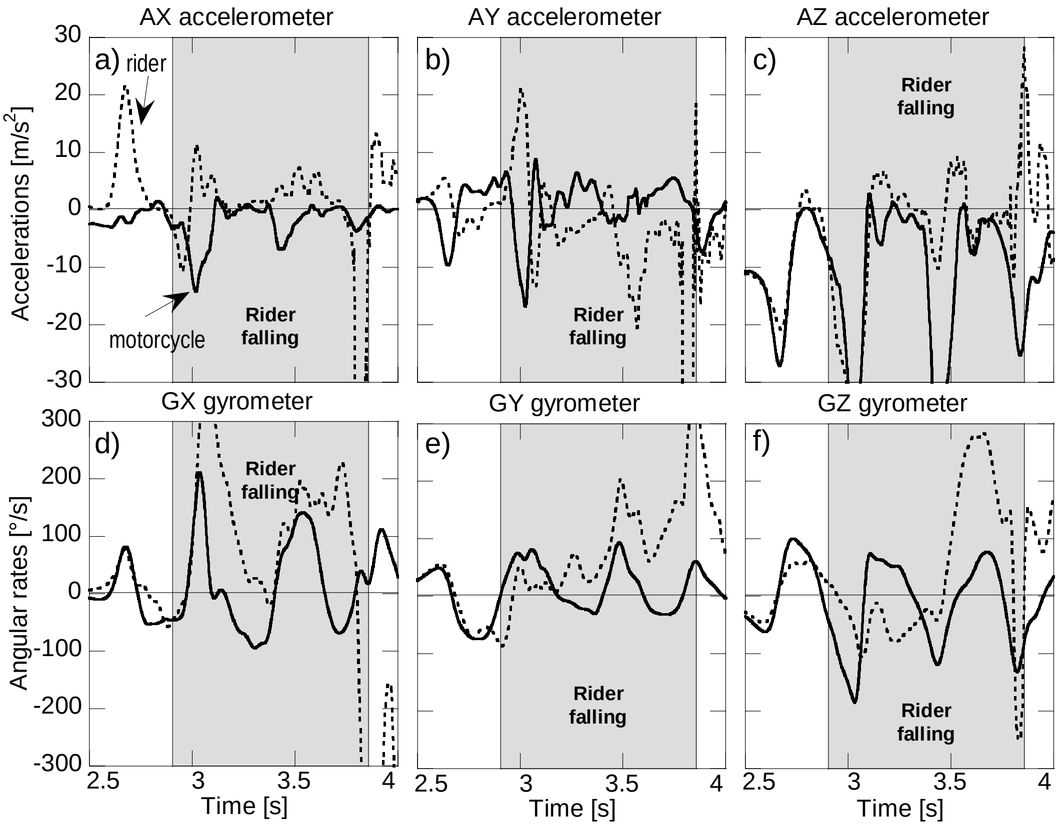


Fig. 10 - Accelerations and angular rates experienced by motorcycle and rider during a high-side fall.

The high-side presented in Fig. 10 starts when the vehicle has a speed of 26m/s and a roll inclination of about 35°. The high-side dynamics is completely different from that of the previous cases. In this example, a small braking torque is applied to the rear wheel but interrupted abruptly as soon as the motorcycle starts to slide. This event produces a load transfer that discharges the rear tire and generates an unbalance in the repartition between rear tire longitudinal forces and lateral forces. As an effect there is more lateral force acting on the rear tire than needed for equilibrium. The motorcycle starts to violently twist and vibrate, in the end ejecting the rider upward [11] [8] [7]. This twisting moment is particularly evident looking at rider signals in Fig. 10. At the end of the fall the rider touches the ground before the motorcycle actually hits the ground; this is clear when looking at the acceleration AX and AY of the rider in Fig. 10a, 10b, at the end of the fall. The rotation of the rider with respect to the motorcycle is also visible from the gyrometer signals in Fig. 10d, 10f.

4.4 SUMMARY OF RESULTS

Tab. 1 and Tab. 2 report peak values simulated for motorcycle and rider, for the three different maneuvers, compared to a reference case with no fall occurring.

CASE	AX peak [m/s^2]	AY peak [m/s^2]	AZ peak [m/s^2]	GX peak [°/s]	GY peak [°/s]	GZ peak [°/s]
No fall	1.1	1.5	15.9	70.9	23.3	21.4
Low-side	8.6	27.8	20.0	135.4	186.9	127.1
Low-side	1.3	6.7	15.9	121.2	34.5	28.3
High-side	14.3	16.8	42.8	211.0	93.3	184.5

Tab. 1- Peak values simulated for the motorcycle in the three cases with respect to the reference case (no fall).

CASE	AX peak [m/s^2]	AY peak [m/s^2]	AZ peak [m/s^2]	GX peak [°/s]	GY peak [°/s]	GZ peak [°/s]
No fall	6.7	2.4	14.4	56.1	25.0	48.1
Low-side	11.2	50.0	21.3	151.4	166.5	222.8
Low-side	8.1	6.2	14.4	93.8	25.0	48.1
High-side	68.9	122.7	37.3	652.4	342.0	283.7

Tab. 2 - Peak values simulated for the rider in the three cases with respect to the reference case (no fall).

Excluding AX acceleration that is difficult to consider suitable because of the acceleration and deceleration motion affecting a traveling motorcycle, all other measurements opportunely tuned, could provide a possible way of identifying the non-equilibrium state preceding a fall. However in normal driving conditions, the motorcycle is normally subjected to strong vibrations that could cause the accelerometer reading to be difficult to interpret. Gyrometers instead are more noise-resistant and even if the ratio between fall signal and normal signal is not as high as that of accelerometers, they can prove very significant in identifying the first stages

of a fall. In particular among all the gyrometers, GX and GY signals peaks seem extremely correlated to the fall start. Looking again at the Tab. 1 and Tab. 2 we can reach some conclusions. High-side is very violent but before the actual fall of the rider occurs, much time passes. Rear low-side is less violent, but the rider fall is quicker. Finally we have front low-side which is even more rapid, and presents small signal peak values; for this reason it is the most difficult to identify.
The following pages provide an overview of how an algorithm of possible implementation could work.

5. FALL PREDICTIVE ALGORITHM

The simulations and the available recorded data of falls show that both linear accelerations and angular rates increase significantly in the first phase of a fall event. The elaboration of the data measured on the motorcycle and on the rider has been used to define a penalty function to represent the level of risk involved during the execution of a maneuver.

$$Risk = f(GX, GY, GZ, AX, AY, AZ)_{rider,motorcycle}$$

In Fig. 11 the behavior of a hypothetical risk function is depicted during the real case scenario reported at the beginning, in Fig. 12, Fig. 13, Fig. 14 three similar graphs report the same evaluation made for the simulated cases.
At the side of the simulated events, pictures of the state of the system are also reported to aid in understanding the dynamics of the fall.
From Fig. 11, Fig. 12, Fig. 13, Fig. 14, it is possible to understand that the vehicle simulation exceeds the threshold in every case before contact between the upper body part and terrain occurs. Choosing an adequate value for the threshold it is possible to correctly assert a coming fall.

5.1 PREDICTION OF REAL CASE LOW-SIDE FALL

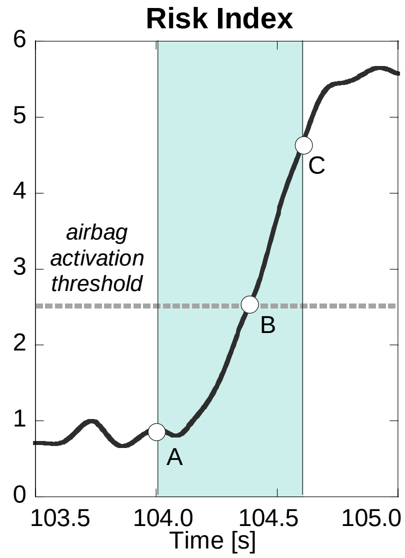


Fig. 11 - Real case fall prediction.

In the real scenario in Fig. 11, the algorithm triggers before fall ending: probable contact with upper body parts happens at least 0.22s after the triggering.

5.2 PREDICTION OF REAR LOW-SIDE FALL

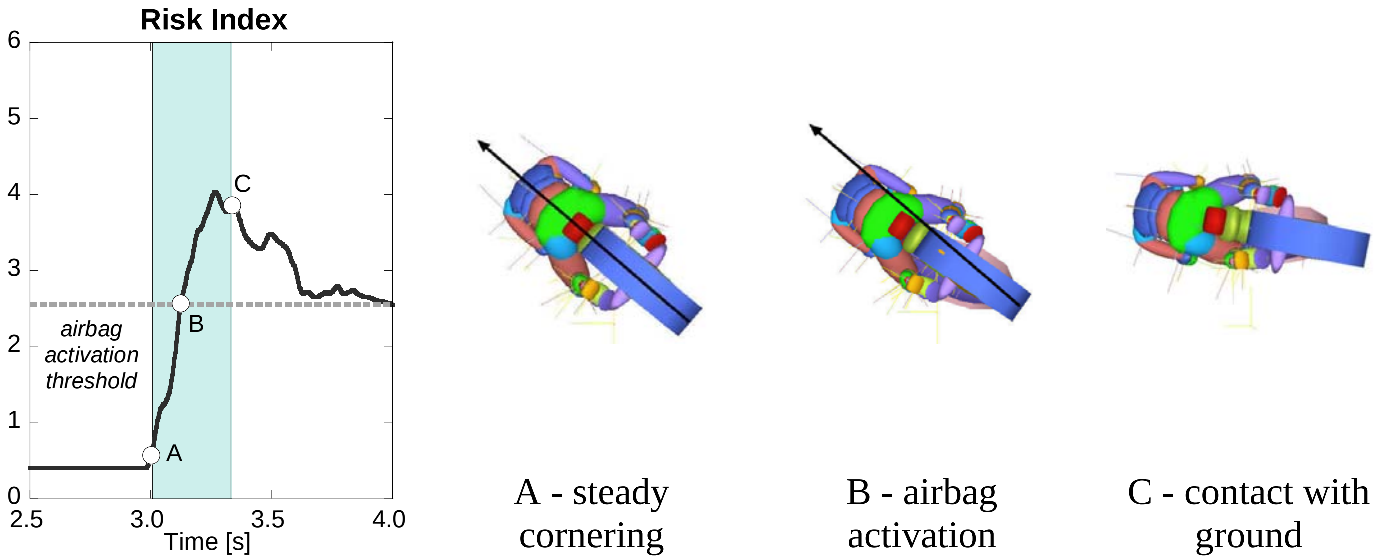


Fig. 12 - MADYMO simulation and fall prediction of a rear low-side.

The black arrow reports the starting inclination of motorcycle. Contact between upper body parts and the ground happens 0.20s after the triggering of the algorithm.

5.3 PREDICTION OF FRONT LOW-SIDE FALL

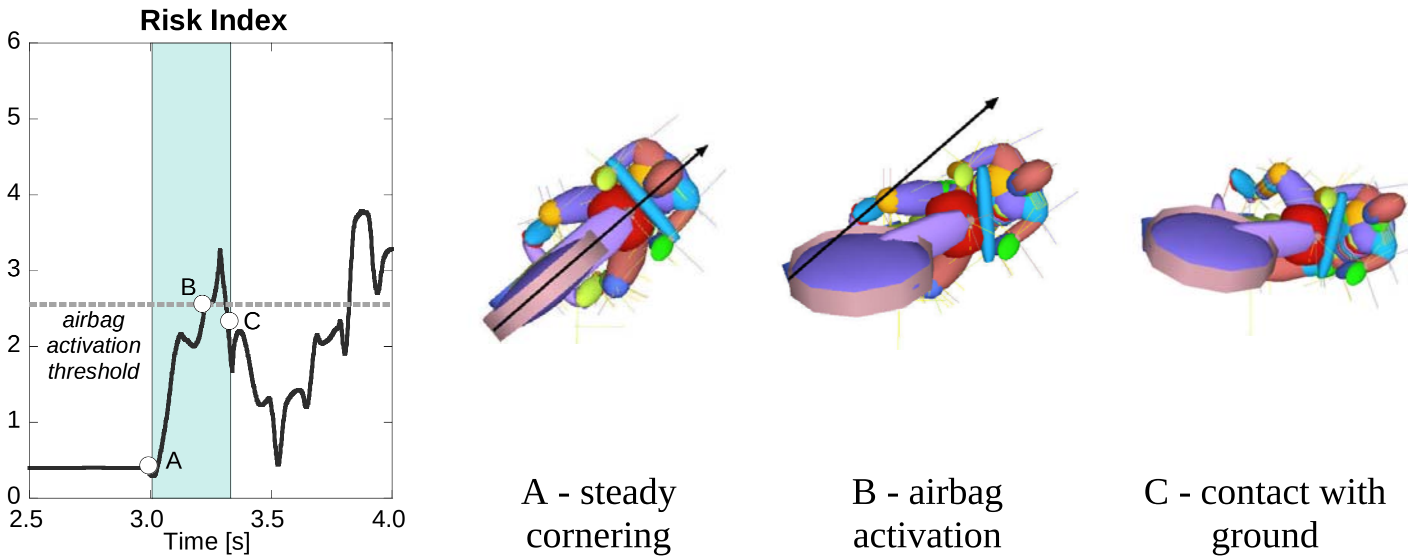


Fig. 13 - MADYMO simulation and fall prediction of a front low-side.

In the front low-side the rider remains attached for a longer time to the motorcycle because of the forward pitching movement of the motorcycle. Contact between upper body parts and the ground happens 0.10s after the triggering of the algorithm.

5.4 PREDICTION OF HIGH-SIDE FALL

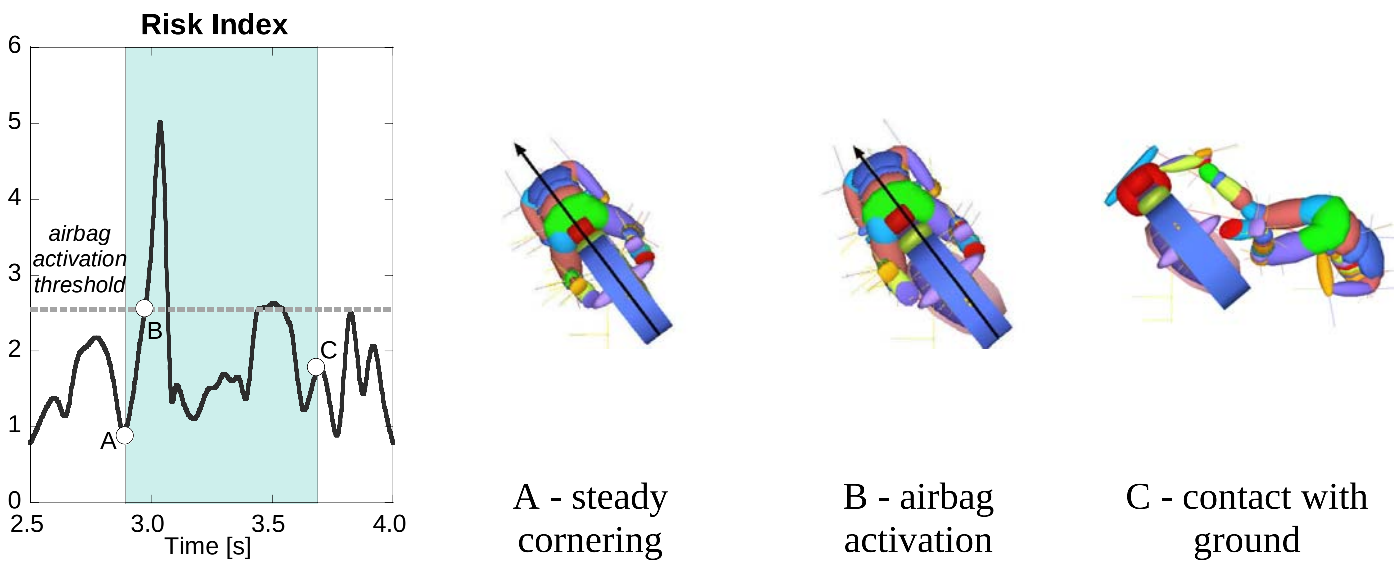


Fig. 14 - MADYMO simulation and fall prediction of a high-side.

In the high-side the rider hits the terrain before the motorcycle concludes its tilting movement, but the fluctuations recorded in the measurements activates the triggering of the algorithm 0.90s before actual contact of the rider with the ground .

5.5 FINAL CONSIDERATIONS ON FALL PREDICTION

Tab. 3 reports maximum values reached for the risk function in the real case example and in the other simulated cases. The “fall duration” row reports the length of the period between the start of the tilting movement and the contact of rider with the ground. In the same tables are also reported: the “trigger time”, which is the time elapsed from the beginning of the fall and the triggering of the algorithm; the “time to crash” which is the time elapsed between the algorithm triggering and the contact of the dummy upper body parts with the ground.

		no fall	Rear fall	Front fall	Highside
real case	**Risk Index peak**	1.03	5.5		
	Fall duration [s]	n. a.	~0.60		
	Trigger time [s]	n. a.	~0.39		
	Time to crash [s]	n. a.	~0.22		
simulations	**Risk Index peak**	0.45	4.00	3.29	5.00
	Fall duration [s]	n. a.	0.32	0.32	0.96
	Trigger time [s]	n. a.	0.12	0.22	0.06
	Time to crash [s]	n. a.	0.20	0.10	0.90

Tab. 3 - Values and timings of the fall predictive algorithm in the real and simulated cases.

The four different falls presented cover a wide range of possible scenarios: a race low-side, two extremely rapid low-side, and a high-side. Even if timings involved in the different falls varies, in every case the algorithm triggers before an actual contact between rider and ground occurs. Moreover in the different falls examined the time between the triggering and the ground contact varies between 0.1s and 0.9s, which for airbag inflation is a sufficient time.

Actual time needed should range between 0.03 s and 0.05 s depending on the volume of the airbag. These considerations give space to the possible application of an air-based protection system triggered by the fall predictive algorithm.

6. AIRBAG PRELIMINARY ANALYSIS

Simulations and crash data report that on impact with bare terrain from a height of 1.85 meters, a rigid dummy can experience an acceleration up to 200g in 0.01 seconds which is much more than the human body can withstand. With a soft protection of about 20 centimeters in thickness it is possible to reduce the acceleration to a value around 25g, a level at which there is no significant injury risk. It is clear however that it is not feasible to realize a portable protection of such a dimension, because it would completely compromise the freedom of movement of the rider. A solution could be found using an airbag system, inflated only when necessary. With such a system it should be possible to reduce the acceleration to a value of about 15g in about 5ms, level which can be absorbed by the human body without experiencing any injury [14]. The more the human body deforms the airbag the greater energy absorbed; the more the penetration the less the pressure needed to stop the movement of the body. The problem is that deeper penetrations imply larger airbags with bigger volumes, which can create trouble during the inflation.

6.1 DIRECT CONTACT AND AIRBAG CONTACT IMPACTS

Fig. 15 reports the results of different MADYMO impact simulations. In these simulations the motorcycle is subjected to an abrupt front low-side fall. The virtual dummy during the tilting motion of the motorcycle hits the ground violently with the left shoulder. This is a common scenario encountered during races and normal driving. In the occurrence of a similar fall, often the rider can break his upper arm bone. Fig. 15a reports the shoulder acceleration in the case of no airbag inflation. Fig. 15b reports the same acceleration in the case of inflation of two different airbag protective systems fitted on the shoulder: an airbag of 3.3 liters of volume and an other 12 liters, both inflated at a pressure of 80000Pa. It is clearly visible how the presence of the airbag cancels out the peaks in the accelerations reporting the level of the accelerations experienced by the dummy below the biomechanical warning level [14]. To be noted, that in Fig. 15b the fact that in the small bag case acceleration starts 0.025s later because since the bag is smaller, contact with the ground happens afterwards. Fig. 16 and Fig. 17 report the simulated graphical output of the airbags inflation sequence, in the two cases considered.

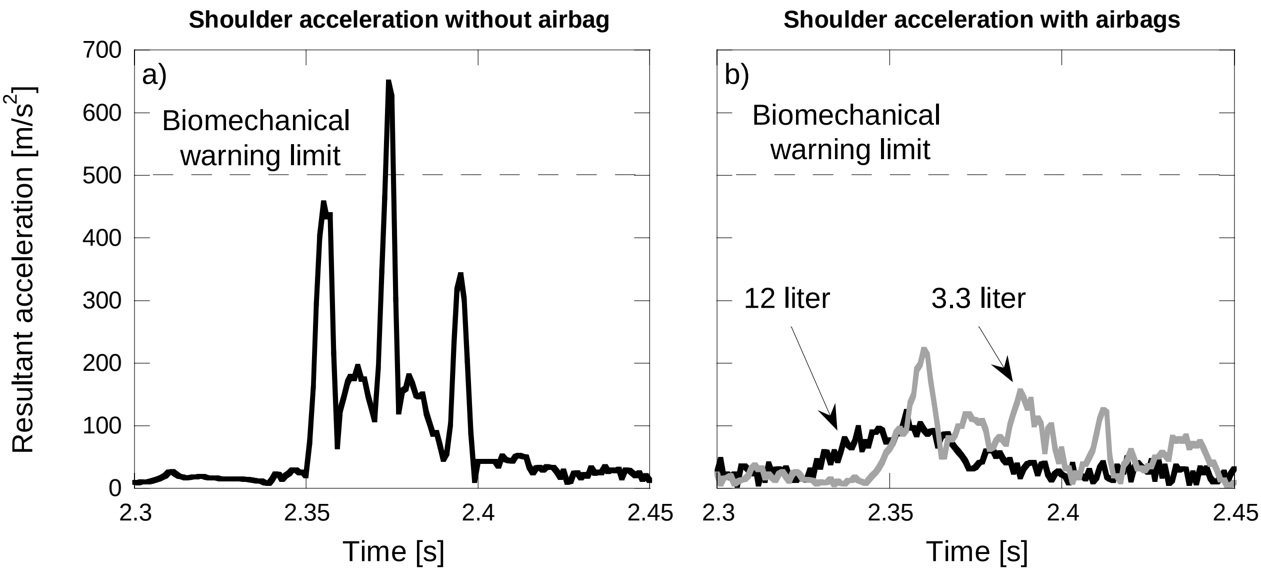
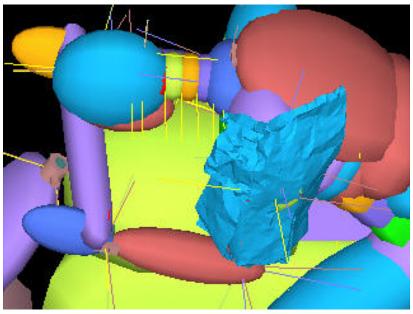
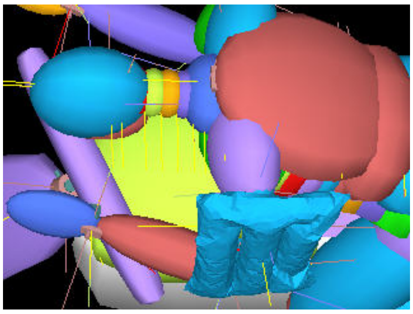


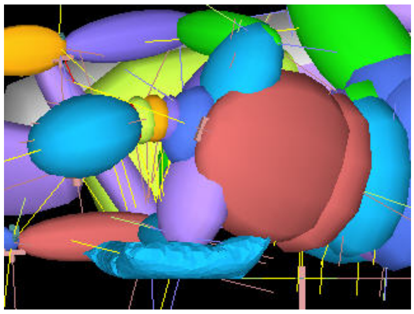
Fig. 15 - Accelerations experienced by dummy shoulder without or with airbag



2.150 [s]: triggering

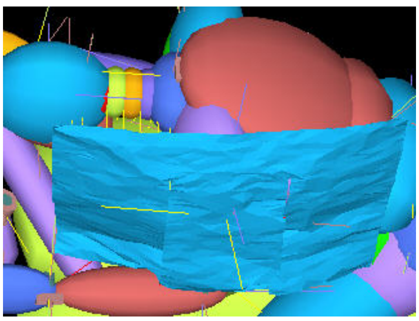


2.180 [s]: complete inflation

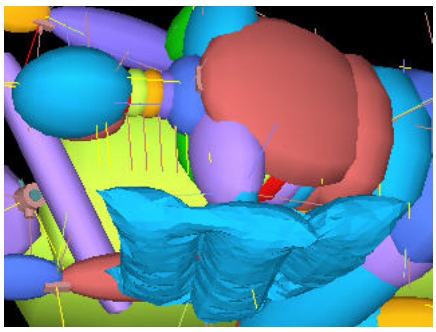


2.340 [s]: contact with ground

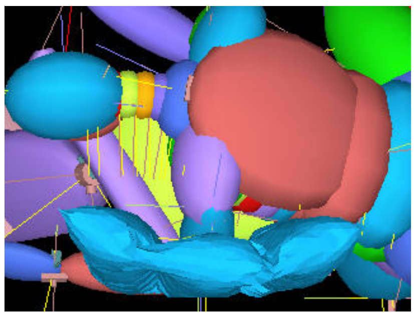
Fig. 16 - Inflation sequence of a simulated 3.3 liter airbag system.



2.150 [s]: triggering



2.190 [s]: complete inflation



2.325 [s]: contact with ground

Fig. 17 - Inflation sequence of a simulated 12 liter airbag system.

6.2 AIRBAG CONSIDERATIONS

To better understand the influence of the airbag parameters on rider safety, a series of simulations have been realized with MADYMO with the aim to help in the understanding of these two important parameters. Acceleration on the shoulder of a dummy have been measured during the same fall, varying the width and the inflation pressure of the two different airbag systems considered previously. Fig. 18 reports the measured peak acceleration registered in two airbag systems of different volume varying the inflation pressure. Choosing a particular value for the inflation pressure in the two systems it is possible to reduce the accelerations to similar amounts. In the two simulations highlighted by means of a white dot, bag parameters are very different: in the 3.3 liter case, the airbag has a small volume and a high pressure, in the 12 liter case the bag is four times larger, but the inflation pressure is less than half. This can be explained with the following considerations. If a bag is small, it will perform better at a high inflation pressure: lower pressure could allow the possibility of a direct contact between the protected surface and the ground. A bigger bag instead should perform better with a lower inflation pressure: it has sufficient volume for stopping the protected dummy body before contact occurs, so the less pressure, the smoother the deceleration.

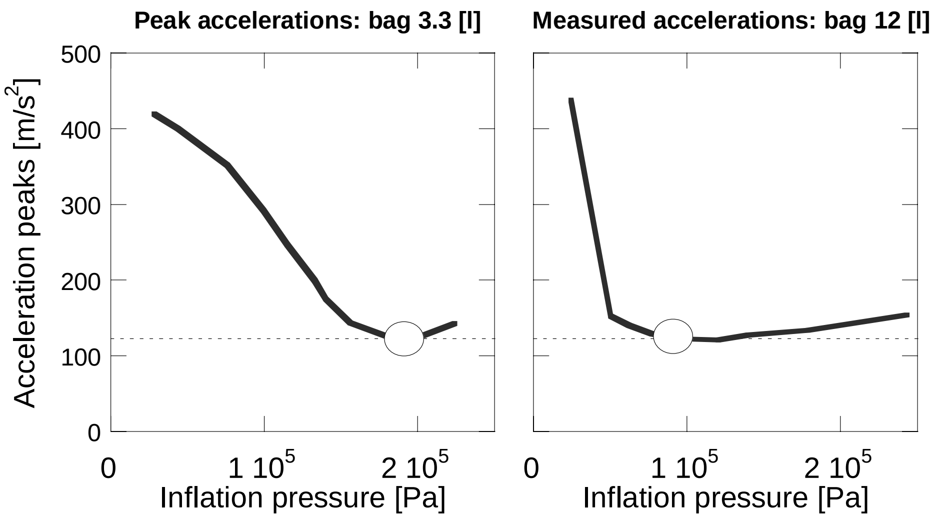


Fig. 18 - Peak acceleration registered varying inflation pressure, for two different bags.

With the presence of an airbag between the dummy and the terrain it is possible to reduce the impact acceleration to one fifth of that computed in the no-airbag simulation.
In the cases analyzed only two sizes of airbag were simulated, but it is clear that augmenting the dimension of the airbag, it should be possible to additionally reduce the acceleration transferred to the rider's body.

7. Conclusions

In this paper the technical problems encountered in fall data acquisition have been discussed. As an example, one experimental low-side fall was reported and analyzed showing how from measured data it is possible to recognize the initial stages of the fall with good accuracy. The possibility of numerical simulation of motorcycle falls was then introduced and a brief comparison between experimental and numerical data was presented. Three additional examples of fall simulations were then presented to cover a wide range of possible fall events: low-side falls caused by rear wheel slippage, low-side falls caused by front wheel slippage, and high-side falls. Also in these simulations it was possible to recognize in advance the fall by examining accelerations and angular rates. These results suggest the possibility of developing a fall predictive algorithm for triggering a rider airbag protection system. One implementation of the aforementioned algorithm was then tested using both experimental and simulated data, and the timings involved were discussed confirming the possibility of airbag inflation before rider impact with the ground.
In the end, a simple case study of an airbag system fitted on a virtual dummy was reported, the influence of airbag volume and inflation pressure on impact accelerations was discussed.
These preliminary studies suggest that airbag technology is a prominent possibility for improving the passive safety of motorcyclists. Utilization of proper hardware and of opportunely tuned airbags, could raise rider protection gear to a new level of performance and safety.

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