Evaluation of a 'One Size Fits All' Motorcycle Airbag Concept using Finite Element Human Body Models

Shashank Gowda, Bengt Pipkorn, Shiyang Meng

Abstract Riders of powered two- and three-wheelers represent nearly one-third of the 1.19 million annual road traffic fatalities worldwide, and rib fractures are among the most common injuries sustained by motorcycle riders in crashes. Despite advancements in motorcycle safety technology, airbags, a standard safety device for passenger cars for decades, are not widely adopted, especially on small and medium-sized motorcycle models. To address this gap, a 'one size fits all' airbag concept and evaluated its effectiveness in reducing rib fractures across three motorcycle types: naked, scooter, and touring. A finite element human body model was positioned using volunteer posture data specific to each motorcycle type. Rib fracture risk was assessed with and without the airbag using a tissue-based injury predictor. The results showed that the airbag was effective in reducing rib fracture risk for the naked and scooter models but added neither benefit nor risk for the touring model. These findings highlight the potential of an airbag system in substantially reducing the risk of rib fractures for motorcycle riders. Further evaluation is needed to evaluate its robustness under a variety of real-world collision conditions and rider postures, as well as to evaluate injury risk for other body parts, such as the head.

Keywords Airbag system, computational simulation, human body model, motorcycle safety, rider protection.

I. INTRODUCTION

Riders of powered two- and three-wheelers (PTWs) account for 30% of global road traffic deaths and 46% in the South-East Asia region [1]. While helmet use is often mandated by law, the thorax remains relatively unprotected as thoracic protective devices are generally considered optional. In regions with high helmet usage, thoracic injuries have become the most common among serious injuries [2].

The effectiveness of an airbag on a large touring motorcycle in reducing rider injuries during frontal collisions was demonstrated using the motorcyclist anthropometric test device (MATD) [3]. MATD is a modified Hybrid III 50th percentile anthropometric test device (ATD) [4] designed for motorcycle crash testing, to evaluate injury risk for riders and to enable the development of countermeasures. Honda pioneered the first production-series of airbags for motorcycles in 2006 with the Gold Wing model. An airbag requires a reaction structure to absorb rider kinetic energy during a crash. In cars, this is the steering wheel, and in large touring motorcycles it is the instrument panel and surrounding structures. However, in small and medium-sized motorcycles, finding an adequate reaction structure and airbag-mounting location is challenging due to space constraints. Previous research has explored various airbag designs for smaller motorcycles, including an airbag system with a back plate [5], an airbag concept using the opposing vehicle's structure as a reaction structure [6], and a standard driver airbag mounted on the motorcycle handlebar [7]. These designs have demonstrated effectiveness in reducing rider chest injuries for scooter-type motorcycles, using MATD. In addition, a simulation study using Hybrid III 50th percentile ATD has stated that an airbag mounted on the fuel tank of a medium-sized motorcycle reduced the rider's chest acceleration [8], though no quantitative results were presented.

These studies often focus on a specific motorcycle type, leaving a gap in understanding the effectiveness of a standardised airbag system that could be used across different motorcycle types. By standardising airbag components like the airbag textile, inflator, housing and vent, design cycles and costs could potentially be reduced, making airbag systems more accessible and practical.

Finite element (FE) human body models (HBMs) provide a more comprehensive representation of humans

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compared to ATDs, like the MATD, which has restricted degrees of freedom and inappropriate thorax compliance [9]. HBMs provide enhanced injury prediction capabilities based on deformation at the tissue level, offering advantages over ATDs. In this study, we utilised SAFER HBM [10] and high-fidelity FE motorcycle models to conduct simulations for three motorcycle categories (naked, scooter, and touring). Risk of two or more rib fractures both with and without a 'one size fits all' airbag was analysed to evaluate its effectiveness.

II. METHODS

Three detailed FE models of motorcycles (Fig. 1) were developed in-house, each representing a distinct type of motorcycle: naked, scooter and touring. The weight and centre of gravity of the three motorcycle models were verified and showed close agreement with their physical counterparts, with weight differences of up to 3%, differences in the position of the centre of gravity along the vertical axis of up to 6.6%, and along the longitudinal axis of up to 2.5%. The frontal stiffness of the model was tuned such that the kinematics and rigid-barrier wall force matched closely with observations in physical tests (Fig. A1), in which motorcycles were crashed into a rigid wall at 40 km/h. All three models conformed to the SAFER HBM mesh quality criteria 95% target [11].

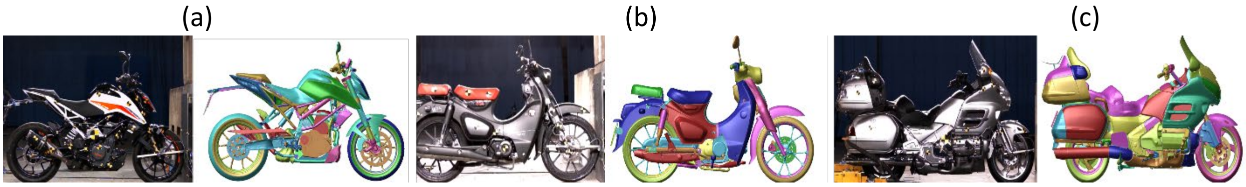

Fig. 1. Three motorcycle types in rigid wall tests (left) and in simulations (right): (a) KTM Duke 390; (b) Honda Super Cub; (c) Honda Gold Wing.

SAFER HBM v11 [12], representing a 50th percentile male, was positioned on the motorcycles (Fig. 2) based on average posture data from 3D photometric measurements on anatomical landmarks of 20 volunteers [13]. A Bell Qualifier helmet was mounted on the HBM's head and the motorcycle impacted a Honda Accord 2011 model year FE model [14]. The simulation used LS-DYNA (solver version: mpp s R12.2) and replicated a common real-world crash scenario from post-mortem human subject (PMHS) tests [15], involving a motorcycle impacting the side of a stationary car at 50 km/h and 30° forward of perpendicular.

The reference simulation replicated a series of PMHS tests [9]. Loading to the upper thorax and the thoracic contact point on the car were mimicked (Fig. 3). The same conditions were recreated for the two other motorcycle types. Thoracic injury risk was evaluated using the first principal membrane strain in the mid-layer of the cortical bone of the ribs and the number of fractured ribs [16-17].

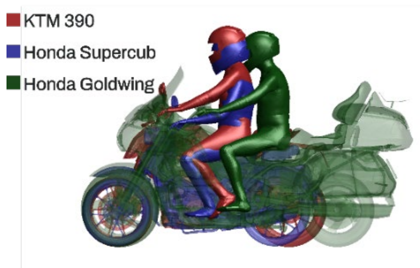

Fig. 2. HBMs positioned on three FE motorcycle models.

Fig. 3. Images from two KTM 390 crash tests with PMHS [9] (left) and reference simulation (right) moment before thorax impact.

A validated airbag model (Fig. B1) was implemented across the three motorcycle models (Fig. 4). The airbag was mounted behind the handlebar at a height to ensure good thorax coverage upon deployment. Physical inflator mass flow data modelled with the *AIRBAG_HYBRID_JETTING keyword was used to inflate the airbag, which included a vent defined using the fabric venting option. Only those bike parts highlighted in red in Fig. 4 were considered for contact with the airbag, a simplification made to avoid redesigning the tank.

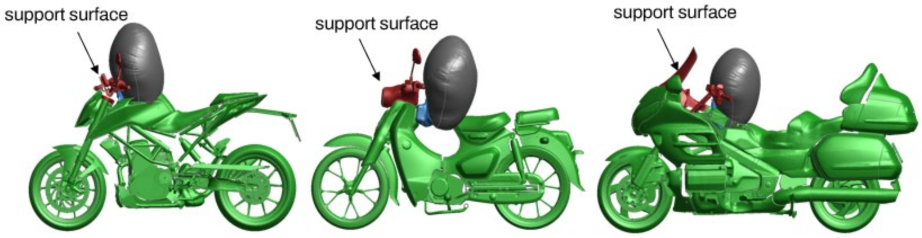

Fig. 4. The 'one size fits all' airbag model integrated and deployed across three types of motorcycle (from left to right: KTM 390, Honda Super Cub and Gold Wing). The parts shown in red are the support structure of the motorcycles and are in contact with the airbag.

III. RESULTS

The first 200 ms of simulations with and without airbag are shown in Fig. 5 to Fig. 7 for the three motorcycle models: KTM 390, Honda Super Cub, and Gold Wing. For the KTM 390 without the airbag, during the initial phase of the crash the pelvis impacted the tank, causing the upper body to pitch forward. This movement brought the arm and upper thorax into contact with the roof-rail of the car. In contrast, with the airbag it deployed before the rider pitched forward and positioning itself between the car and the rider. This altered the rider's trajectory and prevented impact with the car's side structures (Fig. 5). In the case of the Honda Super Cub without the airbag, the rider continued to move forward until the abdomen and pelvis impacted the display panel and handlebar. Consequently, the upper body pitched forward, bringing the thorax into contact with the car's B-pillar and roof-rail. However, when equipped with the airbag, it deployed and positioned itself between the thorax and the car's structure, effectively preventing direct impacts involving the rider's abdomen and thorax with both the bike's own structure and car structures (Fig. 6). For the Gold Wing, both with and without the airbag a distinct phenomenon was observed: the rider avoided thorax contact with the car due to the larger frontal structure. As the rider moved forward, the pelvis slid over the tank of the bike. The rider's knee was then stopped by the fairing parts, causing the rider to rotate along the pelvis without any thorax-to-car contact. With the airbag, the airbag deployed between the rider and the display panel or visor, cushioning the thorax (Fig. 7).

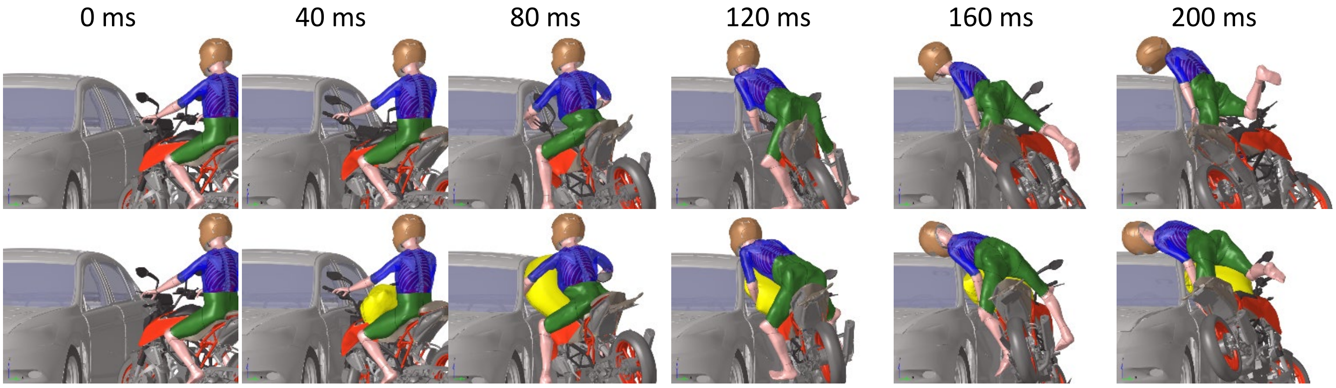

Fig. 5. Comparisons of KTM 390 simulations without airbag (top) and with airbag (bottom).

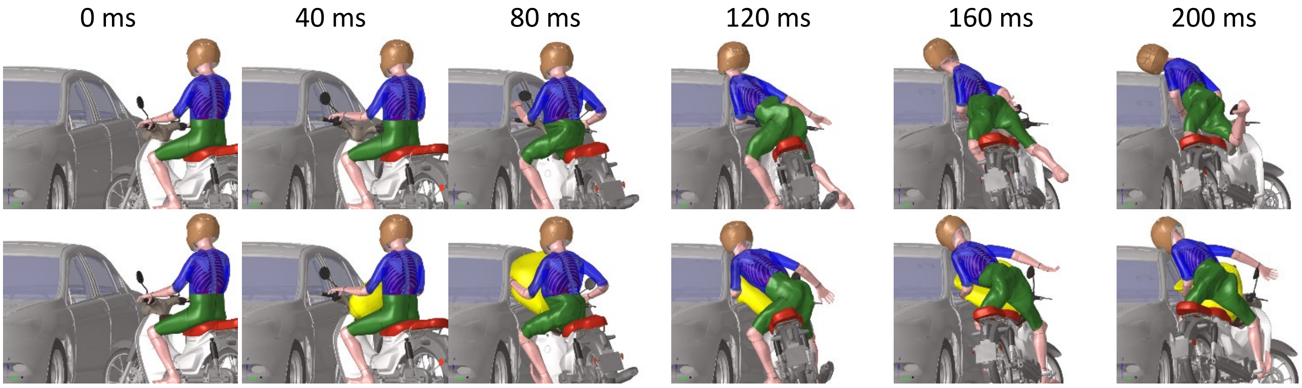

Fig. 6. Comparisons of Honda Super Cub simulations without airbag (top) and with airbag (bottom).

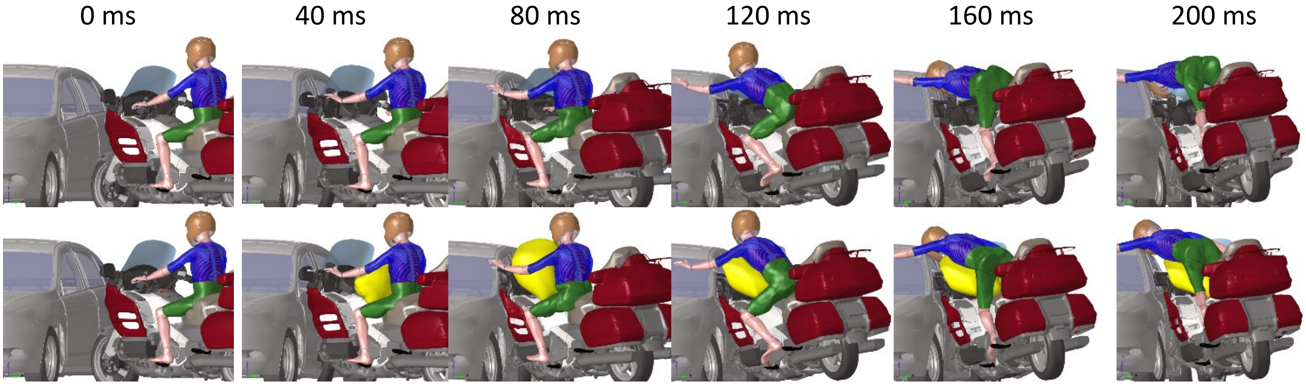

Fig. 7. Comparisons of Honda Gold Wing simulations without airbag (top) and with airbag (bottom).

The baseline simulations showed higher rib strains in upper ribs, particularly rib one, due to loading by the roof-rail of the car for the KTM 390. For the Honda Super Cub, higher rib strains were observed in upper and right ribs due to the loading by both roof-rail and B-pillar of car. With the airbag, a reduction in rib strains was achieved for naked and scooter models (Fig. 8 (a) and (b)). While the Honda Gold Wing showed lower rib strains due to the SAFER HBM thorax not contacting the car, rib strains were still observed. This was due to the abdomen shifting upwards during the pelvis-to-tank interaction, causing the rib cage to expand. With the airbag the rib strains were reduced, as shown in Fig. 8 (c).

A reduction in the predicted risk for two or more fractured ribs was achieved with the airbag-equipped KTM 390 and Honda Super Cub across riders of ages 25, 45 and 65 years old, see Fig. 9 (a) and (b). The Honda Gold Wing showed no significant rib strains and hence no rib fracture risk, except for 65 years old in the baseline model simulation. The airbag did not result in any rib fracture risks (Fig. 9 (c)).

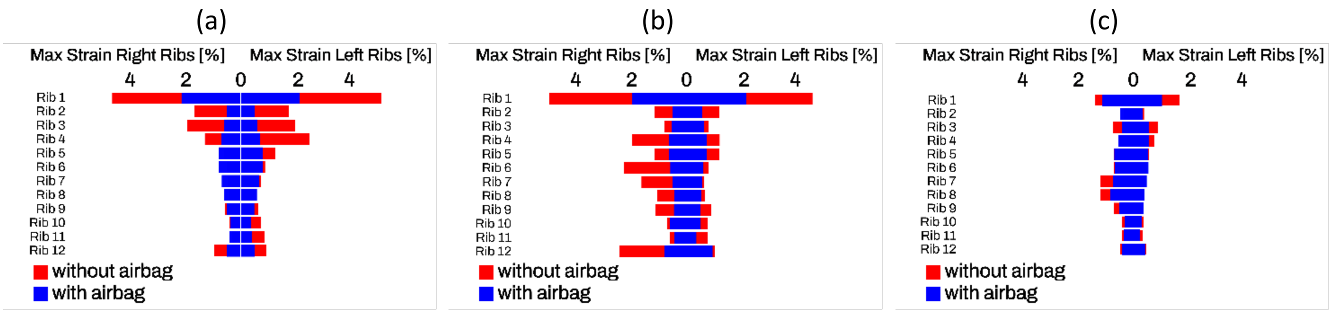

Fig. 8. Comparison of rib strain for simulations without airbag (red) and with airbag (blue):
(a) KTM 390, (b) Honda Super Cub, and (c) Honda Gold Wing.

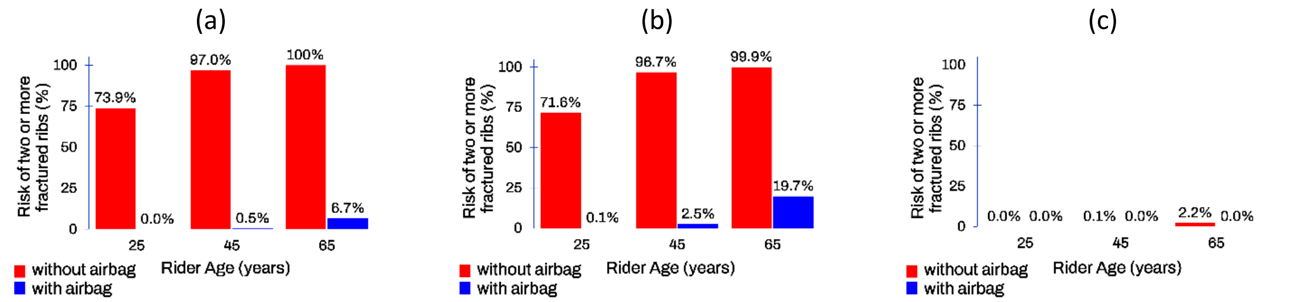

Fig. 9. Comparison of predicted rib fracture risk at 25, 45 and 65-year-old for simulations without airbag (red) and with airbag (blue): (a) KTM 390, (b) Honda Super Cub, and (c) Honda Gold Wing.

IV. DISCUSSION

This study demonstrated for the first time the safety benefit of a 'one size fits all' airbag concept for three types of motorcycle. For the KTM 390, the airbag prevents the thorax from contacting the vehicle by reducing and redirecting the rider forward motion. In the Super Cub model, the airbag stops the thorax, avoiding hard impacts with the bike and vehicle. This aligns with the findings of [3][6-7], which show that airbags reduce injury severity by absorbing kinetic energy and preventing hard contacts. The Gold Wing's larger frontal structure positions the rider initially farther away from the crash partner and a knee-bike contact induces rider rotation. This may explain the absence of a thorax impact. Notably, the airbag did not increase injury risks, consistent with [3]. A more nuanced understanding was provided of the potential mechanisms.

This study poses several significant advances in safety evaluation of motorcycle airbag compared to previous studies. Earlier studies often used metrics such as chest deflection measured at a single point [3] or at two points [6] on the rib cage or acceleration [8] data from the ATD. This can lead to assessments of injury risks being less comprehensive, as ATDs do not replicate the anatomical details and injury mechanisms for omnidirectional impacts. Additionally, SAFER HBM offered the age-specific fracture risk predictions for different ages. In this study twenty-five, forty-five and sixty-five years old were chosen to represent PTW riders with wider age range.

The use of the same airbag model across all three types of motorcycle models paves the way for a standardised airbag system. The harmonisation of various airbag components can reduce costs, ultimately encouraging wider adoption of airbags in motorcycles.

While the airbag's benefits in reducing thoracic injury were observed, several limitations highlight the need for further research. Only bike parts behind the airbag, like the handlebar and instrument panel, were considered for contact, ensuring handlebar rotation didn't hinder deployment but provided minimal support. The fuel tank was excluded, which could be a worst-case scenario with less reaction structure for the airbag, affecting simulation accuracy. Focusing on a single load case may limit the generalisability of findings. Average posture data for positioning the SAFER HBM may not capture real-world rider posture variability. Injuries to the head, neck or lower extremities were not assessed. Future research should include the tank in contact considerations, explore optimal airbag positions, evaluate impacts on other body regions, and include rider posture and opposing vehicle variations. Addressing these areas could further develop a 'one size fits all' airbag system, enhancing rider safety across various motorcycle types and crash scenarios.

V. CONCLUSION

This study demonstrated the effectiveness and benefits of a 'one size fits all' motorcycle airbag in reducing rib fracture risk for naked and scooter-type motorcycles. For the touring motorcycle, there was no predicted risk for rib fractures with and without the airbag. The reduction in predicted rib fracture risk highlights the airbag's effectiveness in providing thoracic protection. However, it is important to note that these benefits were observed only in a single crash configuration and without considering injuries to other body regions. Further research and evaluation are needed to better understand the airbag's overall protective capabilities for motorcycle riders.

VI. DECLARATION OF COMPETING INTEREST

The authors work at Autoliv (www.autoliv.com), which develops, manufactures, and sells protective safety systems to car manufacturers. Results from this study may impact how Autoliv chooses to develop its products.

VII. ACKNOWLEDGEMENTS

This work received funding from FFI (Strategic Vehicle Research and Innovation) by Vinnova (Sweden's Innovation Agency), the Swedish Transport Administration, the Swedish Energy Agency, and the industrial partners. We are deeply grateful to Linus Lundin from Chalmers University of Technology for providing the average volunteer posture data; to Maria Oikonomou and Thanassis Lioras from BETA CAE for assistance with SAFER HBM positioning using the average posture data; and to Philip Singh and Madelen Fahlstedt from MIPS AB for providing the helmet model.

VIII. REFERENCES

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IX. APPENDIX

Appendix A: Rigid wall Test Comparison of Three Motorcycle models between Test and Simulation

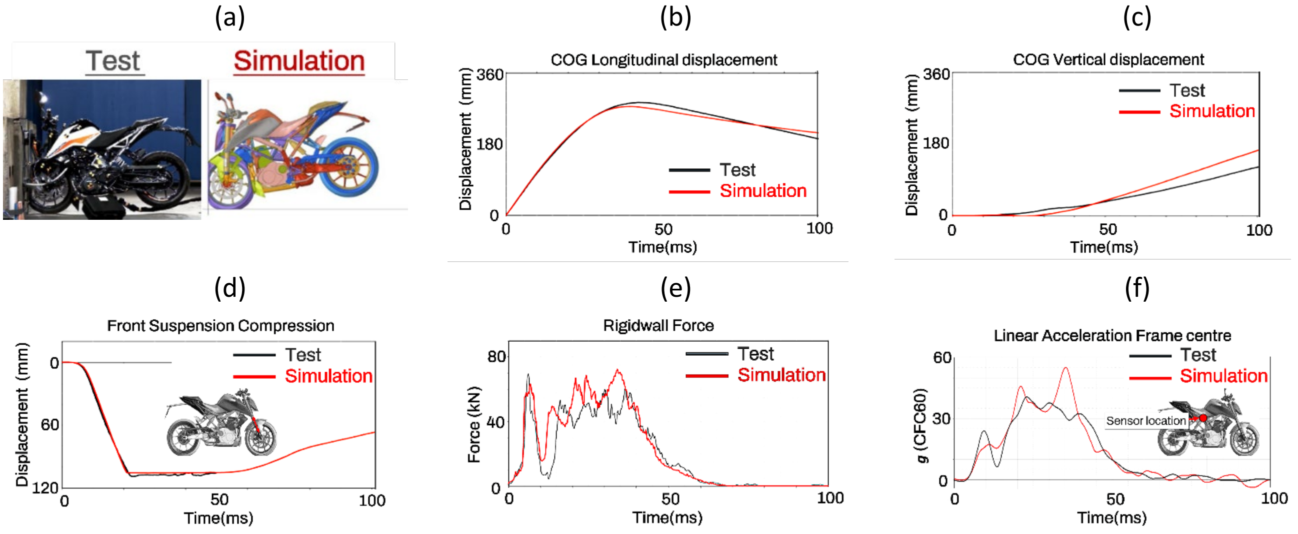


Fig. A1. KTM 390: (a) Image at the moment of rebound, (b) and (c) Centre of Gravity tracking, (d) Front Suspension compression, (e) Rigid wall force, (f) Linear Acceleration measured at frame centre.

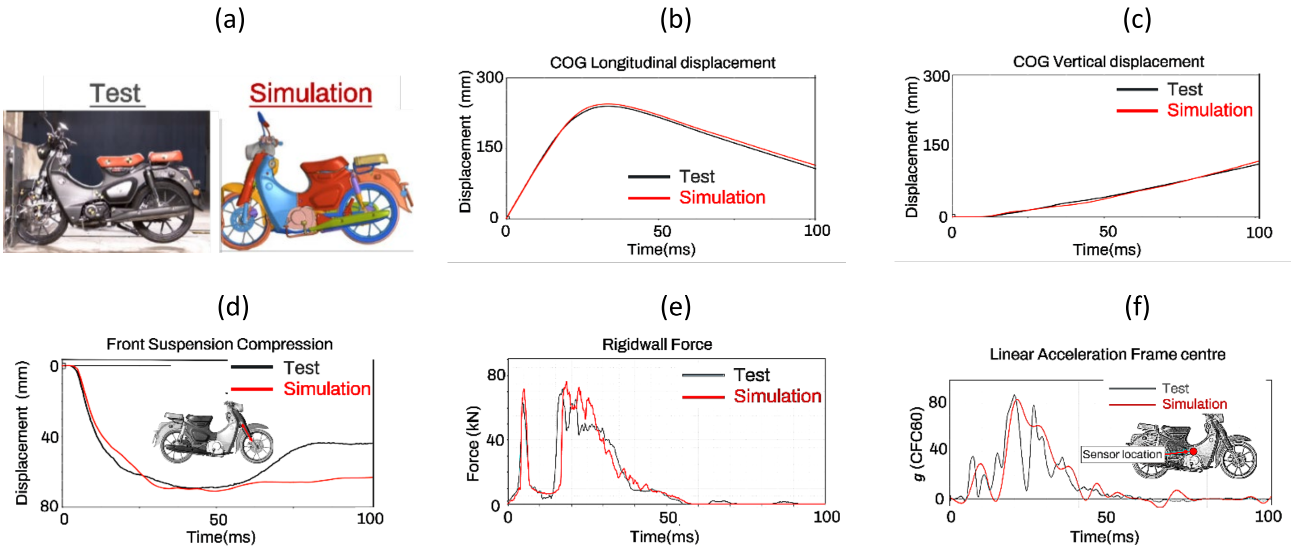
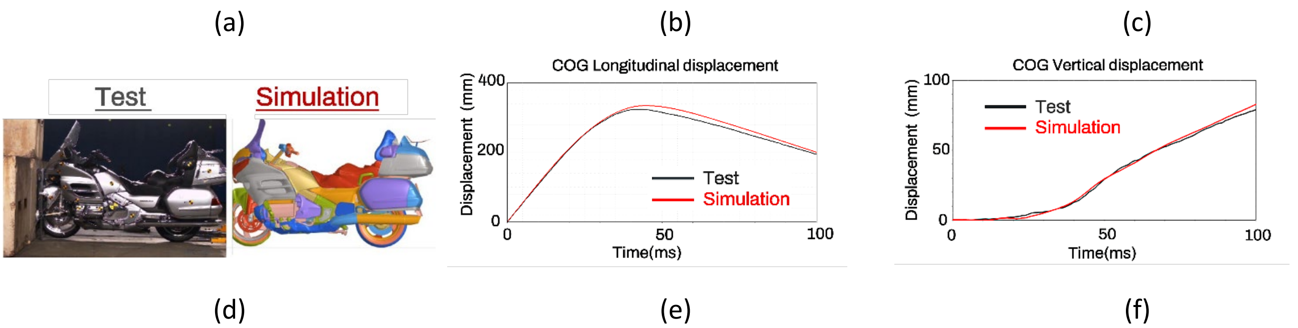


Fig. A2. Honda Super Cub: (a) Image at the moment of rebound, (b) and (c) Centre of Gravity tracking, (d) Front Suspension compression, (e) Rigid wall force, (f) Linear Acceleration measured at frame centre.



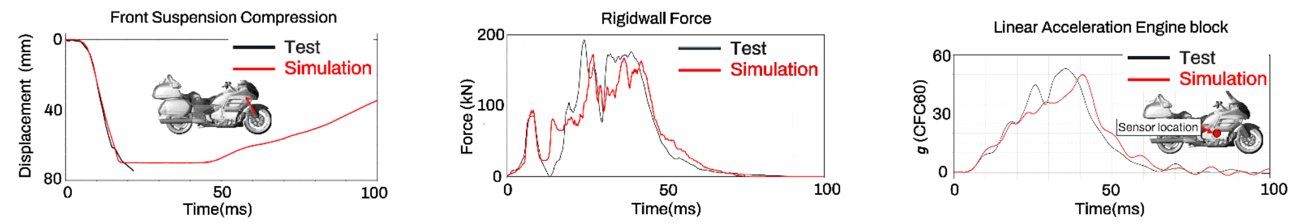


Fig. A3. Honda Gold Wing: (a) Image at the moment of rebound, (b) and (c) Centre of Gravity tracking, (d) Front Suspension compression, (e) Rigid wall force, (f) Linear Acceleration measured at frame engine block.

Appendix B: Airbag Linear Impact validation results comparison between Test and Simulation

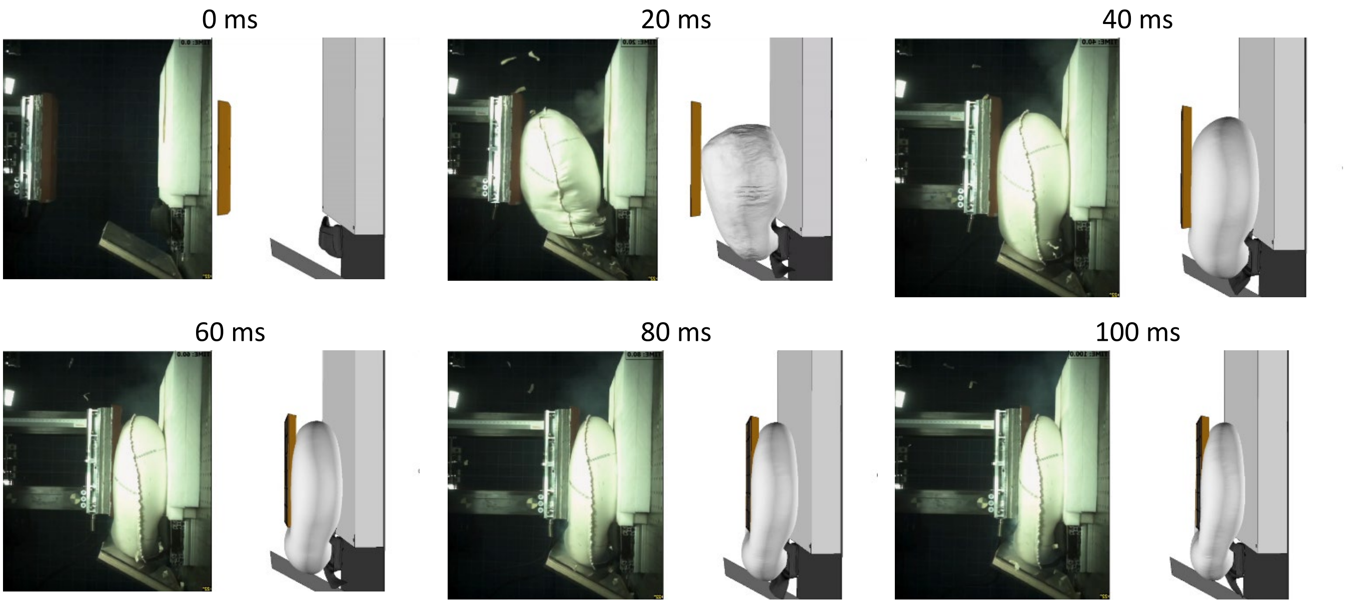


Fig. B1. Visual Comparison of Airbag Linear Impact test in 20 ms interval: Test (left) and Simulation (right). (Note: the interaction between airbag and thorax of rider begins only after 30 ms in all three with-airbag motorcycle simulations.)

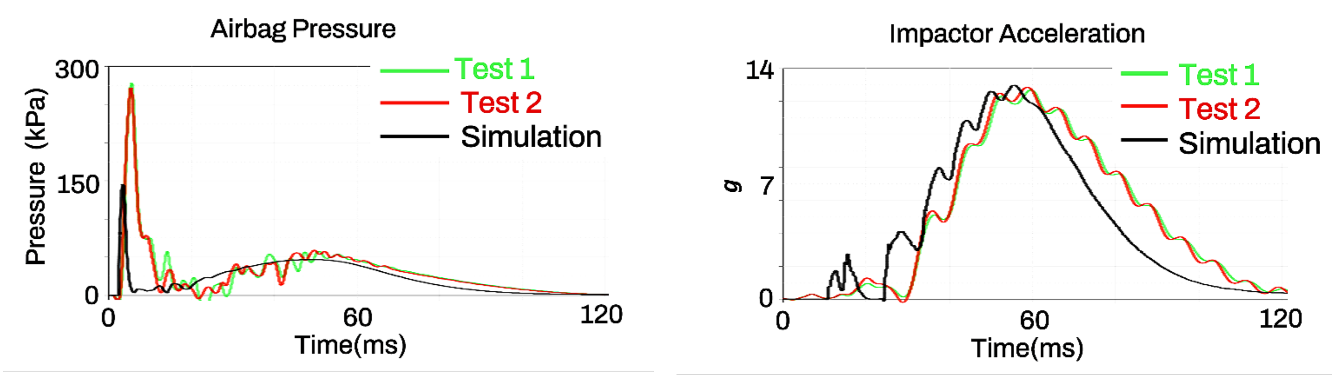


Fig. B2. Airbag pressure and Impactor Acceleration agreement between Test and Simulation. (Note: the interaction between airbag and thorax of rider only begins after 30 ms in all three with-airbag motorcycle simulations.)