Facial Impact Conditions for Assessing Motorcycle Helmets, Informed by Reconstruction of Real-World Collisions.

Lucas Low, Claire Baker, Will Dawber, Shiyang Meng, Mazdak Ghajari

I. INTRODUCTION

Motorcycle helmets are a major focus for improving motorcyclists' safety in road traffic collisions (RTCs), as they can significantly reduce the risk of head injuries [1]. However, facial impacts are minimally tested in helmet safety standards, despite having been reported to account for over 50% of head impacts [2]. Facial impacts often present together with injuries remote to the location of impact, such as basilar skull fracture (BSF), which is in turn associated with brain stem injuries [3]. There is therefore a need to better understand the loading conditions and injuries associated with facial impacts and develop new test methods for assessing helmets.

Real-world RTC databases can provide information on vehicle impact conditions and resulting injuries. The information can be used to develop computational reconstructions of the collision [2][4-5], to provide insight into the rider's head impact conditions. Identifying representative head impact conditions informs helmet test protocols, typically involving a drop on an angled anvil.

A previous study parsed the cost-free UK Road Accident In-Depth Studies (RAIDS) database for motorcycle collisions involving facial impact [5]. In that study, thirty cases were reconstructed in Madymo (Siemens, Germany) and a parameter sweep uncertainty analysis on impact speed, angle, stature and posture was conducted to capture a range of possible impact configurations, resulting in 1476 simulations [5]. The aim of this study is to determine representative facial impact conditions from that set of 1476 simulations, using clustering analysis which can provide scenario-based test conditions for helmet safety assessment.

II. METHODS

Three parameters required to design a helmet test method were identified: (1) head orientation, (2) head impact speed, and (3) anvil angle (Fig. 1). The head orientation was extracted as an Euler ZYX rotation sequence, calculated from the transformation matrix of the head relative to the impacted surface. The k-means clustering algorithm was implemented to sort head orientations from all simulations into four clusters, based on the author's judgement of how impacts could be grouped. The clustering method allows relationships between quantities to be maintained, which produces scenario-based configurations.

The head impact speed and angle (the angle between the head velocity vector and surface) were also extracted from the reconstructions (Fig. 1A). Helmet tests involve impact against a steel anvil, rather than a relatively compliant car body. Madymo simulations of the lab test with a rigid anvil were developed to determine the lab head impact speed needed to produce the same peak resultant force in the head as the reconstructions. The lab head impact speeds and anvil impact angles were sorted into three clusters following the author's judgement.

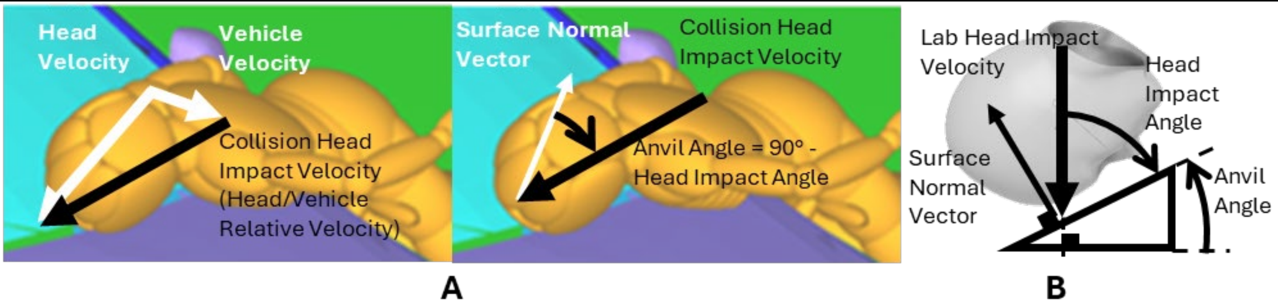

Fig. 1 – (A) Head impact orientation, speed, and angles are extracted from computational reconstructions of motorcycle collision. (B) Schematic of lab test condition for helmets based on reconstructions.

L. Low (lucas.low15@imperial.ac.uk) and W. Dawber are Research Associates, C. Baker is a Research Fellow, and M. Ghajari is a Reader, all at the Dyson School of Design Engineering at Imperial College London, UK. S. Meng is a Biomechanics Expert at Autoliv Research, Sweden.

III. INITIAL FINDINGS

The k-means clustering algorithm produced four representative head orientations shown in Fig. 2A and C, with one orientation representing 71.3% of the cases. We proposed a fifth head orientation which involves an impact on the chin bar. Imposing this orientation in the clustering by replacing the first head orientation and keeping the other three unchanged showed that it represents approximately half the reconstruction dataset (49.4%).

The k-means clustering of the lab impact speeds and angles produced one centroid at 7.3 m/s and 48.5°, representing 63.8% of simulations (red cluster in Fig. 2B). Interestingly, higher head impact speeds were observed in cases where the head impact angle was lower (glancing impact) or higher (impact normal to surface) (left and right clusters in Fig. 2b).

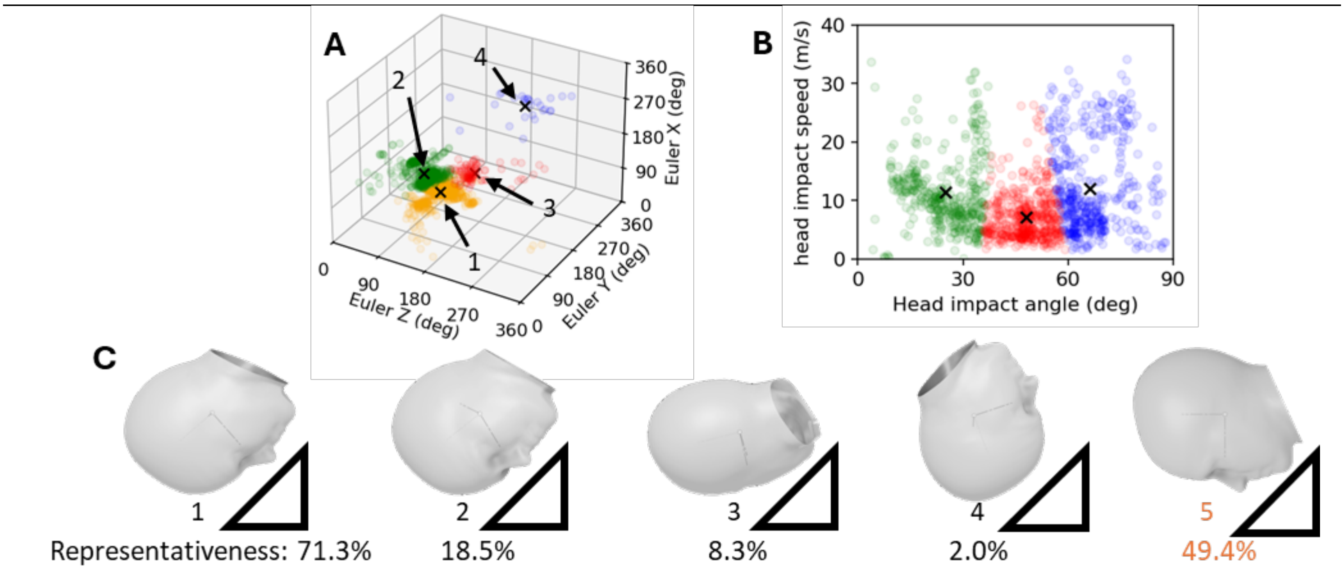

Fig. 2 – Plots of k-means clustering on (A) the Euler ZYX values that define the head orientation at impact, and (B) head impact speed and angle. (C) Representative head orientations for impact on a 45° anvil. A fifth head orientation is proposed as an additional configuration, with representativeness calculated by replacing the first orientation.

IV. DISCUSSION

We found that 71.3% of head orientations in reconstructed motorcycle/car collisions could be represented by an impact to the centreline of the face, with the head rotated approximately 135° in the sagittal plane (Fig. 2c). In addition, 63.8% of the head impact speeds and angles could be represented by 7.3 m/s and 48.5°, where the angle is similar to the median value of 47.9° (interquartile range = 33.3-59.8°).

The two head orientations with the highest prevalence from clustering analysis (Fig. 2C) involve impact to the facial area, in contrast to oblique impacts of UN ECE 22.06, which only prescribes impact to the forehead. The most prevalent head orientation produces a centreline impact to the facial area, which is similar to one of FRHPhe-02's oblique impacts. However, none of these methods represent a chin bar impact. Therefore, we proposed a fifth head orientation aimed at evaluating the performance of the chin bar in mitigating head and brain injuries.

The impact angle of the dominant cluster is similar to the anvil angle in oblique impact tests prescribed by UN ECE 22.06 and FRHPhe-02 standards, 45°. However, its speed is lower than those prescribed by these standards, 8.2 m/s and 8 m/s respectively. We, however, found that the median lab impact speed was 8.7 m/s (interquartile range = 5.1-12.6 m/s), which better agrees with the speeds prescribed in standards.

Overall, this study identified facial impact conditions, including head orientation, impact speed and anvil angle, based on real-world motorcycle collisions. We identified that impacts to the helmet visor and chin bar represent the majority of facial impacts, but they are minimally tested in current standards. An avenue of further analysis is to determine representative angular velocities of the head on impact, which is assumed to be zero in standards. Our results can guide the design of more representative test methods for simulating facial impacts, helping to improve facial protection measures.

V. REFERENCES

[1] Richter M *et al*., J Trauma, 2001
[2] Chinn B *et al*., COST Transport, 2001
[3] Whyte T *et al*., J Neurotrauma, 2016
[4] Baker C *et al*., Accid Anal Prev, 2024
[5] Low L *et al.,* IRCOBI, 2025