Fracture Sensitivity of a Human head Model in Surrogate Drone Impacts

Clément Pozzi, Bastien Paccard, François Bermond and Philippe Beillas

I. INTRODUCTION

The increasing use of professional and personal Unmanned Aircraft Systems (UAS), or drones, raises the issue of injuries such as skull fractures [1] in case of impact with humans, triggering regulatory responses. For the Federal Aviation Administration (FAA), drones over 250 grams can fly over humans only if they do not create a higher injury risk than the one that would result from a 15 J impact with a rigid object [2]. The European Union Aviation Safety Agency (EASA) uses an 80 J energy level transmitted to the head as one of the criteria to separate drone categories [3]. However, few studies addressed the risk of head injury associated with drone impacts and how it relates to energy. As the impact velocity can be over 20 m/s, injury mechanisms may differ from those observed in the automotive field and dummies or human models may lack appropriate validation. But only reference [4] used PMHSs to study drone impacts. They observed one AIS2+ fracture associated a high Head Injury Criterion value (HIC_{15}=5473), for multiple tests without injuries. These values are far above injury thresholds used in automotive applications. However, the PMHS tests are challenging to reproduce numerically in the absence of publicly available model of the test drones, and complementary tests that could be easily reproduced could be useful for model or dummy validation.

To start preparing for these tests, this study aims to explore the effect of parameters such as kinetic energy, mass or velocity on the occurrence of fracture predicted by an existing finite element model of the head.

II. METHODS

An impactor (drone surrogate) was developed to represent the drone mass and energy absorption capability. It is composed of a 45 mm thick honeycomb tip for energy absorption in front of a rigid body (that could represent the stiff battery). Parameters included mass (from 0.3 to 5 kg), honeycomb pressure (10 MPa, 15 MPa, 20 MPa, rigid), a 45 mm square section and initial velocity (10 to 30 m/s). The whole 50th percentile male detailed occupant model from the Global Human Body Model Consortium (M50-O v6.0) and LS-DYNA (R9.3.1, LST, Livermore, CA, USA) were used for the simulations. The tip of the drone surrogate impacted the forehead as shown in Figure 1. Fracture was defined as the elimination of at least one element of the skull. The threshold for element deletion was 0.0088 maximal principal strain for cortical bone.

III. INITIAL FINDINGS

Results are shown using the 15 MPa honeycomb simulations (n=52) as they illustrate the main mechanisms, include fracture and non-fracture cases and exhibit a honeycomb deflection lower than 12mm, which is considered possible even for a small drone.

While fracture occurrence increased with kinetic energy (Figure 2), a large overlap was found between non-fractured (15-120 J) and fractured (50-400 J) cases. In many cases, for the same energy level, increasing the velocity (while reducing the mass) led to fracture. For example, at 80 J, fracture only occurred at 15m/s and over. The lowest energy with fracture was 50 J (at 30 m/s), which is below the 80 J defined by EASA for transferred energy. With a rigid impact at 30m/s, the lowest energy with fracture was 37 J, which is above the 15J used by the FAA.

Similarly, for the HIC_{15}, there was a large overlap between fractured (4000-16000) and non-fractured (500-7200) cases. Increasing the velocity (for similar HIC_{15}) also led to fracture in some cases (i.e. fracture at 20m/s HIC_{15}=5854 but not at 10 m/s HIC_{15}=6011). The first fracture was for HIC_{15}=4087, which is slightly lower than in [4] (HIC_{15}=5473). Using the 80 J at 30 m/s as an example, a few changes were made to check what could affect the HIC_{15}. Regarding the measure itself, changing the acceleration measurement from a constrained interpolation using nine nodes on the base of the skull to skull nodes in a location similar to the instrumentation in [4] or to the whole diploe changed the HIC_{15} from 10570 to 10290 and 2647, respectively. Rigidifying the skull using an aluminum material as in the dummy changed the HIC_{15} from 10570 to 1313 (which is more in line with magnitudes measured in [5-6] on dummies). Finally, as the HIC_{15} was obtained over durations typically lower than one millisecond, which questions the use of a 1000Hz filter in the calculation, higher frequency filters were tested leading to higher values (e.g. 20730 for 1500Hz and 23060 for 2000Hz).

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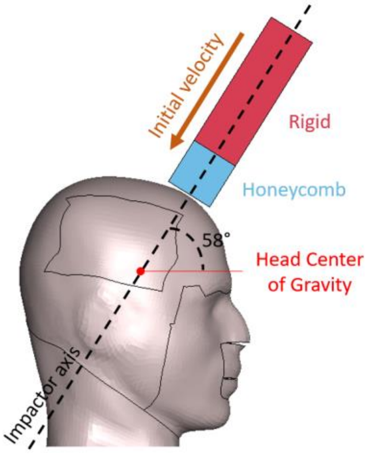

Fig. 1. Impact condition between the drone surrogate and human model. The angle of 58° was selected as in [4].

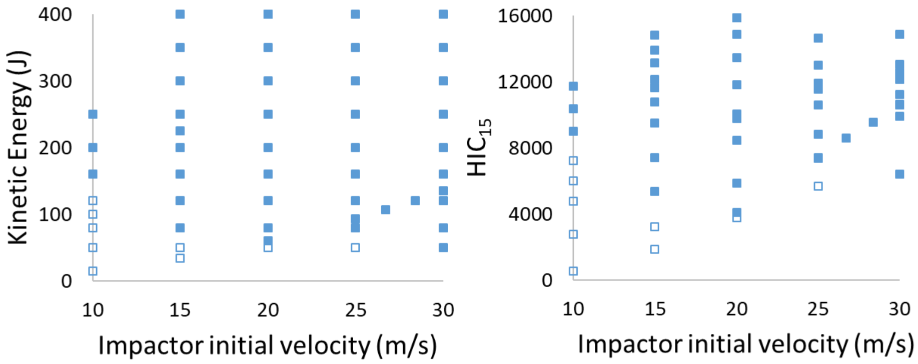

Fig. 2. Kinetic energy (left) and HIC_{15} (right) vs. velocity (15 MPa honeycomb). Simulations with fractures are denoted by the solid dots.

IV. DISCUSSION AND PERSPECTIVES

Simulations results highlighted an effect of the impact velocity, the importance head deformation, and the difficulty to separate fracture from non-fracture using kinetic energy or HIC_{15}. The main limitation about this preliminary study is that the biofidelity of the human model is unknown for such high impact velocity. Published validation conditions are all at lower velocities [7]. The model was already checked against woodblock lateral impacts up to 12 m/s [4] but this is also below the simulated velocity range. Efforts were initiated to simulate the drone tests from [4], and drone testing at a project partner (the French Aerospace Lab, ONERA) will help model the impact conditions. Additional metrics, beyond element elimination, will also need to be developed to better characterise the fracture and its pattern.

Regarding the test preparation, after additional verifications regarding the model validity, the current simulation approach will be used to select the test severity in order to avoid conditions which are too injurious or too benign. The results suggest an interest for a wide range of velocities (e.g. 10 to 30 m/s) to study the skull deformation mechanisms. Drone characterisation ongoing at ONERA will help support the choice of honeycomb pressure. Also, although HIC_{15} limitations were already highlighted, head acceleration could be useful for model validation but a particular attention will be needed regarding the measurement location. An additional acceleration measurement will be considered on the drone side using an on-board acquisition system to help with the simulation. A sensitivity analysis using other impactor shapes and sizes is also ongoing (results are not presented here) which will help select the final drone surrogate dimensions.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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