Skull Fracture Risk Transfer from a Human Body Model to a Dummy Head for High Speed Impact Conditions.

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I. INTRODUCTION

A case of comminuted depressed skull fracture following an impact from a recreational drone was reported in literature [1], demonstrating that a risk of head fracture exists even with low-mass drones. Regulatory frameworks proposed for drone safety by both the Federal Aviation Administration and the European Union Aviation Safety Agency include energy levels (e.g. 15J rigid impact risk equivalence or less than 80J transmitted to the head) but no such injury criteria are measurable on a dummy. The specificity of drone impact conditions (low mass, highly deformable, high speeds often over 20m/s) and the few drone-like tests on post-mortem human subjects (PMHS) [2] raise some questions about the selection of an injury criterion.

In that context, a human body model (HBM) head was subjected to numerous impact conditions matching literature PMHS tests [3] including the drone tests from [2], high speed rigid impacts and lower speed rigid and deformable impacts. Skull fracture risk curves were developed based on 156 cases using peak strains in the skull and matching fracture status (67 skull fractures out of 156 cases). Many had a good or fair quality index (in the sense of ISO TS 18506:2014) over a large range of risks.

The objective of this study is to assess the feasibility to transfer this risk prediction to a test device (Hybrid III) using matching head impact conditions by simulation.

II. METHODS

The HBM head and neck (GHBMC M50-O v6.0) and risk curve with the best quality index (predictor: peak 2nd principal strain in the skull outer table) from [3] were used. The dummy head and neck were extracted from LSTC HIII 50th model version 190217 and: (1) the skin material was replaced by Ogden properties provided by LSTC (2) the head centre of gravity (CG) position was adjusted. The dummy head was checked against previous tests [4].

Impacts on the forehead at 58° from the horizontal were selected as a possible worst case scenario as impacts to the side of the head would likely engage the arms of small drones and mitigate the impact [2–3]. The head CG, impactor CG and velocity were all aligned with the 58° axis. Six impactors (two drones, one battery, three parametric simplified impactors, Fig. 1) were launched at initial velocities of 15, 22 or 30 m/s. Combined, this corresponds to 165 impact conditions per head. All simulations were run in Ls-dyna R12.2 (ANSYS/LSC). The process was automated to calculate the risk (HBM) and acceleration based criteria (HBM, dummy). Accelerations were sampled at 100 kHz and filtered using an SAE J211 CFC 1000 filter.

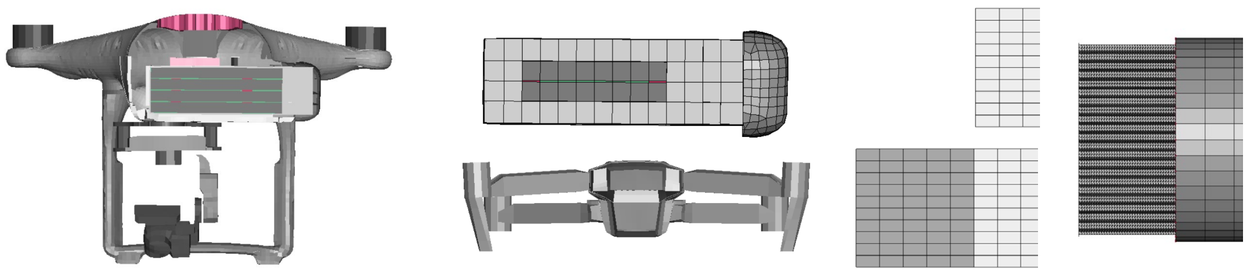

Fig. 1. Impactors models. From left to right: DJI Phantom 3 [3] and its battery, DJI Mavic Pro [3], rigid 45 mm square optionally covered with simplified honeycomb (5, 10 or 15 MPa) [5] and 63 mm rigid cylinder covered with a detailed shell honeycomb model (20x20 or 40x40 square or 60mm diameter as shown, 2, 7 or 15 MPa peak) [4]. The idealised impactors had masses of 0.15, 0.3, 0.6 or 0.9 kg. They were previously used to try to represent drones in simplified impact [4–5].

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III. INITIAL FINDINGS

All simulations ran successfully. The impact duration was short (much lower than 1ms for 30 m/s rigid impacts, a few ms for drones at 15m/s). Paired simulations were first used to build scatter plots linking peak acceleration and risk prediction (Fig. 2). A trend was noted, with a saturation for high risks. Also, while the idealised impactors and battery results are largely overlapping, the drones are on the right edge of the cloud (higher acceleration for a given risk). In order to visualise the spread of the prediction, mean, minimum and maximum acceleration corridors were built using a moving average (values for 15 risk levels considering points within 10% of the risk range around). The same approach was used for the Head Injury Criterion (HIC) over 15 ms but the spread was found to be much higher in that case (the width of the corridors divided by the mean was over 2.5 while it was below 1 for the peak acceleration over most of the risk range).

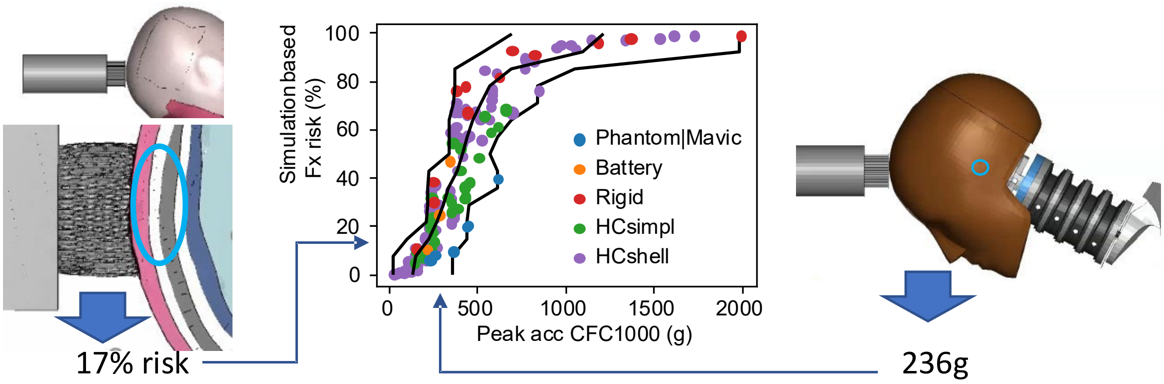

Fig. 2. Overview of the transfer methodology. For each impact condition (e.g. 22m/s 7MPa shell honeycomb 40mm side 0.3 kg shown), a simulation with the HBM is used to predict the risk based on skull strains (here 17%) while a simulation with the dummy is used to predict the acceleration (here peak, 236g). This is repeated for the 165 conditions to build a transfer scatter plot (centre). Colours correspond to the impactor type.

IV. DISCUSSION

A methodology was developed to attempt the transfer HBM based skull fracture risk predictions to a dummy over a wide range of impact conditions potentially relevant for drone impacts. The methodology was automated, facilitating its use for other impact locations, more impact conditions or improved risk curves. While this is purely empirical, a clear trend can be observed between the dummy peak acceleration and the HBM risk. However, there are also significant variations at a given risk level. More work is needed to better understand the possible causes, and especially why the drones are on the edge of the response cloud. Their larger contact surface or load duration could play a role but this needs further investigation. Also, the analysis suggests a higher spread for the HIC which could be due to the short duration of the impacts but this would need to be confirmed and other criteria or parameters (e.g. durations) could be tested. Finally, a simple normalised corridor width was used to quantify and compare the criteria (similarly to the approach of ISO TS 18506:2014 in which the confidence interval is divided by the mean) but alternatives and further statistical analyses should be investigated.

V. REFERENCES

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