Adjusting Drone Surrogate properties for PMHS testing: experimental response and numerical model

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I. INTRODUCTION

The growing popularity of drones, both for commercial and personal use, has raised concerns about injuries from drone-human collisions, particularly skull fractures [1]. Regulations by aviation authorities (FAA in the USA [2], EASA in Europe [3]) restrict drone flights over populated areas. However, there is limited research on head injury risk from drone impacts. Drone speeds can exceed 20 m/s, potentially resulting in different injury mechanisms compared to traffic injuries. Only one study, by Stark *et al.* [4], used PMHS to investigate impacts with actual drones. They observed a single skull fracture (AIS2+) for a very high value of the injury criterion (HIC_{15}=5473). All other tests had no injuries despite HIC_{15} values significantly higher than those used in vehicle safety standards.

Replicating these tests (physically and numerically) is difficult as the drones tested by [4] are (1) not commercially available anymore, and (2) not publicly available as numerical models. Therefore, developing reproducible tests methodologies using drone surrogates would be valuable to validate existing Human Body Models (HBM) or Anthropomorphic Test Devices (ATD). Based on preliminary numerical work [5-6], a drone surrogate divided into a rigid body representing the drone effective mass (60 mm diameter, 0.4–2 kg) covered by a honeycomb tip representing the energy absorption capability (up to 15 MPa) may be usable to represent drones during the brief contact with the head.

In preparation of upcoming PMHS tests, these drone surrogates were physically implemented. This study aims to: (1) compare them to actual drones in physical tests on rigid surfaces and ATDs to preselect characteristics for future non/injurious tests; and (2) develop their numerical models to ensure their usability in simulations.

II. METHODS

Drone surrogates were tested against a Hybrid III forehead at a 58˚ angle (as in [4][7-8]). Head CG resultant accelerations were compared to past tests with the actual drones: a DJI Mavic 2 (non-injurious in [4], dummy tests at Univ. Eiffel [7]) and a Phantom 3 (injurious in one test of [4], dummy tests at NIAR [8]).

Tests on a rigid surface were used as references for the simulation work to avoid introducing possible errors due to the dummy model. The same actual drones were tested at 22.0 m/s against a fixed rigid surface similar to a Hybrid III skull shape at ONERA. Ten drone surrogate configurations were also tested against a fixed similar shape (Hybrid III skullcap). In both cases, a load cell measured the impact force. The model of the surrogate was divided into a rigid cylinder and a honeycomb tip. For the honeycomb (Hexcel 7 MPa 1/8-0015-5052 or 15 MPa 1/8-0025-5052), an actual representation of the cells with shell elements (0.9 mm side triangular elements) was adapted from examples provided with the solver used (LS-DYNA R9.3.1, LST, Livermore, CA, USA). The honeycomb aluminum (5052 H39) was modelled using a piecewise linear plasticity material with parameters derived from [9].

III. INITIAL FINDINGS

A. Comparison of actual drones and surrogates in dummy tests (Fig. 1)

Peak head accelerations are similar for the Mavic 2 and Phantom 3 (below 2200 m/s²), with a slightly longer duration for the Phantom 3 (about 2 ms). Combinations of honeycomb pressure and surface area listed in Fig. 1 result in a wide range of responses comprising the peak accelerations and durations of the actual drones. It includes conditions with a much higher peak and similar duration as the Phantom 3 (Fig. 1, H3_43 curve), much lower peak and duration as the Mavic 2 (Fig. 1, H3_40 curve). The peak acceleration can be modulated by changing the honeycomb pressure or the surface area (2827, 900, 400 and 225 mm² tested).

B. Comparison of physical and numerical drone surrogate model against rigid surfaces (Fig. 2)

With the two actual drones, the forces peak at 11.7 kN and 17.9 kN. Among the ten configurations tested, drone surrogates using 60 mm diameter 7 MPa and 15 MPa honeycomb tips lead to similar peak forces (11.1 kN and 20.7 kN) with different load profiles and durations. For the simulations, the maximum principal strain at which elements are eroded required adjustments as low values lead to the erosion of most elements and high values to very high forces. Using the same value of 14% in the erosion card for the ten configurations, the simulation and experimental force time histories closely match (examples Fig. 2, peak, shape, and phase). Oscillations late in the physical tests are likely due to vibrations of the mount, which was rigidly fixed in the simulations.

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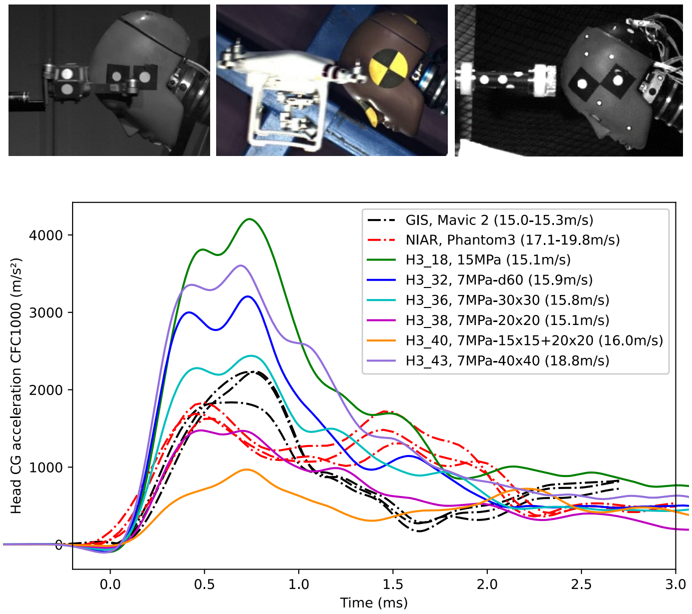

Fig. 1. Examples of Hybrid III tests: setup (top, Mavic 2, Phantom 3 [8], 0.34 kg surrogate) and head accelerations (bottom).

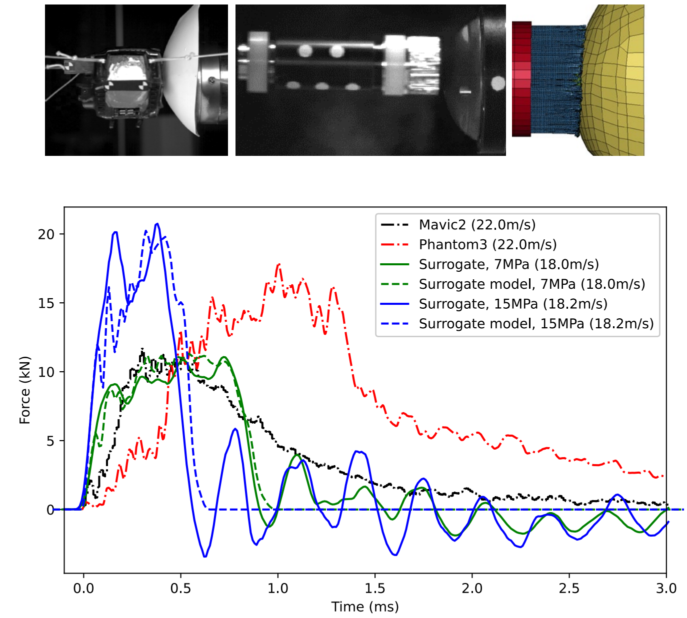

Fig. 2. Examples of rigid surface tests and simulations: setup (top, Mavic 2, 0.4 kg surrogates) and forces (bottom).

IV. DISCUSSION

Adjusting drone surrogate parameters (mass, surface area) within their design range leads to acceleration curves with magnitudes and durations ranging from significantly larger than the injurious conditions in [4] (peak twice as large) to significantly lower than a non-injurious condition of [4] (peak and duration) at similar impact velocities. The surface areas are possible for drones (e.g. contact area between approximately 600 mm^2 and 4,000 mm^2 in Mavic 2 tests depending on the configuration [7]). This suggests that drone surrogate parameters could be adjusted to conditions potentially injurious or not injurious in future PMHS tests while remaining close to the real-world behavior of actual drones. Additional pressures and masses may be tested to have more variations of contact area for a given peak force.

In the rigid setup, the drone surrogate model was able to approach its experimental reference with the same modeling parameters in all conditions simulated. Although this required a detailed honeycomb model, this suggests that it will be possible to represent the drone model in future simulations (reproducibility).

Future work will test (physically and numerically) additional drone surrogate parameters to refine the future PMHS test condition and to ensure the usability of its model against Hybrid III and human body models.

V. ACKNOWLEDGEMENTS

This work was conducted as part of the Ground Impact Study II project, which is a collaborative project with ONERA funded by the French Directorate General for Civil Aviation (DGAC). The findings and conclusions of this study are those of the authors and do not necessarily represent the views of the funding organisation.

The authors acknowledge Ohio State University and NIAR for sharing detailed test results.

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