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Development of a surrogate model to represent drones in head impacts

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1. Introduction

The increasing use of professional and personal Unmanned Aircraft Systems (UAS), or drones, raises the issue of injuries such as skull fractures in case of impact with humans, triggering regulatory responses. Due to speed and energy differences, injury criteria developed for automotive safety may have important limitations. Stark et al. (2019) used Post-Mortem Human Surrogates (PMHS) to study drone impacts with real drones. They observed a fracture and measured injury criteria that are inconsistent with values typically encountered in automotive safety. However, these tests are challenging to reproduce numerically in the absence of publicly available model of the test drones. Complementary tests that could be easily reproduced could be useful to understand the loading mechanisms and validate numerical models or procedures, especially at high speeds for which numerical models or dummies were not validated. Rather than using actual drones in these tests, it would seem desirable to use drone surrogates representing their key characteristics while being simple enough to implement in physical tests and in simulations.

The objectives of this study are to (1) design and validate numerically a concept of drone surrogate in preparation of future tests (2) test a drone model to use to simulate the tests from Stark et al. For this, the responses of models representing either a drone structure (simplified model) or a model with a rigid mass covered by honeycomb (surrogate model candidate) will be compared against various test conditions. The drone test case is the DJI Mavic 2.

2. Methods

2.1. Drone models development

Two finite element models were developed in LS-DYNA (Figure 1): (1) a simplified model based on a surface scan of the drone components (plastic shell, reinforcements, electronic cards, battery cells, arms, etc.) and (2) a surrogate model with a rigid mass

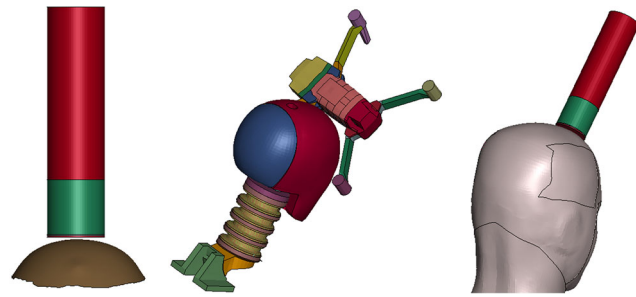


Figure 1. Rigid surface (left), Hybrid III (centre) or GHBMC (right) were simulated against both simplified (centre) and surrogate models (left, right).

covered by honeycomb aiming to represent the effective drone mass and its energy absorption capability, respectively. The honeycomb is composed of several layers to allow progressive compression and energy absorption. Such model could be implemented physically and used in testing.

2.2. Test conditions and simulation process

First, to help adjust both components of the simplified model and characteristics of the surrogate model, three reference physical tests with an actual drone were performed at Onera against a rigid surface similar to a skull shape (22 m/s, just over the highest speed in Stark's study). Then, to see if further adjustments were needed, the models were used against a Hybrid III dummy as in tests with actual drones performed in the past at Univ. Eiffel (15 m/s) (Berthe et al.). The models were finally used against a head model (Global Human Body Model Consortium, GHBMC M50-O v6.0) in conditions similar to Stark et al. (18.5 and 21.5 m/s). The impact condition between the side of the drone body and the forehead was selected for all simulations.

3. Results and discussion

3.1. Impacts on rigid surface

Different combinations of surrogate mass and honeycomb layers as well as properties of the simplified model were simulated to try to match the experimental reaction force-time curve (Figure 2, top). The selected drone surrogate (Figure 2, top) has a mass of 300 g (actual drone: 730 g) and three honeycomb layers, with thicknesses of 42.5, 1, and 1.5 mm and pressures of 7.0, 3.0 and 1.3 MPa, respectively. Both models were able to approximate the experimental response during the loading phase (0–0.3 ms). Then, both approached the magnitude of the experimental force plateau (0.3–0.6 ms) although a short peak force is present for the simplified model. However, both models had a quicker rebound and their unloading

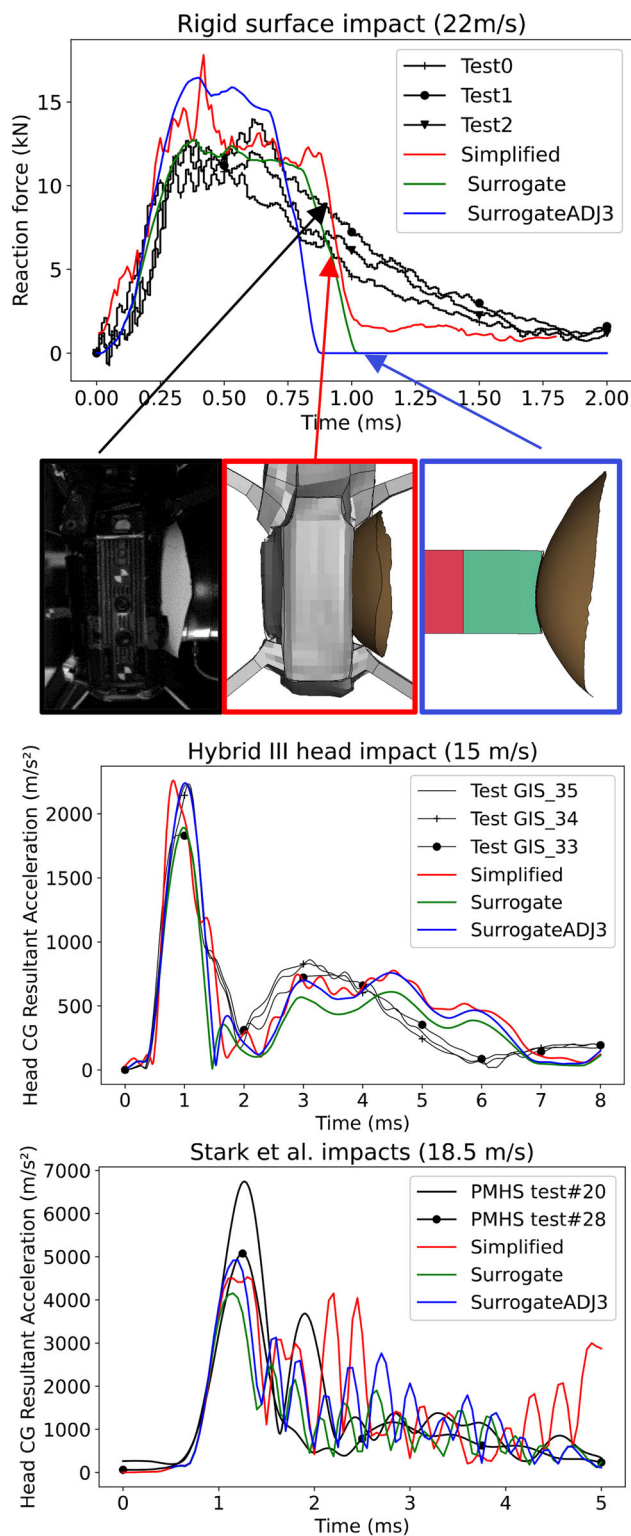


Figure 2. Responses in the three load cases. Accelerations are filtered with a SAE CFC1000 filter. Only 18.5 m/s results are shown for Stark. Images at 1 ms. Physical tests in black.

phase (from 0.6 ms) did not match the experimental curve. This was attributed to the extensive damage on the physical drone decoupling some of the mass from the bulk of the drone.

3.2. Impacts on the Hybrid III head

The drone surrogate rebound occurred much earlier than for the simplified model and physical drone. As defined for the rigid impact, the drone surrogate led to a lower head acceleration (peak and duration) compared to the simplified model and two of the three physical tests (Figure 2, center). Increasing the mass by 75 g and honeycomb pressure by 20% was required to align its response with the others. The new surrogate was labelled surrogateADJ3. Such properties would have led to an overestimation of the force in the rigid shape simulation (Figure 2, top).

3.3. Impacts on GHBMC human model

As for the Hybrid III, the drone surrogate rebound was too early. The accelerations measured at Stark's location varied substantially between the different models and the two tests (Figure 2, bottom). The adjusted surrogate and simplified model approximated the first peak of test #28, hence underestimating the one of test #20. After that, large vibrations were visible in Stark's test #20 and simplified model while these were less marked on other curves. Similar trends were observed at 21.5 m/s. These may result from the deformability of the skull and seem difficult to predict.

Finally, none of the simulations (18.5 and 21.5 m/s as in Stark) resulted in GHBMC skull fractures. This is coherent with Stark et al. (2019) tests and previous simulations underlining the absence of fracture in the GHBMC for honeycomb pressures below 10 MPa (Pozzi et al. 2022).

3.4. Effective mass

When analyzing the response of the simplified model, it was observed that a large proportion of the drone was still moving forwards after the head peak acceleration was reached. This could explain the low value of the effective mass of the drone surrogate (compared to the physical one) and the early rebound. The effective mass to consider was affected by the boundary condition (fixed vs. interaction with a moving head), suggesting impacts on a fixed surface are not sufficient to determine drone surrogate properties although they are useful to identify initial parameters.

4. Conclusions

Both simplified and adjusted surrogate models were able to load the head in a way that is close to the physical test (first acceleration phase). Larger differences were visible later (rebound). Considering the large

differences between actual physical drones (Stark et al. 2019), this confirms the interest of using drone surrogates in future tests to load the head in a plausible manner while helping with the reproducibility (numerically or by other teams). However, due to limitations related to the effective mass and rebound, the simplified model approach should be favored if trying to validate a human head model against the tests from Stark et al. Future work will include the application of the same method to another drone tested by Stark et al. and testing on dummy and PMHS using a physical implementation of the drone surrogate.

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