DRONE STRIKE ON A HELICOPTER CANOPY DEMONSTRATOR

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Abstract
The evaluation of structures under impact where large-scale projectiles like birds or drones are involved needs analyses at full-scale. The reason is that size effects can yet not be scaled from smaller samples. Hence, a canopy demonstrator with representative dimensions of a medium sized helicopter was developed.
The two objectives for the demonstrator were the design development of a purely bonded windshield concept and the sizing of the windshield. For the windshield, polycarbonate (PC) was used while the carbon fibre reinforced plastics (CFRP) composite frame was adhesively bond by polyurethane.
The experimental results of bird impact tests at different temperatures were used to validate the modelling and simulation approach for the final component design in the real 3d design.
For the drone strike analysis, drone configurations and sizes were analysed. The work was then focused on the widely applied quadcopter configuration. Several steps were taken to validate the material and structural behaviour of the selected drone.
With the generated quadcopter model, several loading conditions on a fast compound helicopter were modelled and the impact of the drone was applied. For the first experiment of a quadcopter drone strike on a plastics windshield a critical impact load case was selected.
To further improve modelling and simulation, there was applied a path for the correlation by means of an instrumentation by force measurement.

1. INTRODUCTION

The impact of foreign objects is a safety relevant issue with probably bird strike as the best-known impact in aviation. Due to the fact that drones might impact a rotorcraft with similar impulses (and kinetic energy) as birds, there is a reason to compare these two problems. Moreover, not only the impulses but the impact speeds and weights of birds and small commercial drones are comparable. However, the composition of the two impactors are different which defines the need to study both threats in detail.
Bird strikes on rotorcraft were scrutinised by a working group initiated by the FAA and pointed out that in the US about 40-47 % of all bird strikes in the period from 1990 to 2016 the front glazing is affected [2] (Figure 1). While bird strike on medium to heavy helicopters (FAR Part 29, EASA CS-29) is covered by a requirement since 1993 [3], light helicopters (FAR Part 27, EASA CS-27) are not certified against bird strike.
EASA has observed an increase of bird strikes involving civil rotorcraft [4] and only 10% of the EU civilian helicopter fleet has been certified with a bird strike requirement.

The beforenamed activities led to the following recommendations:

- Bird strike protection rulemaking, policy, and guidance for normal category rotorcraft should be improved.
- An evaluation of the existing bird strike protection standards for transport category rotorcraft should be performed.
- Recommendations for enhancement of rotorcraft not certified with a bird strike requirement are intended.

The latest step is already covered by a notice of proposed amendment [1] which indicates a future bird strike requirement for CS-27 helicopter windshields similar to the existing CS-29 paragraph. This outlines that already the safety against bird strike, considered as soft body impact, is under current improvement.

The drone strike, indicated as hard body impact, is a relatively new issue compared to bird strike and evolved out of the increasing and massive spread of commercial light drones in the past decade. But the risk is not easy to quantify while a few cases of drone strike in rotorcraft aviation which point to penetration damages in the windshield [5][6] (Figure 3). The statistics indicates increased sightings and occurrences [7][8] of drone operation close to

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Presented at 47th European Rotorcraft Forum, United Kingdom, 7-9th September, 2021

aviation which is driven by the excessive business with small drones [9][10] (Figure 2). However, exact numbers are hard to find.
Currently, with both sightings and selling numbers, a probability-based approach for drone strike cannot directly be derived. Furthermore, there are means to avoid commercial drone impact (geo fencing, e. g.) instead of making windshields in a sturdy design against drone strike.

The most comprehensive and earliest studies with respect to drone strike in aviation are given by the ASSURE network in the US [11]. The latest drone strike tests on windshield (passenger aircraft) were covered in [12] and further drone strike work from component loads, numerical simulations and experiments shall be acknowledged here [13][14][15]. However, the published material does not cover the drone strike on polymeric windshields of rotorcraft in detail and studies the severity of such impacts. Polymers like PMMA and PC are widely used for helicopter transparencies.

Here, the influence of a drone strike on a polymeric windshield in the dimension of a medium helicopter shall be studied. The windshield is adhesively bonded to a CFRP canopy frame. This setup shall be called helicopter canopy demonstrator. Comparisons are drawn to bird strike as a reference case which was performed on the identical demonstrator and with the same measurement systems.

2. DEVELOPMENT OF CANOPY DEMONSTRATOR

The canopy demonstrator was developed in the course of a windshield development for a technology demonstrator of a high-speed compound helicopter [16]. The canopy demonstrator replicates the thickness and length while in transverse direction it has half of the pilot windshield width (Figure 4).
The demonstrator applies a coated polycarbonate windshield which is exclusively bonded by a paste adhesive (Figure 5). The task was to demonstrate the mechanical performance under impact. In this respect, the canopy demonstrator served as a validation unit for numerical modelling & simulation.
The canopy demonstrator was the largest of various specimen tests at various detail levels. Some key validated models shall be given here with the polycarbonate which was modelled under strain rate and temperature influence [21], the adhesive which as characterised in two loading modes and modelled by a cohesive zone model [22]. The artificial bird model was validated against normal and inclined impact [27].

3. MODELLING AND SIMULATION OF IMPACTOR MODELS

3.1. Bird Model

The modelling of the artificial bird was done by means of smoothed particle hydrodynamics (SPH) applying a novel particle distribution with a smoother load response [20]. In the experimental world, the patented reinforced artificial bird [17] was studied in various test configurations under normal, inclined and splitting conditions [19][27]. For the normal loading a comparison with a real bird was performed using the identical measurement setup (Figure 11).

3.2. Drone Model

The considered drone should be a widely used model as pointed out earlier. Furthermore, it should be privately piloted by persons presumably unconscious for aviation safety. These small drone type falls under the EASA C2 category [23] with a weight limit of currently 2 kg.
The selected multi-copter was a quadcopter (i. e. a multi-copter which has four arms) with a motor and one rotor at each end of the arm. With an operating weight of approx. 1.2 kg [25][26] it falls under the EASA C2 category [7][23]. This type was involved in earlier studies, too [11][12].
The modelling was done by a parametric modelling to ease studies with variations of the quadcopter setup [24]. The components battery, motors and camera where tested at lower impact speeds to create a validation basis [27]. A morphed version of the entire drone (Figure 8) was tested on a load measurement system (Figure 11) before subjected to the impact test the canopy demonstrator.

4. MODELLING AND SIMULATION OF WINDSHIELD AND CANOPY DEMONSTRATOR

The canopy demonstrator was modelled to study the impact performance of the windshield which is bonded to the CFRP frame. Moreover, the test bench consisting of the aluminium support structure with a clamping fixture of the CFRP frame only plus the load cell instrumentation completes the simulation model. This comprehensive model was created for the purpose of bird strike analyses [16]. The simulation scenes and video frames from the test in Figure 6 show the behaviour on a corner impact of a 1 kg artificial bird at 110 m/s with a low canopy demonstrator temperature.

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5. RESULTS OF IMPACT STUDIES

The impact studies comprised several tests with centred and corner impact with high and low temperature for the bird strike [16] and a centred impact at high temperature for the drone strike.

5.1. Results of Demonstrator under Bird Strike

The result of a bird strike on the corner was discussed in paragraph 4 as is shown in Figure 6.
All load cases were both simulated and tested. These did not lead to a failure of the windshield or the CFRP frame. In the adhesive bonding, a local delamination between PC and past adhesive was present after impact under corner impact in the right side of the demonstrator. Even a post-impact residual strength test with static loads did not lead to a disintegration of the windshield and CFRP frame.

5.2. Results of Demonstrator under Drone Strike

The drone strike was performed on the windshield centred to the CFRP frame (Figure 7) with a load instrumentation at each corner of the test bench and with two high-speed cameras. The quadcopter's arms were morphed to house it in a sabot (Figure 8). Due to the restrictions by the institute's gas gun this was necessary. For the testing, the rotors were removed as they represent only a minor weight [24][27]. The centred impact was performed with a demonstrator temperature above 25 °C with a weight of 1.177 kg at 107 m/s.
The impact process is covered by Figure 9 and shows three frames. First, the attitude of the quadcopter just prior to the impact, second, the compressed status of the drone. Third, the status of the demonstrator after the drone fully slipped off the demonstrator and the windshield partly lifted of the CFRP frame at the right side.
The drone impact did not lead to a penetration or fractures of windshield or the CFRP frame. A visual inspection after the testing revealed only surface scratches (Figure 10) particularly around the point of impact. Comparable to the bird strike test, a local delamination was visible between the glazing and the adhesive layer at the right edge (see above with Figure 9, c). Therefore, a classification of the impact effect assessment with 'low' along [7] can be given for the entire canopy demonstrator.

6. SIMULATION VALIDATION APPROACH

A validation based on the load response at three levels is suggested and is outlined in the three following paragraphs.

6.1. First step – drone component load

The drone components battery, motors and camera – the hardest and heaviest parts – were subjected to impact testing at 30 m/s to study the failure modes under various attitudes and to create a data basis for simulation validation [27].

6.2. Second step - drone strike load

A measurement system applied for the soft body impacts (real and artificial bird) was used identically for the impact of the morphed quadcopter (Figure 11). The load response graph is based on the impulse of 1 kg and 110 m/s. It uses a normalisation of forces and time based on average real bird responses on this system. In comparison to the real bird, the experimental artificial bird #DLRRAB [17] in cylindrical shape and its simulation model replicate similarly the rising pulse of the real counterpart but create a load level of approx. 125 %. The drone exhibits a different load pulse shape with a first peak of approx. 100 %, supposedly by the impact of the motors. Subsequently, the load drops and rises again with increased stiffness of the drone body plus the camera body. The overall peak of more than 200 % is created by the battery and centre of the drone body with its electronics. A similar pulse length can be seen compared to the bird.

6.3. Third step – drone strike on demonstrator

The drone test and simulation use a similarly morphed shape of the drone (Figure 12) to account for a possible geometry effect. The comparison between the experiment and its simulation was performed with the same attitude of the drone given in the first frame of Figure 13. The second and third frame show synchronously test and simulation with its respective peak load in the graph. While the visual drone status in the test and simulation appear comparable, the load response, here given by the load sum of the two upper load cells have a delay. The maximum load level can be reached in the simulation and the general characteristics of the test pulse is captured.

7. DISCUSSION

The canopy demonstrator was tested under impact while the test bench was load instrumented by piezo load cells. The testing of the demonstrator comprised several impacts with 1.0 kg artificial bird tests on two locations and a 1.2 kg drone impact test. All tests were performed at approx. 110 m/s.
The complexity of both the demonstrator together with the instrumented test bench and the drone,

requires high modelling effort in simulation (Figure 14). The complex drone behaviour under impact needs to be covered to replicate its load response during fragmentation (Figure 15).
With respect to the canopy demonstrator, there were found limitations to represent the delamination in adhesive bonding of the coated windshield on the CFRP canopy frame.

8. CONCLUSION

A flat canopy demonstrator derived from a rotorcraft windshield development was applied for a drone strike severity analysis. Adhesively bonded polycarbonate can be applied as a windshield for impact safety. Studies with bird strike and drone strike show safety but can be further improved against local delamination. A possible solution is to allow more deformation under impact by the design of the front section to avoid the delamination.

Identically to earlier bird strike analyses, a load instrumentation in the test bench was used in this full-scale testing by drone strike. The load responses measured at the test bench were used to validate a comprehensive simulation model.
The latest techniques in modelling and testing of the artificial bird can used for the development of windshields. A parametric modelling of a commercial drone was performed to support modelling & simulation. In parallel, characterisation and validation of the simulation is ongoing.
The load instrumentation may be not sensitive enough when a large test bench is involved like in the given setup. A more local instrumentation based on the deformation might be less disturbed by the inertia of the test setup.
Overall, the modelling needs to incorporate both test article and test bench with fixtures to create realistic comparability of simulation and test results. Further work on the validation of the drone modelling is considered.

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Acknowledgment

The contributions by the DLR colleagues are greatly acknowledged.

This work was supported by the robust rotorcraft research programme within the German Aerospace Center DLR. Part of the work has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 754336 (Wimper).

Biographies

Stefan Ritt is the principal researcher of this topic. He studied mechanical engineering in Germany and Norway and received his diploma engineering degree at RWTH Aachen, Germany. He works at the DLR Institute of Structure and Design, Stuttgart for more than 16 years on impact simulation and experiments both in scientific and industry projects. In DLR’s design organisation he is involved in certification projects for bird strike. Since 2016 he is active in the SAE working group G-28 for the standardisation of an artificial bird for ingestion testing. From the beginning he hold the position of co-chair, from 2018 he is the chairperson.

He has 5 years earlier experience in static stress of composites, wing and high-lift structures.

Florian Hoefer holds a bachelor degree from TH Ulm and a master from HAW Hamburg, both Germany. Since 2020 he works on impact modelling & simulation plus experimental validation in the same department.

Dorothea Schlie holds an engineering degree from FH Rosenheim, Germany and works as test engineer at the DLR institute of structures and design since 2012. She is involved in all experimental impact setups, testing and instrumentations.

Johannes Oswald completed his bachelor degree at University of Stuttgart on the parametric drone modelling and impact simulations in 2018 with his thesis and subsequently worked as student research assistant until 2020 on the same topic plus drone component validation.

Appendix - Figures and tables

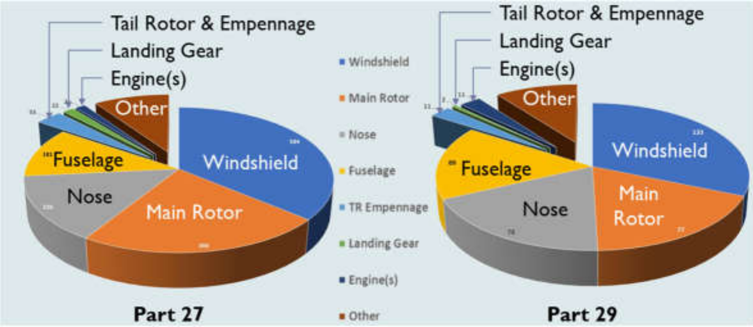

Figure 1 Observed bird strikes on rotorcraft between January 1990 and February 2016 based on FAA's National Wildlife Strike Database (NWSD) [2]

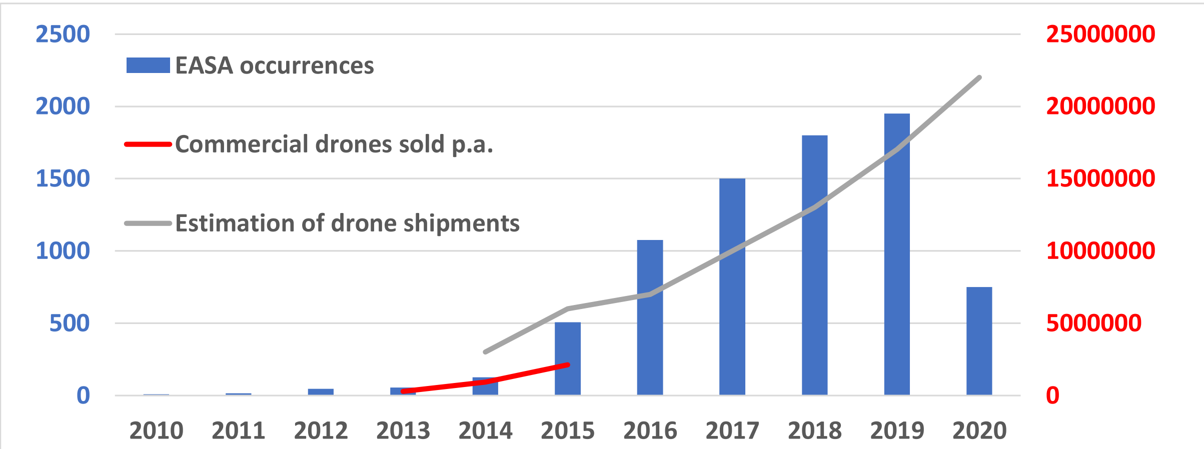

Figure 2 Drone sightings / occurences along EASA [7][8] and commercial drone business [8][9]

Figure 3 Midair collision in June 2020 on a Bell UH-57B with a cracked windshield and injuries to occupant [5]

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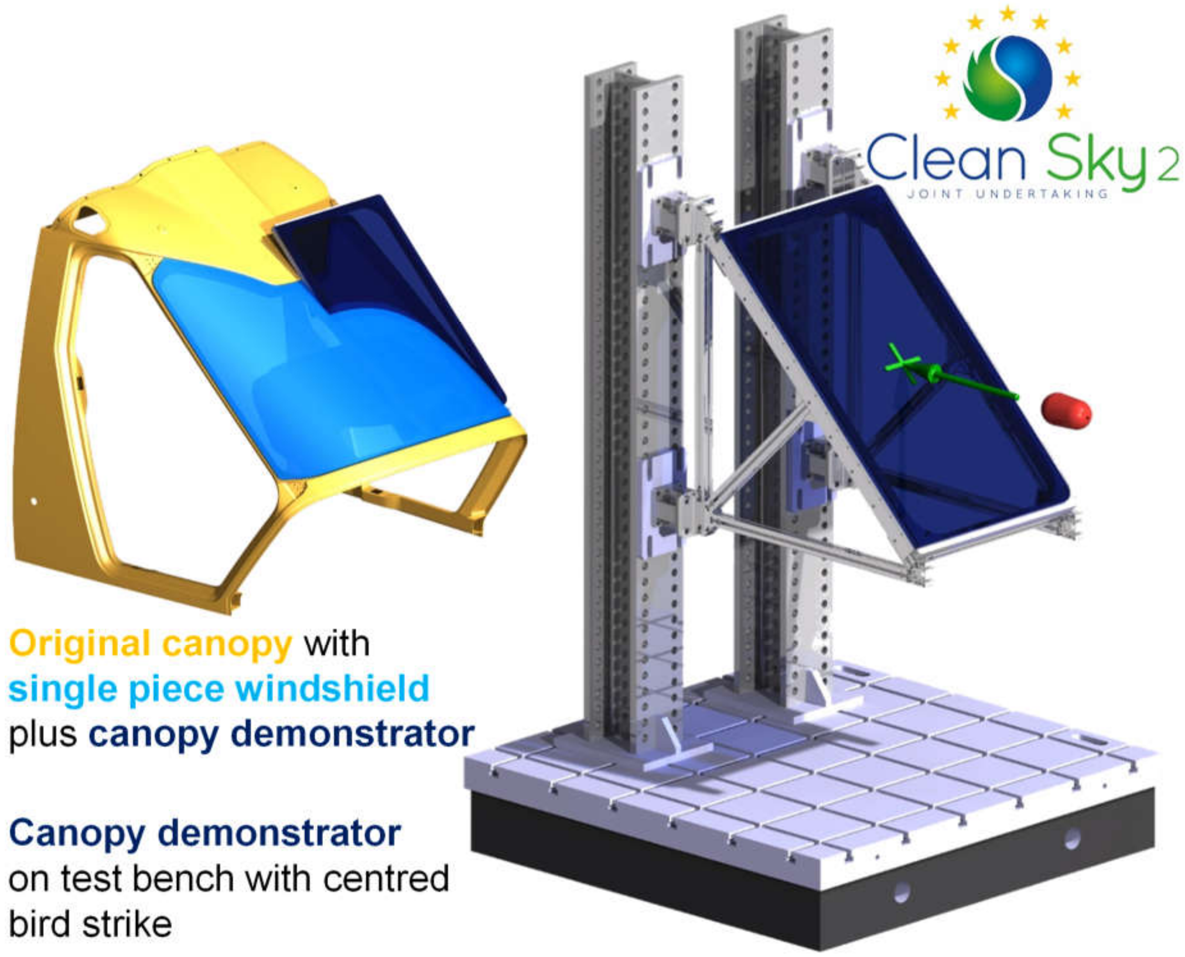

Figure 4 Development of demonstrator out of canopy and windshield from a rotorcraft technology demonstrator [16]

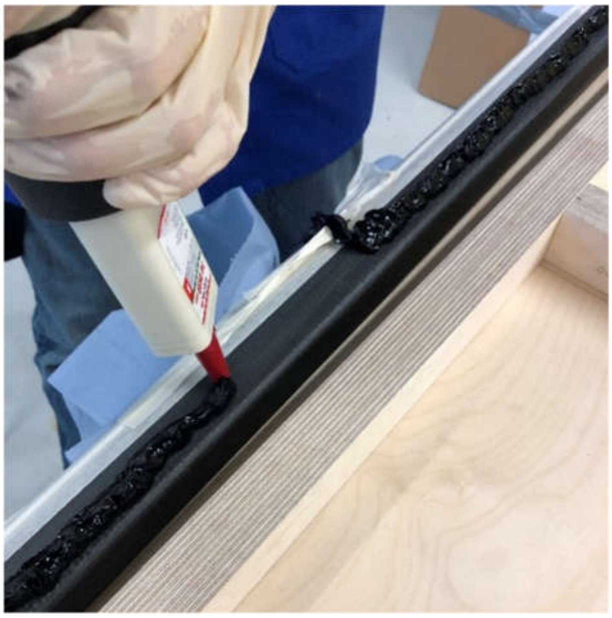

Figure 5 Application of paste adhesive on the CFRP frame of the canopy demonstrator [16]

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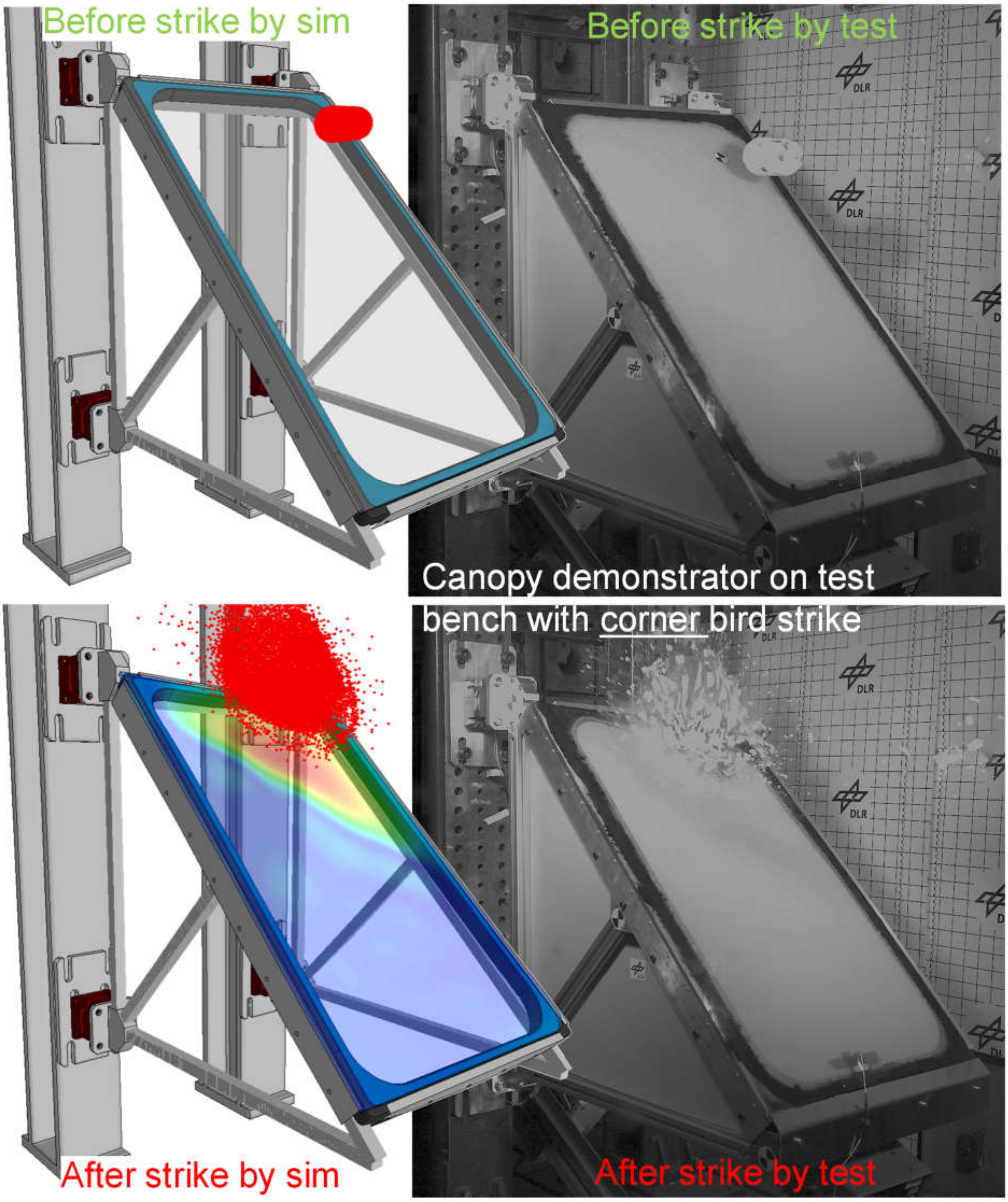


Figure 6 Simulation versus test of a corner bird strike on the canopy demonstrator with the patented artificial bird [17] with 1.0 kg weight

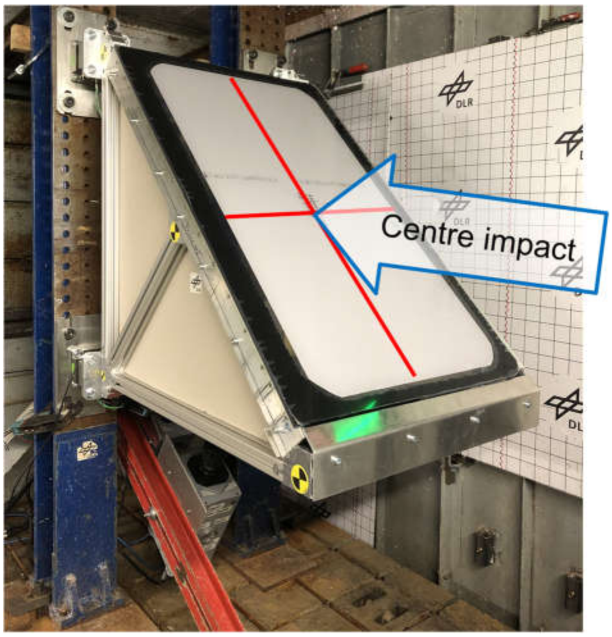
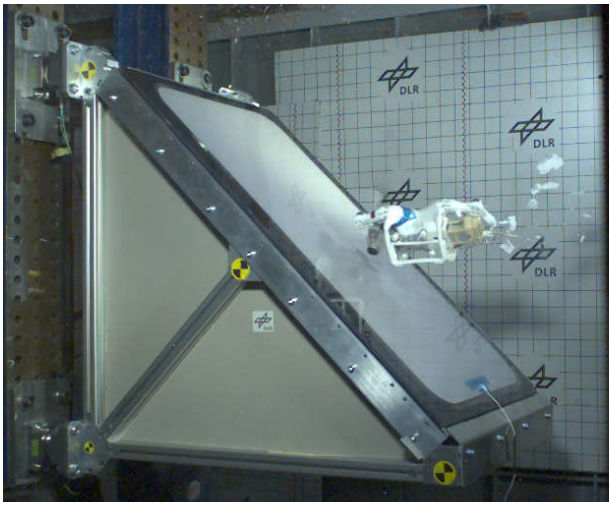
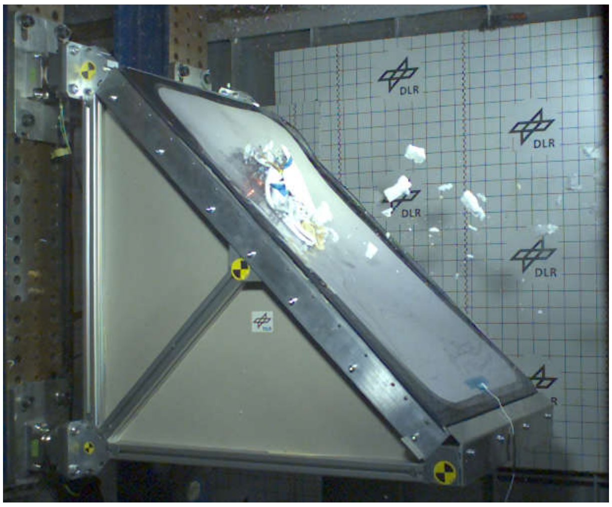


Figure 7 Measurement setup during drone strike test on canopy demonstrator

Figure 8 Morphed quadcopter prepared for drone strike test


(a) Just prior to impact


(b) Drone fully compressed after impact

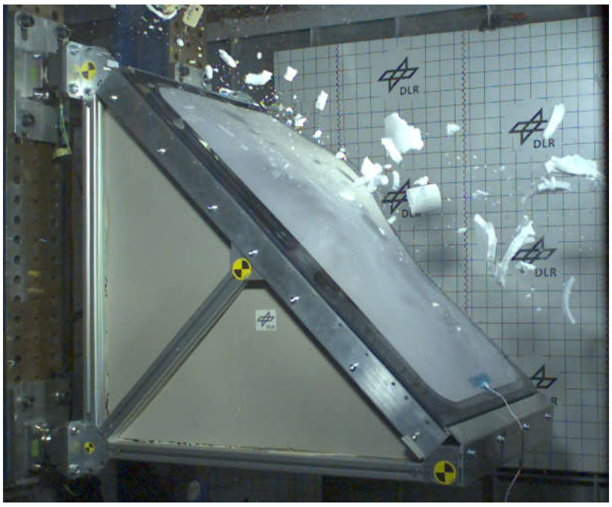

(c) Deformed windshield after drone fully slipped off

Figure 9 Single frames from high-speed video of drone strike test by quadcopter with 1.177 kg weight and 107 m/s speed

Figure 10 Surface scratches on windshield of canopy demonstrator at drone impact location

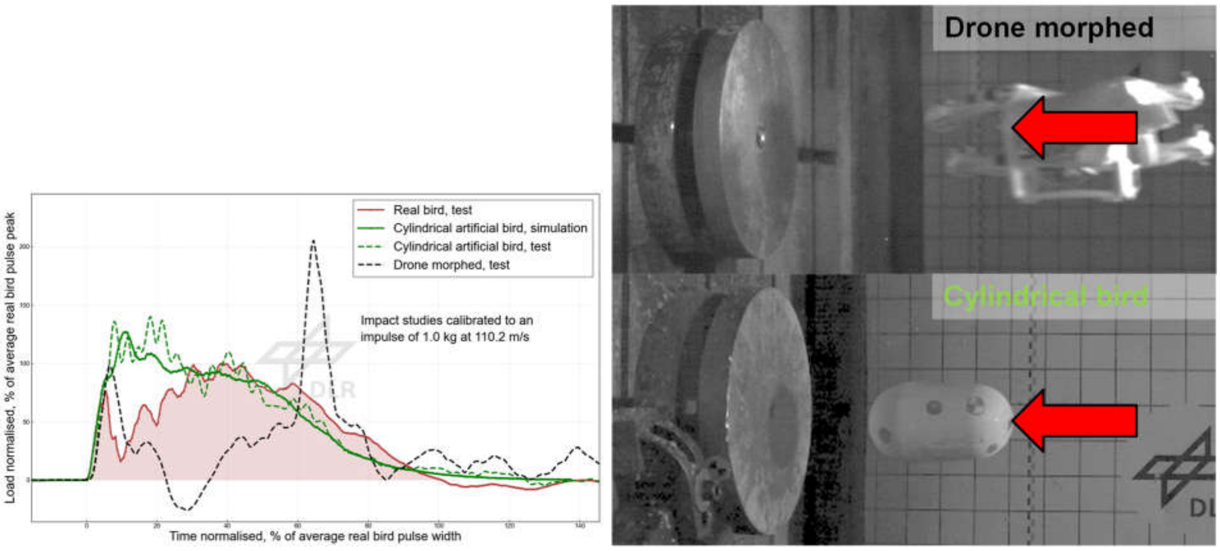


Figure 11 Drone impact load measurement in comparison with bird strike loads

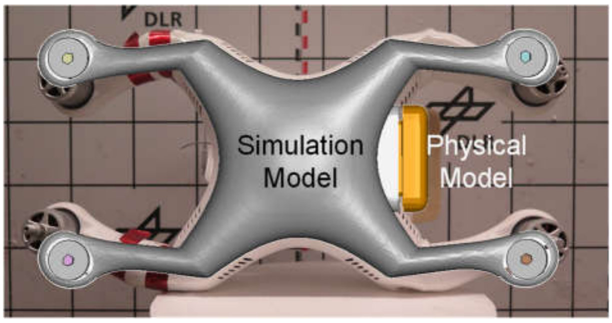
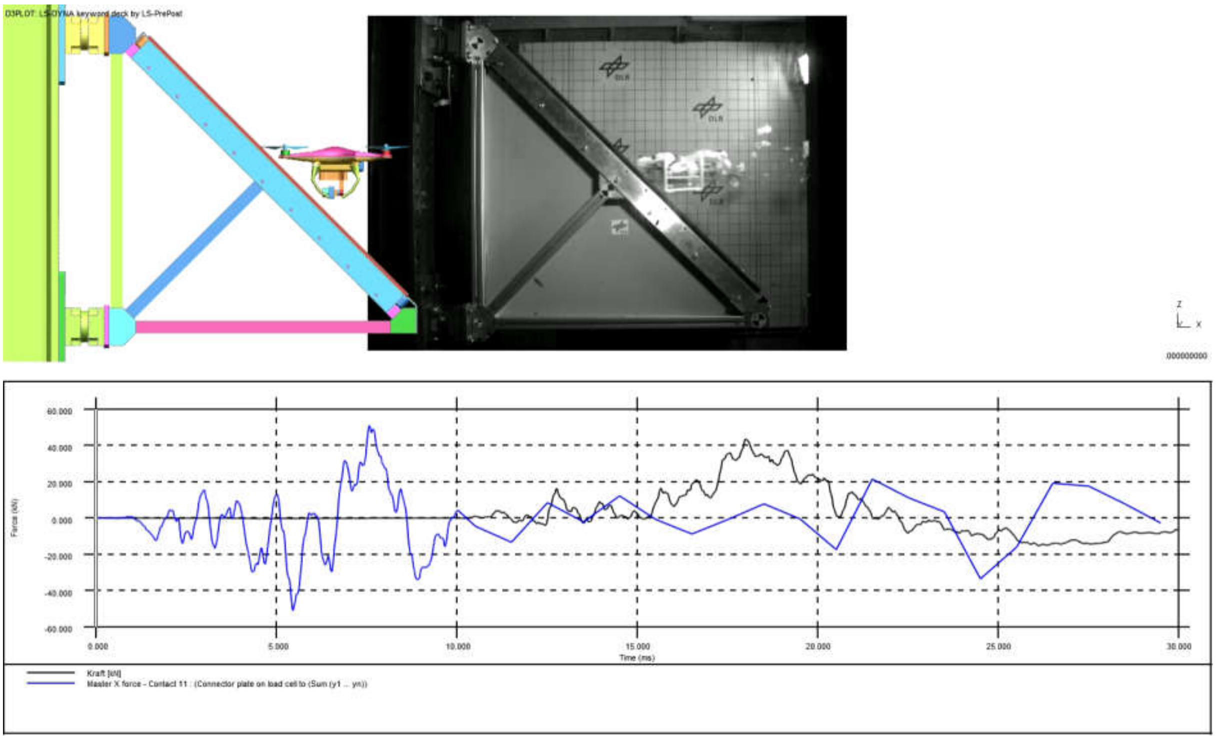
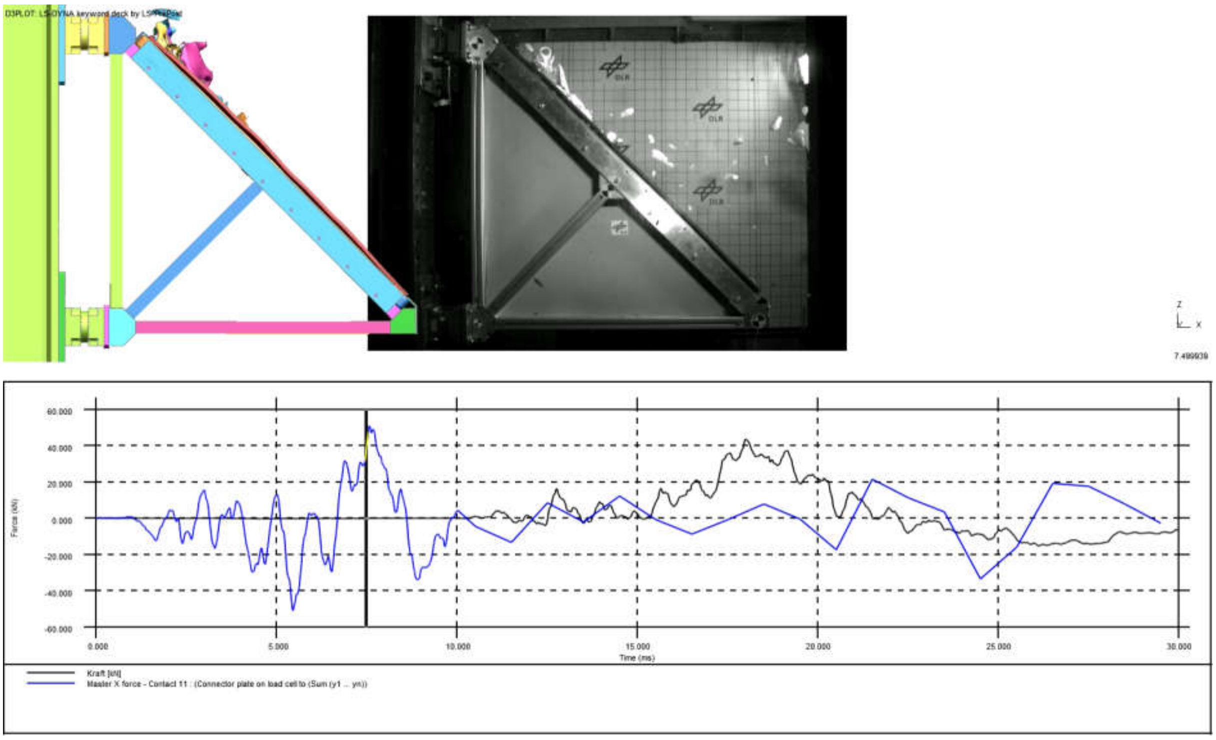


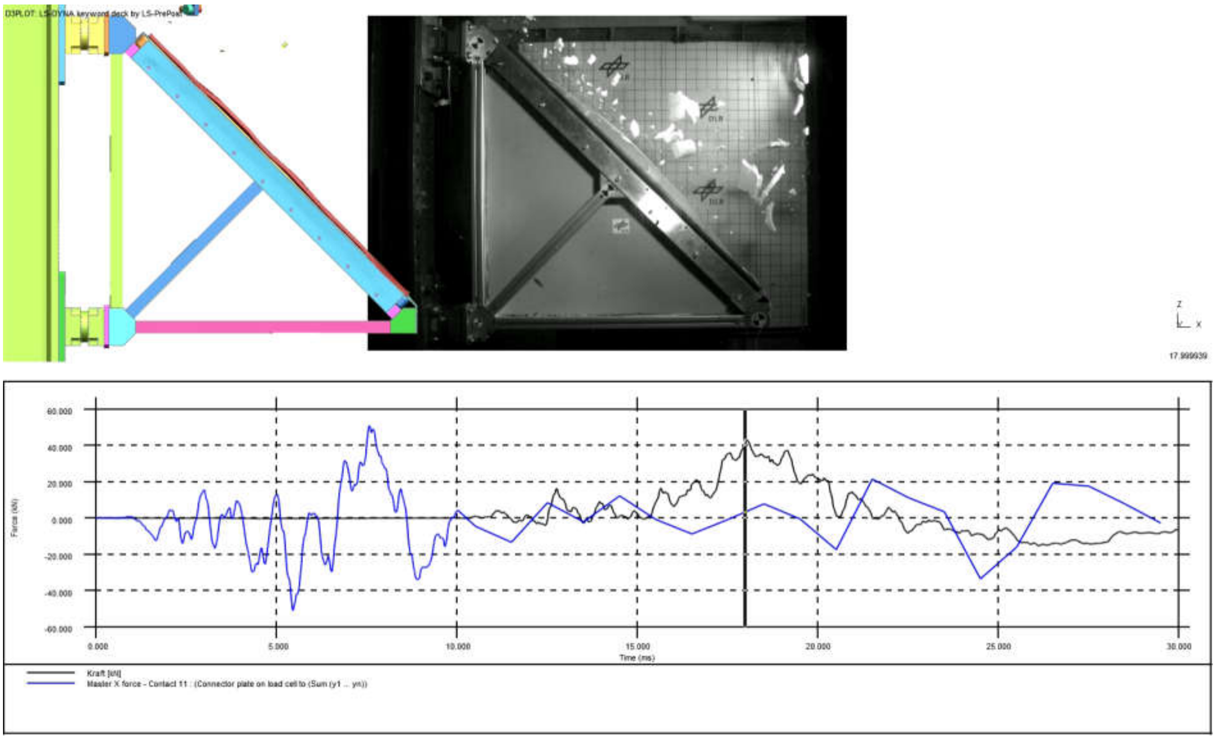
Figure 12 Overlay of morphed quadcopter and its morphed simulation model



(a) Demonstrator status just prior to impact of quadcopter



(b) Demonstrator and quadcopter status at peak load in simulation



(c) Demonstrator and quadcopter status at peak load in simulation

Figure 13 Three frames from test-simulation comparison in video on measured signals

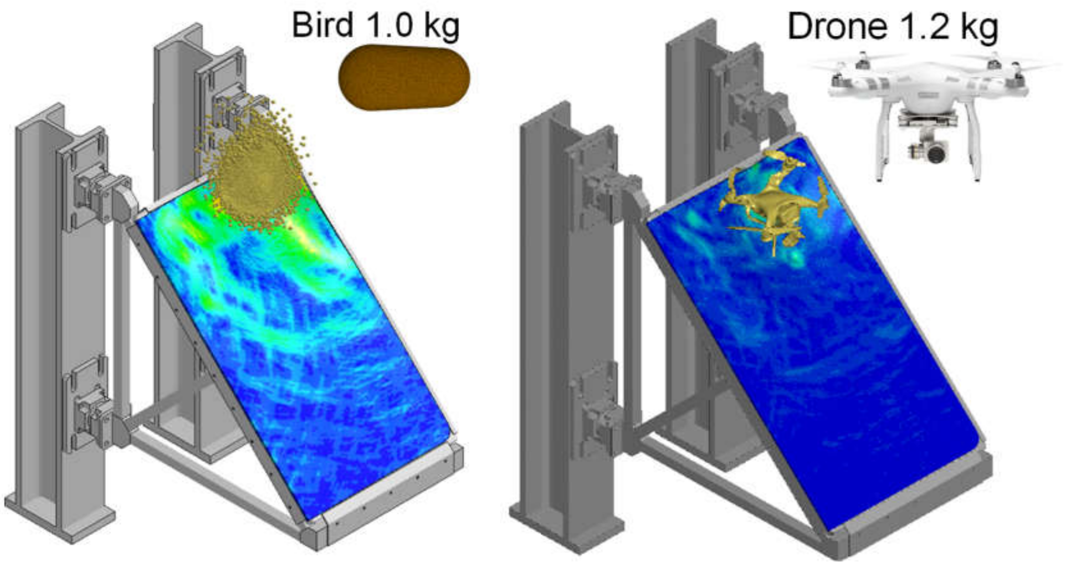


Figure 14 Canopy demonstrator with equivalent stress distribution in windshield from simulation just after strike of bird (left) and drone (right) with size comparison of the two impactors

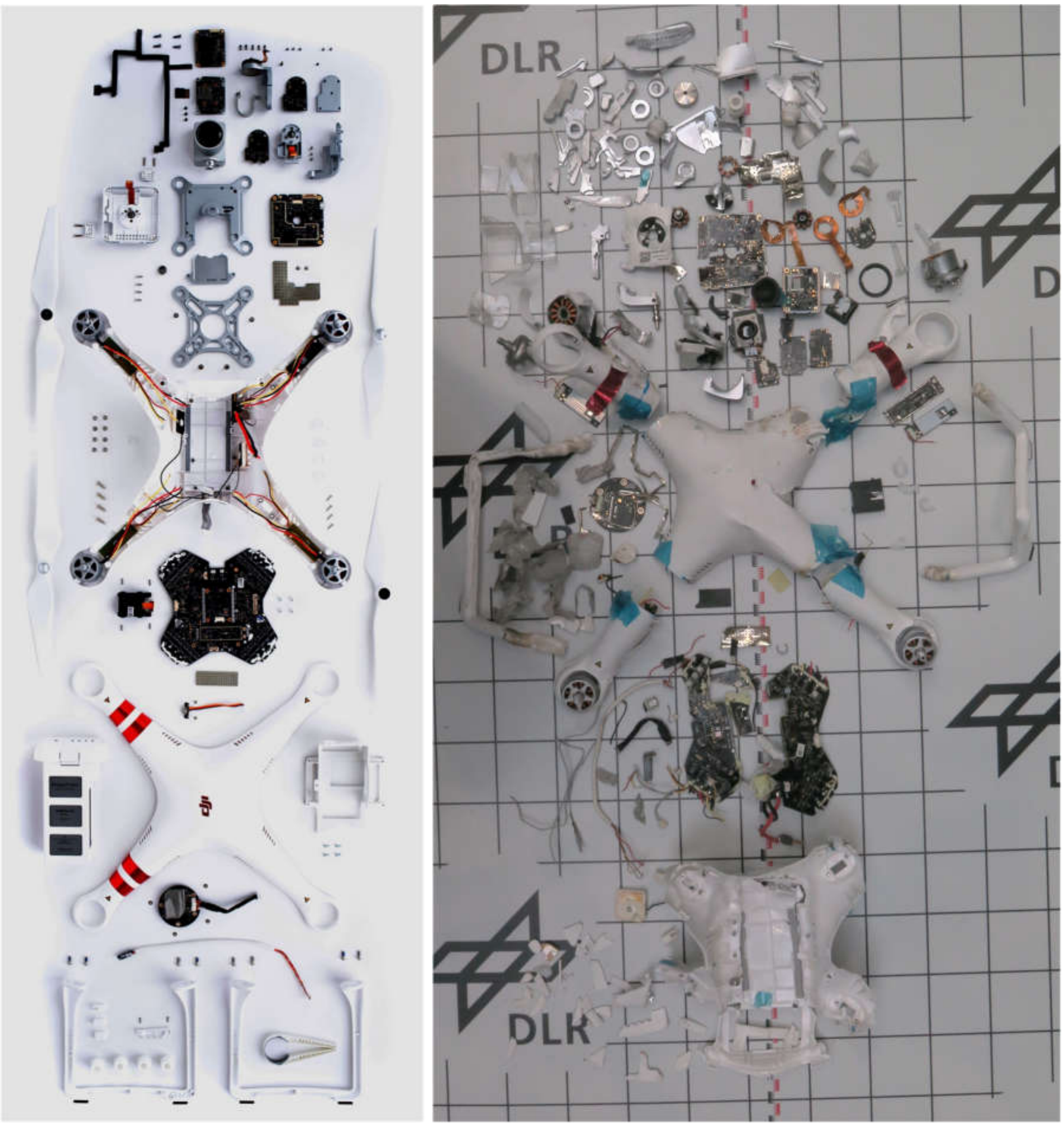


Figure 15 Exploded view of quadcopter [26] and its fragments after strike on helicopter canopy demonstrator without battery (right)