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BIRD STRIKE SHIELDING MATERIALS: DEVELOPMENT OF A HIGH VELOCITY IMPACT TEST PLATFORM

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SUMMARY

Commercial aircraft structures are exposed to bird strike events causing serious damages. Certification is thus required by regulation organizations and tests are performed using gas guns and birds of mass 1,8kg (JAR 25.631) (or 3,6kg for tail parts), which are launched at approximately 175m/s. In the design phase, modelling and simulation are rather used to assess and optimize the response of materials and structures under bird strike. However, it is difficult to correlate simulations with tests because of the very limited availability of test platforms for characterization and qualification from the smallest coupons to shielded structural component. The purpose of our work is to set up a test platform in close partnership with Institut Clément Ader (ICA), equipped with advanced metrology and combined with a virtual testing approach for correlation of tests and simulations up to 1m scale shielding concepts. New bird strike shielding materials could then be further developed at a lower cost in reduced time frames. Nonetheless the platform and virtual testing approach could be derived to other high velocity impacts (hail, engine debris, tire debris).

1 INTRODUCTION

Since the beginning of aviation, bird strike has always been a serious threat for any aircraft [1]. Whereas it may cause critical damages and crash, most of bird strike events are not so tragic but have important economic consequences. The annual cost of wildlife strikes to the USA civil aviation industry is estimated to be in excess of 593,000 hours of aircraft downtime and 628 million dollars in monetary losses [2].

Two kind of safety measures are taken to mitigate the risks due to bird hazards. First measure consists in wildlife management at airports since most of bird strike occur in the vicinity of airports during take-off and landing [3]. This paper aims to address the second measure, which relies on considering bird strike as a design constraint for aircrafts. This measure is included in aircraft certification standards set forth by aviation authorities like Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA) and others. Certification rules regarding bird strike on commercial aircraft structures are summarized in Table 1. These rules define structural performance requirements for an aircraft component which must be demonstrated by a bird strike test in an accredited laboratory.

Authority	Clause	Component	Bird mass	Impact speed	Operability after impact
FAA & EASA	25.571	All parts	1.8 kg	V_C at sea level / $0.85V_C$ at 2438m (8000 ft)	Continue flight
EASA	25.631	Empennage	1.8 kg	Idem 25.571	Land safely
FAA	25.631	Empennage	3.6 kg	V_C at sea level	Land safely
FAA & EASA	25.775	Windshield	1.8 kg	Idem 25.571	No penetration, no fragmentation
FAA & EASA	25.1323	Pitot tubes	Unspecified	Not specified	Duplicated Pitot tubes must be far enough from each other

Table 1: Certification Rules Regarding Bird Strike on Aircraft Structures (sources: FAA, EASA)

The different aircraft components exposed to bird strike (see Figure 1) are treated separately by certification rules. It is worth noting the difference in the bird mass which the empennage must support (3,6kg) compared to other components (1,8kg).

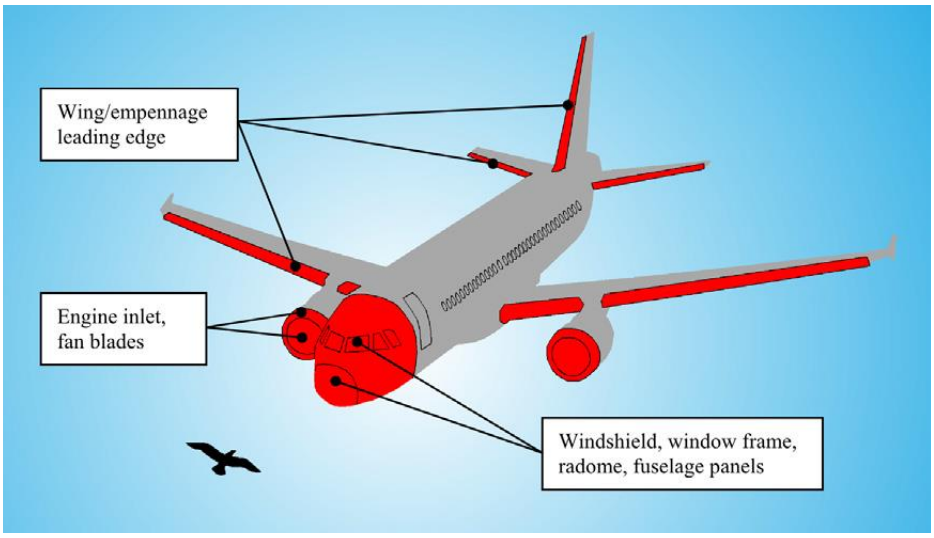


Figure 1: Illustration of Aircraft Components Exposed to the Risk of Bird Strike [4]

The development of structural components of aircrafts is more and more based on tests and simulations from the scale of small coupons to the scale of full aircraft.

Numerical simulations (virtual tests) reduce the number of tests to be performed and enable the prediction and optimization of structural performances at larger scales [5]. Money and time can thus be saved. Nowadays, it is expected to derive such pyramidal approach in the case of the development process of bird strike shielded components as illustrated in Figure 2.

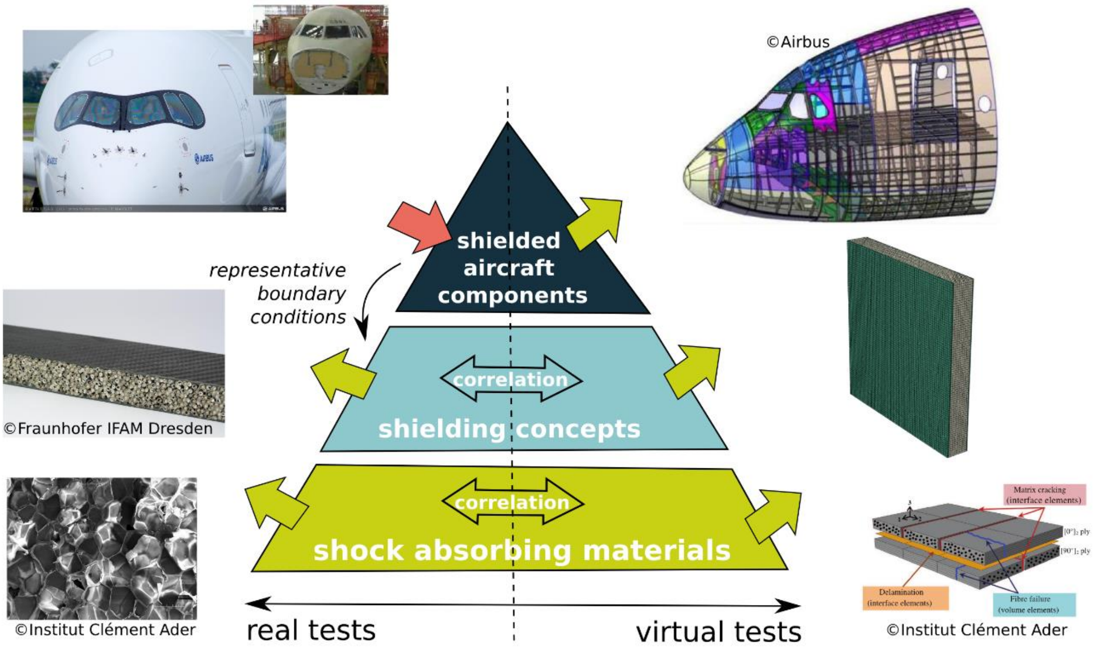


Figure 2: Pyramid of Structural Validation Adapted to Bird Strike Shielding Materials

In the current development process of shielded aircraft components, at the material scale, research laboratories have facilities for characterizing various shock absorbing materials and they work on developing adapted numerical models [6]–[8]. At the largest scale, shielded components are tested for certification by accredited authorities but there are very few numerical simulations performed. The scale of technological concepts (assembly of materials, sandwich panels and other shock absorbing structure) is nowadays not much considered in the process for pre-selecting promising solutions.

In order to optimize solutions and to make certification tests right first time, middle level of the test pyramid should actually be strengthened by offering an easier access to test facilities (gas gun), by the development of methodologies for selecting shielding concepts and by scaling up material models by the means of multi-scale methods. This is the purpose of the project COMPINNOV TD conducted by IRT Saint Exupéry, currently focusing on the particular case of bird strike shielding of nose section in the framework of collaborative project FUI SAMBA driven by Stelia Aerospace.

In this paper, the development of a high velocity impact (HVI) test platform for bird strike, in close partnership with ICA, is presented first. This platform will enable the selection of shielding concepts (sandwich panels of dimensions 800mm by 800mm) proposed by partners of project FUI SAMBA. Second, the project of associated virtual test platform is introduced. Finally, the future evolution of the HVI test platform is discussed.

2 BIRD STRIKE TEST PLATFORM

Several impact test platforms exist in the world with capabilities to carry out bird strike tests (Imperial College, DLR, DGA-TA, NTNU SIMLab, etc.). Such platform do not only include a gas gun but validated projectiles, high speed instrumentation, safe test procedure and authorized staff at least. In the context of access improvement for companies and laboratories to such facilities for the development of new shielding materials and the selection of shielding concepts, IRT Saint Exupery and ICA collaborate to upgrade existing facility at ICA. With the best standards in mind, main features being set up are presented below.

2.1 Large-Diameter Gas Gun

Figure 3: Impact test facility under development (located at Institut Clément Ader)

Bird strike tests require a gas gun with a large barrel of inner diameter between 100 and 200mm to be able to launch 1.8 to 3.6kg birds (or substitute). Existing gas gun at ICA has an inner diameter of 100mm and length 3m. It is equipped with a fast opening valve (exploding membrane) in front of a 100L/40bar pressure tank. It has been demonstrated by preliminary tests that this gas gun is capable of launching 2kg projectile at the speed of 190m/s at less than 20bar pressure in tank. The gas gun is currently being secured and the barrel is extended to 6.4m in order to work at lower pressure and to increase the range of projectile velocity.

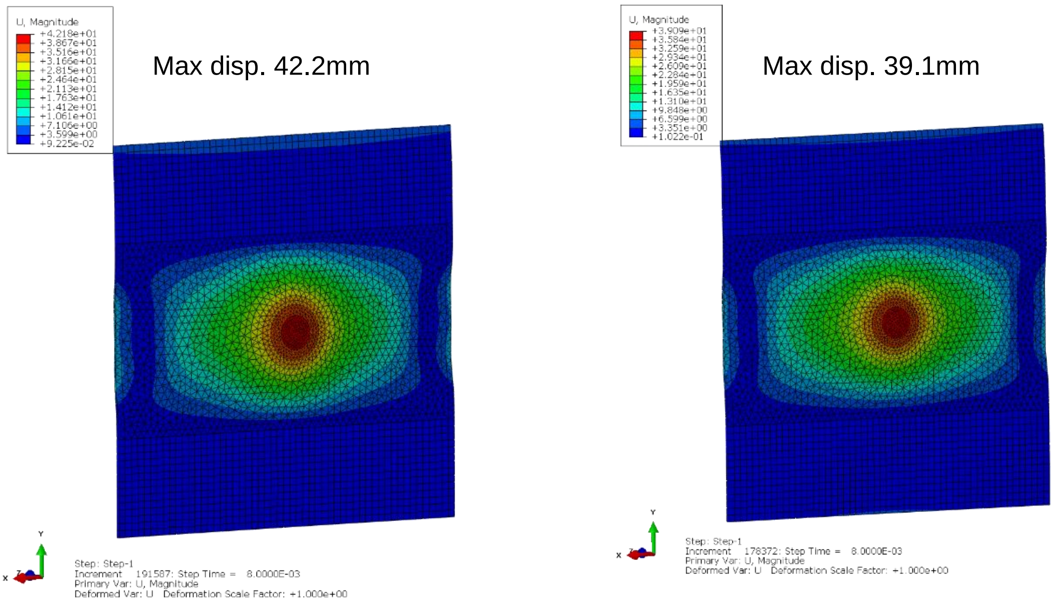
2.2 Substitute Bird Projectile

It was shown by Wilbeck [9] that birds behave like porous water during high velocity impact. Consequently, substitute bird projectile have been developed since 70’s in order to improve repeatability of tests. For such substitute bird, literature agrees for a density of projectile between 900 and 1060 kg/m^3 [4], [10], [11] and a shape ratio of two between length and diameter. Substitute bird projectiles are usually made with water, gelatin and other ingredients controlling porosity (see Table 2).

Bird mass for certification tests is specified by aviation authorities. In the case of tests for material characterization and selection of shielding concepts, it is not mandatory to comply exactly with certification requirements. The main concerns are the representativeness of testing conditions and the activation of energy absorbing mechanisms. For these reasons, and considering the constraints related to existing facility being upgraded at ICA, a projectile with diameter 100mm and density 970kg/m^3 is being developed on the basis of literature recipes. We expect reaching a mass between 1.5 and 1.6 kg, which produces similar effects on targets than 1.8kg projectile (see Figure 4).

Sources	Recipe	Density	Observations
[9]	Ingredients : - Water - Ballistic gelatin (10%) - Phenolic micro balloons	Depends on quantity of micro balloons	Difficult to obtain a homogeneous mixture
[11]	Ingredients : - 1000g cold water - 100g of gelatin powder - 25g sodium carboxymethylcellulose (CMC) - 6g aluminum acetate basic (AAB) - 4 drops of cinnamon oil	930-970 kg/m^3	Sodium CMC creates porosity. Cinnamon oil controls the size of porosities.

Table 2: Recipes of substitute bird projectile extracted from literature



(a) (b)

Figure 4: Comparison of the effect produced on 7mm aluminum plate by the impact at 175m/s of a 1,8kg projectile (a) and a 1,5kg projectile (b). Simulation carried out with Abaqus Explicit software.

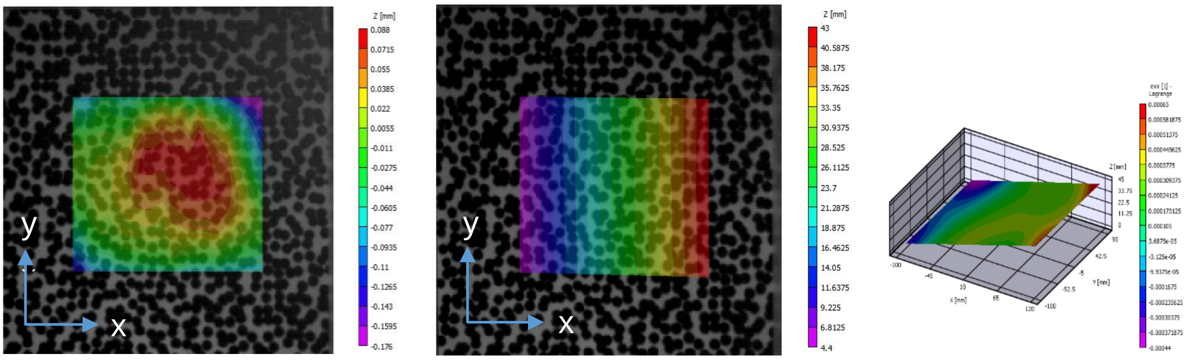
2.3 Advanced Metrology

Among the quantities of interest measurable during a bird strike test, one is the deformation of the target. Deformations are often measured by strain gages [12] but particular attention has been paid recently to 3D digital image correlation (DIC) for HVI or blast [13]–[15] when region of interest (ROI) remains properly visible during test. The main challenge is to find a compromise between measurement accuracy and size of the ROI because of the low resolution of high speed cameras.

The back side of shielding concepts against bird strike remains visible during test. The ROI of such one square meter target may span several hundred millimeters side length. In the case of FUI SAMBA, ROI reaches 400mm by 400mm corresponding to the average width between stringers of the structure to be protected.

Figure 5: Stereo-correlation device comprising high speed camera and large scale target with coarse speckle pattern.

Before tests, 3D DIC capabilities are being evaluated. As shown in Figure 5, two high speed cameras (Photron APX) are used for stereo-vision. At a rate of 30000 frames per second, resolution was 256 by 256 pixels. A mock target plate has been painted with a coarse high contrast random pattern (bullet points $\Phi 10$mm) so that the transition between black and white area corresponds to approximately four pixels [16].



(a) (b) (c)

Figure 6: 3D surface reconstruction of the target in reference position (a) vertically rotated position (b) and computation of strain field in rotated position ($\epsilon_{xx} < 6.10^{-4}$) (c)

After calibration, correlation was successful in the ROI. Figure 6 shows the mock target in reference and rotated positions and its shape reconstruction by stereo-correlation. As it is planar and not deformed, computed strain is logically close to zero with a satisfactory accuracy ($\epsilon_{xx} < 6.10^{-4}$). Interesting prospects are open for the use of 3D DIC for bird strike tests on shielding concepts.

3 DEVELOPMENT OF A VIRTUAL TEST PLATFORM

A virtual test platform for simulation of HVI on various shielding concepts relies on the proper modelling of projectile. A SPH (Smooth Particule Hydrodynamic) model of the substitute bird will be identified in a wide range of speed (from 100 to 200m/s), on rigid and compliant targets. In the same time, a data basis of material models will be built up from literature and from the work done by researchers at ICA [7], [8].

4 TOWARD A VERSATILE HVI TEST PLATFORM

Beyond bird strike, Aircrafts are subjected to the impact of many other foreign objects. Accordingly, HVI of tire debris, hail, engine debris are studied in literature [15].

In the near future, our test platform could evolve to make possible the selection of materials and structures having the best properties against all of these events. The gas gun of diameter 120mm is one of the base components because it covers a wide range of speed (up to approximately 250m/s) and size of projectiles. Other existing gas guns (diameter 40mm and 60mm) are better suited for lower energy impacts. This platform already offers the possibility to address several kind of HVI to which aircrafts are subjected. The versatility of the test platform is ensured by the parallel mounting of the three gas guns and the easy switching from one to the other. The further development of the capabilities for tackling higher energy and/or speed issues (i.e. small engine fragment of 80g at 600m/s) could be managed by the addition of another gas gun (possibly reusing interchangeable components of existing gas guns like barrels, tanks or valves).

5 CONCLUSION

The development of new bird strike shielding materials relies on a specific high velocity impact test platform. This kind of test platform is set up together by IRT Saint Exupery and Institut Clément Ader with special attention paid for metrology, representativeness of test conditions, modelling and simulation aspects.

This work opens up interesting prospects for the development of new shock absorbing materials and shielding concepts at the scale of structural component not only against bird strike but against all foreign objects threatening aircrafts.

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