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AIRCRAFT BIRDSTRIKE SIMULATION USING SMOOTHED PARTICLE HYDRODYNAMICS

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Abstract. Bird strike incidents are not uncommon and cause significant flight safety threats to aircraft operations. An aircraft must show compliance with “continued safe flight and landing” requirements following specified types of high-energy bird impact (See FAR 25.571/25.631). A bird strike is classified as a high-velocity soft body impact, because the stresses which are generated in the contact region are significantly greater than the strength of the bird, but lower than the strength of the impacted structure. High deformability of the impactor (bird) causes spreading of the impact load over a certain area of the structure that requires the use of special strain-rate-dependent material models. If the structure is deformable, the impact load depends on the structural response that, in turn, depends on the impact load. During the design process, a means to predict the structural behavior on a birdstrike event has to be employed to size the structure. Final certification is usually made by tests.

To simulate this phenomenon, the soft impactor body is modelled using smoothed Particle hydrodynamics. An equation of state is used to provide a hydrodynamic material model, it describes the pressure as function of specific internal energy and density. Aircraft (Target) structure is modeled using a Lagrangian Finite Element Mesh. Large displacements and material plastic behavior (strain rate dependant) are considered. This paper presents the bird strike simulation methodology used at FAdeA SA based on the Smooth Particle Hydrodynamics technique. Examples of analysis models developed using ABAQUS Explicit are presented.

1 INTRODUCTION

Bird strikes are a common problem for the aerospace industry and can cause serious damage to an aircraft, being a serious threat to flight safety. Figure 1 shows the consequences of an impact over the wing leading edge of a IA-63 “Pampa” Jet trainer. The bird impacted the wing shortly after the aircraft takeoff. Fortunately, the crew safely returned to the airport and no injuries were reported.

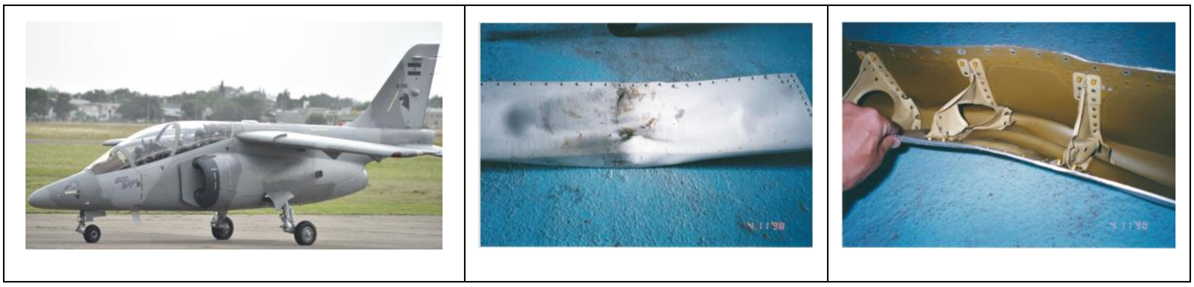

Figure 1: Structural damage on a leading edge caused by a Birdstrike.

Certification tests are conducted using actual bird carcasses; however, ballistic gelatin is frequently used as a surrogate material for preliminary testing (see Blaine, S. Wes, Brockman, Robert A., 1980), Figure 2 shows the setup used during the development and certification tests of the IA-63 “Pampa” Jet trainer, carried during late 80’s.

Development/Certification tests are expensive and time consuming. The main advantage of using gelatin for testing is repeatability. No two birds are identical, even if they are of the same species. These natural variations make it difficult to perform repeatable experiments. In addition, there are obvious sanitary benefits to testing with gelatin opposed to actual birds.

The trend actually in the aerospace industry is to dimension the structure and replace part of the tests by simulation (see Owens, Steve D. ,Caldwell Eric O., Woodward, Mike R., 2009). Various numerical treatments of the bird model are used, including Lagrangian, Coupled Eulerian Lagrangian (CEL), and Smoothed Particle Hydrodynamics (SPH). The present paper focuses in the SPH approach.

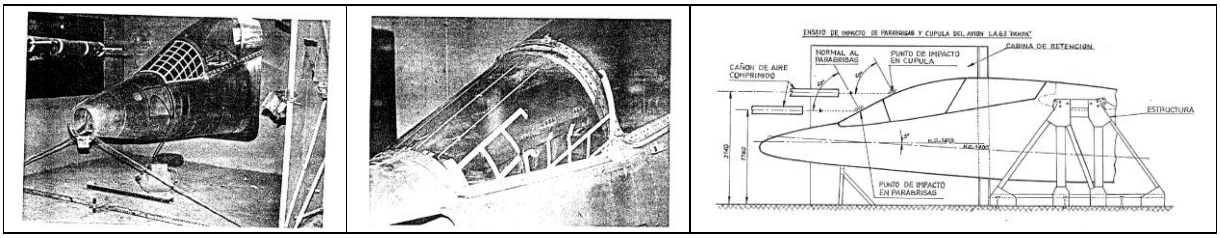

Figure 2: IA-63 “Pampa” jet trainer, development/certification birdstrilke testing setup.

During 2019 year, FAdeA is working with an external customer to adapt a FAR 25 transport aircraft for electronic warfare. Part of the modification implies the installation of several fairings in the aircraft fuselage. For the certification of the modification, birdstrike compliance with FAR 25.57 (e) (1) requirements has to be shown (impact with a 4lb bird at cruise speed, 224 kts; sea level and 8000 ft).

In the present document, a resume of the metodology used and the ressults obtained are presented.

2 METHOD OF ANALYSIS

A bird strike is classified as a high-speed soft body impact because the stresses, which are generated in the contact region, are significantly greater than the strength of the bird but lower than the strength of the impacted structure. High deformability of the impactor (bird) causes spreading of the impact load over a certain area of the structure that requires the use of special strain-rate-dependent material models. If the structure is deformable, the impact load depends on the structural response that, in turn, depends on the impact load.

To simulate this complex coupled behavior a dynamic explicit analysis was performed using ABAQUS/Explicit:

- Bird Modeled using Smoothed Particle Hydrodynamics.
- Aircraft Fairing / Structure modeled using a Lagrangian finite element mesh.
- Large displacements and material plastic behavior (strain rate dependent) were considered.

2.1 Bird Model

2.1.1 Bird Material

As shown by Barber, Taylor and Wilbeck, 1974, at high impact velocities a bird impacting a structure—rigid or deformable—behaves as a fluid (hydrodynamic impact condition). Therefore, a hydrodynamic material model is a viable approximation to the complicated constitutive behavior of a real bird in a high-velocity impact event.

As real bird impacts are not repeatable, surrogates are used for bird strike experiments/simulations. A surrogate bird guarantees test repeatability, and is fairly simple to model.

Experiments show that bird strike is characterized by the following three phases: (1) shock wave stage; (2) pressure release stage; and (3) steady-state flow pressure stage (Dassault Systèmes, 2014). Important parameters, which are obtained from the experiments, include the peaks of the impact forces and pressures and the steady flow pressure.

The bird material is described by the so-called “elastic-plastic hydrodynamic” material model, which is widely accepted in the literature. At high pressures, the hydrodynamic pressure-volume behavior of the bird is modeled in Abaqus/Explicit using a tabulated equation of state (EoS); this provides considerable flexibility modeling the hydrodynamic response of materials. The EoS (See Dassault Systèmes, 2014) allows describing the pressure-volume behavior of the bird, with the internal energy contribution to the pressure being neglected.

As real bird properties vary considerably (see Barber, John P., Taylor Henry, R., and Wilbeck, James S., 1974), a sensitivity analysis is performed for three surrogated bird porosity values (0%, 10% and 15%). EoS for the different porosity values is provided in Dassault Systèmes, 2014, as shown in Figure 3.

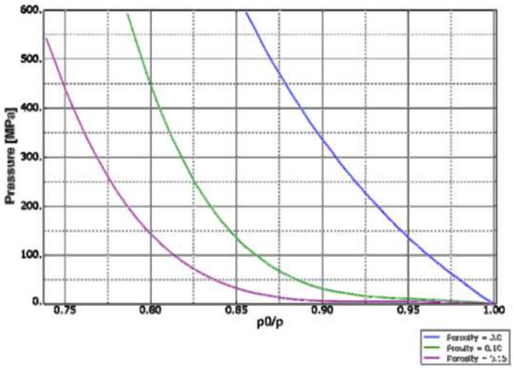

Figure 3: Projectile Material EoS for different porosity values.

2.1.2 Bird Shape

The shape of the bird is idealized by means of a cylindrical body with hemispherical caps (Figure 4), which is referred to as the “bird” in this report. This simple geometry allows predicting both the shock and steady state pressures with good accuracy (Dassault Systèmes, 2014). A length-to-diameter ratio of 1.6 is commonly used (Dassault Systèmes, 2014). This value produces contact force peaks close to the average experimental value obtained by Blaine, S. Wes, Brockman, Robert A., 1980 and do not significantly overestimate the pressure at the center of the impact zone in the steady-state flow pressure stage. Thus, the requirements for aircraft structures to survive impacts from a 1.82 kg (4 lb) bird, together with the adopted bird material density at atmospheric pressure, 938 kg/m3 (Seit J.D., Pereira, J.M., Hammer and A. Gilat J.T., Ruggeri C.R., 2012), dictate the bird length, L, to be equal to 200 mm and the bird diameter, D, to be 125 mm.

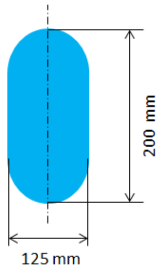

Figure 4: Projectile Geometry.

Finally, a Smoothed Particle Hydrodynamics (SPH) approach is used for the bird, in this way the big distortions are handled without issues.

2.1.3 Bird Model Validation

Before the bird model can be used to study the impact response of a deformable structure, it must be calibrated and validated.

For bird model validation, a test model is built to reproduce the results obtained by Seit J.D., Pereira, J.M., Hammer and A. Gilat J.T., Ruggeri C.R., 2012, report NASA/TM—2012-217661 “*Dynamic Load Measurement of Ballistic Gelatin Impact Using an Instrumented Tube*”. In this reference, a surrogated bird made of ballistic gel is impacted against an aluminum tube with a tick plate in the tip, obtaining measurements of the impact forces. The tube dimensions were chosen such that the waves transmitted along the tube would remain elastic during the impact loading. Forces are relieved at two locations using strain gages (See Figure 5).

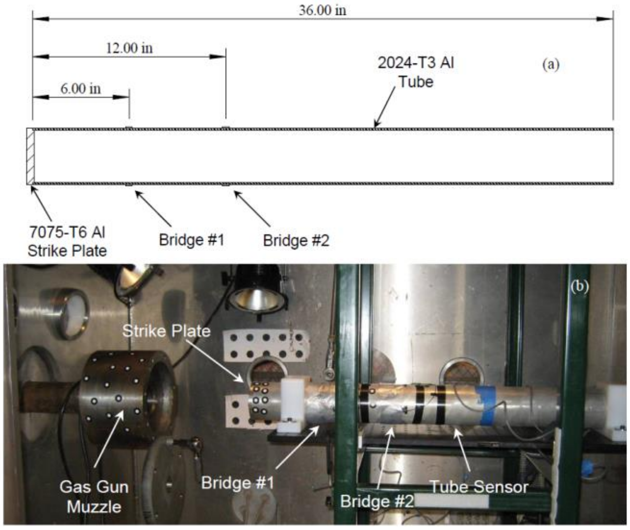

Figure 5: Tube sensor: (a) section schematic of the tube, (b) photo of the sensor and experimental setup.

A finite element model of the setup previously shown was built in ABAQUS. Similar mesh (element types and sizes) as used in the analyzed installations shown later in this paper was chosen. A Shell element size in the tube of around 8 mm was used.

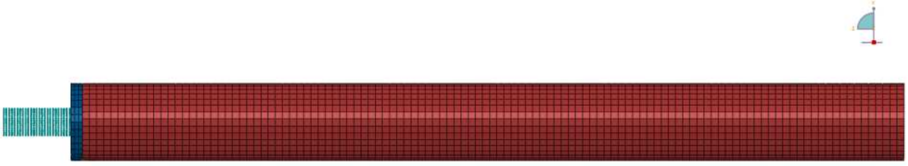

Figure 6: Validation Finite Element Model.

Figure 7 shows a series of sequential images from a high speed camera oriented normal to the projectile path. 100μs elapse between each image. The debris present in the images is part of the support used for the projectile in the gun.

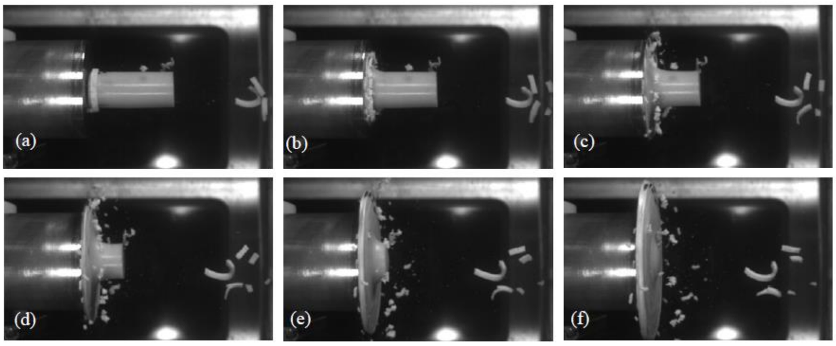

Figure 7: Sequence of a gelatin projectile impacting the strike plate of the tube at 504 ft/s.

Figure 8 shows the simulated sequence, similar timing between captures as in Figure 7 has been chosen.

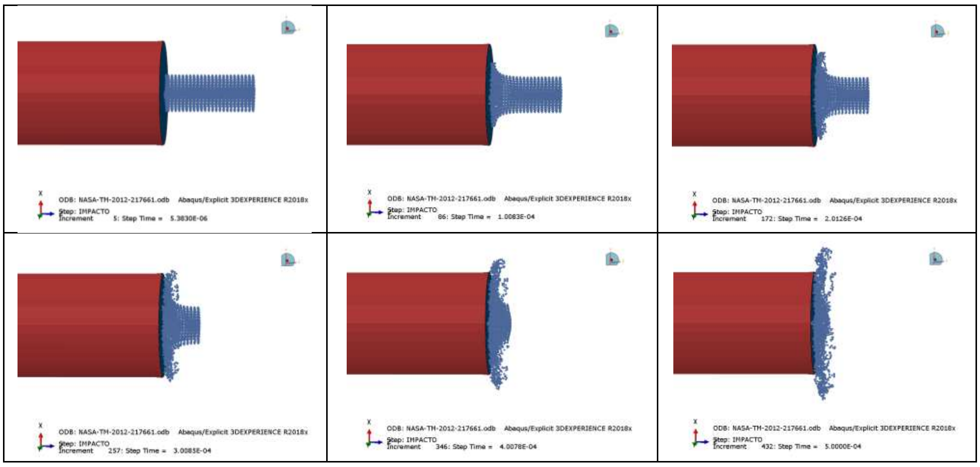

Figure 8: Simulated sequence, SPH.

In Figure 9 the results of experimental measurements are presented at the two locations in the tube (left graph) and compared with the simulation results (impact forces are retrieved at the approximate bridges locations using a Freebody approach).

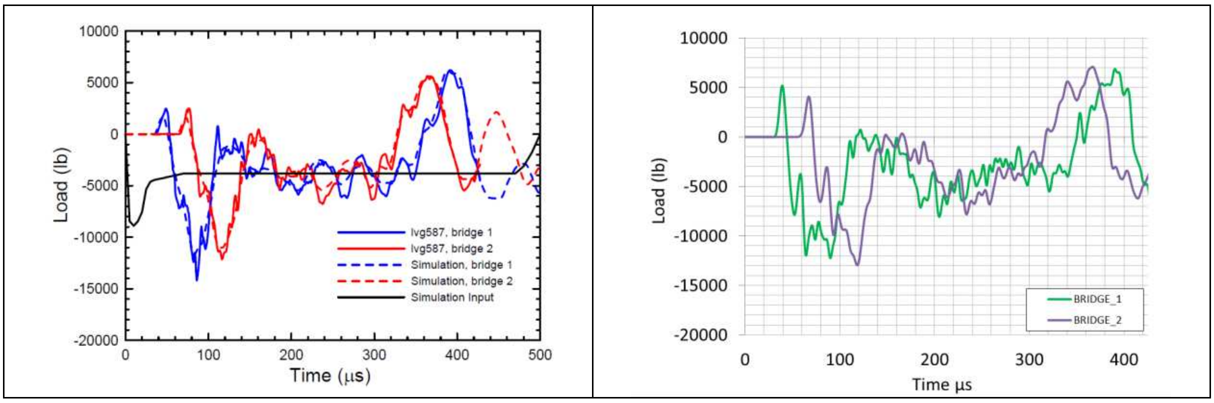

Figure 9: Tube sensor data from a gelatin impact test, projectile velocity 504 ft/s.

Comparing the simulation results with the experimental measurements, it can be seen that Force vs time history agree quite well.

The initial tensile force (Time between 20 and 40μs) is originated in the deformation of the strike plate.

Between time 80 and 120μs, the compressive spikes are obtained. According to NASA/TM—2012-217661, the measurement method (elastic tube) overestimates these values. In Figure 9 (left plot) the tube measurements, against simulations performed using LS-Dyna are presented. In this plot a maximum compressive load value similar to the obtained by the author of this report using ABAQUS and SPH.

Other discrepancies between the results presented in NASA/TM—2012-217661 and this report can be attributed to the Equation of State (EoS) used for the projectile material. Reference NASA/TM—2012-217661 does not detail the porosity of the projectile. By using different EoS, the values of maximum compression spike and steady flow phase characteristics can be considerably altered.

Finally, the results are compared against a Coupled Eulerian Lagrangian (CEL) model. The same mesh is used for the tube and strike plate, the projectile is modeled using an Eulerian mesh. The reason for comparing these two modeling techniques is that are the ones

commonly used for aircraft Birdstrike simulation (see Dassault Systèmes, 2014).
Figure 10 shows the results obtained for the CEL modeling approach. Correlation level is similar than for the SPH approach.

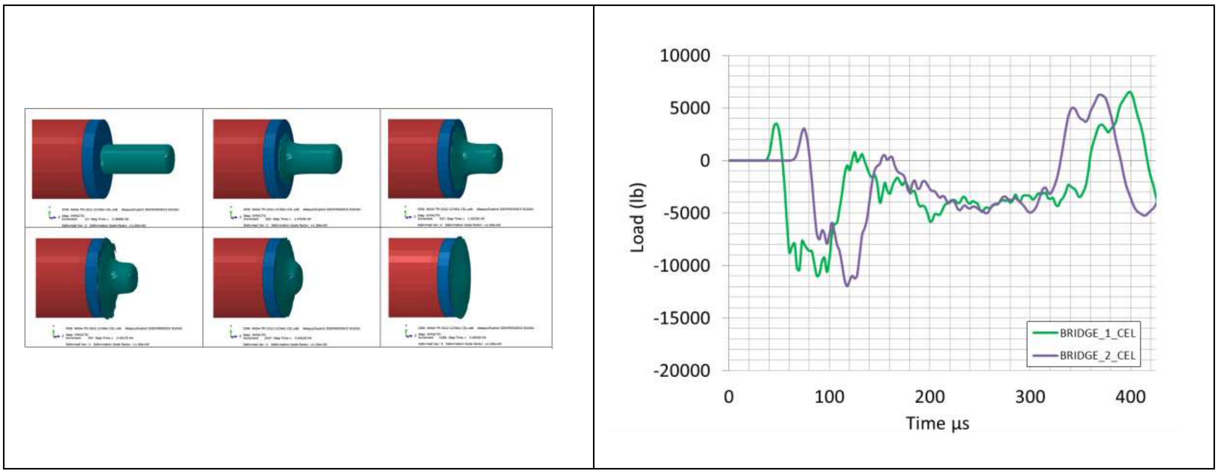

Figure 10: Force vs time history for the CEL modeling approach.

Comparing simulations for different mesh sizes, impacting speeds and EoS clearly CEL needs a higher computational cost than SPH to achieve the same accuracy.

2.2 Aircraft Structure

Aircraft Structure is modeled using a Lagrangian finite element approach. Strain rate dependent plastic material behavior is taken into account using the Johnson Cook material model. Johnson Cook material constants are taken from G. Kay, 2012 and Brar N.S., Joshi V.S., Harris B.W., 2009. When several strains are found, Johnson Cook damage model has been included to take into account progressive material damage and stiffness degradation. In this case, elements are removed from the simulation once the maximum damage is reached.

Background structure surrounding the analyzed installations is considered in the models, this is to assess the behavior of the fittings and fairing vinculation to the structure during and after the bird impact. In other words, the response of the structure surrounding the installation during and after the impact is assessed.

As a general approach, skin, frames and stringers are modeled using plate elements, beam elements are used for the fasteners. Equipment installed in the considered zones is represented using concentrated masses, connected to the attachment points using Multi Point Constraints (MPC).

Mission equipment and sensors installed in the fairing are assumed as rigid bodies, connected using MPC to the attachment points. This approach was chosen since no data of the equipment materials/internal structure was available, a conservative approach, in a real impact event part of the energy will be absorbed by the equipment.

As shown in Figure 11, the presented installation is a small fairing (aprox 400x350 [mm]). The structure is made of 2024 T351 aluminum alloy, with the sensor attachment and lower frames made of machined 7075 alloy. The Fairing is attached using solid fasteners to the aircraft structure; a 1.2 [mm] thickness doubler is installed between the fairng and the aircraft fuselage skin. The last has 0.8 [mm] of thicknes with stringers and frames with different thicknesses from 1 to 2.5 [mm].

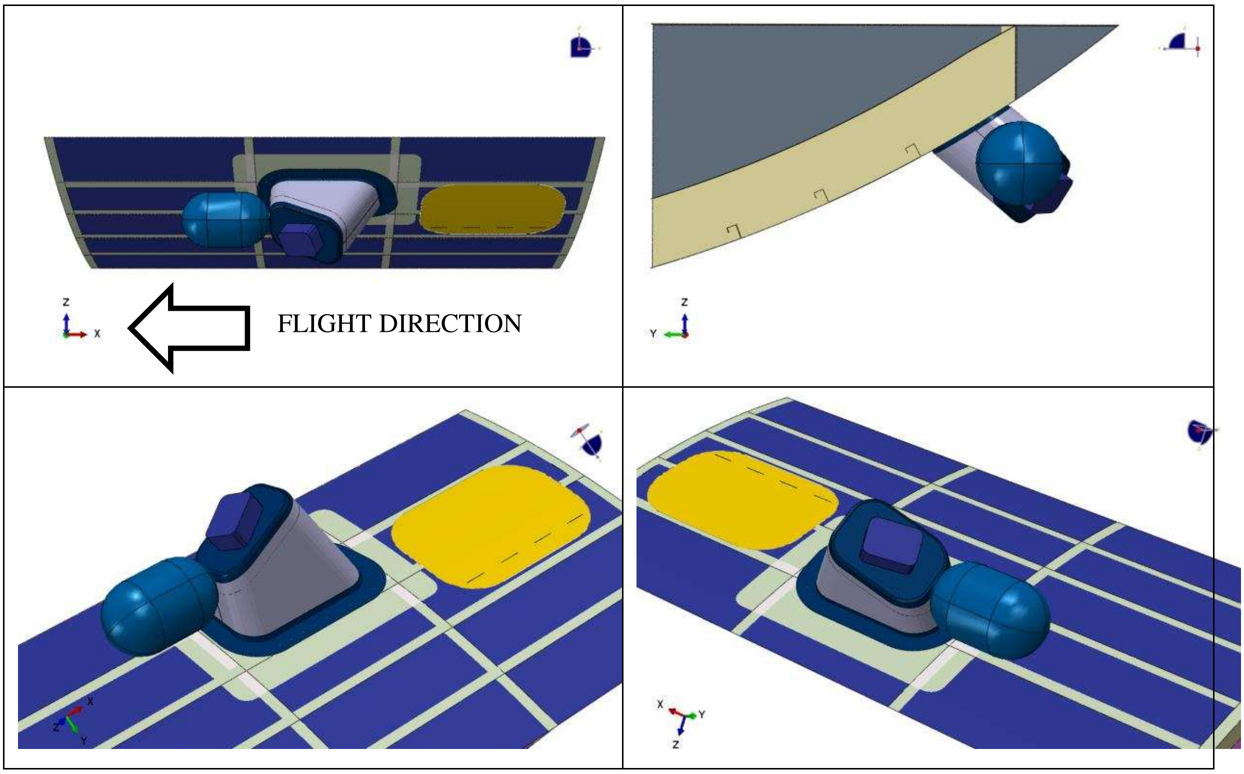

Figure 11: Installation 1, model setup.

3 ANALYSIS RESULTS

Impact sequence for Installation 1 is shown in Figure 12, total simulation time 3,5E-3 [s], timing between frames 0.35E-3 [s].

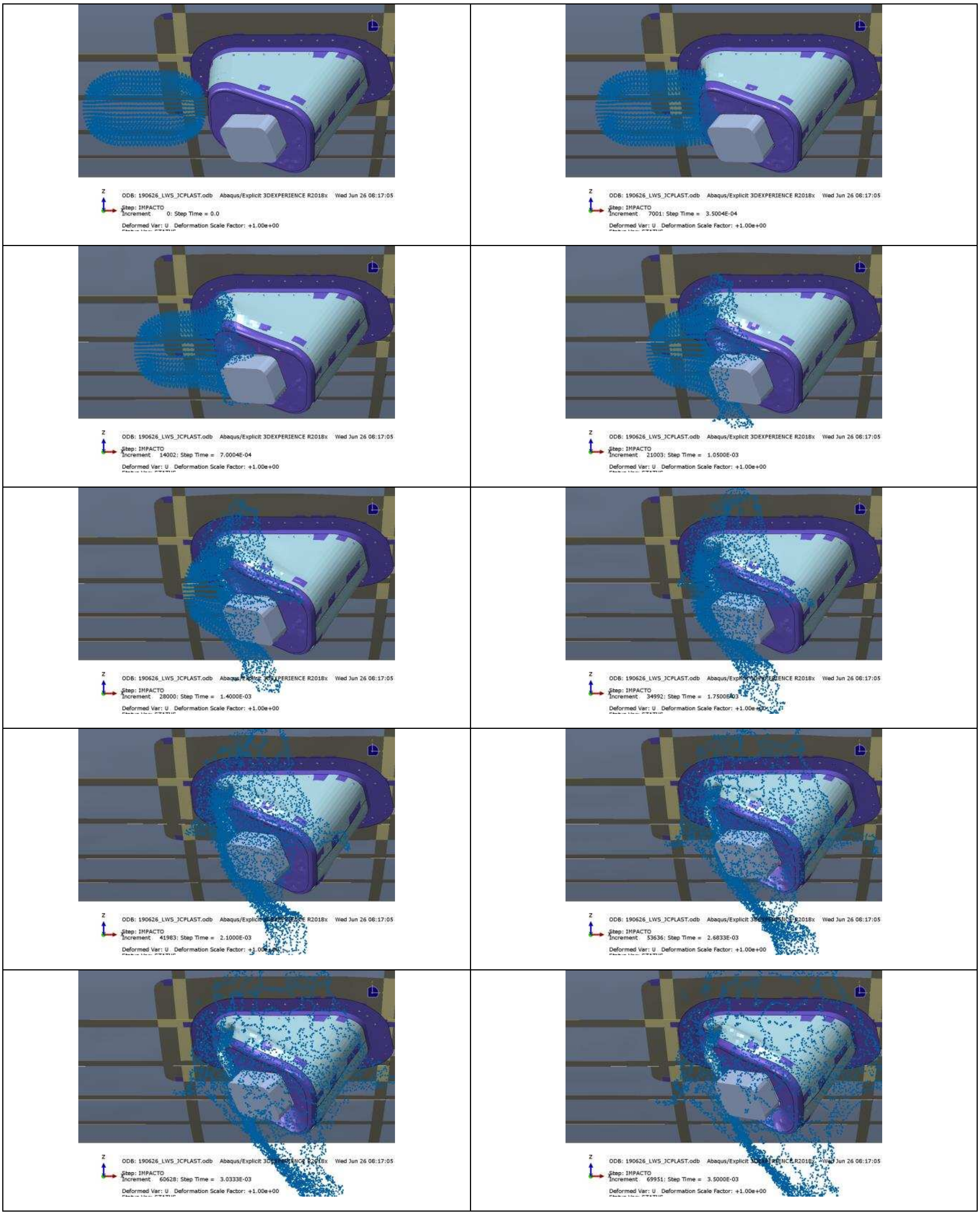

Figure 12: Installation 1 impact sequence, timing between frames 0.35E-3 [s].

Resulting status of the structure after the impact is shown in Figure 13. As can be seen for this installation, several damage focused in the impact zone can be expected after a birdstrike. But the installation will remain attached to the airplane. Resulting plastic deformations in the surrounding structure are far below the material rupture value ($\mathrm{PEEQ_{max}} \approx 0.06$).

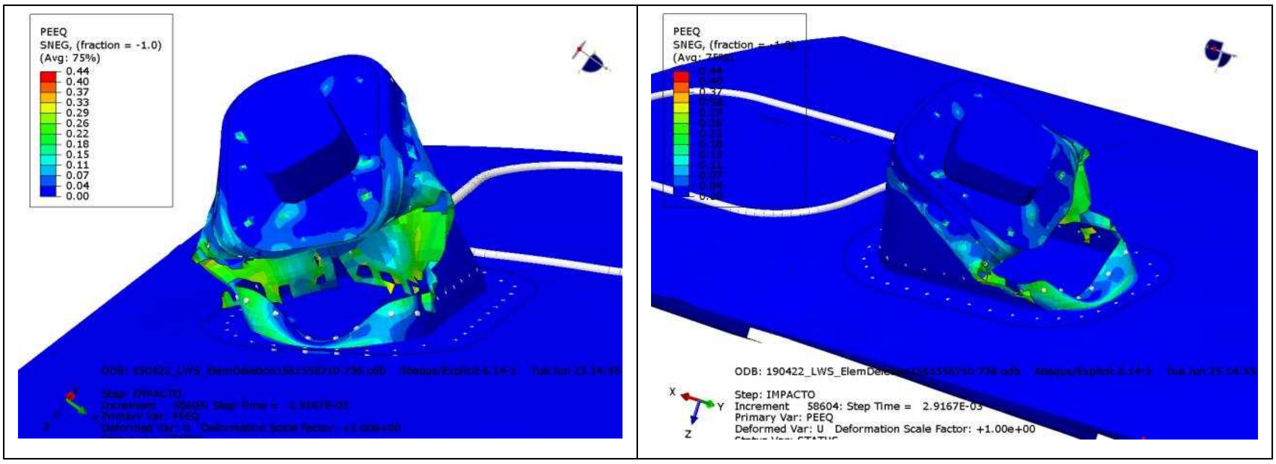

Figure 13: Installation 1 status after impact.

4 CONCLUSIONS

An elastoplastic hydrodynamic gelatin projectile model has been developed and validated against theoretical & experimental results**.** This model has been used to simulated a birdstrike and to validate a design against the requirements of the applicable regulations, safely completion of the flight after an impact at 224 kts with a 4 lb Bird.

Future improvements in this job will be oriented to impact simulation over composite material structures.

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