WATER IMPACT: EXPERIMENTAL TESTS AND NUMERICAL SIMULATIONS USING MESHLESS METHODS

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ABSTRACT

The outcomes of a research focusing on water modelling and fluid-structure interaction, are here presented. A number of water impact drop tests using a typical aircraft skin panel were performed. The tests were numerically reproduced modelling the fluid region using the two meshless methods implemented in LSTC/LS-Dyna 971: the Smoothed Particle Hydrodynamics and the Element Free Galerkin method. The accuracy of the models was evaluated referring to the data collected in the tests.

Keywords:

Water impact drop-tests, Fluid-Structure Interaction, EFG, SPH.

Introduction

As shown also by recent statistics [1, 2], ditching and water impact still represent a serious menace for the aircraft safety. The losses, *economical* and in *human lives*, justify the interest in the development of design methodologies to improve aircraft crashworthiness with regard to water impact.

Loads acting on the structures during a water landing are difficult to reproduce and, therefore, experimental tests are necessary to deepen the knowledge of the event and to develop water impact worthy structures. Unfortunately, experimental tests are expensive, difficult to perform and often not repeatable.

At LAST Crash Labs of Politecnico di Milano, a water impact experimental test campaign was carried out and data collected were used to develop and validate numerical models to investigate the mutual dependency between the hydrodynamic loads acting on a structure and the structure response.

The research consisted of two phases: a *tests phase* and a *simulations phase*. In the *tests phase*, an intense test campaign was carried out and impact decelerations and deformations of a deformable test article were acquired. In the *simulations phase*, the tests were numerically reproduced adopting the Smoothed Particle Hydrodynamics (SPH) and the Element Free Galerkin (EFG) methods to model the fluid region.

Meshless methods were chosen to override the limitations of Lagrangian Finite Element (FE) approach in the description of events characterised by large deformations and the drawbacks of coupled Eulerian/Lagrangian analyses.

The SPH is a genuinely meshless method firstly introduced in astrophysics [3] and then applied to continuum mechanical problems. The EFG method was first introduced to study crack propagations [4] and its applications to fluid-structure interaction are rare.

The results obtained with the SPH and EFG models of the water region were initially compared with the experimental data and then the with each other. The stability of the SPH model and the feasibility of the EFG model were investigated. The accuracy of both these methods was quantitatively evaluated referring to the data collected in the tests (i.e. test article decelerations and base panel deformations) and a close numerical-experimental correlation was eventually obtained. Findings and guidelines for further investigations are drawn.

Water impact tests

Water impact drop tests were performed to collect impact decelerations of the test article and deformations of a typical aircraft aluminium skin panels.

Impact decelerations are important because the severity of the accident in term of injuries to the aircraft passengers depends on them. Deformations are important because they allow to estimate the stresses on the structure (when it is not possible to measure the impact pressure) and then to design crashworthy sub-floors.

Test article. In effort to evaluate the impact behaviour of a typical aircraft skin panel a specific test article was manufactured. The test article, shown in Figure 1, was meant to be simple and representative of the typical aircraft structures (geometry, materials and manufacture). A 2 mm Al 2024-T6 CLAD panel was installed on a deformable structure realised riveting together aluminium alloy panels and L-shape stiffeners. The base panel was riveted to the support structure after performing a thermal treatment to avoid plastic effects on the folded sides. The structure was design to avoid water inrush. The specimen was sealed to avoid the water leakage.

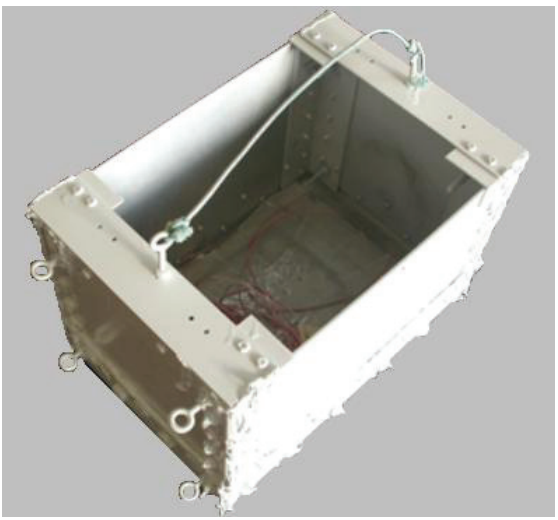


Figure 1: The deformable specimen used during the tests

Test facility. Thanks to the small dimensions of the test article, it was possibly to perform the drop tests using the indoor facilities of the LAST Crash Labs: in particular a 1.5 m diameter and a 1.4 m depth PVC water basin was used. The test article was hanged to a quick-release system and four steel cables were used to guide the test article during the fall and to maintain the impact incidence of the test article within acceptable limits (i.e. less than 3 deg).

Impact decelerations of the test article and deformations of the base panel were measured during the tests because of the relevance that these quantities have in designing structures safe in ditching.

Twelve strain gages were radially installed on the target panel at different positions to acquire impact deformations and to guarantee a redundancy of the measurements (Figure 2). Four accelerometers were mounted on the test article to acquire impact decelerations, to guarantee a redundancy of the measurements and to verify the horizontality of the impact.

The accelerometers and the strain gages were connected to a Power-Daq 14 bit and 16 channels data acquisition system. Signals were acquired with a sample frequency of 15 kHz to avoid *aliasing* and to guarantee a reasonable number of *measures* during the initial phase of the impact when accelerations and deformations have a sudden growth.

The tests were filmed using a high speed camera to capture the dynamics of the event and to have a deep insight in it. Furthermore the movies were also used to estimate the impact velocity and incidence of the test article.

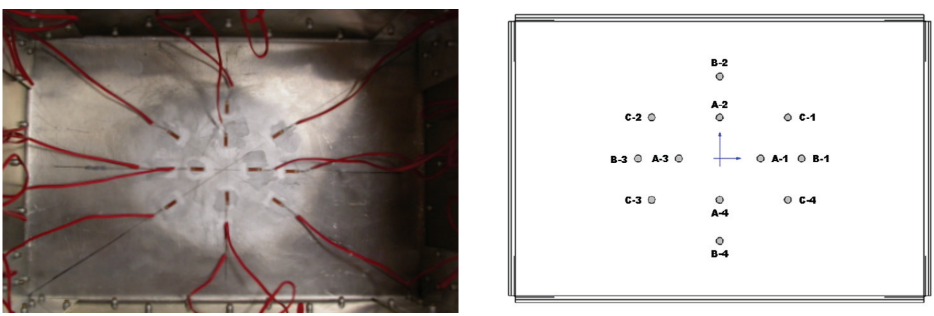


Figure 2: The strain gages layout on the target panel

Carried out tests. The water impact tests were carried out unhooking the test article from a prescribed height. The test facility used in the tests allows a maximum drop-height of 3.5 m. Tests were carried out with drop-height from 0.5 to 3.0 m and impact velocity from 3.1 to 7.7 m/s.

In order to guarantee the accuracy of the measures and to verify the repeatability of the tests, for every drop-height the tests were repeated until the measures in five similar tests fall within the decided tolerance: impact incidence within 3 deg and impact velocity within ±0.2 m/s.

Data acquired. Accelerations and deformation were measured. The agreement in the measures collected (impact decelerations and deformations) for the different drop heights and the comparison between dimensionless measures indicate the reliability of the tests.

Numerical simulations

Numerical models reproducing the tests were worked out and SPH and EFG methods were used to model the fluid region.

As the impact incidence of the test article was negligible, the double symmetry of the problem was exploited and only a quarter of both the test article and the fluid region were modelled.

FE model of the specimen. The geometry of the test article was rather simple and the mesh uniform and fine. The choice of the reference length depended on the characteristic length of the water elements. In fact, the ratio between the reference length of the structure elements and the one of the fluid elements has a deep influence on the accuracy of the treatment of the fluid-structure interaction.

Eventually, the FE model of the test article consisted of 2776 four-node shell elements, Belytschko-Tsay formulation with three integration point in thickness. The elastic piecewise linear plasticity material model (MAT_24) was adopted to represent aluminium behaviour and the influence of the strain rate was considered by means of Cowper-Symonds coefficients.

The test article was placed over the fluid surface (Figure 3) and the impact velocity was imposed to it.

Fluid region. In effort to avoid rigid motion of the fluid mass and to limit required CPU-time and memory usage, the dimensions of the fluid region in the simulations were smaller than the actual one. The fluid region was modelled as a 500 m edge length square box.

The fluid behaviour was reproduced using a material that allows to compute only isotropic stresses and deviatoric ones after defining a numerical viscosity, with a linear polynomial equation of state and the possibility to numerically cavitate (*pressure cut-off*). The constitutive law was chosen after trial-and-error simulations and following the remarks from previous research works [6].

SPH model of the fluid region. The distance between the SPH particles was chosen as to fill the fluid region with a *reasonable* number of particles in term of computational resources and, at the same time, to guarantee the accuracy of the solution and an appropriate representation of the dynamics of the event. The fluid-structure interaction was reproduced via contact algorithm [5]. The boundary conditions at symmetry planes were imposed using ghost particles procedure [5] whilst the boundary non-reflecting condition was applied on the outer faces of the fluid region. A portion of the SPH numerical model of the fluid is visible in Figure 3-A.

EFG model of the fluid region. The geometry and the number of nodes in the EFG water region model were the same as the SPH model. The constitutive law and the contact between the fluid region and the test article were also the same as in the SPH model. Reflected waves were avoided imposing a non-reflecting boundary condition [5]. The symmetry constraints were imposed simply applying the symmetry single point constraints on the nodes. A portion of the EFG numerical model is visible in Figure 3-B.

Numerical-experimental correlation

Numerical results were eventually compared with experimental evidence referring both to the dynamics of the event captured by the high-speed movies and the measured impact decelerations and deformations. Furthermore, the required CPU time was considered because it is a central parameter for any *design-by-analysis* procedures.

Impact dynamics. The SPH and the EFG models provided a commonsense description of the event. The behaviours both of the test article and the water (the *splash* in particular) are alike the ones in the high-speed movie (Figure 4).

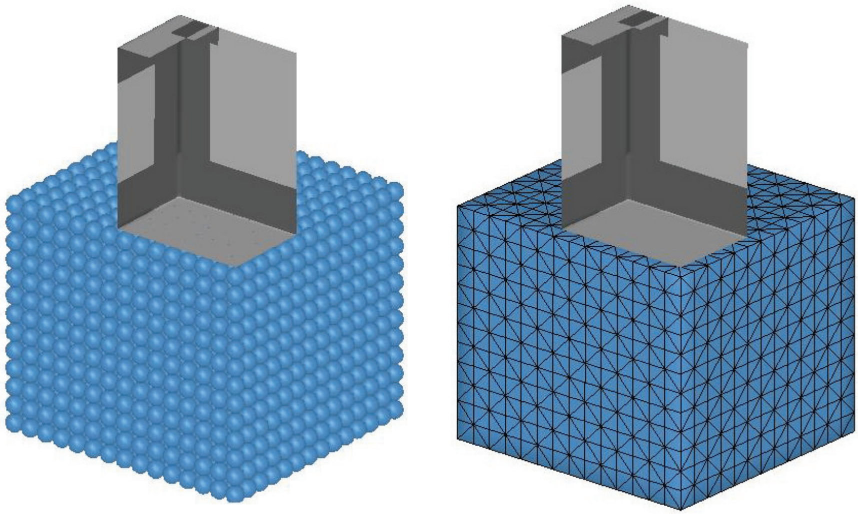


Figure 3: Numerical models of a drop test - SPH (RHS) and EFG (LHS).

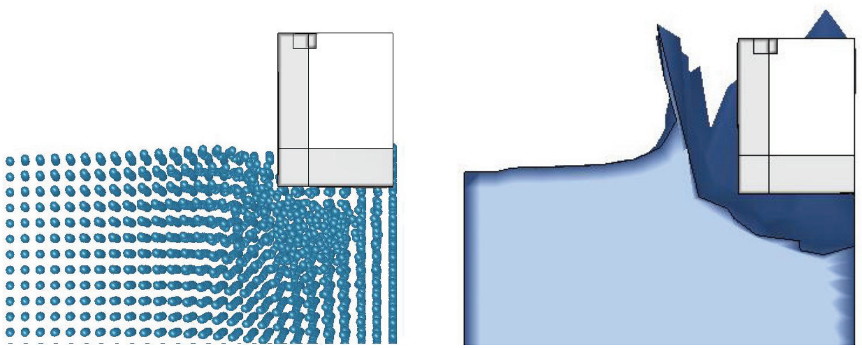
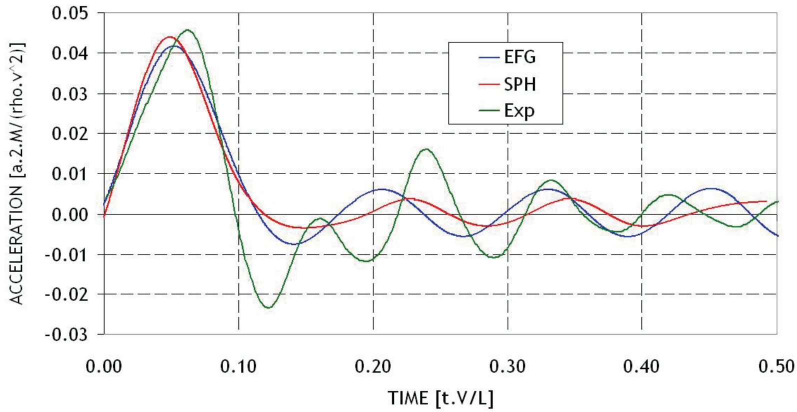


Figure 4: Numerical simulation of a drop test - SPH (RHS) and EFG (LHS).

Impact deceleration. The correlation in terms of impact decelerations is rather close. It is apparent in



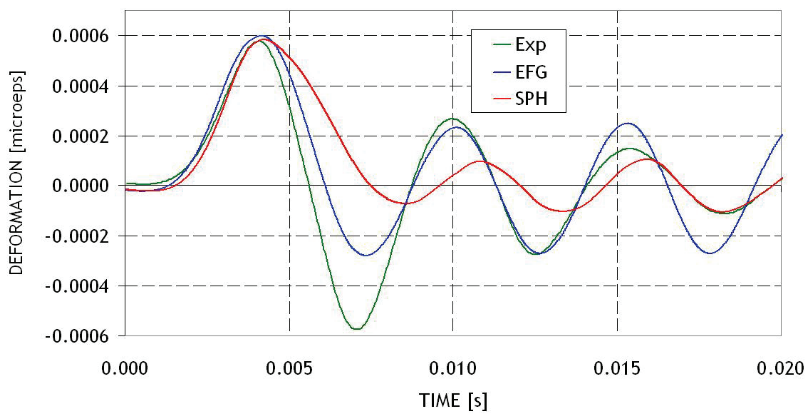
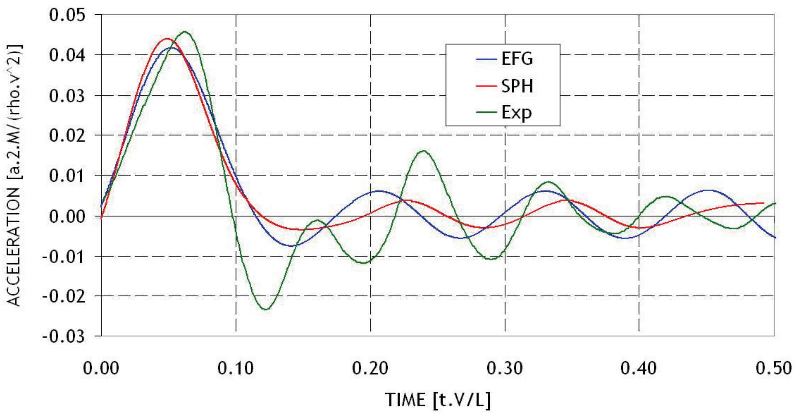


Figure 5-A, that the numerical peak is slightly lower (less than 8% of the peak) relative to the measured one for both the models, whilst the first peak duration is slightly longer. Also the slope of the curve is well reproduced.

Impact deformation. Referring to the inner strain gages (



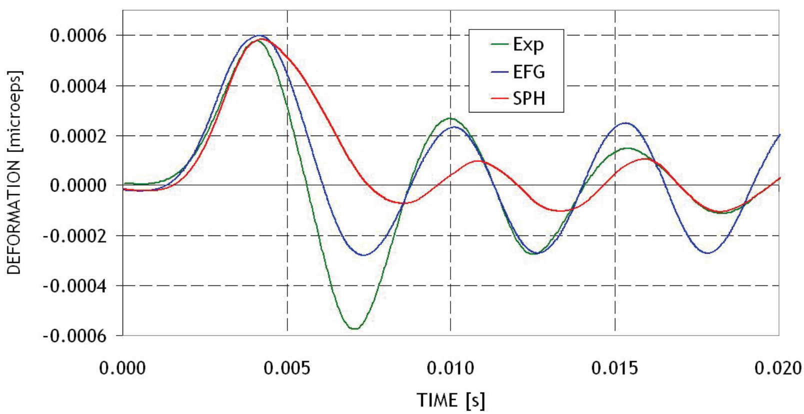


Figure 5-B), the numerical-experimental correlation is over the 95% for both the peak values. The numerical peak is slightly higher than the measured one. Considering the duration of the first peak, the EFG model provided a good correlation, whilst the SPH model computed a 15% longer interval than the experimental one.

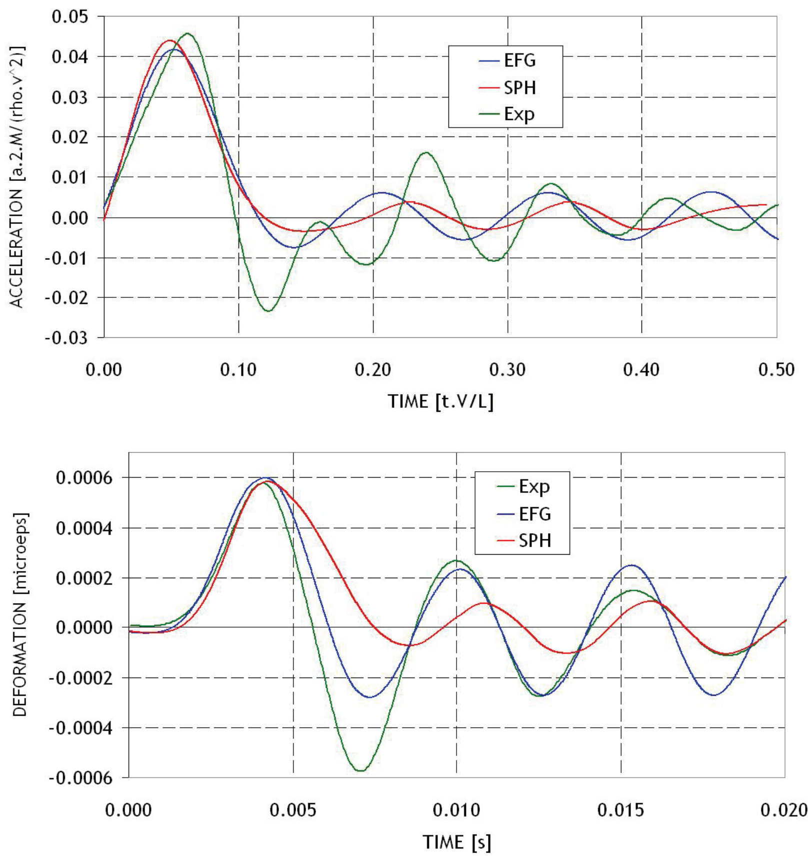


Figure 5: Comparison between experimental and numerical values.

Required CPU-time. The first 40 ms of the event were simulated. The same simulation was run ten times and the average required CPU-time was evaluated and referred with the one required by simulation where the fluid region was modelled with FE solid elements. The SPH and the EFG models required about two and three times the CPU required by the FE model, respectively

Nevertheless, it must be notice that increasing the simulated time to 80 ms, the FE model simulation crashes with an error termination before the termination time was reached.

Discussion

The SPH and the EFG models provided a common-sense description of the impact of the test article. Comparing numerical results and experimental data a close correlation for both impact decelerations and deformations is obtained. In particular the peak values and the duration of the first peak were well reproduced but the time-profiles were slightly different. The required CPU times are acceptable – especially when compared with the ones of other approaches (such as the customary Lagrangian FE approach or the coupled Lagrangian/Eulerian approach) and referring to the accuracy of the solution. In view of these results, the SPH and the EFG methods proved to be effective approaches to analyze the water impact phenomenon and the fluid-structure interaction.

Conclusions

Water landing of an aircraft in emergency is likely to turn into a tragic event. In view of this, it is essential to develop numerical tools to design worthy structure with regard to this event.

At the LAST Crash Labs of Politecnico di Milano a number of water impact tests were carried out using a deformable test article meant to be a simple structure representative of the typical aircraft structures. The tests aimed at collecting reliable data to develop and validate numerical models focusing on water model and fluid-structure interaction. During the tests impact decelerations and deformations were measured.

The tests carried out were numerically reproduced using the SPH and the EFG methods to model the fluid region. A satisfactory numerical to experimental correlation was obtained in terms of dynamics of the event and impact decelerations and deformations. The SPH and the EFG approaches proved to be feasible numerical tools to analyze the event and they are effective in the description of water impact phenomenon.

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