COMPARATIVE ANALYSIS OF DIFFERENT METHODS TO COMPUTE DITCHING LOADS

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Abstract: Ditching is an emergency condition that ends with a planned "landing" of the aircraft on water. Four main phases may be considered in a ditching event: Approach, Impact, Landing and Floatation. This paper will address the loads aspects of the second phase, an extreme case of fluid-structure coupling where high pressures are developed during the impact of the sliding aircraft with water, which in turn may cause rupture of the structure, jeopardizing the required safe evacuation of crew and passengers.

This problem is gathering significant attention from public and institutions especially after some recent events with large media coverage (like the ditching on the Hudson River, US Airways Flight 1549, 15 January 2009).

Currently there are very few tools available to determine the loads generated during the ditching impact phase. This paper will present (and compare among them) ditching loads methodologies, one experimental and four different numerical simulation approaches:

- **Experimentally measured** ditching test results obtained in two European funded research projects: SMAES (Smart Aircraft in Emergency Situation, 2011-2014) and SARAH (Increased Safety and robust certification for ditching of aircrafts and helicopters, 2017-2019).
- **Synthetic pressures** derived analytically by matching SMAES experimental results.
- **Smooth Particle Hydrodynamics** (SPH) technique embodied in an explicit FEM code
- **Computational Fluid Dynamics** (CFD).
- **Semi-Analytical Water Entry Approach**

The main objective of the paper is to compare different alternatives, decide which are currently the most suitable ditching loads methodologies that could be used to simulate this event during aircraft design and certification. The ditching loads have to be obtained as a function of the aircraft classical landing parameters (e.g. horizontal and vertical speed, pitch angle etc). and should be applicable to any aircraft geometry. The paper concludes with the application of these methodologies to a real case of a medium transport aircraft and suggestion for further research in this area.

1 INTRODUCTION

January 15th 2009 was a cold winter day in New York City. At 15:25 in La Guardia airport, Chesly “Sully” Sullenberger released the breaks of the Airbus A320 he was piloting bounded to Charlotte (NC). Just 208 seconds later he landed in the chilly waters of the Hudson River. All, crew and passengers up to a tally of 155, survived the ditching that day.

Ditching is a planned aircraft event that ends with a controlled emergency landing in water. Four main phases may be considered in a ditching event:

— **Approach**: Characterized by aircraft/environment conditions before impact.
— **Impact:** Structural response during the impact (fluid-structure interaction).
— **Landing:** Subsequent motion of the aircraft until stoppage.
— **Floatation:** evacuation of passengers and crew.

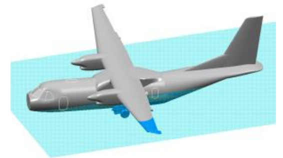
Approach	Impact	Landing	Floatation
			

Figure 1: The Four Ditching Phases

This scenario is reflected in the Airworthiness Regulations that requires the aircraft manufacturer to take all necessary measures to minimize risk during ditching to allow the crew and passengers to evacuate the cabin safely.

At Airbus DS Military Transport Aircraft Aeroelasticity and Structural Dynamics department ditching loads has been a topic of continuous research for more than 12 years [1-15]. This interest is also shared by universities, research laboratories and industrial partners that have gathered together in two recent consortia in the European funded research projects SMAES (Smart Aircraft in Emergency Situation, 2011-1014) and the on-going SARAH (Increased Safety and robust certification for ditching of aircrafts and helicopters, 2017-2019).

SMAES devoted part of its activities to perform experimental ditching test of flat plates with different stiffness, material (metallic, composite), curvature, impact speeds and pitch angles. **SARAH** extended the SMAES results to more complex and realistic aircraft hull geometries. Data obtained from these tests can be used both, directly or indirectly to validate numerical tools / analytical theories for solving the fluid-structure behavior during ditching. The tests were performed at the Italian CNR-INM Institute of Marine Engineering in Rome.

Papers published in ASIDIC 2015 [8, 9] described respectively SMAES experimental ditching loads on **rigid plates** and subsequent numerical simulation of plate structural response. Paper published in ASIDIC 2017 [12] was devoted to SMAES experimental ditching loads and structural response on **flexible plates**. The novelty herein in ASIDIC 2019 is the comparative analysis of four different methodologies, the selection of one or two of them, the first publication of some SARAH test results and finally the application of the ditching loads methodologies to **real aircraft** Finite Element Method models (not only plates like it was the case before). The final conclusion is that there is available at Airbus DS a predictive methodology to determine the pressures and loads in a ditching scenario which in turn can be used for design and certification of aircraft.

2 EXPERIMENTALLY MEASURED DITCHING PRESSURES

2.1 SMAES Ditching test summary and instrumentation

The SMAES ditching tests are set of guided impact tests of panels against water at horizontal speeds representative of aircraft at landing condition. The objective was to measure the pressures acting on the panel and the structural deformation during the impact. To provide with a complete database, the most relevant parameters were varied during the test:

- Horizontal speed (30m/s, 40m/s, 50m/s) & Pitch angle at impact (4°, 6°, 10°)
- Panel curvature (flat, concave, convex) & Panel stiffness (rigid, flexible, very flexible)
- Panel material (metal –Al2024-T351–, composite)

Vertical speed:	-1.5 m/s
Total guidance structure length:	64 m
Trolley mass:	~ 600 Kg
Trolley + specimen mass:	~ 800 Kg

The trolley is accelerated by a catapult composed by a total of 8 elastic cords

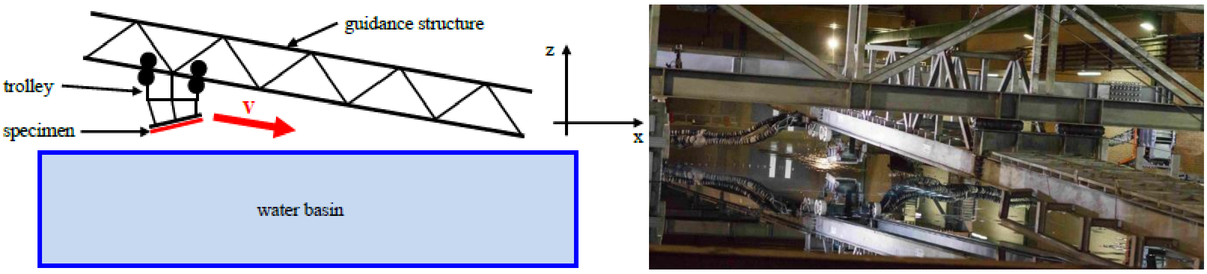


Figure 2: Schematic sketch of the guided ditching test setup

The instrumentation of the guided ditching tests was very complete and differs slightly depending on the specimen and the test conditions. The typical set of instrumentation for deformable plates would be:

- 14 pressure transducers (14 channels)
- 8 strain gauges – two directions (16 channels)
- Velocity (1 channel)
- 2 biaxial and 2 single axis accelerometers on the panels (6 channels)
- 6 load cells to measure forces from the panel to the trolley (4 channels)

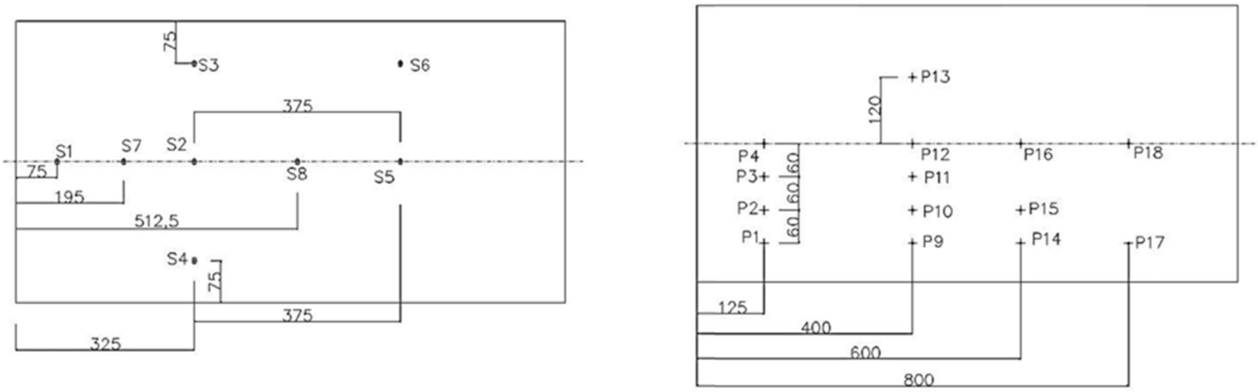


Figure 3: Positions of strain gauges (left) and pressure transducers (right) for deformable plates.

2.2 SMAES Ditching test execution

The panel specimen, with a size of 1000 x 500 mm (typical fuselage skin panel size), was installed in a frame. The frame embedded in a trolley and the trolley guided using an auxiliary structure up to reaching the desired test conditions at the impact.

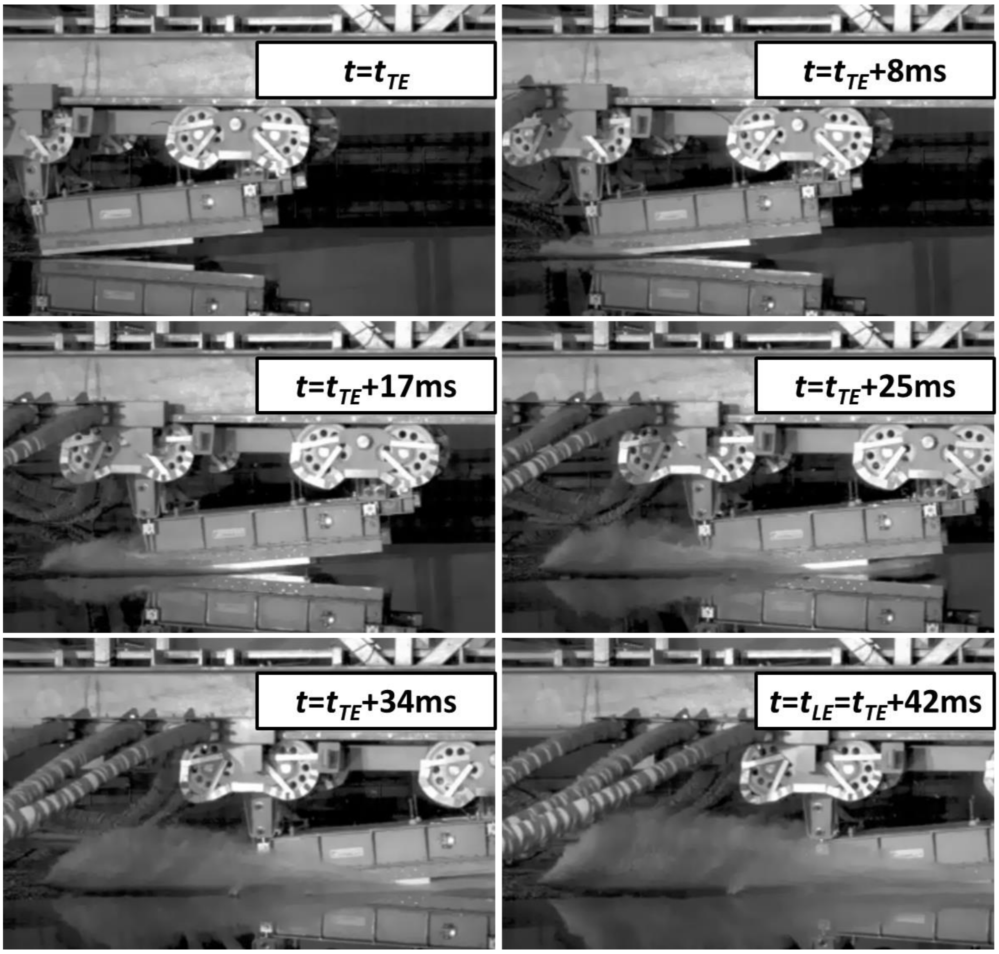


Figure 4: Pictures illustrating the guiding structure, the trolley and the specimen at impact phase

During the complete execution of each run test, six phases could be identified

1) Release
2) Acceleration: 1.00 s approximately
3) Constant velocity: 0.20 s approximately
4) Impact and natural deceleration: 0.30 s approximately
5) Forced breaking: 0.44 s approximately
6) Stop

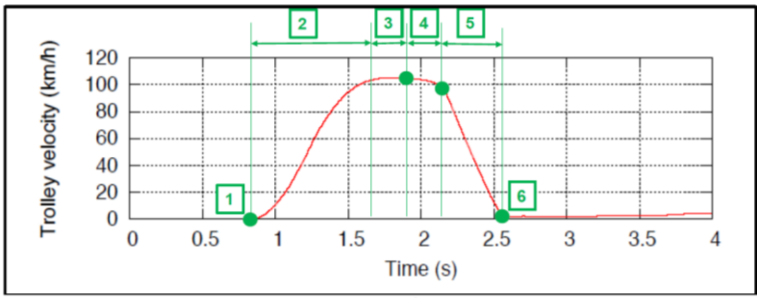


Figure 5: Phases of each SMAES ditching test run

3 DITCHING PRESSURES OBTAINED SYNTHETIZING TEST RESULTS

In a general way, the pressure time history can be expressed as a function of the (x, y) position in the panel and the initial conditions described in figure 6. In light of the test results, the expression (1) plotted in figure 7 seems appropriate to approximate analytically the pressure time histories obtained experimentally for a flat quasi-rigid panel ditching.

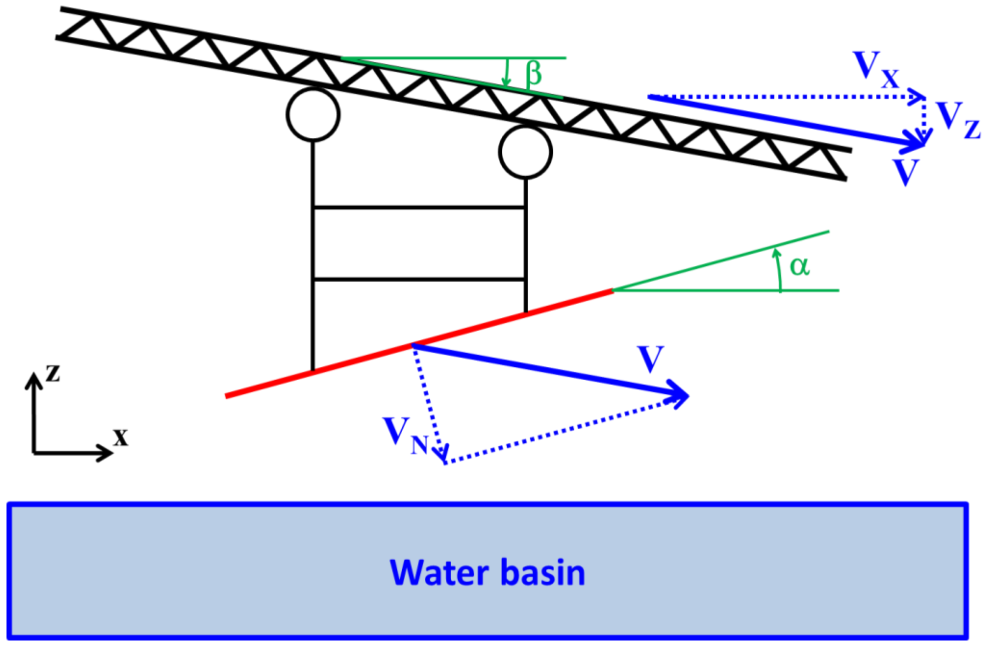


Figure 6: Initial ditching conditions sketch

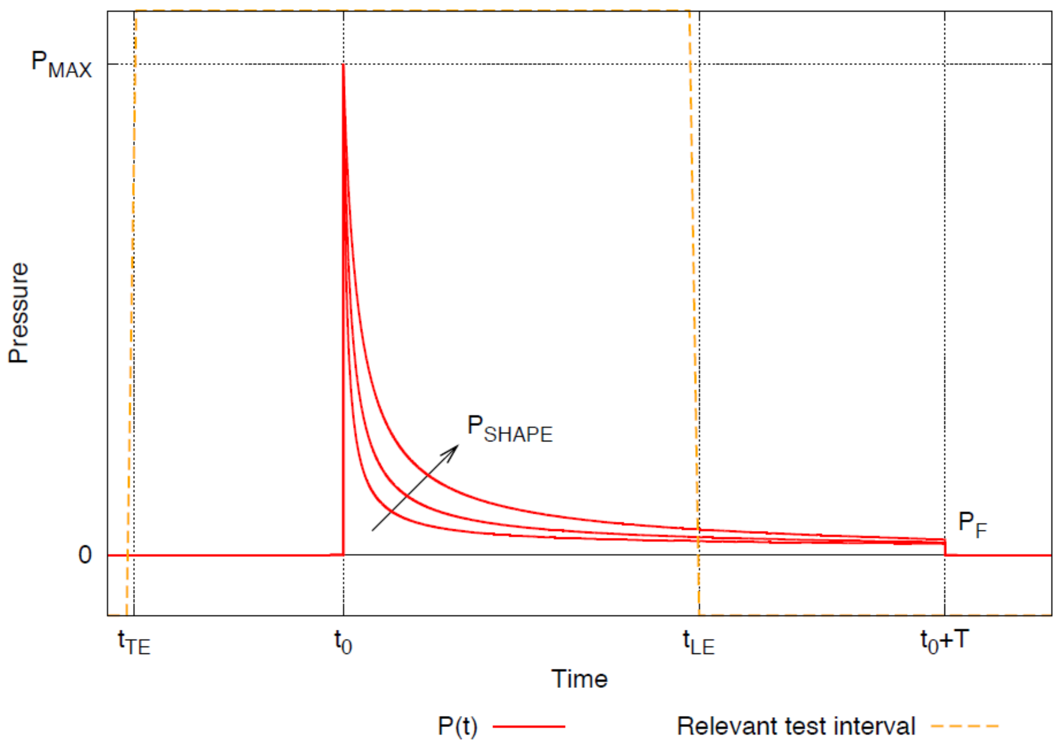


Figure 7: Analytical approximation for the pressure time histories

$$P(V_X, V_Z, \alpha, x, t) = \begin{cases} P_F + \dfrac{P_{SHAPE}}{\tan\left[\dfrac{t-t_0}{T}\dfrac{\pi}{2} + \arctan\left(\dfrac{P_{SHAPE}}{P_{MAX} - P_F}\right)\right]} & , \quad t_0 \le t \le t_0 + T \\ 0 & , \quad t < t_0 \;\&\; t > t_0 + T \end{cases} \tag{1}$$

Where:

V_X, V_Z, α are the initial ditching conditions: horizontal speed, vertical speed and pitch angle

(x, y) are the panel coordinates, with the origin in the central point of the trailing edge, x positive towards the direction of motion and y positive to port

t is the time

$t_0 \equiv t_0(V_Z, \alpha, x)$ is the time instant for which $P = P_{MAX}$

$P_{MAX} \equiv P_{MAX}(V_X, V_Z, \alpha, x)$ is the peak value of the pressure time history

$P_{SHAPE} \equiv P_{SHAPE}(V_X, V_Z, \alpha, x)$ is a shape factor that determines the decay rate of the pressure time history

$P_F \equiv P_F(V_X, V_Z, \alpha, x)$ is the final pressure value at $t = T + t_0$

$T \equiv T(V_Z, \alpha)$ is an arbitrary but sufficiently large time as to make sure that the pressure time history has become almost flat

Figure 8 shows the shape of these synthetic pressures with 40% of the panel surface wet and at the instant when the water reaches the flat panel leading edge.

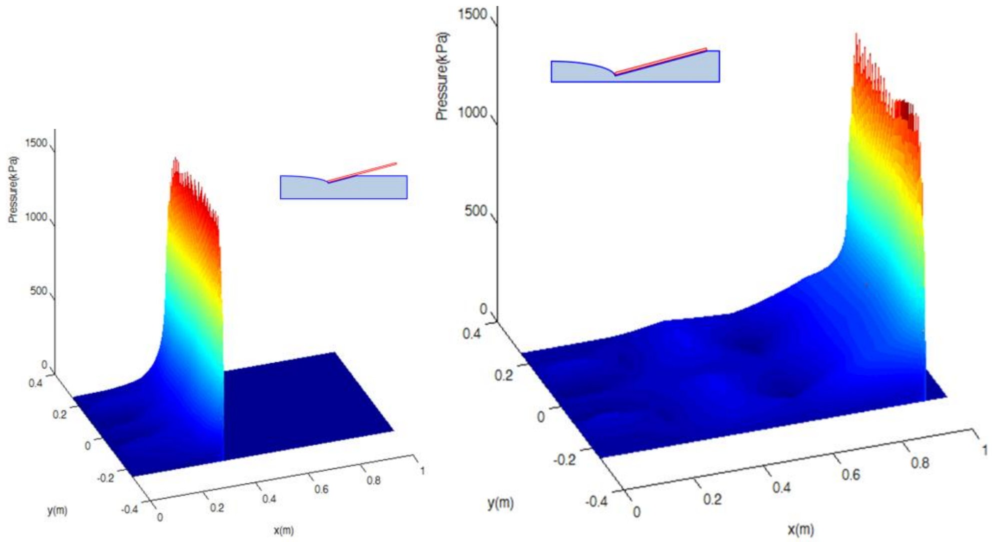


Figure 8: 3D pressure distributions with 40% panel surface wet (left) and with 100% panel surface wet (right)

By construction, the synthetic pressures reproduce the SMAES test results and they could be considered a perfect match of ditching loads inside the conditions tested in SMAES:

- Geometry: Size (up to x=1 m) and curvature (flat, concave, convex)
- Horizontal speed [30m/s - 50m/s]
- Pitch angle at impact [4° - 10°], etc.

Outside these ranges (especially for x > 1 m), some level of extrapolation could be needed based on conservative criteria.

4 DITCHING PRESSURES OBTAINED USING SMOOTHED PARTICLE HYDRODYNAMICS (SPH) TECHNIQUE

4.1 Smoothed Particle Hydrodynamics (SPH) technique

The Smoothed Particle Hydrodynamics (SPH) is a grid-less computational technique where each SPH particle represents an interpolation point. Particles interact based on a weighted summation of their properties within a zone of influence controlled by the smoothing length. This technique has been widely used in Airbus DS Military Aircraft with the ©ESI Virtual Performance Solution (former PAM-CRASH) software.

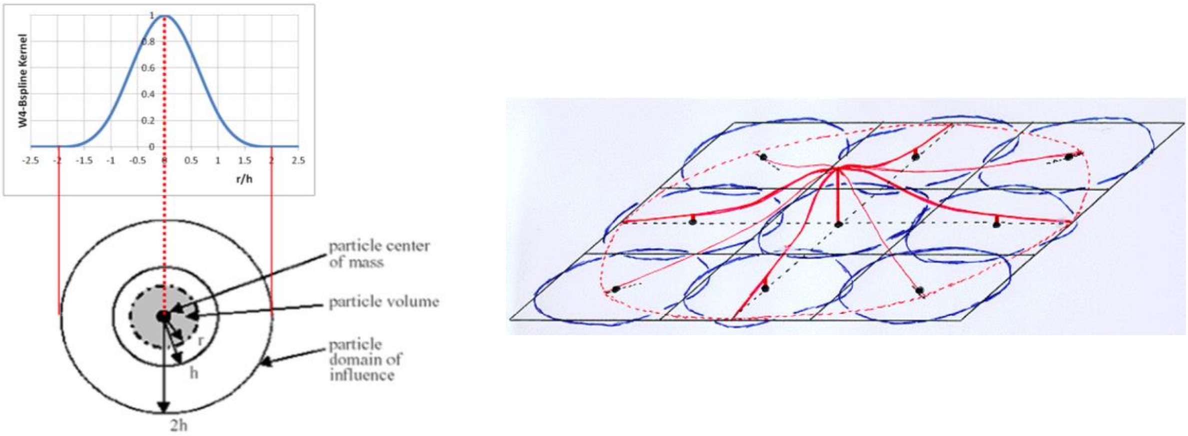


Figure 9: SPH main control parameters. Virtual Performance Solution ©ESI [18]

SPH technique has been a very powerful tool in numerical simulation of impacts of aeronautical structures. The capacity of the **SPH** to properly handle very large deformations without exhibiting numerical instabilities has made them **the ideal way of modelling impactors** (bird, ice, stones, tire fragments, debris…). The **SPH technique** is identified as one of the **key contributors** of the success of impact numerical simulations in aero structures [7]. Past experience in Airbus DS Military Aircraft shows that, when the most important effect is the inertia effect, the SPH technique is the most suitable candidate to model the impactor.

Would the SPH technique also be a suitable candidate to model the sea in a ditching scenario? In fact, promising results have been obtained for helicopter ditching simulation [1]. Could these promising results in helicopters be extended to aircraft ditching with significant horizontal speed? To try to answer this question, the SMAES plate explicit FEM model has been considered in combination of a SPH sea. Figure 10 shows this simulation in which the plate has been launched on an SPH sea.

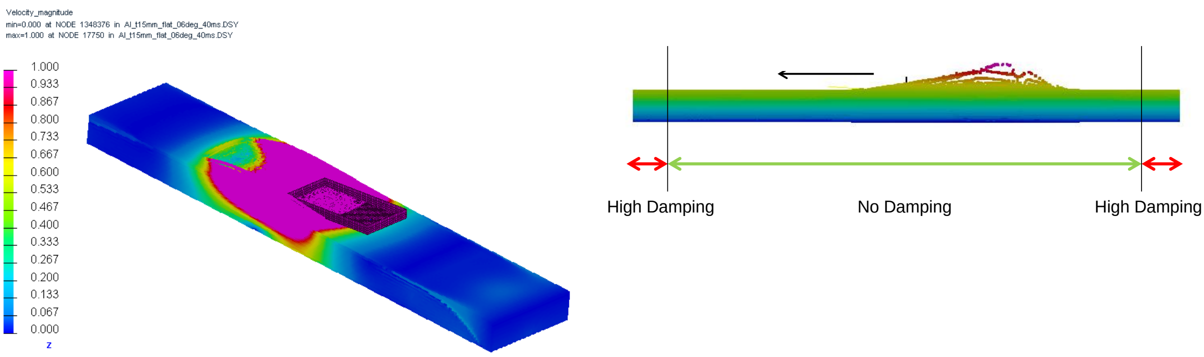


Figure 10: Periodic boundary conditions in ditching simulations: translating domain with undisturbed flow conditions (left). Damping zone example in ditching simulation with high horizontal velocity (right)

4.2 SPH results

Figure 11 shows the comparison of SPH pressures versus SMAES rigid plate ditching test.

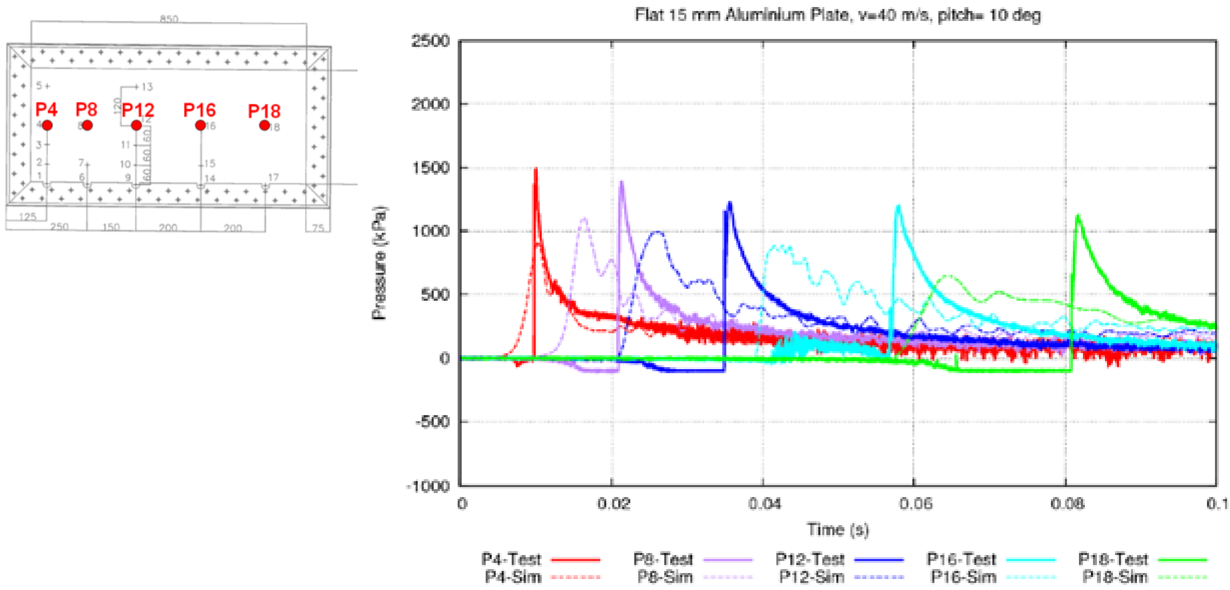


Figure 11: Comparison of SPH pressures versus SMAES rigid plate ditching test

Comparison shows that the shape of SPH pressures and order of magnitude of pressure peak values are adequate (although not conservative). Results are sensitive to the SPH particle size. For flat rigid plates, an adequate size of SPH has been found around 16 mm. For that size, results have already converged. Finer SPH sizes do not improve the comparison with test results. For flexible plates, the size of SPH is even lower (5 mm) but comparison in terms of pressures or deformations with test results do not improve compared with what is shown in Figure 11.

	No. of SPH Particles	SPH size (spacing)	CPU Time (20 processors)
Rigid Plate 1m x 0.5m	0.4 Millions	16 mm	6 hours
Flexible Plate 1m x 0.5 m	10 Millions	5 mm	1 week
Flexible Full Aircraft (estimated)	250 Millions	Variable [5-16 mm]	25 weeks

Table 1: CPU time of SPH ditching calculations

The conclusion at Airbus DS Military Aircraft about the usage of SPH for ditching simulation is:

- In pure vertical ditching (with Vx=0) like helicopter ditching (and again because the most important effect in this helicopter ditching scenario is the inertia effect), the SPH technique could be a suitable way of simulating this event.
- For aircraft ditching at landing horizontal speeds, the SPH technique lacks the physics laws needed to obtain the accuracy required in design and certification of aircraft. The technique allows simulation of plates with 3D effects both rigid and flexible, although the computer cost of these last ones are in the limit of what could be an industry run (Table 1). Estimation of what could be the computer cost of a full flexible aircraft against an SPH sea show a prohibitive figure (Table 1). Although some work could be done to improve this figure (parallelization, usage of half symmetry aircraft model, etc.) the cost is still considered unaffordable.

Further developments of ditching simulations using this technique have been stopped at Airbus DS and will not be resumed if there is no a significant breakthrough in the SPH technique that recommend to reconsider this policy.

5 DITCHING PRESSURES OBTAINED USING COMPUTATIONAL FLUIDYNAMICS (CFD)

5.1 Computational Fluid Dynamics (CFD)

The next logical step after having tried the SPH technique is to jump in a methodology that indeed includes what the SPH lacks: the proper representation of the physics of fluids laws: computational fluidynamics (CFD).

Taking the rigid flat plate of the SMAES as the simulated case of study the first attempt was to simulate a 2D version in CFD and then compare the obtained pressures with the SMAES test in the plane of symmetry. The code used is ANSYS Fluent, versions 18.0 and 19.2.

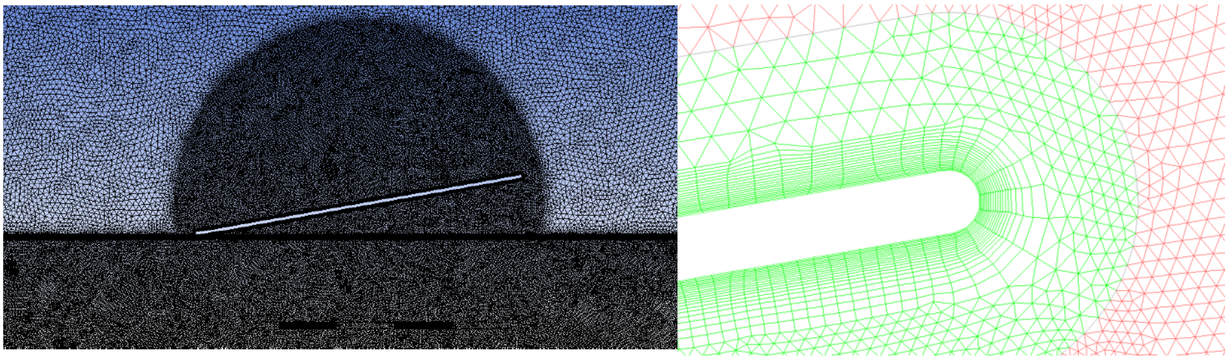


Figure 12 (Left) SMAES guided ditching test model implemented in ANSYS Fluent (2D). (Right) CFD Mesh

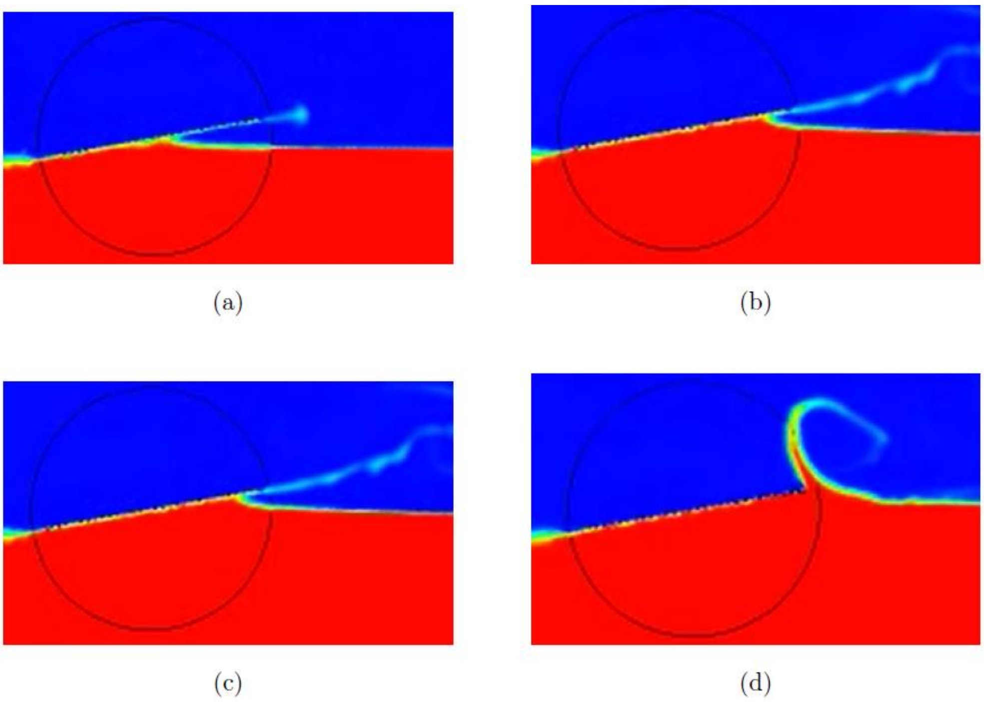


Figure 13 Evolution of fluid free surface during the plate impact

5.2 Meshing and Solver

The meshing strategy assigns finer mesh in the most relevant zone of the fluid domain that is the closest to the plate and coarser elements as the distance to the plate increases.

Implicit Volume of Fraction (VOF) modelling was used to capture the multiphase nature of the simulation. This algorithm is used in finite difference numerical simulations to approximate free boundaries. Free boundaries are considered to be surfaces where discontinuities exist in one or more variables, such as material interfaces, shock waves or interfaces between fluid and deformable structures. The energy terms are neglected i.e. disabled in the solver. Two turbulence model strategies were investigated:

- The realizable k-ε with standard wall functions.
- Shear Stress Transport (SST) k-ω turbulence model with turbulence damping enabled.

In the simulation, vertical velocity is imposed to the plate with an analogous function and the horizontal movement is introduced to the fluid using the boundary conditions in the domain (the left and right boundaries necessary to introduce the horizontal velocity of the water which are velocity inlet and pressure outlet respectively).

5.3 CFD Results

Figure 14 shows the CFD results (filtered) and figure 15 the comparison of CFD (unfiltered) with SMAES test results.

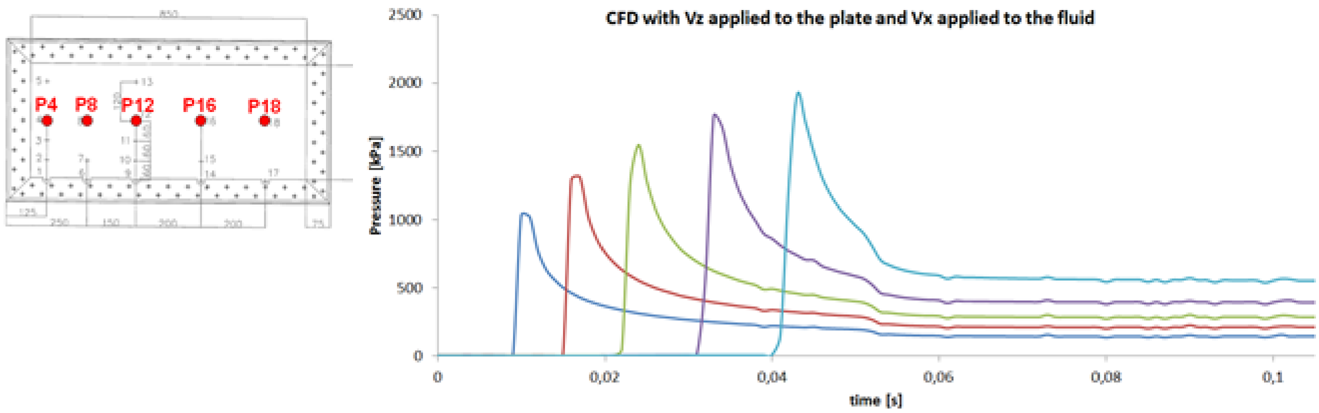


Figure 14 CFD results (filtered) for Vz=1.5 m/s, Vx= 40 m/s & Pitch angle = 10 deg.

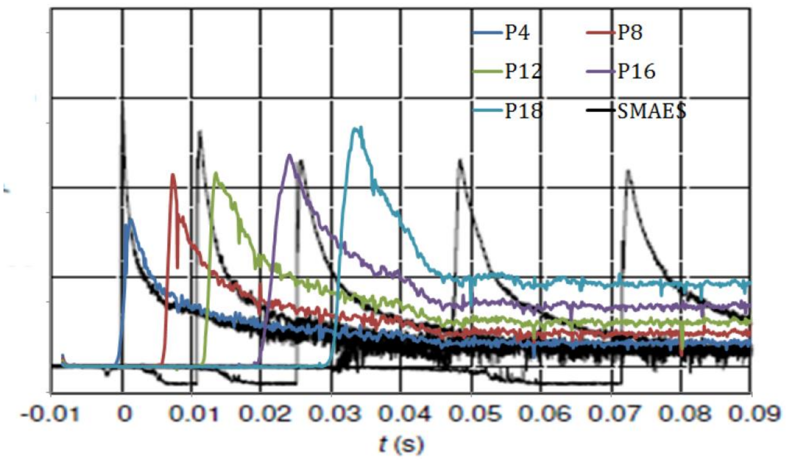


Figure 15 Comparison of CFD results (unfiltered) Vs. SMAES test (Vz=1.5 m/s, Vx=40 m/s, Pitch =10 deg.)

Comparison shows that the shape of CFD pressures is -as expected- similar to test shapes. The order of magnitude of pressure peak values is slightly below test values for the first 3 gauges, adequate for the 4th gauge and too conservative for the 5th gauge. The tendency of peaks is the opposite between CFD and test: while in the CFD simulation the peaks grow with X, in the test the peaks decrease with X. Finally, the remaining pressure at the end of each time history that in the test is always a low value, it seems to be a relatively large value in CFD and growing with each gauge:

(CFD Remaining pressure P4 < CFD Remaining pressure P8…< CFD Remaining pressureP18).

All this deficiencies in the CFD results are attributed to the simplification of a 2D simulation. A 3D simulation would be required to check whether the 3D effects are the responsible of the deficiencies in the 2D comparison. Table below shows the expected CPU time required for a 3D simulation (plate) and a likely extension of the foreseen computer cost of a full aircraft CFD ditching simulation.

	CPU Time (32 Processors)		Scalability (128 processors)
2D Rigid Plate 1m x 0.5m	4 days		No scalable
3D Rigid Plate 1m x 0.5 m (estimated)	40 days	⇒	10 days
Full Aircraft (estimated)			1 year?

Table 2: CPU time of CFD ditching calculations

Because of the expected cost, no 3D simulation has been performed.

One of the advantages of the use of CFD is that any condition can be simulated. Therefore, CFD may be used for conditions far from those tested at SMAES. Next plot shows an example of these sensitivities: the effect of change of pitch angle.

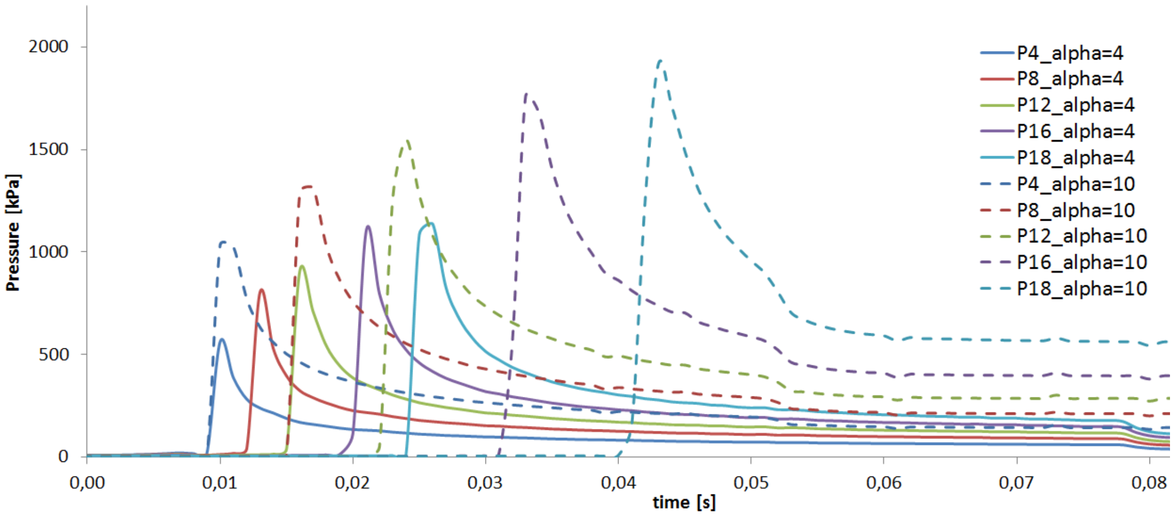


Figure 16 Sensitivity Analyses to Pitch Angle (10 deg. Vs. 4 deg.).

6 SEMI-ANALYTICAL WATER ENTRY PRESSURES

This method is based in Korobkin's analytical models for water impact [15] which in turn is based on classical Wagner water impact theory [16]. Korobkin proposes that the pressure distribution on a body that enters the water at a certain speed has the following analytical solution:

$$P(x,t) = \rho \dot{h}^2(t)\left[\frac{\dot{c}}{\dot{h}}\frac{c}{\sqrt{c^2-x^2}} - \frac{1}{2}\frac{c^2}{c^2-x^2}\frac{1}{1+f_x^2} - \frac{1}{2}\frac{f_x^2}{1+f_x^2} - \frac{\dot{d}}{\dot{h}} + \frac{\ddot{h}}{\dot{h}}\left(\sqrt{c^2-x^2} + f(x) - h(t) - d(t)\right)\right]$$

where h is the vertical displacement of the body, f is a function that represents the shape of the body, $d(t)$ is a function that represents the splash up height, and in this solution is assumed $d(t) \equiv 0$, and c is a geometrical quantity determined by the Wagner condition as shown in the following equation. The real contact point must then be solved from it:

$$\int_0^{\pi/2} f[c(t)\sin(\theta)]d\theta = \frac{\pi}{2}h(t)$$

To be able to represent the influence of the horizontal velocity, two additional corrections are added to the equation:

— A correction to account for the horizontal velocity, based on the study presented in [17] is applied to both the vertical speed and acceleration $\dot{h}$ and $\ddot{h}$, as shown below:

$$\dot{h} = v_z - \tan(\theta+\alpha)\,v_x + \frac{\dot{\theta}}{\cos(\theta+\alpha)}(\cos(\alpha)\,x + \sin(\alpha)\,z)$$
$$\ddot{h} = a_z - \tan(\theta+\alpha)\,a_x + \frac{\ddot{\theta}}{\cos(\theta+\alpha)}(\cos(\alpha)\,x + \sin(\alpha)\,z) + G$$

where v_x, v_z, a_x, a_z are the velocity and acceleration in x and z aircraft axis respectively, θ is the angle of attack, α is the local geometrical angle of the spatial point of interest and G is an additional geometrical dependent term, as described in [17].

— An experimental correction based in the SMAES test results [8] is applied to the final resulting pressure as follows:

$$P_c(x,t) = (P(x,t) - k_m P_{MAX})\frac{1-k_f}{1-k_m} + k_f P_{MAX}$$

where P_c is the final pressure after this correction, P_{MAX} is the maximum pressure that appears on each spatial point and the factors k_m, and k_f are experimental factors that relate the maximum pressure with the assumed constant pressure over time that remains after the impact, and take values of 0.123 and 0.03 respectively.

Finally, to obtain the pressure distribution over the wetted surface, the movement of the body is solved with an explicit time integration scheme, assuming initial conditions for the speed and acceleration. The results compared with the SMAES test are shown in figures 17 & 18. As stated previously, the wave rise effect is not taken into account in this formulation, which causes the noticeable difference in the initial start of the pressure evolution on each point considered.

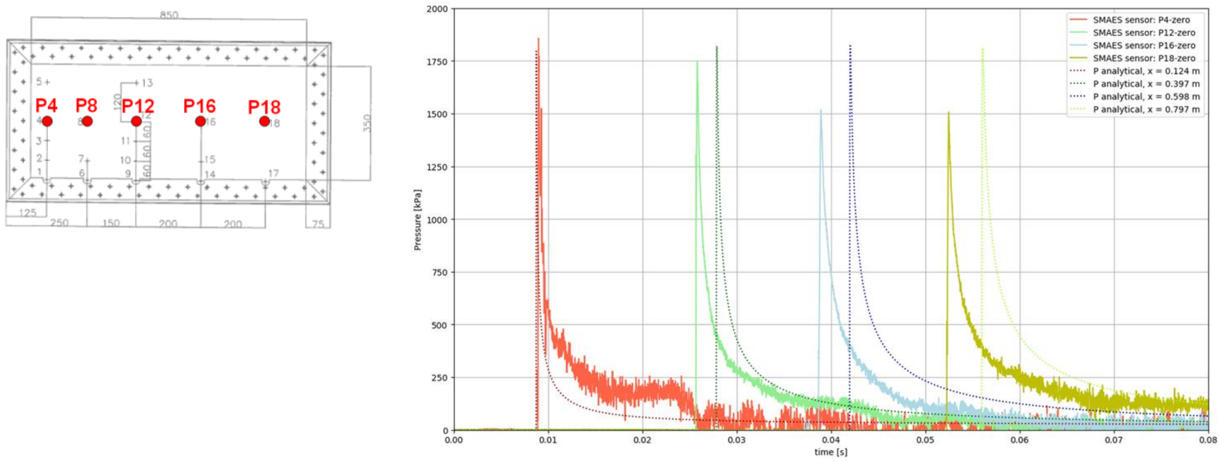


Figure 17 Comparison of Semi Analytical Water Entry Pressures Vs SMAES test

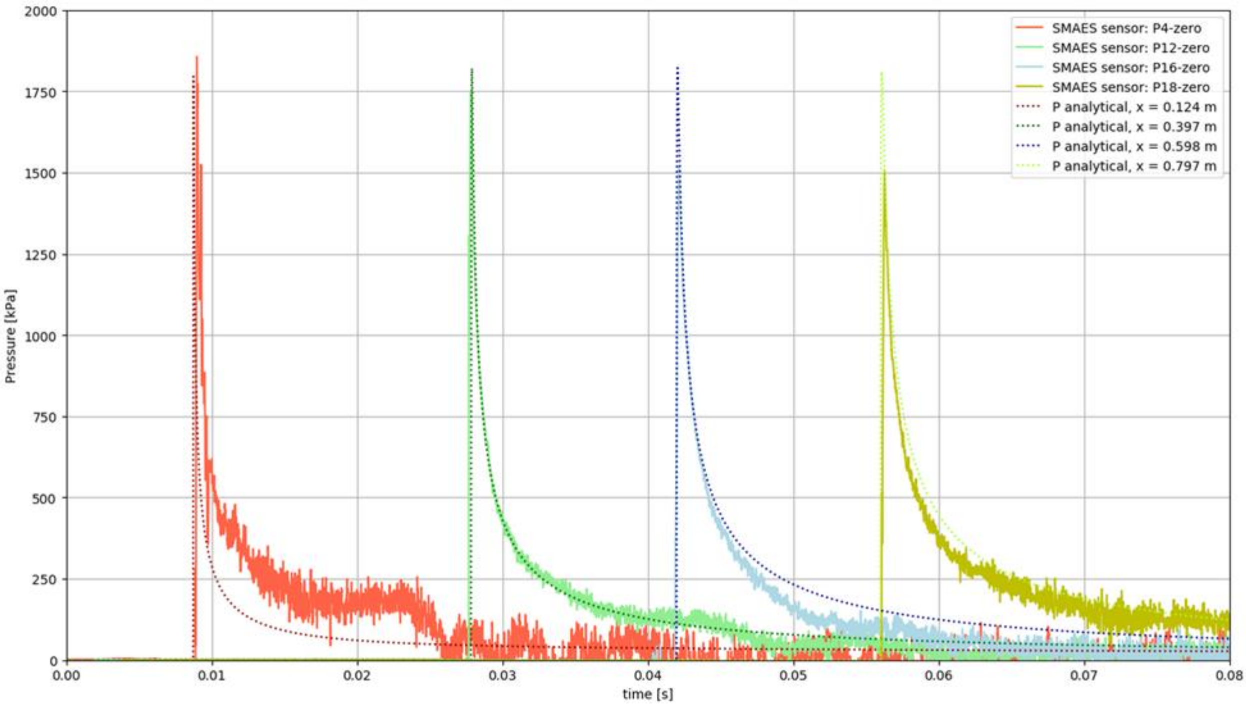


Figure 18 Comparison of Semi Analytical Water Entry Pressures Vs SMAES test removing wave rise effect

Comparison shows good match of pressures time history shapes and peak values, especially for gauge P12. For forward gauges (P4), the semi-analytical method is slightly non-conservative because the method has a singularity at the starting point while on the other hand for rearward gauges, it is slightly over conservative, attributed to the presence of water rise. This approach will be maintained (with the synthetic pressures) for subsequent application to complete aircraft simulations.

7 APPLICATION TO DESIGN AND CERTIFICATION OF A REAL AIRCRAFT

7.1 Detailed explicit FEM model of the aircraft

The aircraft is modelled using the explicit Finite Element Method (FEM) technique, suitable to simulate any impact scenario and in particular ditching. The starting point is the Global FEM model of the structure. The bottom part of the fuselage where the ditching impact will take place is extracted and the mesh of this part significantly refined (always keeping the time step within reasonable margins). Figure 19 illustrates this process and Figure 20 shows a zoom of the refined zone to illustrate the mesh size.

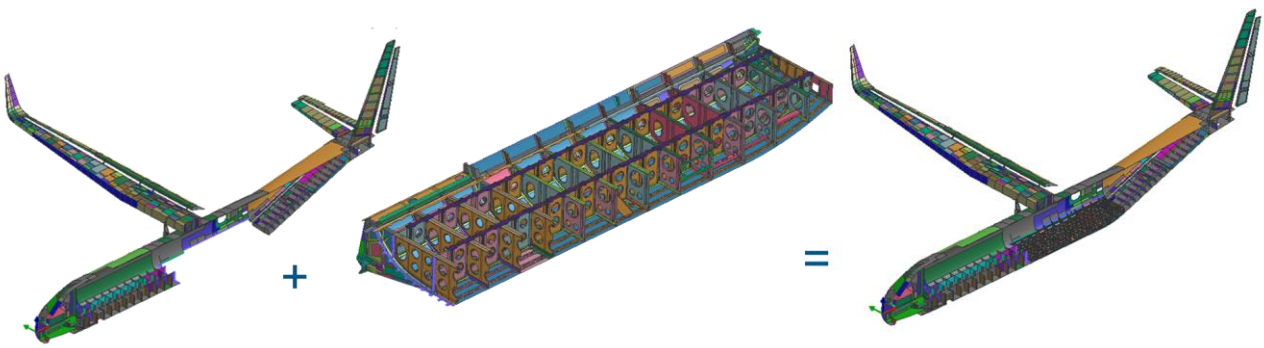


Figure 19. Global FEM model. Detailed bottom fuselage model. Integrated model for ditching calculations.

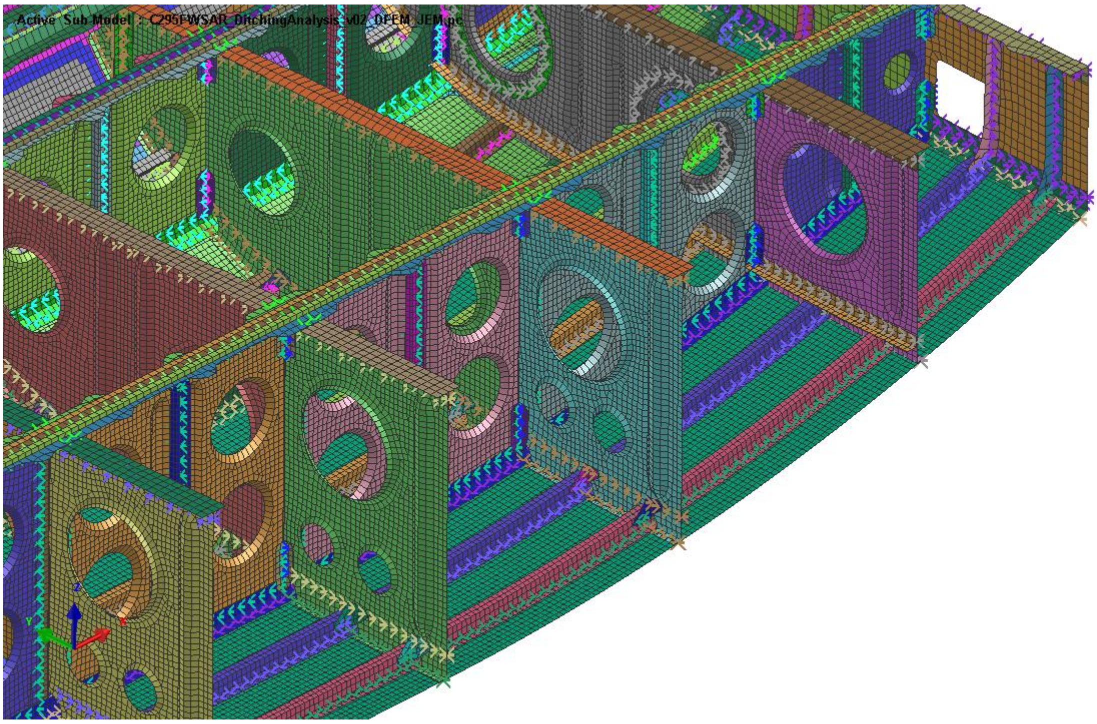


Figure 20. Zoom of the detailed bottom fuselage model to illustrate mesh size.

7.2 Selection of ditching loads methodologies

From the four numerical approaches, two of them, the semi-analytical water entry approach and the synthetic pressures have been selected for application to aircraft design.

As these methodologies are essentially related with "rigid structures", a reasonable question is whether they could be also applicable to flexible structures. From 2016 to 2017, the effect of flexibility in ditching loads was object of significant research in Airbus DS Military Aircraft (see for instance [12] presented at last ASIDIC 2017). The reason was the promising intention to prove the conjecture that flexibility alleviates ditching loads. After many analysis and comparisons [11],[12],[13] the outcome of this research was that although local flexibility may play a role in modifying ditching pressures, the different flexible effects (local deformation, local pitch angle, etc.) induce a correction that is on one hand, relatively small, and on the other they have similar order of magnitude and different signs thus partially compensating each other's in many conditions. This conclusion tends to suggest that the application of methodologies obtained for rigid plates to real flexible aircraft structures will provide conservative results with enough accuracy.

To verify this conclusion a test has been performed in the SARAH project in 2018 in which an extremely flexible aluminum plate (t=0.4 mm) was tested under representative ditching loads. Figure 21 shows the comparison of the tested deformation with the numerical predictions using synthetic pressures obtained in rigid cases. Figure 21 (right) shows an overlap of both test (transparent grey) and simulation (colored) results. The simulation results achieve a very high level of correlation. The peak deformation predicted by the simulation is of 55.6 mm, which is just a 3.8% smaller than the test results.

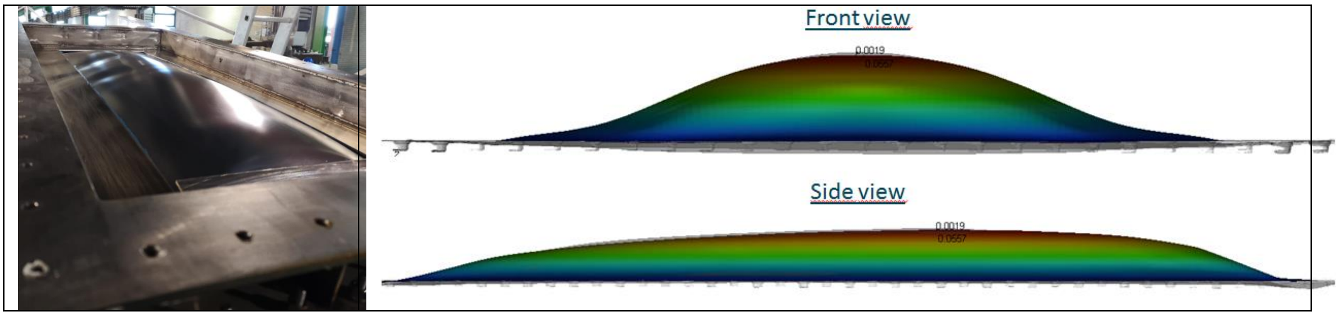


Figure 21. (Left): extremely flexible aluminum plate (t=0.4 mm) tested in SARAH project (Right).Test vs simulation comparison of the permanent deformation on a 0.4 mm aluminum panel result of ditching loads.

7.3 Results for design and certification

Figure 22 shows the deformation exhibited by the bottom part of the fuselage of a medium transport aircraft explicit FEM model once subjected to the semi-analytical water entry approach (left) and the synthetic ditching pressures (right).

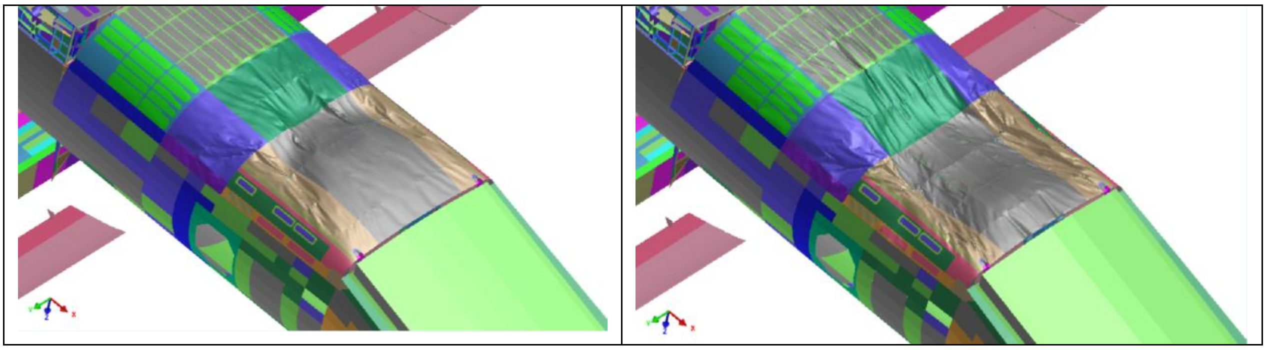


Figure 22. Left: aircraft structural deformation due semi-analytical water entry approach.
Right: local structural deformation due to synthetic pressures

By definition, the pressures of the semi analytical water entry approach vanish when Vz=0. Run with synthetic pressures has been truncated also when Vz=0 to allow proper comparison between the two methods. Deformations shown in figure 22 tend to suggest that the synthetic pressures will provide more conservative results than the semi analytical water entry approach.

In addition to analyze the FEM model deformation, it is possible to integrate the loads in riveting-joints areas for subsequent checkstress analyses. As an example, figure 23 shows a schema of the fuselage bottom part (longitudinal lines are stringers, transversal lines are frames) with a normalized map of loads (in KN) of riveted-joint areas to be transmitted to the checkstress offices.

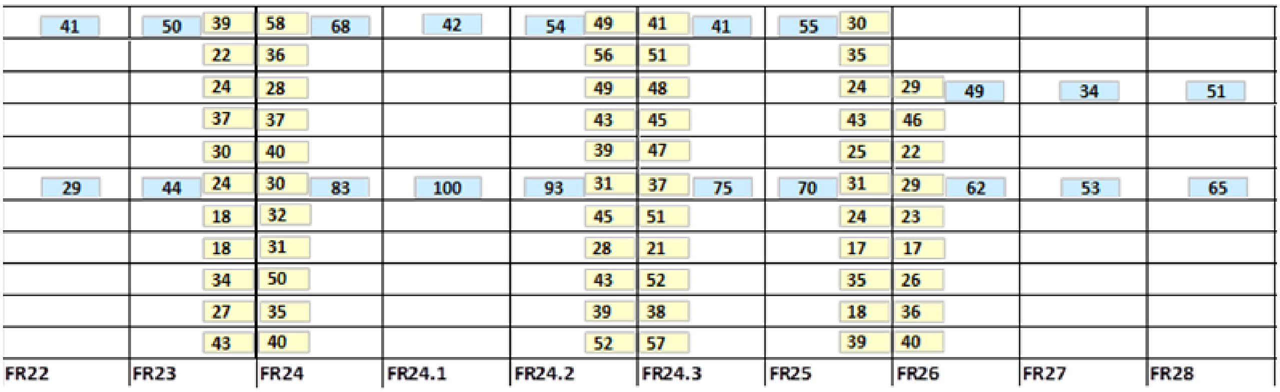


Figure 23. Example of integrated loads in bottom fuselage riveting-joints areas (in kN, normalized)

8 CONCLUDING REMARKS AND FUTURE ACTIVITIES

The paper has presented a comparative analysis among four different numerical methodologies to simulate ditching loads: SPH; CFD, semi-.analytical water entry approach and synthetic pressures (analytical expression that matches ditching test results). The four of them have been compared with ditching test results measured in the SMAES program.

The SPH technique is a key contributor of the success of numerical simulation of aircraft impacts technology, especially in the modelling of the impactors. It has provided also promising results when dealing with pure vertical ditching simulations (helicopters). For aircraft ditching with horizontal speed, SPH allow obtaining approximately the shape and peaking values of ditching pressures (although being non-conservative). The difference between test and SPH simulations makes this technique not suitable for design and certification of real aircraft. The lack of fluid dynamics physical laws embodied in the SPH technique suggest that improvements in this methodology in the direction to better match ditching test results are not expected unless a breakthrough happens in the SPH methodology. Further work in this line of research has been stopped at Airbus DS Military Aircraft.

The CFD technique indeed embodies all the fluid dynamics physical laws present in a ditching scenario. Unfortunately, the level of calibration of the CFD models is still too far apart from what a proper comparison with test results requires. Investigations are almost unaffordable as the cost of each run is several days for a 2D flat plate case, and expected to be of several weeks for a simple 3D flat plate case. Extension to full aircraft is –by today- not possible.

The remaining two approaches have been selected for application to real aircraft design. The paper has finally presented the approach for design of aircraft structure in which the explicit FEM model of the aircraft is produced splitting the ditching impact area (with very fine mesh) from the rest of the aircraft (with a typical global mesh). By applying the selected ditching pressures to the aircraft structure, the evolution of deformation and integrated loads in riveted-joint areas can be produced and delivered. So far, synthetic pressures tend to provide conservative results versus semi-analytical water entry approach.

Future activities in ditching research include extension of flat plate measurements to real aircraft geometries (to be performed in the SARAH project), to determine the "ballistic limit" on thin panels in ditching and further research of the behavior of riveting-joint areas under ditching loads.

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