AIRCRAFT DITCHING NUMERICAL SIMULATION

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Abstract

Ditching is an aircraft emergency condition that ends with the planned impact of the aircraft with water. Three main phases have to be analyzed during ditching:

- *Aircraft conditions before impact*
- *Structural response during the impact*
- *Subsequent floatation*

This paper is mainly devoted to the second phase (i.e. the impact with water). During this phase, the high pressures developed by the impact with water of the sliding aircraft may cause rupture of the structure, jeopardizing the required safe evacuation of crew and passengers.

The classical approach to ditching has been the use of model ditching test under several ditching scenarios. By these means, the global behavior of the model is assessed and extrapolated to the real aircraft size in order to define the optimum ditching conditions. In addition, the model is instrumented with pressure transducers that in turn are used to compute loads on the structure.

Nevertheless, the increase of computer power and reliability of numerical models makes it possible to perform ditching numerical simulations.

For the cases with vertical-velocity only (i.e. helicopters) this is particularly true and large advances has been made in recent years. The use of techniques like Smooth Particle Hydrodynamics (SPH) has proven to be very effective in vertical impacts in which good correlations have been demonstrated with tests including full-scale tests.

The cases with combined vertical speed and horizontal speed (i.e. aircraft) are significantly more difficult. The pressures produced by the water on the aircraft structure may be either positive (over pressures) or negative (suction) and the SPH technique with the available constitutive laws is not able to properly represent suction forces. Hence, more sophisticated techniques are needed (i.e. CFD).

A hybrid approach that combines model test with sophisticated numerical simulation techniques has been followed at EADS-CASA to address these problems. First a detailed explicit Finite Element (FE) model of the structure is prepared and impacted a water block model. Then a complete series of model ditching tests is used to derive critical load cases in the structure.

The FE model, the ditching tests and the procedure to pass from rigid mock-up pressures to real size flexible aircraft will be described in the paper as well as the structural response to these loads.

The paper will end with lessons learned and suggested ways of improvement for future ditching analyses.

1 General Introduction

Ditching is an aircraft emergency condition that ends with the planned impact of the aircraft with water. Three main phases have to be analyzed in a ditching event:

- Aircraft conditions before impact
- Structural response during the impact
- Subsequent floatation

Some authors split the second phase into two sub-phases: impact and subsequent evolution of the aircraft until its stop. The objective in Airworthiness Regulations is to minimize any risk during a ditching scenario to allow the crew and passengers to evacuate the cabin safely.

This paper is mainly devoted to the second phase (i.e. the impact with water). During this phase, the high pressures derived from the impact with water of the sliding aircraft may cause rupture of the structure, jeopardizing the required safe evacuation of crew and passengers.

In recent years, EADS-CASA has increased significantly its capabilities in analyzing and predicting the aircraft behavior and structural response in a ditching scenario. The reason is that one of the EADS-CASA products, the medium military transport aircraft CN-235-300M, has been selected to equip the US Coast Guard in the DEEPWATER program. In this framework, it has been necessary to demonstrate the characteristics of the CN-235-300M aircraft to ditch safely. This demonstration has been achieved by a combination of advanced numerical simulations techniques as well as classical model test.

The first sections of the paper are devoted to survey the most relevant papers on ditching and how this event is accounted in the airworthiness regulations of fixed wing aircraft.

Fig. 1. EADS-CASA CN-235-300M aircraft

The paper continues with sections devoted to the different ditching phases with special emphasis on the numerical simulation of the impact phase.

A set of conclusions, lessons learnt and suggestions for further work about this issue are presented. Finally, the authors propose an exhaustive list of references on this topic.

2 Survey of relevant ditching papers

Scientific research on ditching started when the seaplanes development at the early thirties.

It is remarkable that aircraft ditching on water is a very complex physical problem, which involves a wide range of technical disciplines like kinematics stability, aerodynamics, hydrodynamics and structural engineering.

Two classical references, [1] and [2], established the basic theory of the impact of a solid surface on water. Reference [6] added some modifications to the original theory, based in the momentum method, to estimate aircraft ditching loads. Recent studies based on these simplified theories show good agreement with experimental results, [28].

Tests in hydrodynamic channels have been needed to understand ditching phenomena in a great variety of geometries. Experimental campaigns were done since the beginning and even nowadays experiments using subscale models is an accepted mean of compliance of aircraft performance involved in a planned ditching maneuver.

The research starting point was to study simple geometries to gain understanding about the physics of ditching. The impact of prismatic wedge shapes on water surface has been widely studied. Reference [3] is one of the first works published in literature related to wedge geometries. References [4] and [5] presented results of loads acting on the wedge surface. On the other hand, references [8], [9], [13] and [14] dedicate efforts to measure pressure distributions and finally [10] and [11] extend theory and compare to experiments in V-bottom seaplanes. Works in [12], [15], [16] and [19] presented an extensive effort dedicated to wedges configurations impacting water at different vertical velocities. The interest on this simplified shape was clearly related to the hull sections of seaplanes. However, conventional aircrafts were designed using smooth profiles to minimize aerodynamic resistance, and therefore, there are significant differences with respect to the impact of a seaplane hull. Works [17] and [18] were devoted to rectangular flat plates and arbitrary constant cross section, [25] and [26] were the first in paying attention to inverted V shapes and [23] tested elliptical cylinders considering also horizontal speed. Many of these studies were performed considering just vertical velocity and they were suitable to understand vertical impacts on water. Later on, these results have been used as a valuable source of data to analyze impact of rotorcraft on water surface: [32], [37], [38], and [46].

Reference [22] presented the experimental investigation of the effect of the rear-fuselage shape on ditching behaviour; it is remarkable that this study is one of the first not devoted explicitly to seaplanes hulls, and its conclusions can be extended to regular aircrafts.

A summary of the knowledge gained about ditching of different aircrafts in the early sixties is presented in [24]. This work identified and discussed the effects of design parameters on the ditching characteristics of airplanes based on scale-model investigations. Reference [27] is an extensive review of theoretical and experimental results applied to the seaplane impact.

Investigations about ditching were concentrated between the thirties and the fifties when the basic theoretical developments and experimental techniques were already established. However, during the last decades numerical simulation has experienced a great development, and nowadays it is possible to applied advanced numerical techniques to study aircraft ditching. In particular, smooth particle hydrodynamics (SPH) in combination with finite element (FE) has been used to investigate problems of impact. During the early eighties, the basis of SPH technology was established, [29], and soon it was applied to study free-surface flows, [30] and [31] and high velocity impacts, [33]. Ditching problem has been studied from a global numerical point of view using SPH in [48] and [49], but comparisons with experiments show that improvements need to be done in order to apply this technique in an industrial environment when impacts on water with horizontal velocity are considered.

At the moment, the most extensive research is done in the fluid-structure coupling field. The first steps were done in [20] and [21] using simple models. Recently experimental methods have been used to investigate the hydrodynamic coupling in impact slamming of naval structures: [34], [35], [41] [53], [39] and [47].

Nowadays, the use of classical theories in combination with modern numerical techniques have also been used to study the ditching of transport aircraft, [36], [40], [42] and [43]. This report presents works followed by EADS-CASA to study the ditching of CN-235-300M, [44], combining classical theories, experimental tests, [52], [54] and [56], and numerical structural studies, [51], [58] and [59].

3 Ditching in the Airworthiness Regulations

Here in, a brief summary of the airworthiness regulations related to ditching is presented including the topic of every relevant paragraph:

Applicable regulations (FAR-25, MIL A-88-65 B, (AS), CS-25…):

- ✓ 25.563: Structural ditching provisions
- ✓ 25.801: Ditching
- ✓ 25.807(e): Emergency exits
- ✓ 25.1411: General (Safety Equipment)
- ✓ 25.1415(a): Ditching equipment

Guidance material:

- ✓ AC 25-17: Transport Airplane Cabin Interiors Crashworthiness Handbook.
- ✓ DOT/FAA/CT-84/3: Study on Transport Airplane Unplanned Water Contact

Additionally, airworthiness authorities may suggest some typical ditching conditions as a reference framework:

Typical ditching conditions.

- ✓ 5 f.p.s sink speed.
- ✓ Floatation on salt water.
- ✓ Up to sea state 4 (Douglas scale)

4 Ditching first phase: preparation

In the current Airworthiness Regulations (FAR-25, CS-25…), the emergency condition of ditching is considered as previously known by the crew (“planned”) who has enough time to prepare the aircraft and the passengers for this event. The preparation will consist in activities performed by the crew and the pilots.

Typically the crew will:

- Inform the passengers
- Wear life-vest
- Prepare the evacuation exits
- Prepare the ladder to access the hatch
- Prepare the life-rafts …

Typically the pilots will:

- Set flaps down and reduce speed as much as possible
- Land parallel to the waves
- Switch engines / propeller off just before impact …

5 Ditching second phase: impact

5.1 Approach

During the impact phase, it is necessary to demonstrate that the aircraft structure is able to withstand -without excessive damage- the high-pressure loads acting on the bottom part of the fuselage. This is crucial for the subsequent floatation phase in which the passengers must evacuate the airplane before it sinks. Significant damages on the fuselage would increase the rate of water ingress on the cabin thus jeopardizing a successful evacuation.

At EADS-CASA the analysis of this phase has been addressed in a series of increasingly complex tasks:

1) Vertical drop simulations.
2) Simulations with horizontal velocity component.
3) Application of test-measured pressures.

The methodology selected at EADS-CASA to have a predictive numerical tool of ditching events was an explicit Finite Element (FE) simulation of impacts against a water model that in turn, is simulated using an elastic-plastic hydrodynamic material model with the classical Lagrangian formulation and the Smooth Particles Hydrodynamic (SPH) method. At each step, a series of high-fidelity explicit FE models has been build to represent the aircraft structure. This numerical approach may simulate the fluid/structure interaction during an impact on water.

The commercial explicit FE code PAM-CRASH provided by the ESI Company has been selected as the software tool kit in all these analyses, [45].

5.2 Numerical simulation of vertical impacts on water

5.2.1 Description

Universities, industry, research establishments and software suppliers have done a significant effort in recent years to make available a predictive numerical tool to simulate vertical impacts of aeronautical structures on water. The client of all these efforts is the helicopter industry and the target is to increase the safety of helicopter operators, [32], [37] and [38]. The European funded program CAST (Crashworthiness of Helicopters on Water: Design of Structures Using Advanced Simulation Tools) constitutes a cornerstone in these efforts. In the EADS-CASA ditching project team, DLR (one of the CAST partners) has provided its experience and expertise in this type of simulations.

Vertical drop tests is also the first logical step towards most demanding analysis with horizontal speed.

5.2.2 Validation

The first validation of the numerical methodology has been achieved through a series of increased complexity vertical impact cases with known test results that were analyzed in-depth by DLR, [46]:

- Wedge (rigid)
- Cylinder (rigid)
- Sphere (rigid)
- Fuselage component (flexible)
- Helicopter floor (flexible)
- Full scale WG30 Helicopter

The FE model is solved using explicit integration and the water impact surface was modeled using both classical Lagrangian elements and Smooth Particle Hydrodynamics (SPH). The SPH is a grid-less computational technique where each SPH particle represents an interpolation point. The interpolation function ("kernel") is a spherically symmetric function centered at the particle location spanning a range of influence controlled by the smoothing length, **Fig. 2**.

The advantages of the SPH technique are:

- Able to model discontinuous domains.
- Appropriate for problems with large void areas, fracture (high velocity impact), or chaotic flow field.
- No problem of local and excessive deformation leading to a dramatic decrease of the time step.

The disadvantage is…

- Extremely CPU time expensive due to the computation of contact between the particles.

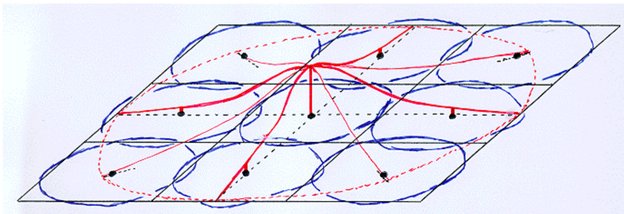

Fig. 2. Scheme of SPH formulation, [45].

As an example of the validation activities performed, **Fig. 3** presents the sequence of the vertical impact of a rigid cylinder on a block of water, and **Fig. 4** shows a comparison of the contact forces between test (red curve) and two numerical simulations (blue and orange curves).

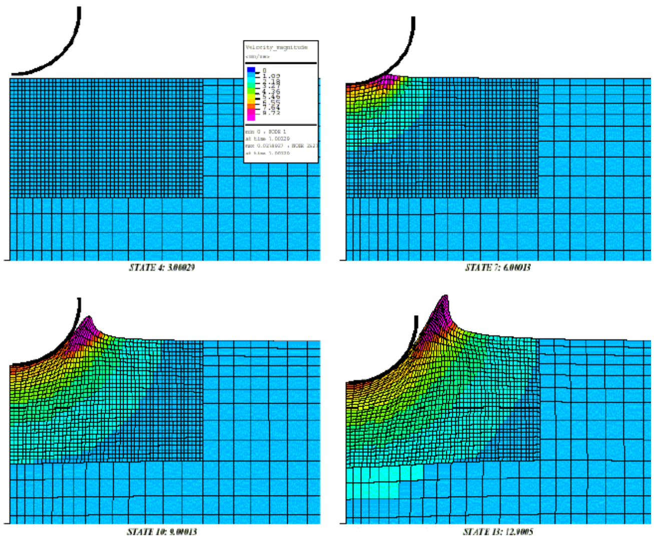

Fig. 3. Simulation of cylinder impacting on water, [46].

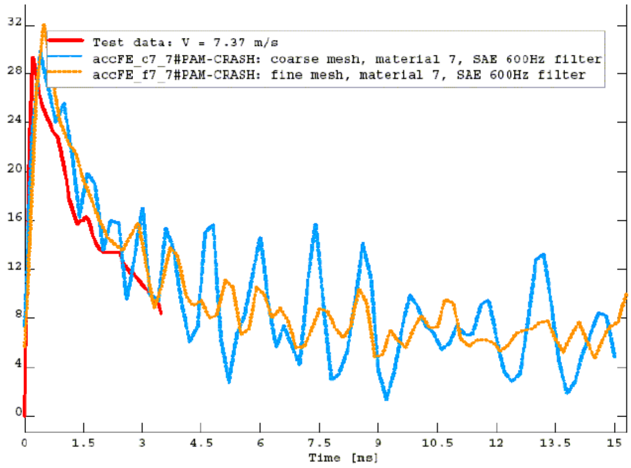

Fig. 4. Contact force time history in the cylinder impact. Test vs. Numerical simulation, [46].

Fig. 4 demonstrates that an excellent agreement can be reached between numerical predictions and test results. Validation was also performed using real aeronautical structures as the WG30 helicopter, **Fig. 5**.

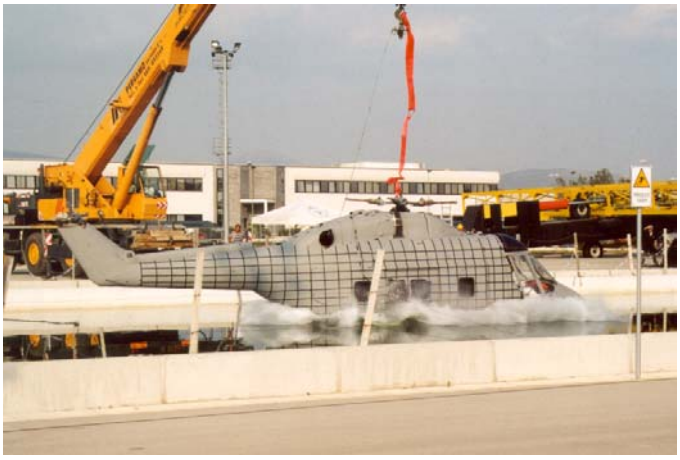

Fig. 5. WG30 Helicopter drop test, [46].

The effect of the impact with water on the helicopter sub-floor structure is shown in **Fig. 6**. Good correlation could be reached between test and the numerical simulation.

The zones of plastification mainly occur at the intersection between the skin and the bases of the stringers, the frames and the keel beams. The frames especially on both sides of the central keel beam of the sub-floor undergo high deformation under the action of the water load.

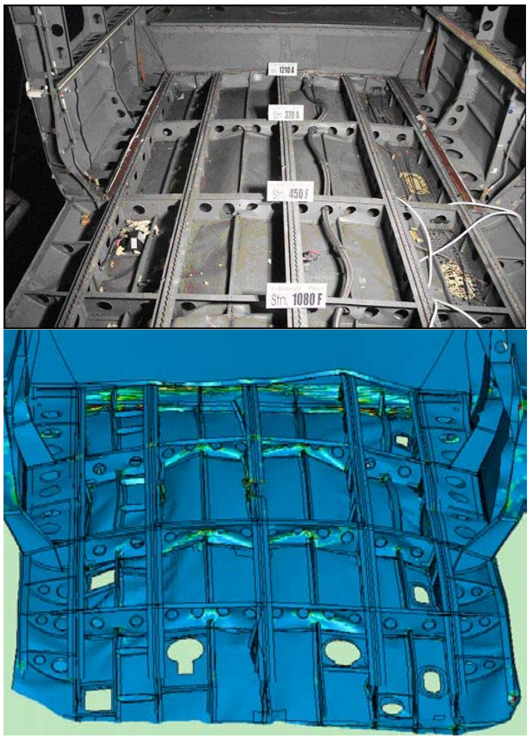

Fig. 6. Global internal view of the helicopter after removal of the floor panels, rear side (model deformation at time t = 80 ms and deformation of the structure after the test), [46].

Measured (red) and calculated (blue) acceleration time histories on the cabin floor are compared in **Fig. 7**. Although there is a time-shift in the signals, the agreement in the peak values is excellent. On the other hand, **Fig. 8** shows a comparison of local pressures in which the numerical simulation is conservative. This measurement point is located on the skin, directly under a frame, which is a stiff area and explains the over-predicted pressure peak in the simulation.

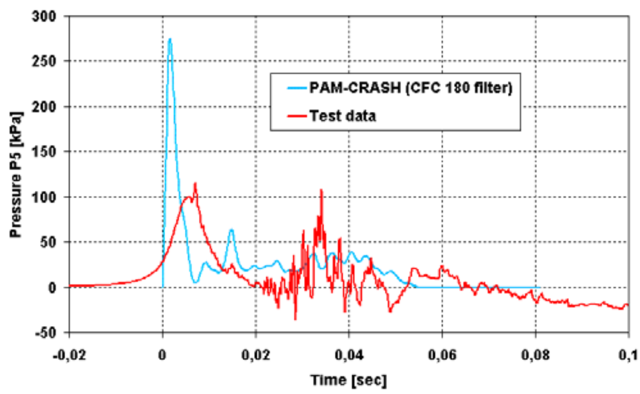

Fig. 7. Accelerations time histories in WG30 drop test. Test vs. Numerical simulations, [46].

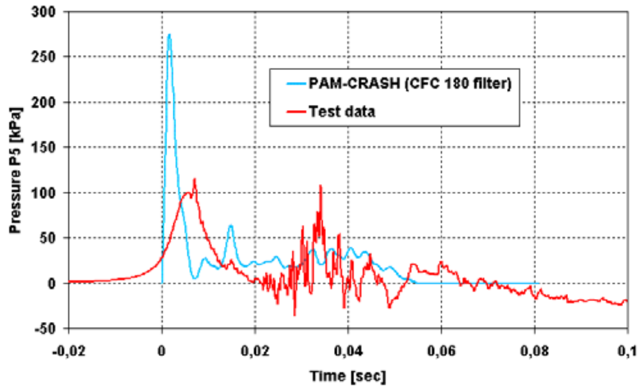

Fig. 8. Pressure time histories in WG30 drop test. Test vs. Numerical simulations, [46].

5.2.3 Application to CN-235-300M aircraft

Once a significant degree of confidence was gained in the methodology, it was applied to the CN-235-300M aircraft, [51].

The first task is to produce an explicit FE model of the aircraft with a high-fidelity representation of the bottom part of the fuselage, which has a major energy absorption function during the impact on the water surface. This accurate model is achieved by studying the CAD drawings (CATIA) and representing all the necessary structural details: frames, skin panels, stringers, webs and stringer caps, etc. Modeling continues with incorporation of material laws and rupture criteria. An exhaustive checklist of modeling verification is then applied to the model including comparison of results with the checkstress model (in linear cases) and several loops of revision for the details with the stress engineers.

In order to capture local deformations on the lower fuselage that occur during the impact, the model mesh in the impact area should be very fine, **Fig. 9**. Complementary, non-linear material laws are included in order to reproduce plasticity and rupture in these elements where structural capacity is exceeded.

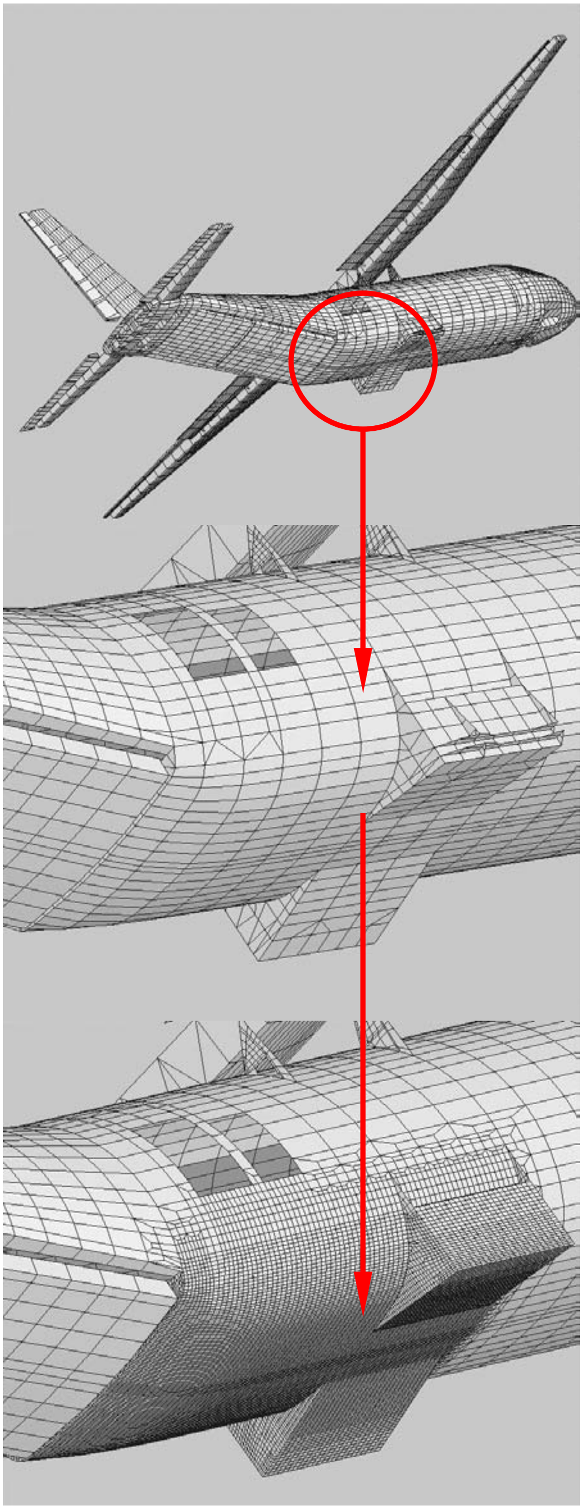

Fig. 9. EADS-CASA CN235-300M FE explicit model. Detail of refined area, [51].

The numerical simulation of the CN-235-300M drop test was successful. **Fig. 10** shows a global view at a fixed time during the simulation.

Although not fully realistic, because of lack of horizontal velocity component, simulations of vertical impacts may play an important role in a ditching study:

- First, they may help in the risk management of the ditching project by giving early information on the fuselage state under likely ditching loads. The CN-235-300M fuselage structure is able to withstand vertical impacts above 7.5 f.p.s without any rupture along fuselage skin panels. (Note that the requirement is 5 f.p.s.). Higher vertical speeds will help in identifying what may be the potential zones for reinforcement, just in case this would be needed.
- The preliminary load results obtained with these vertical simulations may be used for comparison with the bookcases.
- Finally, they are essential to assess some effects like, for instance, the influence of structural flexibility on the load peaks, by comparing vertical impacts of rigid and flexible structures.

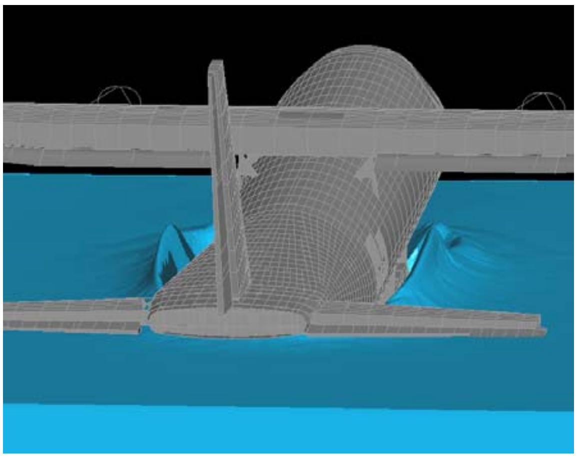

Fig. 10. EADS-CASA CN235-300M Numerical simulation. Vertical drop test, [51].

5.3 Numerical simulation considering the horizontal component of velocity

5.3.1 Scale model ditching test

The classical approach for ditching certification is the use of scale-model ditching tests, [52]. Typically, the objectives of these tests are:

- Assess aircraft behavior in the subsequent seconds after impact until its complete stop.
- Check the kinematic stability during ditching.
- Measurement of pressures on the fuselage and accelerations in the cabin.
- Gather relevant data for subsequent floatation analysis in calm and rough water.

In addition, for the EADS-CASA CN-335-300M ditching campaign, another objective was the assessment of numerical simulations using SPH with horizontal velocity.

The scale-model ditching test has significant **advantages,** to mention some:

- Years of experience & gathered knowledge.
- Accredited by Authorities.
- Sea state may be accounted for.
- Handling of complex shapes.
- Visual and measured parameters give reasonable tendencies.

And among the **disadvantages…**

- Scale effects (i.e. suction and cavitation).
- May have difficult repeatability.
- Test only for one aircraft design.
- Little insight into physics.

The CN-235-300M model was a **1:8** subscale rigid mock-up, instrumented and with a set of structural fuses in critical areas, **Fig. 11**. The UK Company Cape Engineering performed these tests at Wallingford (UK). Cape enjoys large experience in scale model ditching test. Model manufacturing was performed in early 2004 while the effective ditching test runs were performed during spring and summer 2004. A total of **112 runs**, **Fig. 12**, were successfully performed covering a wide range of parameters:

- Several aircraft configurations (Landing Gear retracted/extended sponsons ON/OFF).
- Variations of aircraft weights, positions of center of gravity, vertical and horizontal velocities, pitch angles, bank angles, …
- Calm and rough water.

Fig. 11. EADS-CASA CN235-300M scaled model.

During the test campaign the model was extensively instrumented with:

- 5 accelerometers (3Z, 1X, 1Y)
- 2 gyros (pitch & roll at center of gravity)
- 16 simultaneous pressure transducers. Plus provisions for 4 more.
- High-speed camera film from several angles

The CN-235-300M scale-model test campaign was designed to minimize the effect of the disadvantages of the approach:

- Shape and velocity will reduce cavitation.
- Repeatability guaranteed by three runs for each condition/configuration.
- Insight into physics obtained by combining test images, instrumentation data and numerical simulations results.

Fig. 12. EADS-CASA CN235-300M ditching test.

5.3.2 Numerical simulation of the scale-model considering horizontal velocity

The rigid scale-model of the CN-235-300M used in the ditching tests was also modeled using the explicit FE and SPH techniques. With this model, numerical simulations aimed to reproduce the exact ditching-test conditions that were performed in the water channel, **Fig. 13**.

The SPH parameters were tuned to reproduce planning condition of a flat plate over a water surface described in [17]. Numerical simulation predicted a stable skipping of the model on the water surface as it was observed during tests under similar conditions. Although the numerical simulation presents a nice aspect, the reality is that the evolution of the aircraft does not match the test with enough accuracy. Even more, the comparison between the measured and calculated pressures indicates a large conservatism in the peak values of the simulations and very different shapes of the pressure time-histories -very sharp in the simulations, a lot more flat in the measured tests.

The mean reason why the numerical simulations of the scale-model were not successful is that the SPH formulation –at least as it is currently implemented- does not reproduces the complete physics of the ditching phenomena when the horizontal velocity is predominant.

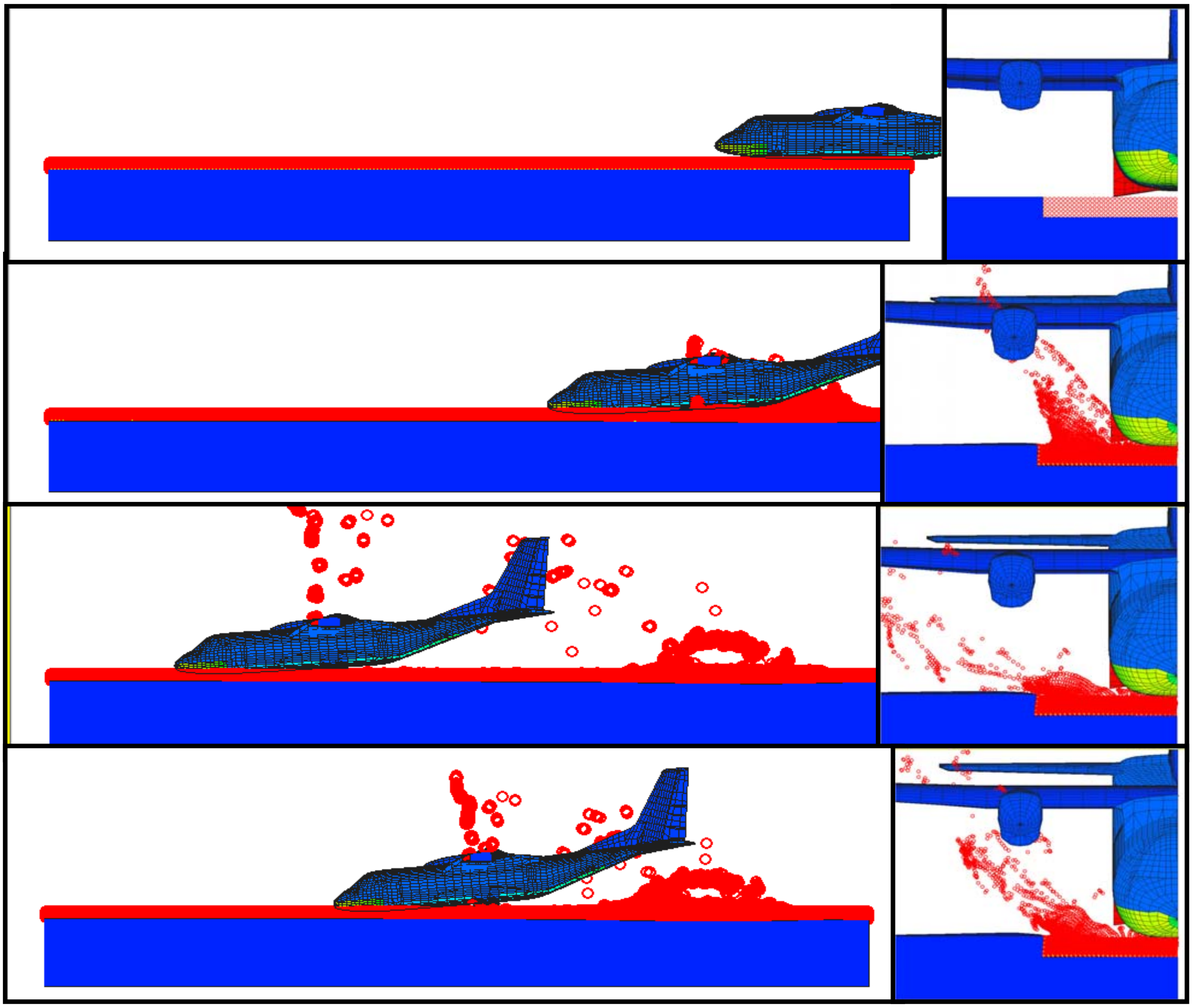

Fig. 13. EADS-CASA CN235-300M Numerical simulation considering the horizontal component of velocity and water modelled with smooth particle hydrodynamics (SPH)

Although the simulation was very successful for ditching with only a vertical velocity component, the presence of a horizontal velocity component makes physics much more complex. It is suspected that a more accurate description of the fluid mechanics is needed (i.e. solving the equations of Navier-Stokes using CFD) to reproduce phenomena like cavitation and spray, which are by no means negligible.

During ditching, significant suction forces (i.e. negative pressures) appeared at the very rear part of the fuselage directly in contact with water. The available constitutive law implemented in the SPH formulation can never reproduced such a negative pressures. As the presence of cavitation and ventilation is critical in the evolution of the aircraft during the first instants of the impact, it is crucial to include it for a suitable prediction of the bottom fuselage pressures and the kinematics of the aircraft.

5.4 Numerical simulation using measured pressures.

5.4.1 Pressures interpolation

Pressures on the fuselage were measured directly in the scale-model. The next logical step of the numerical simulations is the use of the measured pressures to justify the structure under ditching loads, [57]. Because the mesh of the explicit FE model -very refined- and the mesh of the pressure transducers -only 16 transducers- are not coincident, a first task is the establishment of a process that interpolates the pressures on the wetted fuselage surface, Fig. 14, while keeping some constraints:

- The wetted surface is located between frames 20 – 34
- Suitable boundary conditions are imposed at the free surface and at the surface discontinuities (i.e. plane between main landing gear box and rear fuselage)
- The vertical momentum equation (1) should be kept -the product of mass by the measured vertical acceleration should be equal to the integral of pressures through all the surface- neglecting aerodynamics effects.

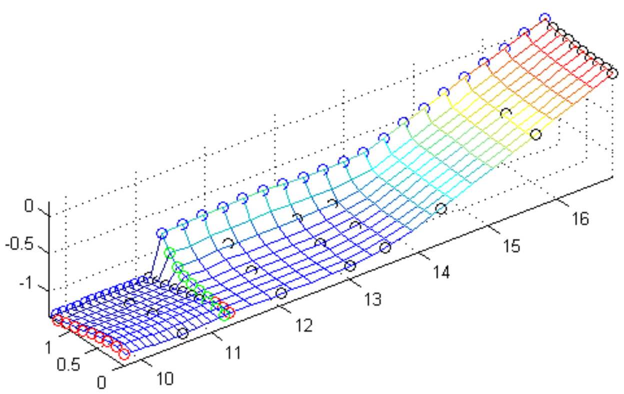

Fig. 14. EADS-CASA CN235-300M mid-lower fuselage -seen from above-, [57].

Once the procedure was established, the time history of the pressures acting on the entire surface could be obtained for each of the 112 runs. The interpolated pressures were used in turn to determine a set of critical cases following the following criteria:

- Peak value of each transducer (20 cases)
- Maximum integral of pressures (1 case)
- Maximum loading close to each frame (14 cases)
- Maximum loading in the interval between frames (14 cases)

The entire set of criteria produced a total of 49 critical cases, where many of them were coming from the same run. Only 7 runs were responsible to satisfy the 49-criticality criteria. In addition to the critical cases, one case was selected as "nominal" in order to reflect the most likely ditching scenario.

In addition, this nominal case may be also used for parametric investigations (variations of pressure pulse peak or pulse duration) in order to determine the sensitivity of the structural assessment to each of these parameters.

5.4.2 Conservatisms in the approach

The approach as described in 5.4.1 includes a significant degree of conservatism. Some of the items contributing to this conservatism are listed in the following:

$$ma_z = \iint_{Sw} -pn_z\,dS \qquad (1)$$

- Aircraft configuration selected considering absence of rear sponsons structural resistance ⇒ Conservatism estimated in 9%
- Each run was repeated 3 times. Instead of the average, the worst of the 3 runs was selected ⇒ Conservatism estimated in 3%
- Interpolation impulse is between 1.9 and 4.5 larger than the impulse measured by the accelerometers.
- Air cushioning effect in the flat rear portion of the fuselage.
- Structural flexibility that may contribute to scale down loads received by the real

structure with respect to those measured on the rigid mockup model.

5.4.3 Effect of structural flexibility

Among all the conservative items, one that may be quantified instead of roughly estimated is the effect of structural flexibility, [61].

The success of the numerical simulation for vertical ditching impacts may be used to determine factors that account for the effect of the flexibility that in turn may be used to reduce the pressure loads.

Two CN-235-300M explicit FE models were prepared to compare the effect of structural flexibility: one RIGID simulating the subscale model, **Fig. 15**, and the other FLEXIBLE as the real aircraft is, **Fig. 16**. Both models were dropped exactly under the same conditions. By comparing pressures obtained with one or the other model, it was possible to deduce a law that may be used to correct the pressures obtained from the rigid scaled models before applying them to the real flexible aircraft structure.

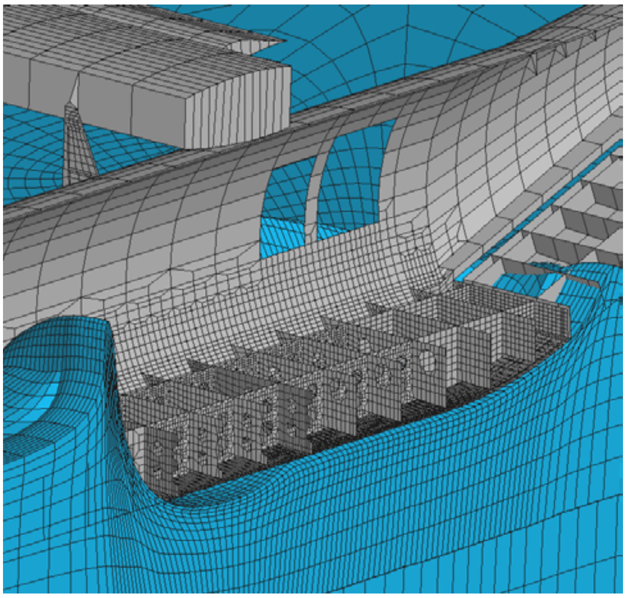

Fig. 15. Drop simulation of an A/C rigid model impacting on water, [61].

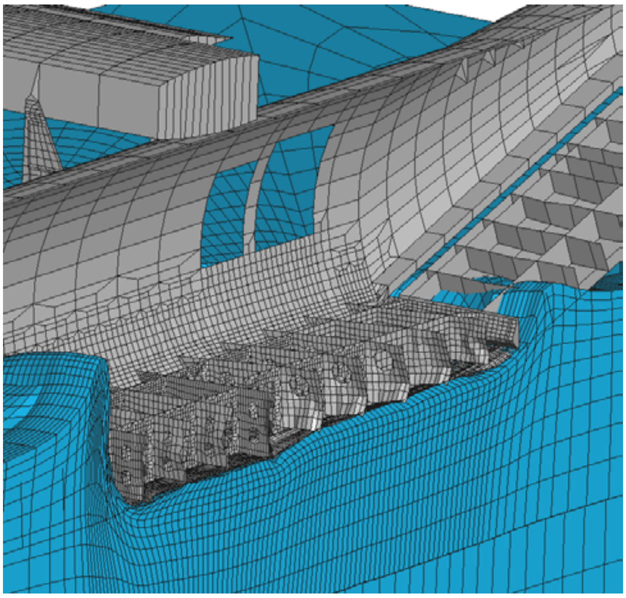

Fig. 16. Drop simulation of an A/C flexible model impacting on water, [61].

Fig. 17 shows the correction law to account for flexibility effects. The study was performed considering all the regions of the lower fuselage and a complete range of peak pressures. Basically, there is no correction factor for low peak pressures for which the effect of flexibility is negligible. When a threshold is reached, the effect of structural flexibility scales down the loads until a rough factor value of 0.58 .

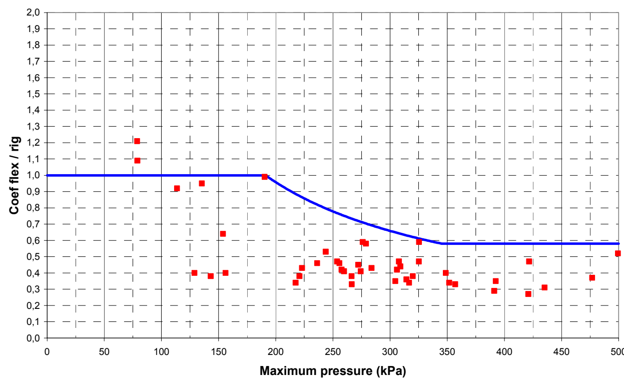

Fig. 17. Flexibility effects corrections law.

5.4.4 Structural assessment of the EADS-CASA CN-235-300M aircraft under ditching loads

Pressures time histories from model tests were corrected for flexibility effects and applied to the FE model of the structure, [58] and [59]. Although additional conservatisms remain in the approach it was considered enough for the CN-235-300M structural assessment.

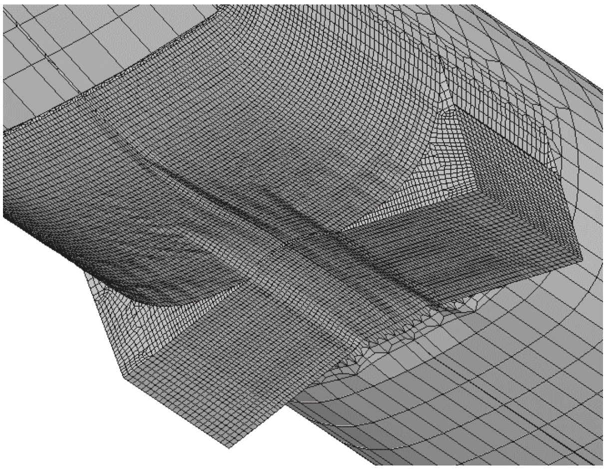

Fig. 18. Fuselage deformations under ditching loads, [59].

The structural analyses performed show that the aircraft is able to withstand the loads derived from the first impact, and that the effects of subsequent touchdowns are covered by the analysis of the first one. Deformation of the lower part of the fuselage in a critical case is shown in **Fig. 18**. Some sensitivity analyses have also been carried out in order to study the influence that the variation of some parameters, such as the magnitude of the loading or the duration of the pulse, might have on the structural performance of the aircraft. The results obtained confirm the robustness of the conclusions derived from the nominal case analysis.

To end, a set of critical cases has been selected and the corresponding loads have been implemented in the FE model. The results obtained from these analyses show that the overall integrity of the aircraft is not threatened in any case, and that no rupture of the skin panels or riveted joints is expected, **Fig. 19**. Hence, the integrity of the structure under ditching conditions was demonstrated.

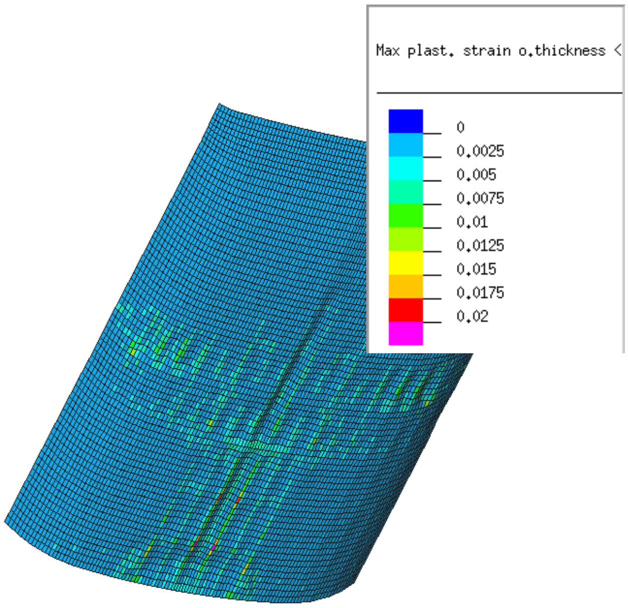

Fig. 19. Maximum and effective strain over the thickness at the skin panels[59].

6 Ditching third phase: floatation

During the last phase, computations are done to study the rate of water ingress and to calculate the remaining time for the crew and passengers to evacuate before the aircraft sinks, [60].

In this phase, the most favorable exits are opened (typically the hatch), the life rafts launched to the sea and the occupants evacuate the aircraft systematically.

The floatation analysis demonstrated that the present CN235-300M configuration, with an additional centre top hatch installed, will provide a safe evacuation for all the occupants, even at more rough water conditions. A safe evacuation could be performed for all probable sea conditions up to sea state 4 (Douglas Scale).

7 Conclusions

This paper has presented a procedure followed at EADS-CASA for the ditching certification of the CN-235-300M aircraft. A methodology has been implemented that takes benefit of the classical approach of scale-model ditching test as well as the most advanced numerical simulations techniques.

Three main phases in a planned ditching event are the preparation of the crew, the impact with water and the subsequent floatation phase. The impact of the aircraft with water is crucial because the structure should withstand impact loads to allow a safe evacuation of the occupants.

Vertical impact of aeronautical structures is representative of rotorcraft ditching. Validations of numerical simulations with experimental tests provide good agreement. These results are also applicable to aircraft as a first approach in order to determine the situation of the fuselage structure under likely ditching loads and to quantify the effect of the structural flexibility on ditching loads.

"Real" aircraft ditching conditions are tested using subscale models to provide insight about optimum ditching conditions, kinematic stability and ditching loads.

The structural assessment has been done using a sophisticated explicit FE model. The EADS-CASA CN-235-300M current structural design withstands ditching loads preventing additional sources of water ingress and fulfilling the strength requirements stated on Airworthiness Regulations.

A combined approach to study ditching in the EADS-CASA CN235-300M aircraft has been followed successfully. Advantages from classical approaches based on tests and those from advanced simulation provide insight into the complex physics of the problem.

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