MODELLING OF WATER IMPACT DURING DITCHING EVENT

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Abstract

When operating over water, helicopters (H/C) may experience emergency situations in which immediate ditching is required. During last years, events of ditching have occurred, particularly in North Sea. As the safety of crews and passengers is a priority for manufacturers and authorities, this subject is the focus of discussions again. Evolution of regulation has been published by Civil Aviation Authority in United Kingdom in 2015 (*CAP-1145*) and a Rule Making Task led by EASA (*0120 Ditching*) is currently proposing new amendments to the Certification Specification for light and large rotorcraft (*CS-27* and *CS-29*). During this emergency event, the manoeuver is still controlled; otherwise it would be regarded as a crash. Floatation systems are inflated to ensure floatation while the crew evacuates. Floats may be inflated before the impact to cushion it and to reduce the risk of capsize during the impact phase. The design and dimensioning phase of the helicopter's floatation system is very challenging. *Ditcher* is the in-house software developed to calculate the loads on the helicopters and its floats during a water impact. The external forces acting on the helicopter and considered for the calculation include the helicopter weight, the lift force, the hydrostatic fluid force obtained from hydrostatic pressure and a hydrodynamic model (including wave pressure field when non calm sea states are considered). The geometrical discretization method chosen is the strip theory, while the Von Karman approach is considered for the wet surface prediction. Despite a sum of simplifying hypothesis, Ditcher is reliable and presents the advantage of being effective in CPU cost. The resolution of the equation of movement gives access to rotorcraft dynamics on six degrees of freedom. H/C kinematics is predictable as well as structural loading during water entry on calm sea and severe wave conditions. A building block approach has been followed to validate the perimeter of use of the software. Correlations with water drop tests of gradual complexity were conducted: simple shapes, partial structures, scaled and full size helicopters. Parameters variation influence studies were performed to check the validity of the software regarding the current regulation. The use of numerical methods to demonstrate survival capabilities is necessary for designers, indeed it completes campaign test approaches, which are often not totally representative of the real operations. Beyond this complementarity on the aspect of reality representativeness, the search of parameter influence is more accessible with numerical studies. Hence one aim of the present work is to highlight that tests are ineluctable for the validation of numerical modelling, and modelling becomes an essential tool to investigate what is not accessible by test.

1. INTRODUCTION

Fig. 1 – Helicopter operating over water

When operating over water (see Fig. 1), helicopters may experience emergency situations in which immediate controlled sea landing is required: it is called “ditching”. More officially, the regulation defines it as an emergency landing on water, deliberately executed in accordance with rotorcraft flight manual (RFM) procedures, with the intent of abandoning the rotorcraft as soon as practicable.

During last years, events of ditching have occurred, in North Sea particularly (see Fig. 2). Consequently, the safety of crews and passengers which takes priority for manufacturers and authorities has been the subject of new discussions.

Fig. 2 – Example of ditching event of one Super Puma in 2012

Safety measures are taken to anticipate ditching and ensure survival capabilities: design with specific resistance to water impact, waterproof volume embedded in structures to insure floatability, Emergency Floatation Systems (EFS) which might be inflated to cushion the impact, but in any case which are inflated to ensure floatation while the crew evacuates in life raft. The design and dimensioning phases of the helicopter’s floatability system and the integration of all the survivability features and related equipment is very challenging.

A recent evolution of helicopter ditching regulation has been published by Civil Aviation Authority in United Kingdom in 2015 (*CAP-1145*) and a Rule Making Task led by EASA (*0120 Ditching*) is currently proposing a new amendment (see reference [1]) to the Certification Specification for Small and Large rotorcraft (respectively *CS-27* [2] and *CS-29* [3]). An exhaustive list of items to be reviewed to increase survivable capabilities has been established thanks to accident analysis (see [4] & [5]) and engineering research (see [6] & [7]). Some foreseen changes and new requirements which might have major impacts on helicopters design and architecture concern mainly: the sea state severity increase, the risk mitigation of capsize during stability phase with additional security items, the emergency exits, size and arrangement. But as mentioned, the subjects addressed in the regulation concern a wide range of items of both technical equipment (emergency exits, lighting, marking, emergency locator transmitters, signaling devices, EFS armament and activation, liferaft system…), and operational conditions (probable water conditions, forward velocity, vertical-descent velocity, rotor lift effect, handling quality, etc…).

The present work will focus on the water entry sequence illustrated by Fig. 3, and more especially on the impact with water. The study described in the following chapters aims at confirming the satisfying capabilities of the chosen numerical approach to predict the ditching loads and helicopter behavior despite the present challenges (technical and operational).

Fig. 3 – Typical helicopter water entry sequence in case of ditching (1 & 2 = Approach, 3 & 4 = Impact, 5 = Tranquilization, 6 = Stability, see [12])

2. DITCHING LOADS EVALUATION METHODS

In order to design the helicopters structures and equipment involved in ditching events, a first step consists in evaluating the probable loads and behavior during the phase of water entry. Two different ways are envisaged:

- the experimental approach with mock-up, partial structure or full-scale tests;
- the numerical approach with validated modelling of the possible event.

Before undertaking one of the two approaches, it is worth highlighting the specificities of such a particular event which is helicopter ditching.

2.1 Non-linear and specific phenomena

Prior to start experiments or numerical simulations of a ditching, it is necessary to understand the various and mostly non-linear phenomena present along the event.

Firstly, the helicopter approach phase will define the tridimensional attitude parameters at the initial contact time with water (trim, roll and yaw), velocities (in translation Vx, Vy, Vz, and in rotation around the main axes of the H/C frame: VRoty, VRotx, VRotz) and potential lift effect. This last parameter is very "pilot-dependent" and will be simplified whatever the chosen approach.

Secondly, the free surface shape has to be defined. In reality, waves are strongly non-linear. Constant period, height and length of waves or regular smoothness of the surface are not common conditions. But the reproduction of high frequency choppy wind waves of low magnitude coupled with irregular pattern with various steepness of larger formed swell is a challenge. In terms of wave modelling, different approaches are available; the most common one consists in idealizing waves as simple sinusoids, the most known model being Airy's one. Methods considering a higher order definition allow taking into account the local wave camber. Stokes model induces more narrow crests and flatten troughs. The Fig. 4 compares these two examples of waves modelling.

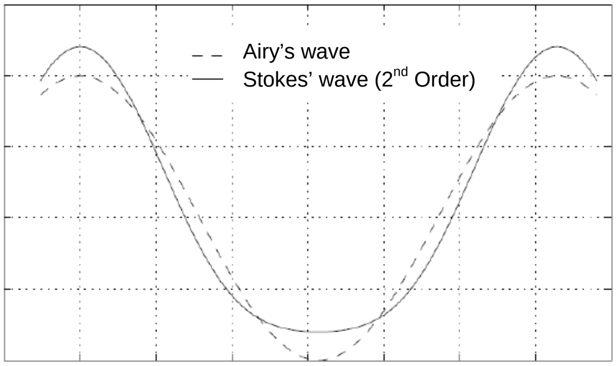

Fig. 4 – Comparisons of wave modelling

Thirdly, the heading of the helicopter relative to the wave propagation, and the location on the wave of the initial contact have to be determined. Both helicopter and its EFS might be regarded as complex assemblies whose geometries may have a significant impact on ditching loads. The following pictures in Fig. 5 illustrate some particularities of H/C implying strong non linearities during water impact.

Fig. 5 – Examples of particularities of H/C geometries and equipment inducing strong non-linearity during water impact

To complete, experience has shown that in the case of flat surface impacting the water with no deadrise angle, the entrapped volume of compressible air would play a cushion effect which would damp the initial contact loads. It is illustrated in the following schema in Fig. 6.

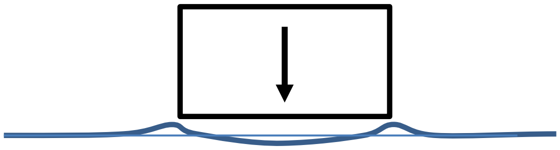

Fig. 6 – Air-pocket entrapment creating a cushion effect

Besides, inflatable floats might undergo deformation and move significantly depending on their anchoring, geometries and inner pressures.

Regarding all these considerations, the reproduction of Fluid-Structure Interaction (FSI) by modelling or by tests starts with the choice of simplification hypothesis and the definition of multiple complex parameters defining the initial contact with water.

It is noticeable that forward velocity is prescribed by regulation and does not exceed 56 km/h (30 knots). At that speed, cavitation effects or planing will not be taken into account in H/C studies.

2.2 Limits of Physical Tests

Experimental tests would consist in performing several drops of structures on water with various initial conditions, part of which is requested by the regulation. They could be for instance:

- initial tridimensional velocities;
- helicopter or structure tridimensional attitudes;
- helicopter or structure shape;
- weight with potential lift effect;
- center of gravity;
- water free surface (calm or several sea state conditions) etc…

It is easily understandable that demonstrating the influence of all these parameters by test will lead to unaffordable test matrix. To reduce cost, the use of helicopter mock-ups (scale up to 1/9 for instance) or partial structures (reduced or full scale) may be an alternative. However, the representativeness of scaled effects may be discussed even if similarities laws have been studied for years, especially for naval architecture needs. Indeed, the similarity approaches are based on the equality of dimensionless numbers like Froude and Reynolds ones at both full and reduced scales. Studies have highlighted that all numbers equality (Reynold, Froude, Mach, Weber, Strouhall) is impossible to achieve with common fluids and gravity at both scales. Froude scaling method is commonly used for ditching tests and open free surface flow problematics. Its equality in model and full scale ensures that gravity forces are correctly scaled along a complete ditching event. But during the same event, it will be difficult to respect also the equality of the other numbers at both scales. For example, Reynolds number inequality will highlight the lack of representativeness of viscous effects at low scale. The viscosity may induce significant effects during stability at a very little mock-up scale. Consequently, between water entry phase and tranquilization stability, there will be a discontinuity of physical parameters when recalculated at full scale if bad initial scale hypothesis are taken.

In addition, the respect of the helicopter inertias at mockup scale is an issue, and to respect those of EFS is even more difficult. Also, an adequate solution to represent the tail rotor effect and influence along the full water impact and tranquilization phase has not been yet fund. Furthermore, apart a true full scale ditching, no method has been found today to represent experimentally the lift effect time history linked to the possible pilot operations during ditching.

The test means available nowadays have known a real disruptive evolution compared to the one used in 70's or 80's. Nevertheless, some measurements are still difficult to perform or to analyze. For example measuring the interface loads between floats and fuselage is still an open question, especially at mockup scale. The choice of the appropriate instrumentation and acquisition means, as well as the adequate use of numerical filter for further data analysis, has to be done carefully to ensure the correct use of measurements for airframe sizing as well as analytical or numerical methods validation.

Consequently, even if a wider range of technologies is used nowadays by test facilities to measure kinematics, loads, pressures, and to record non-linear phenomena with high frequency camera, the representativeness of test campaign will be still limited by similarities law and numerous impact parameters especially for full scale model.

Considering all these reasons, the experiment implies a sum of hypothesis simplifying the real event considered. As a consequence, ditching experimental campaigns, whatever their nature, might not be considered as a common use, systematic and direct mean of compliance, neither a demonstration nor a design tool alone.

2.3 Numerical Approach

The problems of fluid-structure interaction have been treated with several numerical methods. A simplified list could be:

a. Analytical and linearized methods: mostly 2D models with some 3D specific validation – See Fig. 7 and Fig. 12.
b. Semi-analytical methods: extension of 2D model with assembling methods to create 3D model – for example Strip Theory in Fig. 8.
c. Full numerical approaches with Computational Fluid Dynamics (CFD) methods like Smooth Particle Hydrodynamics (SPH) – see Fig. 9 or Arbitrary Lagrangian Eulerian (ALE).

In the family of Linearized methods, two theories are available: von Karman and Wagner. The first one does not consider the fluid elevation which occurs close to water line (see Fig. 12 in the following part) whereas the second one tries to consider it with a correction (see Fig. 7).

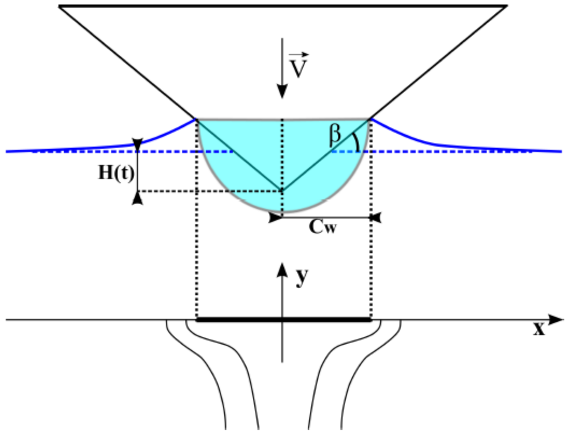

Fig. 7 – Illustration of the water impact of a wedge linearized with Wagner's model and its parameters

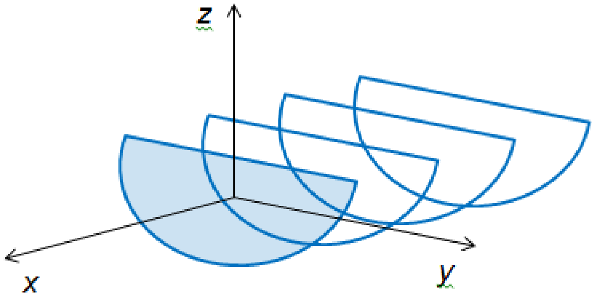

Fig. 8 – Cut of geometry into transverse sections for application of strip theory

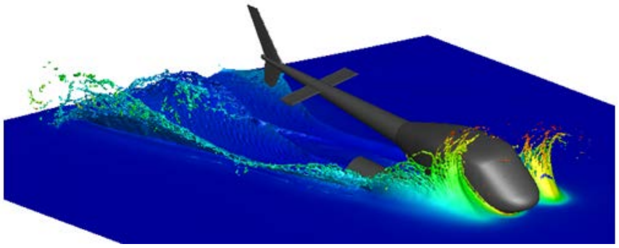

Fig. 9 – Simulation of ditching with SPH-flow illustrating the capability of the code to represent strong free surface nonlinearities

It is not the aim of this article to establish a state of art of the methods in the water impact field, reviews of the landscape establish from 1939 to nowadays are proposed in references [9], [10] and [11]. They clarify the theory behind these methods: potential theory, Navier Stokes equations solving etc…

Whatever the method amongst those already listed, hypothesis are necessary. As for experiments, we can highlight for example: waves will not be 100% realistic, geometries of impacted bodies will be simplified, internal structures will not necessarily considered. But a constraint which is unique to the numerical approach is the processing capacity. Indeed, CFD, SPH and ALE methods are greedy in terms of processing consumption. These methods imply to use High Processor Computing (HPC) hardware installations, coupled with Multi Processor Interface (MPI) and the capacities of hundreds or thousands of Cores. They are even more demanding when the codes are coupled with Finite Element Methods (FEM). An example of Airbus Helicopters' application of this kind of coupled method with the explicit software Radioss is illustrated in Fig. 10.

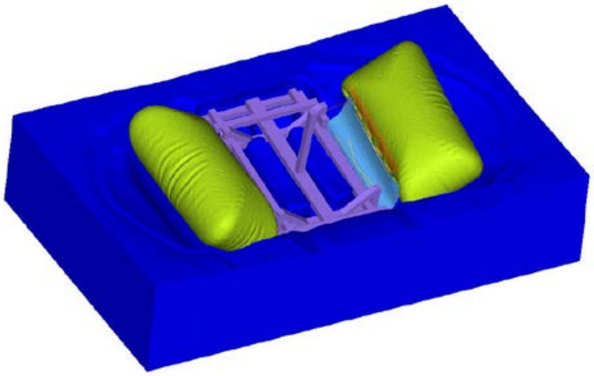

Fig. 10 – Correlation of the water impact of EFS with Radioss

Despite these constraints, once numerical methods are validated for a given scope of applications, they can offer many opportunities to reach local information and prediction of complex phenomenon not achievable with experimental approach. Besides, the power of efficient numerical method lies in the capacity to explore a broad range of input parameters. With batch processing and automatization of pre- and post-processing, it is possible to perform hundreds of calculation varying the floats positions and designs, the attitudes at impact time, the weight and balance characteristics, the sea states, etc… By this way, the optimization of equipment and H/C structures can be performed. Numerical approaches might be very powerful tools for H/C development.

2.4 In House Software: Ditcher

2.4.1 Origin and history

This is due to the reasons listed above that Airbus Helicopters (called at that time SNIAS Société Nationale Industrielle Aérospatiale) decided to adapt the methods developed for naval architecture purposes to specificities of H/C at the end of 70's. Indeed the outcomes of several experimental campaigns of mock-up ditching tests in water tank underlined the necessity to extend the influence study initiated. The emerging numerical methods were already an opportunity to reach unmeasurable data to improve security of crews and passengers.

Ditcher software has been initiated to calculate the loads applied on the helicopter and its floats during a ditching event. The first version of the code was released in 1990. From then, different updates were developed to improve its validity range, its human machine interface, its CPU performance and also to increase the number of input parameters.

The available formulation was the potential theory and the code has been developed with von Karman hypothesis for the wet surface modelling. The wave description is based on the Airy model. Concerning the discretization method, the strip theory was the more accessible regarding hardware capacities. In 80's, processing resolution of complex systems was quickly an issue with an important parameter matrix. CFD, SPH or ALE methods were too young to solve water impact problem.

Today, processing hundreds of cases with Ditcher is a question of minutes. The main revolution was to give access to data like fuselage pressure or to calculate separated loads on each part of the model. Since its implementation, the code has been used for development purposes and studies which are part of H/C certification process.

2.4.2 Formulation and theory

To predict the aircraft kinematics, the equation of movement is solved on six degrees of freedom for loads (1) and moments (2):

(1) $\sum F_{ext} = M.\gamma$

(2) $\sum M_{ext} = I.\ddot{\theta}$

The external loads taken into account in Ditcher are illustrated in Fig. 11. The gravity and lift forces are added to the hydrodynamic forces (impact and drag forces) and hydrostatic forces. In Fig. 11, B is the center of buoyancy, where the Archimedes force is concentrated. G is the Center of Gravity of the helicopter. Additional load components might appear in hydrodynamic forces due to waves when sea states are considered.

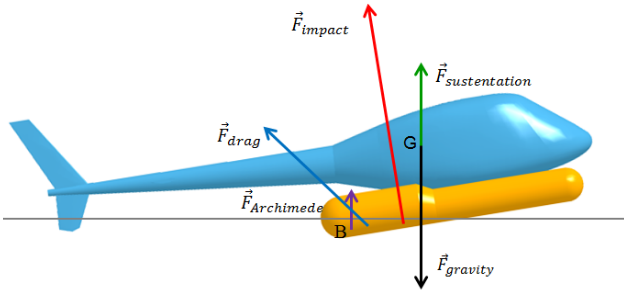

Fig. 11 – External loads considered in DITCHER

Therefore the previous external loads might be decomposed as follows (with wave effect considered):

(3) $\sum F_{ext} = F_{Ma} + F_{Am} + F_{tnl} + F_{wave} + F_{Archimed} + F_{gravity}$

Where:

F_{Ma} is the added mass term, relative to acceleration;

F_{Am} is the damping term, dependent on the relative velocity;

F_{tnl} is the nonlinear drag term, function of the square of the relative velocity ;

F_{wave} is the contribution of the wave (added mass and damping);

$F_{archimed}$ is the hydrostatic term;

$F_{gravity}$ is the gravitational contribution with the sustentation effect.

All these external loads depend on the relative velocity between the helicopter and the wave, the hydrodynamic added mass and damping coefficient defined by the Karman wet surface illustrated in Fig. 12.

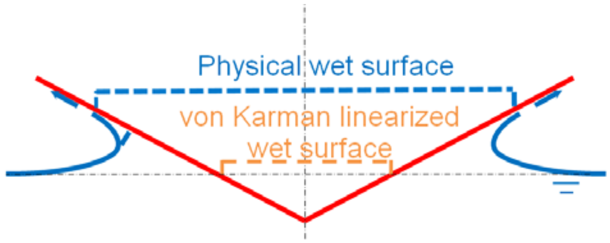

Fig. 12 – Case of a 2D wedge impacting a liquid flat free surface with von Karman theory

Several studies have been led to better represent the water line elevation with the Wagner approach (see a part of the work of Scolan and Korobkin in reference [8] for a 3D parametrized body). But even if progress was significant when the attempt to apply this method to H/C's EFS has been performed (see reference [9]), the final implementation has not been finalized due to its complexity for generic shapes.

2.4.3 Geometrical discretization

The model discretization is based on a strip method as illustrated in Fig. 13. The same method is used for floats.

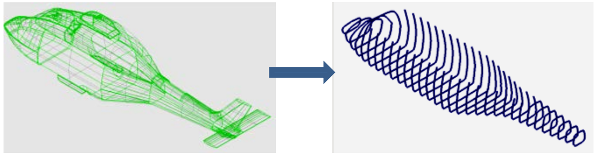

Fig. 13 – Strip method for helicopter discretization

The sum of each strip contribution is applied at the center of gravity of each element of the assembly: cabin and each float. These elements are considered as rigid bodies.

An option allows taking into account the floats deformations and displacement during the impact. This function is based on tabulated law resulting from experimental measures.

The helicopter weight and balance data are also taken into account.

2.4.4 Temporal discretization

The differential equations are of second order. They are solved in time through an integration scheme based on a discretization of time allowing updating accelerations, velocities and positions at each time step. The general time loop is presented in Fig. 14.

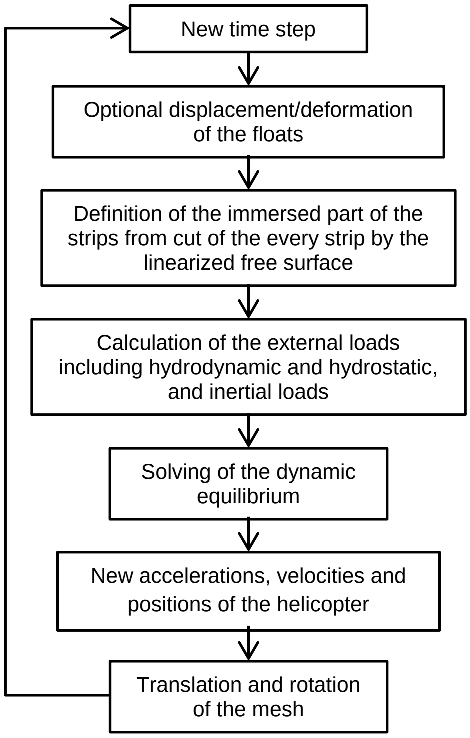

Fig. 14 – General time loop in Ditcher

2.5 Helicopter's Regulation Interpretation

The parameters prescribed or required by the regulation chapters are: velocities at the impact time, yaw, sea states, lift ratio. Requirements are also "handling" oriented. For example, effect of loads coming from inflight inflation of floats has to be estimated. It is also required to define the optimum pitch attitude and forward velocity for ditching in a calm sea as well as entry procedures for the highest sea state to be demonstrated (e.g. the recommended part of the wave on which to ditch). It has to be in agreement with the conditions selected to perform tests or modelling and with expected in service conditions.

As already mentioned for forward velocity, some large differences with fixed wings regulation are noticeable. The sea state consideration and the presence of inflated floats are the two other main differences.

Thanks to an optimized numerical tool, it is now possible to vary impact conditions outside the regulation scope, allowing by this way influence studies on numerous designs, H/C weight and balance characteristics, new local shapes, new equipments… Consequently, the identification of critical cases for the loads and H/C behavior becomes easier.

3. VALIDATION OF DITCHER

3.1 General Approach

The so-called "Building Block Approach" was followed to validate Ditcher tool (see Fig. 15); several ditching tests were performed successively with gradual increasing complexity of shapes, fluid structure interaction and possible deformation.

Also, some correlations have been performed with more severe conditions than the scope of the regulation (higher velocities and higher trim). Indeed Ditcher has been already used in the frame of accident investigation or when authorities have published accident data concerning kinematics, and has led to good correlation between the level of pressure on bottom shell and visible damaged.

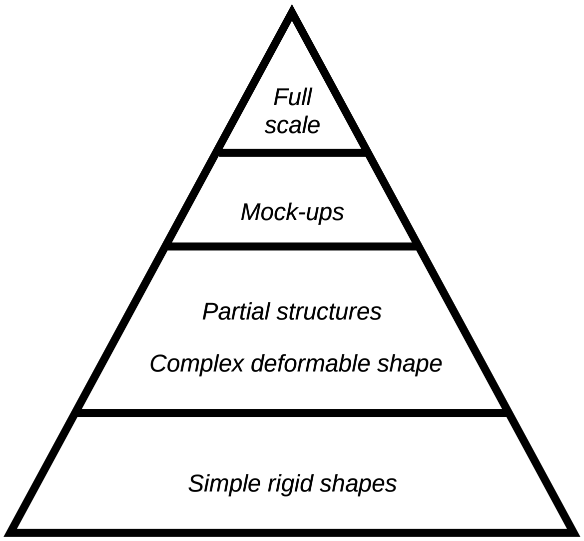

Fig. 15 - Building block approach to validate DITCHER

The parts of this chapter give examples of the different steps of the validation process. They illustrate the different correlated parameters, such as displacements, accelerations, loads, pressure, and global helicopter behavior.

3.2 Simple Shapes Validation

Data from several tests campaign of drop tests have been correlated. Different impact shapes were studied (semicircular and dihedral) with vertical impact speed up to 8m/s. For instance, Fig. 16 and Fig. 17 illustrate the good correlation of vertical impact load we obtain for semi-circular and dihedral rigid shapes impacting water at around 8m/s.

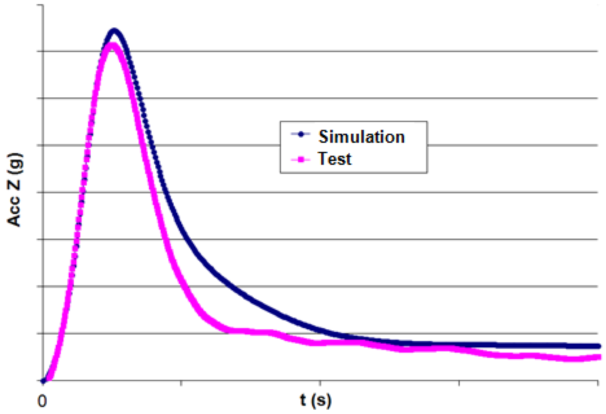

Fig. 16 – Comparison of impact load time history between simulation and test for semi-circular rigid shape

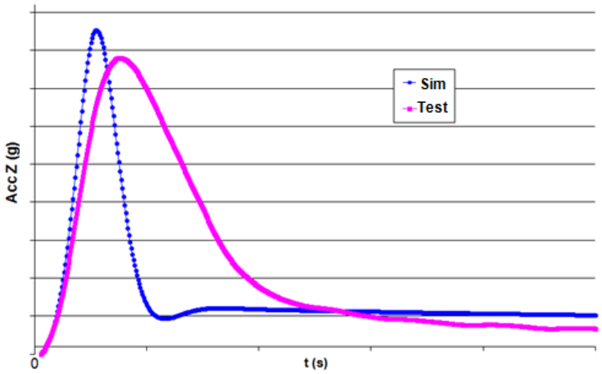

Fig. 17 – Comparison of impact load time history between simulation and test for dihedral rigid shape

3.3 Complex Deformable Shape Validation

Fig. 18 illustrates the test means (before drop) issued from a research project using simple helicopter floats with their containers anchored on a jig. The whole assembly was dropped on a calm water basin.

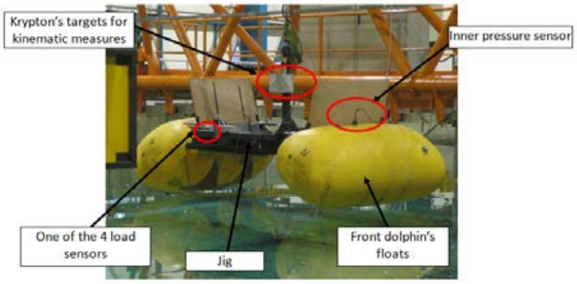

Fig. 18 – Complex assembly with deformable shape test means

The corresponding DITCHER model is described in Fig. 19 in which the floats representation is simplified. Several drop tests at different heights were performed, the vertical velocities varying between 1.8m/s and 2.62m/s.

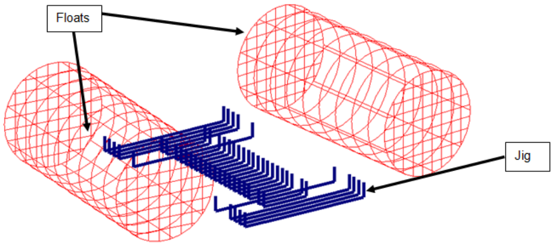

Fig. 19 – DITCHER model of BGO test

The following graph illustrates finally the vertical loads comparison between the experimental data and the numerical ones, which proves a good level of prediction.

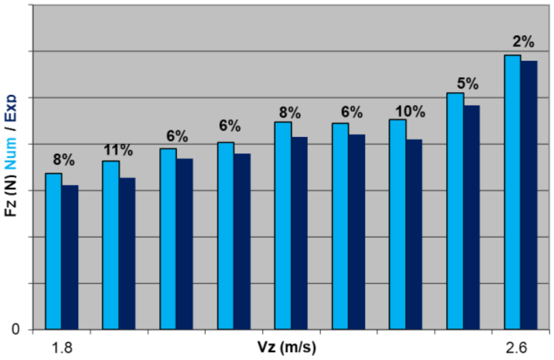

Fig. 20 – DITCHER's loads compared with experimental ones

3.4 Mock-Ups validation

Several experimental campaigns with mocks-up have been performed by AH to study the ditching behavior. Correlations have been led with most of them:

- AS350 scale 1/5
- MKII AS332 scale 1/8
- AS355 scale 1/5
- AS365 scale 1/6

The different phases of the ditching have been analyzed:

- Impact
- Tranquilization
- Stability

During the development of Ditcher, water entry and tranquilization phases have been correlated for AS365 and AS332 cases. Some results of the correlations with the tests of the AS355 are detailed here after. A similar work has been performed for AS365.

The following pictures illustrate the AS350 mockup which has been adapted for AS355 tests with additional local masses and bi-diameter floats, and Ditcher model of the AS355.

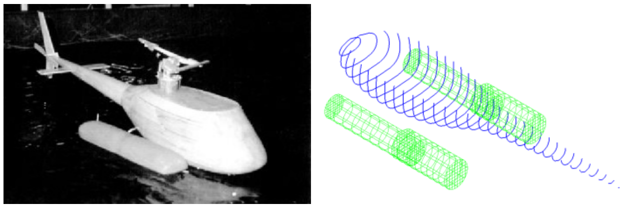

Fig. 21 - AS355 test mock-up and corresponding model with DITCHER

Correlations were done on accelerations data measured on the mockup in vertical and longitudinal directions. The following table provides some comparisons between the test measurements and the Ditcher model results.

Test (w/o lift)	Weight (kg)	Att. (°)	Drift. (°)	Acc.	Diff (%)
Vertical calm free surface Vz = 2.5 m/s	2500	0	0	nz	+10%
	2100	0	0	nz	+17%

Tab. 1 - Relative difference between tests and Ditcher accelerations for AS355 mock up test

Discrepancies and lack of prediction for some cases with wave conditions were observed and might be explained by several factors:

- Lack of information concerning the point of impact on wave;
- Ideal sinusoidal shape of wave in Ditcher different of real ones in tests;
- H/C inertia of the mockup was evaluated theoretically from insufficient available data.

These first order parameters for accelerations were not tracked during the test campaign in 1978. This lack was corrected in the next test campaigns.

3.5 Full Scale

Several full scale tests were performed by AH:

- Flight tests with BK117
- Flight tests with EC120
- Experimental campaign on EC225 (see Fig. 22).

on which Ditcher was validated.

On top of that, real ditching event data have also been recently incorporated into an incident database. A correlation was performed on a Super Puma ditching which occurred some years ago. Thanks to CVFDR records (Cockpit Voice and Flight Data Recorder), the H/C impact conditions were evaluated. Based on that information, Ditcher models were developed to calculate H/C accelerations during water entry phase. Those numerical accelerations were very close to the CVFDR records (+4% on maximum acceleration). From the corresponding wet surface, a fuselage pressure was then estimated by Ditcher and the residual bottom skin deformation was finally determined by classical static analysis. Here again, the calculated deformed pattern was in agreement with the H/C visible bottom shell damage. This final verification loop proves that Ditcher is also reliable on a larger scope than the regulation conditions.

Fig. 22 – EC225 ditching tests – Full Scale

4. CONCLUSION & PERSPECTIVES

The ditching is a highly nonlinear event, driven by numerous parameters which are sometimes specific to helicopters. There is a clear industrial need to estimate correctly the impact loads and H/C kinematics, to finally size the airframe, survivability features and related equipment. For that purpose, a part of this paper focused in listing the pros and cons of both experimental and numerical approaches, to conclude that they finally provide complementary information. Both methods aim at giving accurate prediction of realistic operational ditching conditions. An overview of the Airbus Helicopters in-house numerical tool called Ditcher was given. Some key elements of its development history, typical application and validation by comparison with a wide range of tests were described. Ditcher is now used as a mean of compliance for the demonstration of the current regulation requirements. Ditcher has also already proven a satisfying level of predictability for extended impact conditions occurred in some in service incidents.

The future Ditcher developments may consist in coupled functionalities with handling model of flight simulation tools to better appreciate the approach phase modelling. Besides, the access to ever increasing High Processor Computing (HPC) capabilities allows the implementation of more and more discretized models. This mesh refinement would be a very interesting open door to additional results like temporal local pressure field, which could be used as reliable inputs of structural Finite Element analysis.

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