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## **EXPERIMENTAL ANALYSIS OF THE HELICOPTER DITCHING**

### **ABSTRACT**

The paper presents the method and results of the model tests of helicopter ditching, aimed at adaptation of the helicopter's construction for marine missions. The experiment, realized by Maritime Advanced Research Centre S.A. (CTO) required elaboration of dedicated measurement stand, and solving a number of specific technical problems resulting from the necessity of assuring the repeatability, and required accuracy of the measurements and scalability of the results. Such kind of experiment is not a standard task of a hydrodynamic model testing institution, so it brings an innovation in the testing methodology. The paper presents the details of the test stand and the model itself with rotating rotor, design of the experiment, as well as an overview of the results and main conclusions.

### Keywords:

rotorcraft, helicopter, ditching, scale model test

### **INTRODUCTION**

The analysis presented in this paper is a part of wide test campaign aimed at modification of an optionally piloted helicopter to maritime mission performance. The analyzed helicopter to be adapted for maritime missions is the PZL SW4 (Fig.1). The research conducted by CTO S.A., related to hydrodynamics, included:

- evaluation of the ship motions, to be used as an input data for the modified autopilot, as well as for realistic modelling of the ship in the simulations of helicopter onboard operations;
- evaluation of the ship airwake, to be used as an input data for the helicopter simulator;

- evaluation of the helicopter stability and motion response to waves with taking into account the emergency flotation system, both in intact conditions, as well as for critical failure modes;
- evaluation of accelerations, pressure impulses, and fuselage motion during ditching in waves.

The scope of the CTO S.A. activities included design of the emergency flotation system.

This test campaign was the custom and unconventional task realized for aerospace industry by Maritime Advanced Research Centre CTO S.A., therefore it presented a substantial challenge in respect of model design, development of test stand, as well as planning of the experiment. The paper is thus focused primarily on the experiment methodology. The results of ditching tests are also presented, and main conclusions are drawn.



Fig. 1. PZL SW4 helicopter  
*source: Konflikty.pl, Łukasz Golowanow*

## **BACKGROUND – PRECEDING RESEARCH**

Hydrodynamic tests and computations carried out in order to provide necessary input for modification of the helicopter for maritime missions included the items listed below.

1. Evaluation of the ship motion response to waves, aimed at quantitative prediction of the helideck motion. The experiments included both predictions of the vessel response in irregular waves, as well as evaluation of response amplitude operators (RAOs) for motion. The RAOs, including both amplitude and phase characteristics of the vessel motion, allow simulating the vessel motion in the flight simulator for arbitrary wave spectrum. Moreover, tracking the vessel motion by the helicopter autopilot's sensors before landing allows sufficiently accurate prediction of the helideck position, and velocity at the moment of touchdown [1]. The ship selected for tests is the Oliver Hazard Perry class frigate.



Fig. 2. Oliver Hazard Perry class frigate – actual geometry and model for tests in waves

2. Evaluation of the ship airwake, an input for the flight simulator. Accurate representation of ambient velocity field over the helideck, defined by three mean velocity components and turbulence characteristics, is crucial for realistic simulation of the landing on a vessel. The velocity field data were obtained primarily from CFD, and their reliability was verified based on wind tunnel model tests.

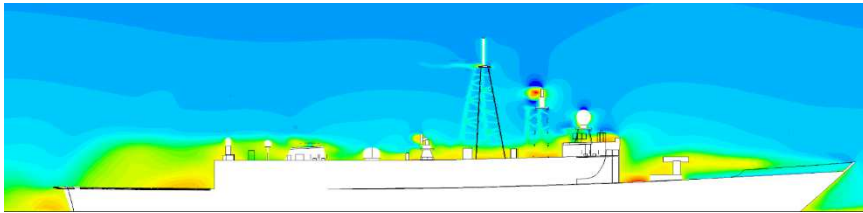


Fig. 3. Axial velocity field resulting from CFD analysis

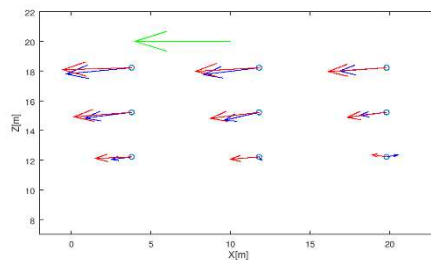


Fig. 4. Experimental validation of the airwake evaluation: wind tunnel model and comparison of computed and measured velocity field (red – CFD, blue – experiment)

3. Design of the emergency flotation system. The system consists of two identical floats, mounted to the skids of the helicopter. They are divided into five compartments (Fig. 5), and considered failure modes consist in

loss of single compartment. The goal of the optimization was to minimize trim and heel angles for most unfavourable failures. Verification of the designed geometry was carried out by means of numerical computations with MAXSURF Hydromax software, and by model tests (Fig. 6)

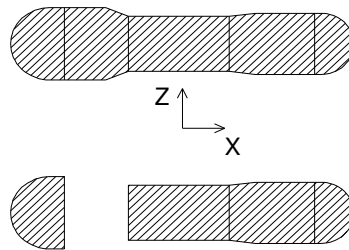


Fig. 5. Geometry of the floats (top), example of failure mode (bottom)



Fig. 6. Computational and model scale experimental verification of the flotation system design

4. Evaluation of the helicopter stability, and motion response to waves. The model manufactured in scale 1:8 from PCV foam and PET was used in the experiments aimed at evaluation of the helicopter stability and motion in waves. The main point of interest was the risk of the contact of main rotor, and tail rotor with the water [2].



Fig. 7. Experimental evaluation of the helicopter motion in waves in model scale

### **MODEL DESIGN FOR DITCHING TESTS**

The initial intention regarding the helicopter model design was to use the same model in motion response tests, and in ditching tests. The model was designed to be extremely lightweight, with stiffeners made of PCV foam, and shell plating made of PCV. Such a construction allowed varying both total mass, as well as location of centre of gravity (CG), and moments of inertia in wide range. Total mass of full scale helicopter varies between 1000 and 1800 kg, and the longitudinal CG location in the range of  $\pm 0.125\text{m}$ . The construction allowing controlling both the CG location, and the moment of inertia for specified mass is presented in Fig. 8 below.



Fig. 8. Interior the model fitted for stability and motion response tests

The construction presented above successfully met the requirements of the stability tests and the tests in waves, where the acceleration values are low to moderate. However, for the ditching tests, characterized by impact loads on the shell plating and very high acceleration values, the model turned out to be not sufficiently robust. Moreover, the elasticity of the external surface was too

high to allow reliable measurement of pressure impulses. For that reason, it was decided to build another model, with the fuselage made of 15mm plywood. Such a model was sufficiently rigid and extremely robust, at the cost of elasticity in modelling the loading condition. The mass of the fuselage with rotor and instrumentation was corresponding exactly to maximum loading condition, and the required location of CG was achieved by proper distribution of the instrumentation inside the fuselage. The fuselage design with instrumentation (accelerometers, pressure sensors and markers of the 6DOF motion tracking system) is presented in figures below.



Fig. 9. Model fuselage – dismantled and assembled



Fig. 10. Pressure sensors

The presented model design allowed also easy access to the data acquisition system located in the fuselage.

One of the crucial requirements for the ditching tests was the modelling of the main rotor rotation, which is important to reproduce correctly the gyroscopic reaction acting on the fuselage when the direction of the rotor's angular momentum changes rapidly at the moment of water entry. The Froude scaling laws apply to the ditching tests, and the most obvious approach to model the rotor would be then to scale the rotation rate and the moment of inertia. The scaling factors resulting from the Froude similarity are:

for rotation rate:  $n_{model} = n_{full} \cdot \lambda^{0.5}$

for moment of inertia:  $I_{yy\_model} = I_{yy\_full} / \lambda^5$

where  $\lambda$  is the scale factor.

The actual rotation rate of the full scale rotor is 437.3 rpm (7.29 rps). An attempt on modelling the rotor according to these formulae revealed considerable problem resulting from the fact that the rotor rotation in the model tests is inertial – there is no propulsion. High rotation rate at model scale (20.6 rps) results in high drag – so that the rotation rate is reduced by as much as 50% within one second. Thus, there is in fact no control of the rotor rotation rate during the experiment. The proposed solution consisted in modelling only the angular momentum of the rotor, without exact modelling of the rotation rate, and the moment of inertia. The moment of inertia was considerably increased (by the factor of approximately 3.5) which allowed reducing the rotation rate by the same factor. Reducing the drag and increasing the inertia allowed maintaining approximately constant rotation rate of the main rotor during the experiment. The moment of inertia was maximized by replacing the lightweight rotor blade tips with metal ones. Quantitative parameters of the rotor model are listed in the table below.

Table 1. Parameters of the rotor model

Quantity	Full scale	Result of direct scaling	Actual value at model scale
Rotation rate [rpm]	437.3	1236.871	350
Moment of inertia [kgm <sup>2</sup> ]	450.0	0.0137	0.0485
Angular momentum [kgm <sup>2</sup> s <sup>-1</sup> ]	20607	1.779	1.779

The rotor head was manufactured of aluminium, with the adapter for external drive. The blades were manufactured of balsa wood, with carbon composite stiffeners and bronze tips. The rotor model details are presented in Fig. 11 below.



Fig. 11. Rotor model

### MODEL TEST STAND

Besides appropriate model of the helicopter, the ditching test requires preparing the model test facility to assure required initial conditions of the ditching. These include:

- horizontal speed;
- vertical speed;
- pitch angle;
- yaw angle;
- main rotor rotation rate.

An initial approach to the design of the measurement stand consisted in using long tracks (slipway) with adjusted angle; varying the angle allows controlling the ratio between horizontal and vertical speed, while the height of release point allows controlling the velocity magnitude in the moment of water impact. An example of using this approach for ditching tests was described e.g. by Thompson [3], and the idea is presented in Fig.13. Preliminary design studies revealed two serious drawbacks of this approach, i.e.:

- regardless the shape of the helicopter support structure on the moving carriage, it is not possible to avoid collision between this structure and rear parts of the helicopter; in other words, when the carriage stops, and the helicopter is released, its tail would hit the supporting elements; in presented example, this problem was solved by using complex mechanisms in the carriage, allowing the supporting elements to get out of the helicopter's way immediately after it is released; this solution is also presented in Fig.12;



- as the helicopter is accelerated due to gravity only, reaching the required speed takes relatively long time, which makes it more difficult to control the rotor speed during touchdown.

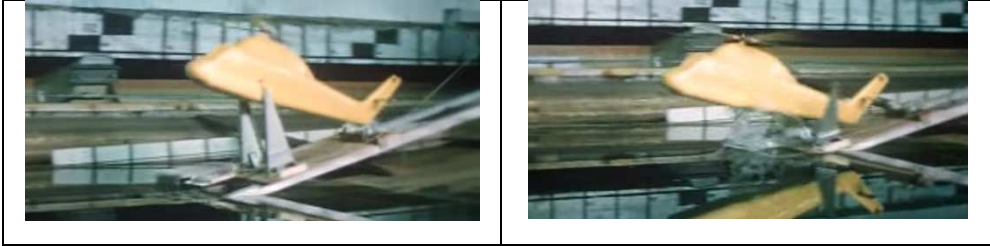


Fig. 12. Ditching model tests featuring tracks

After further studies, and design iterations, the approach described above was abandoned, and an alternative one was used, in which the helicopter is held by rotor head only (Fig.14). The fuselage is also held loosely by the tail fin to prevent rotation.

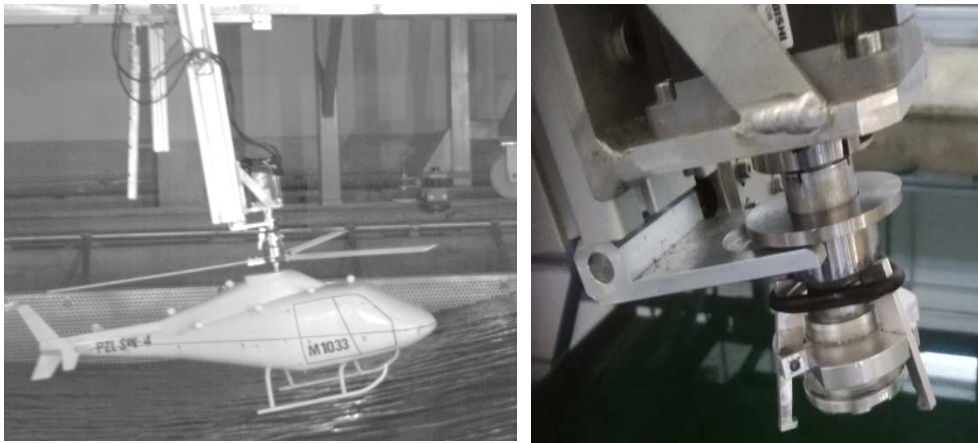


Fig. 13. Measurement stand for ditching model tests, details of releasing mechanism

In this approach, the initial horizontal velocity is controlled directly by moving carriage, and the initial vertical velocity is controlled by adjusting the height of release point. Details of the releasing mechanism (in "open" position") are presented in Fig.13.

The experiment is executed according to the following sequence:

1. The model is held by the rotor head, the rotor is rotating, and the fuselage is standing still; the fuselage is also held by the tail fin to prevent rotation.
2. The model is accelerated to required speed with constant acceleration.
3. The model moves horizontally at constant speed; during this steady motion, the model is released. It is important from the point of view of proper operation of the releasing mechanism to allow the mechanism, and the model move in parallel for some time to let the model fall down gently.
4. The carriage is slowed down, and stopped.

### EXPERIMENT REALISATION AND RESULTS

Complete matrix of the experiment parameters is presented in Tab. 2. Definition and convention of initial pitch and yaw angles is presented in Fig.16.

Tab. 2. Parameters of the experiment

Horizontal speed [m/s]	Initial pitch angle $\alpha$ [deg]				Initial yaw angle $\beta$ [deg]			
	0	5	10	15	0	10	20	
5	0	5	10	15	0	10	20	
10	0	5	10		0	10	15	20
16	0	5	10		0	10	15	

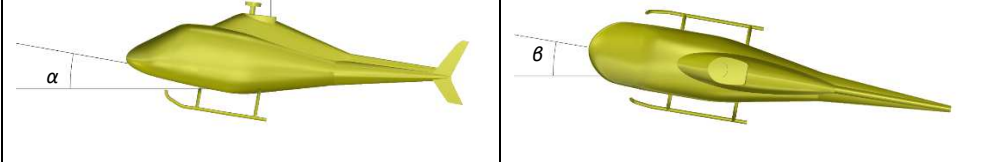
  


Fig. 14. Definition and convention of initial pitch and yaw angles

The ditching is realized in regular waves of large slope (1:10), and the amplitude of 2m. The required initial vertical speed of the helicopter is **1.52 m/s**, which corresponds to **0.537m/s** at model scale. However, due to the fact that the vertical speed of the model is driven by gravity only, and no lift is generated on the rotor, this condition requires that the model is released only 15mm over the water surface, while the wave amplitude reaches 250mm at model scale. Thus, a compromise was applied, i.e. the model was released from lowest possible position, in which the wave crests are touching the skids, but there is no risk of

damage of the launching device. The vertical speed at the moment of touching the water surface by the fuselage is resultant, and equal to 1.8m/s at model scale, i.e. **5.1m/s** at full scale. The results are then conservative in respect of maximum pressure impulses and accelerations.

The location of the impact point was selected according to the following criteria:

- maximum wave slope, resulting in maximum longitudinal acceleration when the helicopter is hitting the wave surface;
- the point located as close to the crest as possible, to minimize the initial vertical speed.

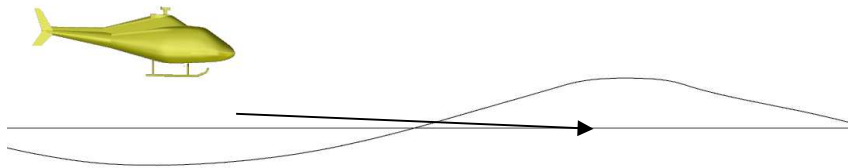


Fig. 15 Initial setup of the model experiment – sketch

Visualization of the ditching for lowest, and highest analyzed horizontal speed is presented in Fig.16. At 5m/s, the helicopter slows down very quickly, and starts following the wave motion, while at 16m/s, large momentum allows the helicopter breaking through the wave crest, get airborne again for a while, and only then, after second impact, the fuselage motion turns into free floating, following the wave motion.

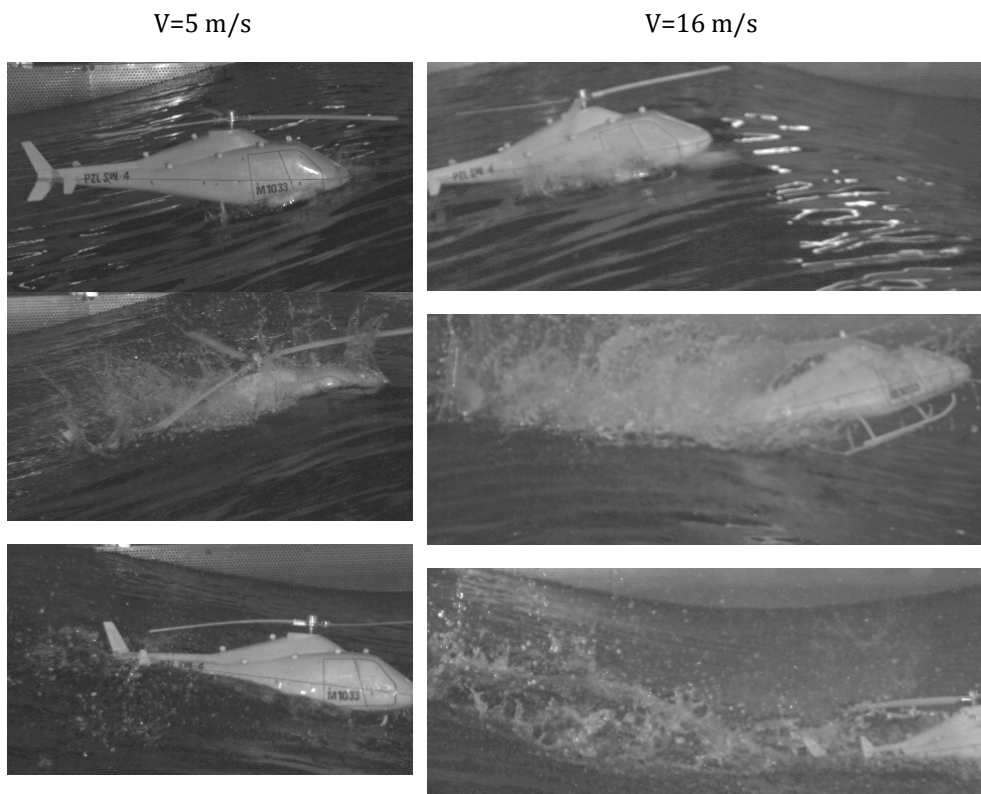


Fig. 16 Examples of ditching model tests at lowest and highest analysed horizontal speed

The phenomena presented above are also reflected in the time series of vertical acceleration at the location of pilot's seat (Fig.17). For low initial horizontal speed (top), the phases of the experiment are clearly visible. At the beginning, the acceleration varies periodically at rotor's rotation frequency due to minor imbalance in the rotor propulsion. After releasing, the measurement shows constant value of the acceleration of gravity. Large peak occurs after impact, and then the acceleration starts oscillating around zero, with visible influence of the wave motion, and local disturbances, resulting e.g. from the contact of the rotor blades with water. At the highest speed, the most important difference consists in the occurrence of second peak of acceleration – lower, but of the same order of magnitude (Fig. 17, bottom). Typical shape of the pressure peak measured during the water impact is presented in Fig. 18. The pressure was recorded in two locations on the bottom part of the fuselage; the location of the

sensors is presented in Fig.10. It is visible that the achievable sampling frequency (1kHz) is an absolute minimum for this kind of measurements.

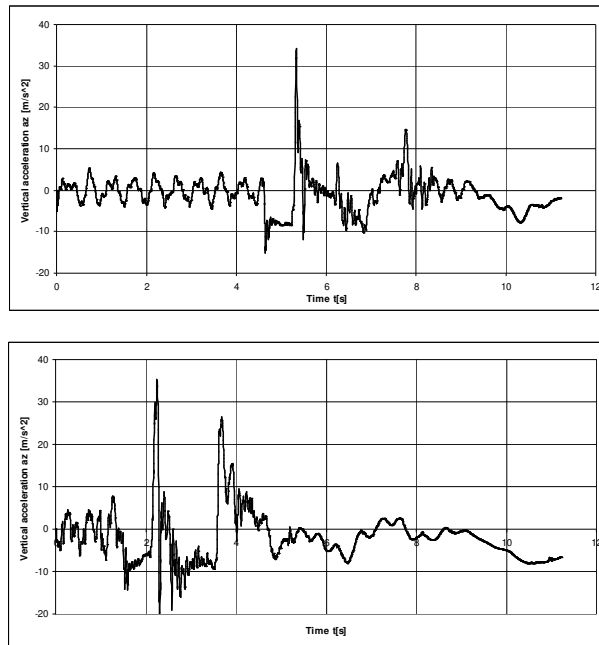


Fig. 17 Vertical acceleration in the pilot's seat location – low speed (top), and high speed (bottom)

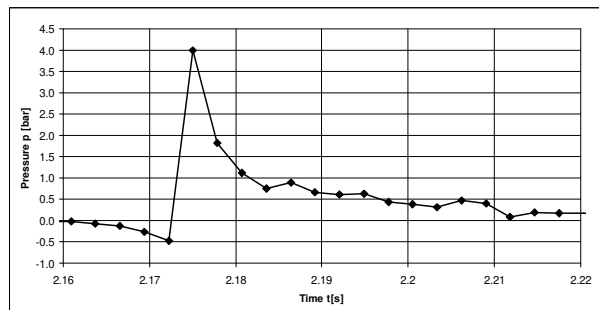


Fig. 18 Example of the pressure record

Summarizing the maximum acceleration, and pressure values for entire test matrix allows identifying the following general tendencies:

1. Initial horizontal speed strongly influences maximum longitudinal acceleration; other parameters, i.e. initial angles of pitch and yaw, have no significant influence on longitudinal acceleration.
2. On the other hand, no clear dependence between initial horizontal speed, and maximum vertical acceleration is visible.
3. Maximum lateral acceleration increases with increasing initial yaw angle, especially for higher speeds.
4. There is no significant and unequivocal influence of the initial pitch angle on maximum acceleration values.
5. It is clearly visible that large initial pitch angle (10 or 15 degrees) strongly reduces the pressure on the front gauge (No.1).

### CONCLUSIONS

Experience with the preparation of the experiment, and the results of the helicopter ditching tests yield the following conclusions:

- modelling the rotor rotation without propulsion requires careful design of the rotor model, to maintain approximately constant rotation rate, and to avoid the damage during the contact with water; in presented case, increasing the moment of inertia, and reducing the rotation rate at model scale turned out to be efficient;
- the launching device, in which the external rotor drive is the only supporting point, caused problems with the control of initial vertical velocity; a compromise was applied, leading to conservative prediction of acceleration and pressure impulses; the results are thus valuable primarily as a reference for CFD validation;
- low influence of initial pitch, and yaw angles on maximum accelerations was observed;
- however, increasing the initial pitch angle allows reducing the pressure impulses in the front part of the fuselage.

### REFERENCES

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