Experimental Research on the Helicopter Sliding Stability after Ditching

Chen Yinghua¹, Wu Ximing² and Yuan Libin¹

¹The China Helicopter of Research and Development Institute, Jingdezhen, 333001, China;
²Aviation Industry Corporation of China, Beijing, 100022, China;

Corresponding author:cyhj2336@163.com

Abstract. As the application of the helicopter increases rapidly, more and more attention is paid to the safety. Thus the survivability and crashworthiness has been an important assessment items for the helicopter design and flight certification. In this paper, a newly designed ditching experiment with a helicopter model scaled 1:8 was conducted to attain the dynamic response of loads and especially the posture. Parameters such as weight, bladder pressure, lateral wind and ditching velocity were set in different groups to investigate the effect on the sliding stability. Based on the result, comparison and analysis was carried out and some conclusions were given. Meanwhile, the method and process of the experiment was presented in detail and proved an effective and available reference for the helicopter flight certification.

1. Introduction

Ditching is an emergency measure when the helicopter is forced to land on water as the last possibility for protecting the passenger safety, which is divided into planed and un-planed cases. According to statistics [1], at least 98 events of helicopter ditching occurred between 1971 and 1992 in the worldwide, which sadly leaded to 338 deaths. In order to improve crashworthiness and safety, a regularity FAR29.801[2] that aim at conducting the rotor aircraft design was promoted by FAA in 1977. In which, the process and methods for the certification of the helicopter ditching such as numerical simulation and model test were prescribed. Similarly in China, the CCAR29[3] was published and refined for several times, in which some requirements were extra added for the stability of slide, balance and floatation after ditching.

For the experimental investigation of helicopter ditching, it has been started and developed for a long time. In comparison with the full-size model, a Scaled model was normally applied to decrease the expensive cost, which primarily based on the Froude similarity principle. In America, Bell-22 helicopter[4] with air bladder was scaly modeled and a series of ditching tests were performed to study the effect on the loads and sliding stability acted by float system. Based on which, a standard ditching process was established, but without taking consider of the effect by some parameters. H-46 helicopter[5] was modeled by a full-scale and scaled as 1:8 model respectively, and then different number and location of float bladders were set to analysis the effect on ditching and stability in different sea conditions. The Waist and England landing and special aircraft company[6] focused on the ditching load and float characteristic, taking the 2/3 lift of rotor into consideration with a scaled model.
In China, the first ditching test was recorded when Z8 helicopter was modeled and dropped into water from a designed height to attain the curve of ditching overload and static characteristic in 1982, however, the influence of float bladder was ignored. In 2008, a helicopter model scaled 1:5 with float bladders was tested to statistic and analysis the ditching overload and pressure in different velocity and posture. In 2016, the civil helicopter AC313 was modeled to investigate the dynamic response in different sea conditions and initial postures. The process and steps of experiment was introduced in detail and the results was analyzed and compare with Russia’s. Based on which, the experimental ability is proved and technologic references were provided for further study. After that, the same model was employed and the floatation experiment was carried out to study the lateral stability. A mathematic method of helicopter lateral stability calculation was established for the first time, considering the influence by the fuel liquid level correction. it was proved that the calculation was in good coincide with test results. But the method was not considering the coupling effect of longitudinal motion. At present, the research on the sliding stability of helicopter is just started and rarely involved in the field so far.

In this paper, a ditching test of a civil helicopter model scaled 1:8 with float bladders was newly designed and carried out. Based on which, the posture and sliding stability after ditching with different parameters such as weight, lateral wind, ditching velocity and bladder pressure were investigated. In conclusion, some advice and consult were given for the sliding stability design, and meanwhile the test process was proved effective and available for the certification of helicopter ditching.

2. Test facility
The facility used in the ditching test included a towing tank, a guide track, wave maker and measure equipment, some parameters of facility are shown as following in table 1.

- Size of the towing tank: length 510m, width 6.5m, while the depth of the tank and water is 6.8m and 5.0m respectively.
- Performance of the track: range of velocity is 0.1m/s～22m/s while the accuracy is more than 0.2%.
- Property of wave maker: range of regular wavelength is 0.5m～15m, range of regular wave height is 0.03m～0.5m; all irregular waves with large wavelength were available.
- Methods of measurement: an automatic data collection and analysis system.

| No. | Name                             | Type    | Range         | Accuracy       |
|-----|----------------------------------|---------|---------------|----------------|
| 1   | High speed track                 | GT02    | 0.1～22m/s    | 0.2%           |
| 2   | Inertial measurement unit        | IMU610H | ±90°          | Dynamic accuracy<0.3° |
| 3   | PCB acceleration sensor          | LW7646  | ±10g          | 0.5%           |
| 4   | Pressure sensor                  | XPM10A1 | 2bar          | 0.25%FS        |
| 5   | Micro data collection system     | DRS104  | ±10VDC        | 0.5%           |
| 6   | Temperature measure system       | SWP-C80 | -10～+55℃     | 0.1%           |
| 7   | Digital electronic scale         | DR-150  | 150kg         | 0.02kg         |
| 8   | Platform scale                   | TGT-100 | 30Kg          | 0.02kg         |
| 9   | Digital angle ruler              | DXL360S | ±90°          | 0.01%          |
| 10  | Mass and inertia measure system  | ZGT-200 | 100kg.m2      | 1%             |
| 11  | Wave probe                       | NHWM-4  | 500mm         | 0.5%           |
In order to record the vertical overload in the cockpit, overloads of the center of gravity in three directions, and the pressure distribution at the bottom, an accelerometer and an inertia measurement unit were located in the inner of model and pressure sensors were located outside the bottom of the model. More details were shown as following:

a) Overload sensor
An acceleration sensor was installed near the header (300mm away from the header) to measure the overload in the cockpit.

b) Inertia measurement unit
The inertia measurement unit was located at the center of gravity (793mm away from the header) to record the overloads in three directions.

c) Pressure sensor
Ten sensors were used to measure the pressure at the bottom of the model, which are shown in figure 1.

![Figure 1. Locations of the pressure sensors at the bottom of model](image)

3. Model and the principle of similarity
According to the References, it is strongly recommended to satisfy a similar principle between the test model and real structure. Mostly, the Froude similarity principle is applied, in which three similarity conditions should be followed.

Geometry similarity: Scale of all geometric sizes between the model and real helicopter is set exactly same.

Kinematics similarity: It is also called the time similarity. As required, the velocity and acceleration vectors of the two corresponding points on the model and the helicopter should be unanimously scaled, which can be also recognized as some combinations of time scale and geometry scale.

Dynamic similarity: The force and moment vectors of the two points at the corresponding location should be scaled the same.

The parameters such as length, Velocity, weight and inertia of both the modal and real helicopter are listed in table 2.

| Parameters | Real value | Scale | Model value |
|------------|------------|-------|-------------|
| Length     | L          | $\lambda^1$ | $\lambda L$ |
| Inertia    | I          | $\lambda^5$ | $\lambda^5 I$ |
| Weight     | m          | $\lambda^3$ | $\lambda^3 m$ |
| Time       | t          | $\sqrt{\lambda}$ | $\sqrt{\lambda} t$ |
| Velocity   | V          | $\sqrt{\lambda}$ | $\sqrt{\lambda} V$ |
The Civil helicopter AC313 was employed for the test and the model scale was designed to 1:8 according to the size of towing tank and available counter weight, and the weight of the model was manufactured to 25.4kg finally, which is shown in figure 2.

4. The supporter installation
The supporter was used for test model installation and posture adjustment. To be installed, a pipe instrument was firstly fixed on the measurement bridge platform of the track with the bolts, and then the angle adjustment set was installed at the bottom of the pipe. After that, the top of the supporter was locked together with the pipe in the connecting holes by some bolts. In order to check the liability of supporting system, a pretest that aim at simulating the motivations of model by lifting or dropping the measure bridge will be carried out, while a solid whose weight is slightly bigger than the model was suspended by a electric magnetic release after energization.

5. The test article installation
Before installed on the bracket, the model was adjusted to be horizontal on a platform. Adjusted the pitch angle, roll angle, and yaw angle to the right value, the model was connected to the bracket to make sure that the two plugs on the bracket match the receptacle on the top of model precisely. The ring on the top of model was inserted into the hook of the release and locked tightly after checking. When installation, a digital angle ruler was applied to set the roll angle and pitch angle of the modal bottom while the yaw angle was set by a mark line in the angle controller. The adjustment was preceded after installation until the angles satisfied the range as required.

6. Test in advance
To depart from the dock freely, the model was elevated to a suitable height by the measurement bridge and then the track was pushed out of the dock and aboard beside after the wave termination. The model was released to the lowest position (visual check) and then lifted to the certain height according to the designed vertical velocity. The electric magnetic release was then opened and the free fall and ditching was observed to check if any resistance exists. Before the formal test, it is recommended to perform the test for several times to make sure the stability of towing system. The installation of the system is shown as Figure 3.
7. Test cases
In order to compare and analysis the effect, 4 groups of cases were designed with 4 parameters including the vertical velocity, weight, lateral wind and bladder pressure. In each group only one parameter was changed while others kept the same. Details about the test settings are shown in table 3 to table 6 as following.

**Table 3.** Test settings with different vertical velocities (group 1#)

| No. | Weight (kg) | β (°) | α (°) | γ (°) | V (m/s) | Vz (m/s) | W (m/s) | P_b (kPa) |
|-----|-------------|-------|-------|-------|---------|----------|---------|-----------|
| 1   | 25.4        | 0     | 8     | 0     | 5.48    | 0.40     | 0       | 30        |
| 2   | 30.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
| 3   | 35.4        | 0     | 8     | 0     | 5.48    | 0.71     | 0       | 30        |

**Table 4.** Test settings with different velocities of lateral wind (group 2#)

| No. | Weight (kg) | β (°) | α (°) | γ (°) | V (m/s) | Vz (m/s) | W (m/s) | P_b (kPa) |
|-----|-------------|-------|-------|-------|---------|----------|---------|-----------|
| 1   | 25.4        | 0     | 8     | 0     | 5.48    | 0.53     | 3.50    | 30        |
| 2   | 30.4        | 0     | 8     | 0     | 5.48    | 0.53     | 4.50    | 30        |
| 3   | 35.4        | 0     | 8     | 0     | 5.48    | 0.53     | 5.50    | 30        |

**Table 5.** Test settings with different weights of model (group 3#)

| No. | Weight (kg) | β (°) | α (°) | γ (°) | V (m/s) | Vz (m/s) | W (m/s) | P_b (kPa) |
|-----|-------------|-------|-------|-------|---------|----------|---------|-----------|
| 1   | 25.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
| 2   | 30.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
| 3   | 35.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |

**Table 6.** Test settings with different pressure of air bladder (group 4#)

| No. | Weight (kg) | β (°) | α (°) | γ (°) | V (m/s) | Vz (m/s) | W (m/s) | P_b (kPa) |
|-----|-------------|-------|-------|-------|---------|----------|---------|-----------|
| 1   | 25.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
| 2   | 25.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
| 3   | 25.4        | 0     | 8     | 0     | 5.48    | 0.53     | 0       | 30        |
8. Test process
Ten steps were included in the process of ditching test.

1) Installation
The bracket was fixed on the platform of the high-speed track and measure bridge, and then fastened to right position.
The pressure of the four bladders were checked and adjusted according to testing requirement (30±2kPa). The model was weighted and installed if the weight was in the range of tolerance. If not, the model would be dried to make the weight to fulfill the range before installed. The angles were adjusted to the value as required and the model was fixed on the bracket at last.

2) The posture adjustment
Angles were measured and finally set to the required value by a digital angle ruler if necessary.
The height of towing position was calculated according to the speed required, multiple the button to adjust the position to ensure the height of model out of water.

3) Camera system
Power on the camera and keep it standby.

4) Final check before test
   • Check the model if the installation is fastened and liable.
   • Check the camera
   • Check the track system and make a safety check around and bottom of the track to make sure that track system run normally and there is no dangerous shelters or other irrelevant personnel.

5) Start the track
If it was okay after checking, an order was given to the track driver to start the track by the test director.

6) Start the micro data collector and camera system
When the track was speeding up, the camera and the data collector was started to capture and record the data from the sensors.

7) Tow
After the speed of track is up to the certain value and kept constant for seconds, the tow toggle was started up. At the same time, the electric magnetic release was activated and the model was released and departed from the bracket, which ditched into water and slide after free fall.

8) Stop the track
After the model ditched into water, track was decelerated and finally stopped.

9) Recycle the model and return to dock
After test, the model was picked up from the water by a steel hook and put to the hook on the hoist track. Once hoist track worked, model rise up and returned to the bottom of dock, while the towing track was restarted and back to dock finally.

10) Data collection and processing
After the model returned to dock, all data were collected by the micro data collecting system which was installed in the model, were transported and saved in the computer for further analysis.

9. Test result
The model experienced four stages totally during the test: acceleration, dropping, ditching and sliding. Photos at different moment were captured and shown in figure 4 as following.
Figure 4. Photos of the helicopter model at different moment in the experiment

After the ditching experiment, the data of each group was collected and filtered with frequency 50HZ and processed. Time history curves of pitch angle, roll angle, the vertical overload of C.G in each group were drawn and posted in figure 5 to figure 7 respectively.

Figure 5. Time history curves of Pitch angle in different groups
From the results, it can be concluded that:
a) As shown in figure 5 to figure 7, the general variation tendency of the pitching and rolling angle as well as the vertical overload of C.G in each group is roughly the same. The pitching and rolling angle
enters a concussion at first after ditching and finally recovers to stable rapidly in approximately 2 seconds, which proves that the pitching and rolling movements of the helicopter is stable during the sliding period after the ditching.

b) For the pitching angle in figure 5, the first trough is obviously relative to the vertical velocity and the weight as well as the pressure of bladder. A higher velocity, greater weight and higher pressure of bladder are more likely to generate a lower trough. Nevertheless, because the time of shaking duration of curves are much close in each groups in figure 5, it is speculated that the dynamic stability of pitching is rarely effected by those parameters.

c) Other than pitching angle, the curve shapes of the roll angle are much different from each other in each group. Because of the inevitable influence by some factors, such as the initial roll angle of model installed, the posture at the moment when the model touched the water and the slight fluctuation of water surface, the time history of roll angle is full of randomness. However, the converge speed of roll angle is inclined to be faster in the groups of 35.4 kg and 20Kpa respectively, which shows that a larger weight and lower pressure of bladder are better for the lateral dynamic stability.

d) In the figure 7, it is figured that a higher velocity, larger weight and higher bladder pressure bring out a heavier overload in Z direction of center of gravity. However, the vibration of curves is finally terminated after the same seconds in each group.

10. Summary
As the application of the helicopter increases rapidly, more and more attention is paid to the safety. Thus the survivability and crashworthiness has been an important assessment items for the helicopter design. In this paper, a ditching experiment with a model of helicopter scaled 1:8 and float bladders was designed and carried out, in which different parameters were set for comparison in groups. The dynamic response curves of loads and especially the posture were captured. Based on the results, the influence by different parameters was discussed. It is concluded that the model of helicopter was statically and dynamically stable in both lateral and longitudinal movements and some advices are therefore given for the design. Moreover the design and process of the experiment was introduced detailedly and proved effective and available, which probably provides the certification of helicopter ditching with references.

Acknowledgments
Supported by the project of Civil Helicopter pre-research (MJ-2014-F-15).

Reference
[1] Westland Helicopters Limited, “A review of UK Military and World Civil Helicopter Water Impacts over the Period 1971-1992”, Stress department report SDR146, November 1993.
[2] FAA. Airworthiness Standards: Transport Category Rotorcraft[S].Washington DC, 2011.
[3] Civil Aviation Administration of China. Chinese civil aviation regulations Parts 29 [S].CCAR29R1-88,Beijing:Civil Aviation Administration of China,2002:24-26.
[4] Alcedo, A.M., Design and Test of Float Landing Gear System for Helicopters,1979 Regional Lichten Award Paper Presented at the American Helicopter Society Southwest Regional Meeting, Fort Worth, TX,1979.
[5] M , J , Reilly,Lightweight Emergency Flotation System For The CH-46 Helicopter NADC-791-69-60, 1981.
[6] Wilson F T, Tucker R C S.Ditching and Floatation Characteristics of the EH101 Helicopter[C].Thirteenth European Rotorcraft Forum,1987,Vol.2: 79.1-12.
[7] Li Mingqi. The subscale test and simulation on water impacting characteristic for emergency flotation system[D].Nanjing:Nanjing University of Aeronautics & Astronautics,2008.
[8] Wang Zhengzhong, Chen Lixia, Suo Qian,Ma Yujie.Test Research on Helicopter Ditching Load[J].Journal of Nanjing University of Aeronautics & Astronautics. 2017,49(2):258-263.
[9] Wang Zhengzhong, Ma Yujie, Jiang Ting. Computation and Test Validation of Lateral Stability for Helicopter on Water[J].Helicopter Technique,173(4):1-7.