INFLUENCE OF FLOAT VOLUME ON HELICOPTER FLOTATION STABILITY

Simon Tödter, University of Duisburg-Essen, Institute of Sustainable and Autonomous Maritime Systems, Duisburg, Germany
Andreas Peters, University of Duisburg-Essen, Institute of Sustainable and Autonomous Maritime Systems, Duisburg, Germany
Jens Neugebauer, University of Duisburg-Essen, Institute of Sustainable and Autonomous Maritime Systems, Duisburg, Germany
Stefan Harms, Airbus Helicopters, Donauwörth, Germany
Ould el Moctar, University of Duisburg-Essen, Institute of Sustainable and Autonomous Maritime Systems, Duisburg, Germany

Abstract

The dynamic flotation stability of helicopters during ditching is a major safety concern for offshore operations. Studies have shown that most ditching fatalities are caused by capsizing and subsequent drowning of passengers and crew. Model-scale experiments were performed to analyse the roll, pitch and heave motions of a light multipurpose helicopter after ditching in a seaway with a significant wave height of 6 m. The capsize events and their occurrence probabilities for a helicopter equipped with cylindrical floats of different sizes were analysed and compared for three different float volumes. It was found that increasing the float size only had a minor effect on flotation stability.

1. INTRODUCTION

Offshore helicopter operations have been popularised by the oil and gas industry and, later, by offshore wind turbine operations. As wind turbines have been sited further from the shore, the demands placed on helicopter operations in terms of passenger and crew safety have increased. Nevertheless, the risk of an emergency while flying offshore remains significant. Unlike an aeroplane, a helicopter cannot glide to a safe harbour, but must land immediately. Consequently, a helicopter must be able to ditch safely and remain stable long enough to evacuate passengers and crew.

Although the rapid landing process is risky, recent studies have shown that ditching itself is not the most dangerous part. The majority of fatalities result from the helicopter capsizing and subsequent drowning. Between 1971 and 1992, 338 people died in ditching accidents involving civil helicopters (Ref. 1), 56.7% of whom drowned. Furthermore, 82.6% of all fatalities involving ditched military helicopters in the United Kingdom were due to drowning. Downie and Gosling (Ref. 2) reviewed accidents involving offshore helicopters operating in the United Kingdom. The Civil Aviation Authority (CAA) reported that 31 out of 38 fatalities in the North Sea between the United Kingdom and Norway were due to drowning between 1976 and 2012 (Ref. 3). Aziz et al. (Ref. 4) analysed ditching accidents listed in the SKYbrary database to identify risk factors for ditching. In addition, the Federal Aviation Administration (Ref. 5) analysed the phenomenon of ditching and the effects of water impact in helicopter accidents in the United States between 1982 and 1989. Their findings revealed that ten out of twenty post-impact injuries were due to drowning.

Brooks et al. (Ref. 6) conducted a detailed comparison of the ditching of registered Canadian helicopters. Of the 46 cases they considered, the helicopter capsized in at least 21 cases and sank in 33 cases. However, the final floating position of the helicopter was not reported in all cases. All accidents occurred during daylight hours, resulting in a high survival rate of 78%. Taber and McCabe (Ref. 7) analysed 511 reports of helicopter ditching. Of the 382 cases that reported the final position of the helicopter, the helicopter capsized in 85% of cases. They also emphasised that attaching external floats does not necessarily increase the probability of survival if the floats are inappropriate or not properly attached. Nevertheless, capsizing, inverting and sinking minimise the survival rate of passengers and crew.

The high number of drowning fatalities and capsized helicopters requires flotation systems to be developed to improve safety for passengers and crew during offshore helicopter operations (Ref. 8). Therefore, an analysis of the performance of existing flotation systems is necessary. Taber and McCabe (Ref. 7) suggest that traditional floats may not provide an adequate level of safety. However, the design of flotation systems still relies on classic designs that may not provide adequate protection against capsizing.

In order to improve the safety of ditching helicopters, the European Union Aviation Safety Agency (EASA) introduced certification specifications (CS-27 and CS-29) for offshore helicopters (Ref. 9). These specifications require an experimental investigation of dynamic floating stability in a sea state modelled by irregular waves. Until now, only a few studies have considered a helicopter's dynamic floating stability. Kidwell and Crago (Ref. 10) studied a helicopter floating in regular and irregular waves. They considered harmonic waves with a height of 4.72 m and varying steepness, as well as irregular waves with a significant wave height of 3.44 m, representing the North Sea with a Beaufort Force 6 wind. They concluded that it is impossible for a twin-float helicopter to capsize in regular, non-breaking waves. Only breaking waves hitting the helicopter in beam seas could cause it to capsize. Conducting model-scale experiments for sea states 4, 5 and 6, Wilson and Tucker (Ref. 11) concluded that, although the helicopter is only likely to survive in sea states 5 and 6, it always survives in sea state 4. Delorme et al. (Ref. 12) analysed the functionality of floats attached to the top of a helicopter's fuselage to prevent total inversion after capsizing, using irregular waves of sea states 3 and 5. This prevents air from escaping the fuselage, protecting passengers and crew from drowning. Kraskowski (Ref. 13) studied the heave, roll and pitch motions of a floating helicopter experimentally and numerically. Additionally, Katsuno et al. (Ref. 14) numerically investigated the dynamic floating behaviour of a helicopter after ditching. Tödter et al. (Ref. 15) experimentally studied the dynamic floating stability of a modern light multi-purpose helicopter with and without open cabin doors, and with and without scoops attached to the floats. They demonstrated that the resulting capsize probabilities were significantly higher than those permitted by EASA (Ref. 9).

In the present study, we first analysed the flotation behaviour of a light multipurpose helicopter equipped with a state-of-the-art flotation system. We then studied the effect of an increased float volume on the helicopter's dynamic floating behaviour and resistance to capsizing.

2. EXPERIMENTAL SETUP

The experiments were performed at a scale of $\lambda = 12$. The helicopter's properties and our results are referred to as full-scale in the following.

2.1. Helicopter and Float Design

The helicopter under study was a light, multipurpose helicopter. We considered its maximum mass configuration of approximately 3000 kg. The model comprised a fuselage with removable doors, a simplified tail boom showing the position of the fenestron and a landing gear system with interchangeable cylindrical front and rear floats. The helicopter is presented in Figure 1. It was not moored during the experiments, allowing unrestricted six-degree-of-freedom motion.

Figure 1 shows schematic side, top and front views of the helicopter, indicating the main features and the origin and orientation of the body-fixed coordinate system. In this system, the X-axis points backwards, the Y-axis points to starboard and the Z-axis points upwards. Consequently, positive pitch angles occur when the helicopter's nose moves upwards, positive roll angles occur when the helicopter's portside moves upwards, and positive yaw angles occur when the helicopter's nose turns to starboard. The helicopter is equipped with a state-of-the-art cylindrical float system referred to herein as float design 1. Table 1 lists the helicopter's main particulars, as well as the positions of its centre of gravity (CoG) X_{CoG}, Y_{CoG} and Z_{CoG}, its moments of inertia I_{XX}, I_{YY} and I_{ZZ} about the X, Y and Z axes respectively, and its maximum draft D_{max} normalised against its length L, width B, height H_H and mass m.

We considered two additional float designs. Design 2 consisted of larger cylindrical floats with a total volume of 188.1% of float design 1. The diameter of the floats was increased by 20%, and the length of the front floats was increased by 44.4%. Due to the increased size and weight of the floats, the helicopter's moment of inertia I_{XX} increased by approximately 22.8% for design 2; the variation of I_{YY} and I_{ZZ} was not monitored.

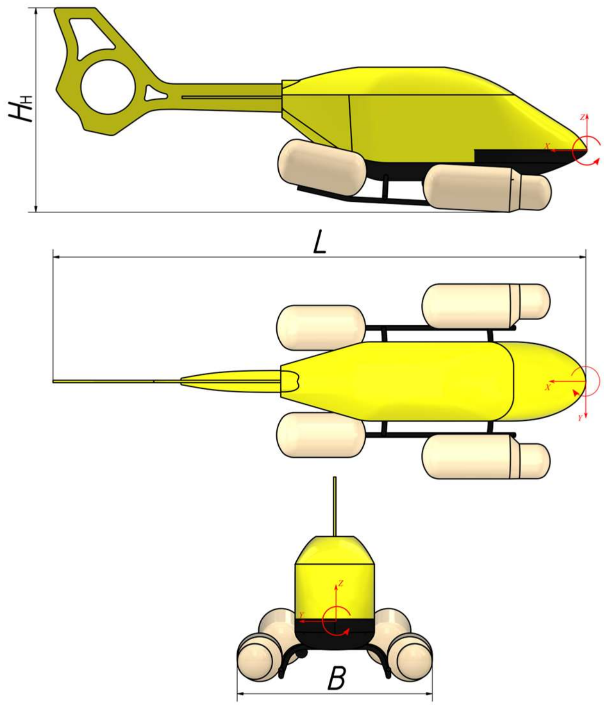

Figure 1: Schematic presentation of the helicopter equipped with state-of-the-art floats (design 1) showing the model-fixed coordinate system at its origin

Table 1: Normalized particulars of the helicopter equipped with state-of-the-art floats (design 1)

L/B	2.794
L/H_H	2.480
D_{max}/H_H	0.163
X_{CoG}/L	0.326
Y_{CoG}/B	0.020
Z_{CoG}/H_H	0.130
$I_{XX}/(mBH_H)$	0.048
$I_{YY}/(mLH_H)$	0.063
$I_{ZZ}/(mLB)$	0.086

Compared to design 1, the total float volume for design 3 increased by 115.8%. The diameter and length of the front floats increased by 40 and 44.4% respectively, while the size of the rear floats remained the same as in design 1. While the total mass and position of CoG were similar to those of design 1, the moment of inertia I_{XX} increased by 46.2%.

Figure 2 shows top, side and front views of a helicopter equipped with floats of designs 1, 2 and 3. Table 2 lists the percentage differences in helicopter mass, CoG position, longitudinal moment of inertia and float volume between the state-of-the-art float design 1 helicopter and those equipped with larger floats (designs 2 and 3).

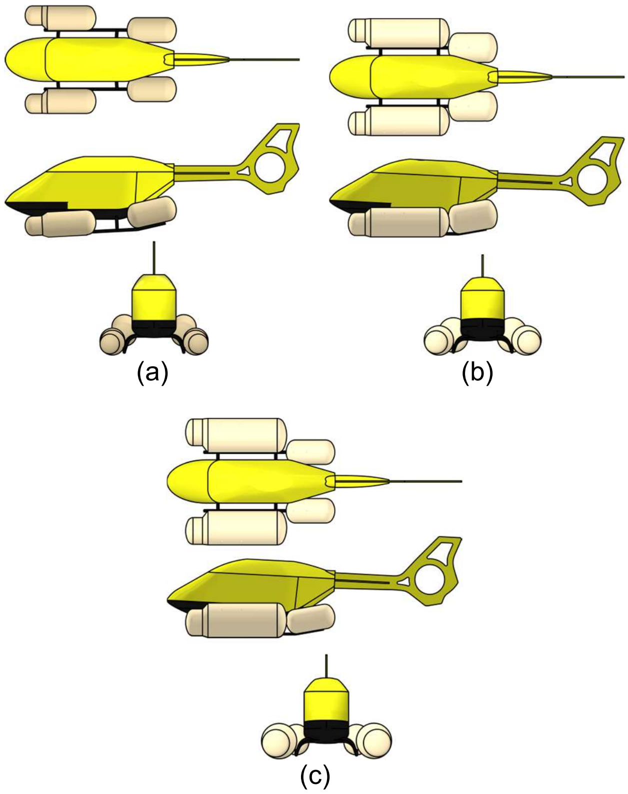

Figure 2: Top, side, and front views of the helicopter equipped with float designs 1 (a), 2 (b) and 3 (c)

Table 2: Percentage differences of helicopter mass, position of CoG, longitudinal moment of inertia, and float volume those between float design 1 and designs 2 and 3.

	Design 2	**Design 3**
Mass m	2.8%	-0.3%
CoG X	1.4%	0.5%
CoG Y	-19.6%	7.8%
CoG Z	-2.2%	1.7%
Inertia I_{XX}	22.8%	46.2%
Float volume V	88.1%	115.8%

Figure 3 shows the floating position of the helicopter equipped with the three float designs. The trim angle was 8.5 deg for design 1, 7.6 deg for design 2 and 9.3 deg for design 3. The heel was 1.8, 2.4 and

1.9 deg for designs 1, 2 and 3, respectively. The normalised maximum draught D_{max}/H_H was reduced to 0.136 and 0.114 for designs 2 and 3, respectively. In this context, the helicopter height H_H always refers to design 1.

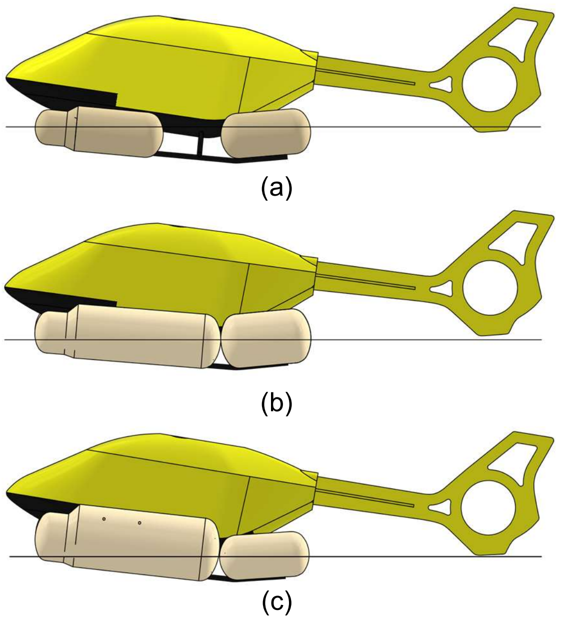

Figure 3: Floating position of the helicopter equipped with floats of designs 1 (a), 2 (b) and 3 (c)

The helicopter was equipped with a small inertia measurement unit (IMU), type Lord 3DM-GX5-25, which monitored translational accelerations in *X*-, *Y*-, and *Z*-direction, as well as roll, pitch, and yaw angles, at a sampling rate of 100 Hz. The recorded data was transmitted wirelessly to prevent model motions from being influenced by cables. For float design 1, the distances between the helicopter's CoG and the IMU's measurement point were 0.062L, -0.020B, and 0.100H_H, respectively.

2.2. Wave basin

The tests were conducted in the deep-water towing tank at the Technical University of Berlin. The basin had a length of 250 m, a width of 8.1 m, and a water depth of 4.3 m. Consequently, all tests were performed under deep-water condition. One end of the basin was equipped with a flap-type wave generator actively damping reflected waves. At the far end of the basin, beaches were placed to reduce wave reflections. Further information on the wave basin and wave measurements can be found in Tödter et al. (Ref. 15).

2.3. Wave modelling

The seaway was modelled as a long-crested JONSWAP spectrum with a significant wave height H_S = 6 m, a zero-crossing wave period T_Z = 7.9 s corresponding to a peak period T_P = 10.2 s, and an overshoot factor γ = 3.3 as expressed by Eq. 1 to 4, where ω is the circular frequency between 0.31 and 2.09 rad/s corresponding to a period of 20 and 3 s, respectively, and ω_P is the circular frequency at the spectrum's peak. This condition, representing the North-Atlantic climate, has been identified as the most severe condition for helicopter operations (Ref. 9). Using a JONSWAP spectrum having the mentioned parameters is prescribed by EASA's certification specification CS-27 (Ref. 9):

$$(1)\quad S(\omega) = \frac{5}{16}\omega_P^4 H_S^2 \omega^{-5} \cdot \exp\left(-\frac{5}{4}\left(\frac{\omega_P}{\omega}\right)^4\right)\gamma^r \cdot \alpha_\gamma$$

$$(2)\quad r = \exp\left(-0.5\left(\frac{\omega-\omega_P}{\sigma\omega_P}\right)^2\right)$$

$$(3)\quad \sigma = \begin{cases}0.07 \text{ for } \omega \le \omega_P \\ 0.09 \text{ for } \omega > \omega_P\end{cases}$$

$$(4)\quad \alpha_\gamma = (1 - 0.287 \cdot \ln(\gamma))$$

Analog wave gauges were placed in front of the test section to record water surface elevations. Figure 4 compares the experimentally measured and computed sea spectra obtained over a 541 min long test duration combining multiple experiments.

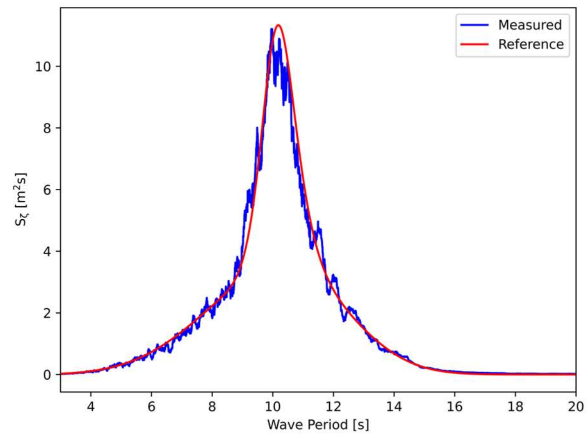

Figure 4: Comparison of measured and computed sea spectra

3. Test methodology

Assessing the capsize probability was required to quantify the helicopter's dynamic floating stability. This was done according to EASA's specification CS-27 (Ref. 9), defining the method to assess a small helicopter's dynamic flotation stability. The capsize probability $P_{capsize}$ was calculated from the number of capsizing events $N_{capsize}$, the test duration T_{test}, and the test criterion $T_{criterion}$ = 5 minutes, which considers the assumed time to evacuate a helicopter after ditching. The required test duration $T_{test,req}$ resulted from the maximum allowed capsize probability $P_{capsize,max}$ = 3% and the associated confidence interval C = 95%:

(5) $$P_{\text{capsize}} = \frac{N_{\text{capsize}} \cdot T_{\text{criterion}}}{T_{\text{test}}}$$

(6) $$T_{\text{Test,req}} = -\frac{T_{\text{criterion}} \cdot \ln(1-C)}{P_{\text{capsize,max}}}$$

The resulting test duration was 499 min. For the present study, the test duration run time was subdivided into multiple shorter test runs of varying randomly selected phase angles for wave generation. At the beginning of each test run, the helicopter was manually aligned at a yaw angle of 0 deg, which corresponded to head wave conditions.

To compare the motions of the helicopter equipped with the three different float designs, short-term statistics were generated considering the exceedance rate r_{ex}. The exceedance rate of amplitude a was determined using the number of larger amplitudes $n_{>a}$ and the test duration T_{test} as shown in Eq. 7:

(7) $$r_{ex}(a) = n_{>a} \cdot T_{\text{test}}^{-1}$$

4. RESULTS

4.1. Floating behaviour

Figure 5 shows the comparative time histories of the roll, pitch and yaw angles of a helicopter floating in irregular waves. Equipped with float design 1, the helicopter started to float at a yaw angle of around 0 deg, corresponding to head wave conditions. Consequently, the helicopter began to pitch in approaching waves. As time progressed, the helicopter yawed about a 90 deg angle. From then on, the helicopter floated in beam waves, which reduced its pitching motions but increased its rolling motions. These time histories illustrate the typical dynamic behaviour of the helicopter after ditching, demonstrating that roll motions are the most important factor in evaluating the helicopter's floating stability.

Figure 6 plots the comparative roll amplitude exceedance rates for the helicopter equipped with float designs 1, 2 and 3 obtained over an average test duration of 379.6 minutes.

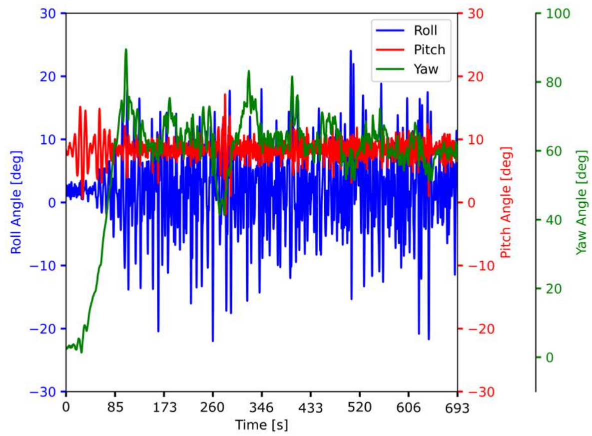

Figure 5: Time histories of roll, pitch and yaw motions for the helicopter equipped with float design 1

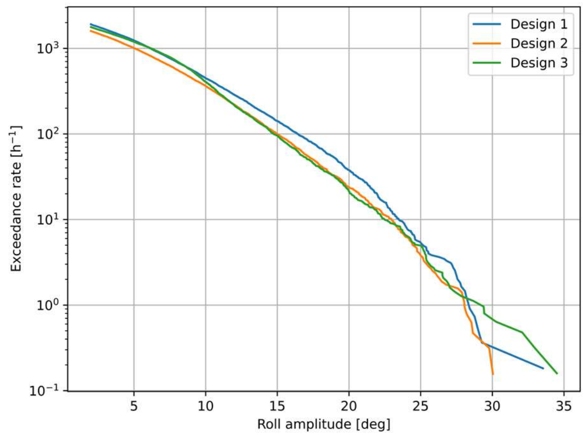

Figure 6: Comparative roll amplitude exceedance rates for the helicopter equipped with float designs 1, 2 and 3

To assess the maximum roll amplitude most likely to be achieved within the assumed evacuation period of five minutes ($T_{criterion}$), the roll amplitude at an exceedance rate of 12 h^{-1} = 5 min^{-1} was evaluated. The roll amplitudes listed in Table 3 were 23.04, 22.31 and 22.01 deg for a helicopter equipped with float designs 1, 2 and 3, respectively. The exceedance probability of the obtained roll amplitudes at an exceedance rate of 12 h^{-1} was between 0.62 and 0.75% (see Table 4).

Therefore, roll angles greater than those at a 12 h^{-1} exceedance rate were unlikely to occur, and these angles were suitable for designing the helicopter's flotation system to provide dynamic floating stability. However, the maximum measured roll amplitudes of 33.55, 30.04 and 34.50 for designs 1, 2 and 3, respectively, were significantly higher than the roll amplitudes at a 12 h^{-1} exceedance rate. Compared to median roll amplitudes of 6.37, 6.28 and 6.87 deg, this indicates that large roll amplitudes, and consequently capsizing, are rare events that must be considered separately.

Table 3: Median and maximum roll amplitudes, and roll amplitudes at an exceedance rate of 12 h^{-1} for the helicopter equipped with float designs 1, 2 and 3

	Design 1	Design 2	Design 3
Median	6.37 deg	6.28 deg	6.87 deg
At 12 h^{-1}	23.04 deg	22.31 deg	22.01 deg
Maximum	33.54 deg	30.04 deg	34.50 deg

Table 4: Roll angle exceedance probabilities at an exceedance rate of 12 h^{-1}

Design 1	Design 2	Design 3
0.62%	0.75%	0.68%

For pitch motions, the median amplitudes were between 6.58 and 8.00 deg and amplitudes at an exceedance rate of 12 h^{-1} were similar at 12.60, 14.03 and 15.77 deg for designs 1, 2, and 3, respectively. Exceedance probabilities at an exceedance rate of 12 h^{-1} were between 0.38 and 0.41 deg. The S-shaped curve pictured in Figure 7 is typical for the exceedance rate of pitch motions resulting from yawing from 0 to 90 deg during one experiment. At 0 deg yaw angle, pitch amplitudes were large while they were for small at a beam wave condition. Table 5 lists pitch motion characteristics. The greatest difference between the three designs occurred at the maximum pitch angle. For design 3, it was 8.83 deg higher than for design 2, which resulted from slower yawing of the helicopter.

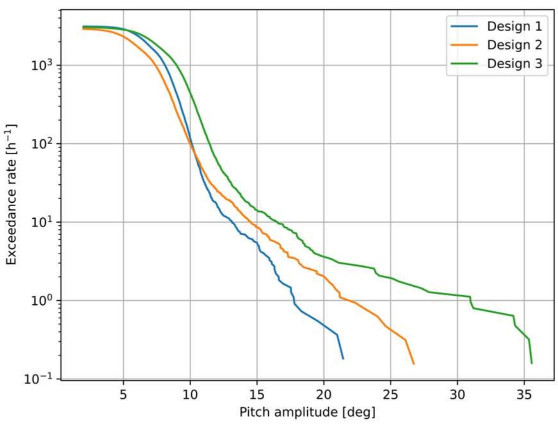

Figure 7: Comparative pitch amplitude exceedance rates for the helicopter equipped with float designs 1, 2 and 3

Table 5: Median and maximum pitch amplitudes, and pitch amplitudes at an exceedance rate of 12 h^{-1} for the helicopter equipped with float designs 1, 2 and 3

	Design 1	Design 2	Design 3
Median	7.28 deg	6.58 deg	8.00 deg
At 12 h^{-1}	12.60 deg	14.03 deg	15.77 deg
Maximum	21.44 deg	26.73 deg	35.56 deg

For heave motions, median amplitudes were between 1.58 and 1.63 m, maximum amplitudes were between 5.92 and 6.03 m, and heave amplitudes at an exceedance rate of 12 h^{-1} were between 4.53 and 4.81 m. Corresponding exceedance probabilities were between 1.25 and 1.58%. Consequently, the float size had no significant influence on the helicopter heave motion. Table 6 lists heave motion characteristics.

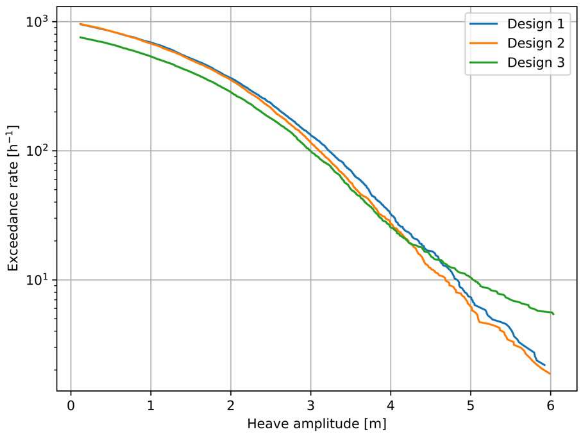

Figure 8: Comparative heave amplitude exceedance rates for the helicopter equipped with float designs 1, 2 and 3

Table 6: Median and maximum heave amplitudes, and heave amplitudes at an exceedance rate of 12 h^{-1} for the helicopter equipped with float designs 1, 2 and 3

	Design 1	Design 2	Design 3
Median	1.63 m	1.58 m	1.61 m
At 12 h^{-1}	4.75 m	4.53 m	4.81 m
Maximum	5.92 m	5.99 m	6.03 m

4.2. Capsizing

From observation of the experimental results, two conditions had to be met for capsizing to occur. The first condition required that the helicopter must remain floating in beam waves (Ref. 10 and 15). Figure 9 shows the evolution of pre-capsize yaw angles for thirteen capsize events. The helicopter always floated in approaching beam seas with an encounter angle between 70 and 120 deg. Note that the helicopter needed some time before reaching a yaw angle of about 90 deg. This time decreased at larger initial yaw angles or when the helicopter initially yawed. For the analysed thirteen capsize cases, the time for the helicopter to reach a yaw angle magnitude of more than 70 deg ranged from 0.7 to 3.6 min. In one case the helicopter took 8.0 minutes to turn about 70 deg.

Assuming that five minutes are required to evacuate the helicopter after ditching, this showed the importance of the helicopter's heading during ditching. If the helicopter's initial wave encounter angle was close to 0 deg and the yaw rate was small enough, it retained its heading for a longer evacuating time, thereby decreasing the risk of capsizing. However, this situation was only valid for ditching in long-crested seas. Short-crested seas might have reduced the turning time due to larger initial encounter angles, even for the helicopter ditching in head waves.

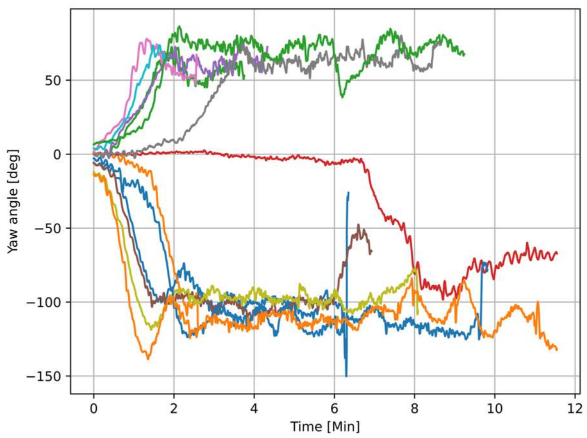

Figure 9: Time histories of yaw angle for thirteen capsize events for the helicopter equipped float design 1

The second mandatory condition to be met was that of a breaking wave hitting the helicopter. Therefore, the total stability failure was then triggered by the external force on the helicopter due to the wave impact. Figure 10 shows the evolution of water surface's vertical velocity $v_{\zeta H}$, indicating the wave steepness for different capsize events at $t = 0$ s. As seen, the water surface elevation changed quickly, indicating that waves became steep and generated breaking waves that hit the helicopter and initiated the capsize event. These breaking waves occurred when the water surface's vertical velocity exceeded 1 m/s. In the figure there is a time shift between the onset of high wave steepness and the moment of capsizing. This was caused by the changing distance between helicopter model's motion and the wave probes.

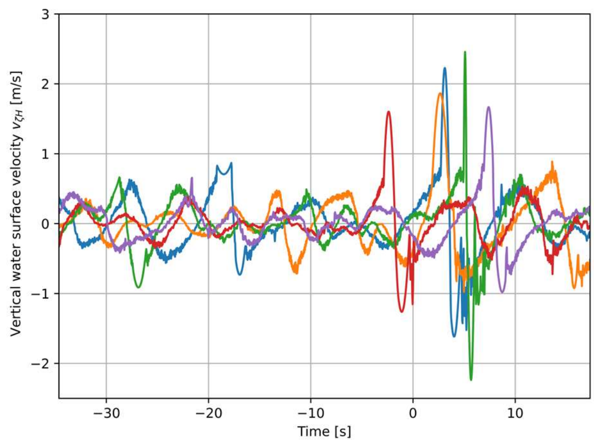

Figure 10: Time histories of the water surface's vertical velocity $v_{\zeta H}$

As a result of a breaking wave hitting the helicopter floating in beam seas, capsizing occurred about its *X*-axis. Figure 11 shows the evolution of the roll angle for the helicopter equipped with float design 1. We defined capsizing when the helicopter exceeded a roll angle of 70 deg. However, the helicopter did not return to the upright position when exceeding roll angles of 35 deg. Most of the time, the roll angle was less than 28.4 deg.

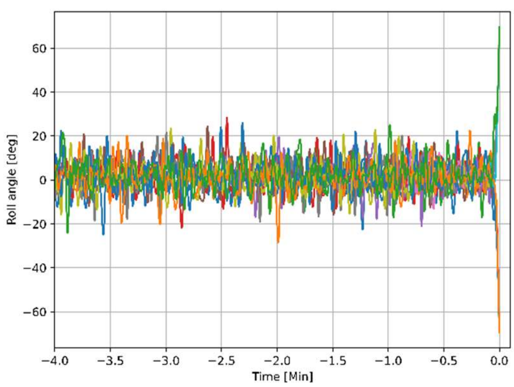

Figure 11: Time histories of the roll angle obtained before thirteen capsize events of the helicopter equipped with float design 1, where $t = 0$ s designates the moment of capsizing

When a breaking wave hit the helicopter, the roll angle increased rapidly, and the helicopter was most likely to capsize. Depending on the float size, the helicopter showed a minor change of resistance to capsizing. When equipped with state-of-the-art floats (design 1), the capsize probability evaluated according to Eq. 5 turned out to be 11.6%. When equipped with float design 2, which total volume was increased by 88.1% compared to the original volume, the capsize probability was slightly reduced to 9.7%. For design 3, the volume was increased by 115.8% yielding a reduced capsize probability of 7.0%. Consequently, increasing the size of cylindrical floats slightly decreased the capsize probability. However, the weight of huge floats make them impractical for helicopter operations. Thus, it is unlikely to obtain a capsize probability of below 3%, which is specified as the maximum allowed capsize probability by EASA, by using cylindrical floats. Table 5 summarizes the evaluated capsize probabilities.

Table 7: Capsize probabilities of the helicopter equipped with the float designs 1, 2 and 3

	Design 1	Design 2	Design 3
Capsize probability	11.6%	9.7%	7.0%

5. Summary

The present study analysed the dynamic floating behaviour and the associated capsize probability of a helicopter after ditching in a seaway having a significant wave height of 6 m. The floating helicopter always tended to yaw about the 90 deg wave encounter angle, i.e., when floating in beam waves, and this demonstrated that roll motions were dominant from a safety point of view. Here, roll amplitudes up to 34.5 deg were evaluated.

The helicopter capsized only when it was hit by a breaking wave while floating in beam waves. Therefore, total stability failure was triggered by external forces acting on the helicopter due to wave impact. The cylindrical floats of different sizes demonstrated that they did not provide a high level of safety against capsizing induced by wave impact. Increasing the float volume slightly decreased the probability of capsizing, but it did not reach the maximum capsize probability specified by EASA.

Author contacts:

Simon Tödter: simon.toedter@uni-due.de

Andreas Peters: andreas.peters@uni-due.de

Jens Neugebauer: jens.neugebauer@uni-due.de

Stefan Harms: stefan.harms@airbus.com

Ould el Moctar: ould.el-moctar@uni-due.de

6. ACKNOWLEDGMENTS

This study was part of the research project EvoS-BraWa, funded by the Bavarian Ministry of Economic Affairs and the Regional Development and Energy (StMWi) of the Bavarian Aviation Research Program (BayLu25), under grant ROB-2-3410.20-04-10-36 / BLU-2109-0036.

7. REFERENCES

1. Clifford, W. S., “Helicopter crashworthiness. Study I. A review of UK military and world civil helicopter water impacts over the period 1971-1992,” CAA Paper 96005. London: Civil Aviation Authority, 1996.
2. Downie, M., Gosling, D., “Offshore helicopter travel: is the UK oil and gas industry failing offshore workers?,” New solutions: a journal of environmental and occupational health policy 29(4), pp. 504-518, 2020.
3. Civil Aviation Authority, “Safety Review of Public Sector Transport Helicopter in Support of the exploitation of oil and gas,” CAP 1145, 2014.
4. Aziz, A., Amir, M.A.U., Roshamida, A.J., Samsudheen, I., Sariff, E.S.M., Rahman, A., Rosly, A., “Helicopter ditching incident analysis: Classification of risk factors,” Journal of Engineering Science and Technology 18(1), pp.113-122, 2023.
5. Federal Aviation Administration, “Rotorcraft ditchings and water-related impacts that occurred from 1982 to 1989 – Phase II,” DOT/FAA//CT-92/14, 1993.
6. Brooks, C.J., MacDonald, C.V., Donati, L., Taber, M.J., “Civilian Helicopter Accidents into Water: Analysis of 46 Cases, 1979-2006,” Aviation, Space, and Environmental Medicine 79(10), pp. 935-940, 2008.
7. Taber, M. J., and McCabe, J., “An examination of survival rates based on external flotation devices: A helicopter ditching review from 1971 to 2005,” *SAFE Journal*, Vol. 35, (1), pp. 1-6, 2007.

8. Reader, D. C., “Helicopter Ditchings - British Military Experience 1972-1988,” RAF IAM Report No 677, 1990.
9. European Union Aviation Safety Agency, “Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft,” Certification specification CS-27, Amendment 9, Technical Report, 2020.
10. Kidwell, J. C., and Crago, W. A., “Model testing to establish ditching and flotation stability characteristics of a helicopter,” Proceedings of the 26th Annual National Forum of the American Helicopter Society, Washington D.C., U.S.A., 1970.
11. Wilson, F.T., Tucker, R.C.S., “Ditching and Flotation Characteristics of the EH101 helicopter,” Proceedings of the 13th European Rotorcraft Forum, Arles, France, 1987.
12. Delorme, L., Denante, M., Santucci, P., De Gelas, A., “New floatation devices to avoid helicopters’ total inversion after capsize,” Proceedings of the 10th International Conference on Stability of Ships and Ocean Vehicles, St. Petersburg, Russia, 2009.
13. Kraskowski, M., “Numerical and experimental analysis of the helicopters’ flotation system,” Proceedings of the 45th European Rotorcraft Forum, Warsaw, Poland, 2019.
14. Katsuno, E.T., Peters, A., el Moctar, O., "Numerical Seakeeping Analysis for a Floating Helicopter after Ditching in Waters," Journal of Offshore Mechanics and Arctic Engineering 147(1), pp. 011401, 2025.
15. Tödter, S., Neugebauer, J., el Moctar, O., Harms, S., Schellin, T. E., “Experimental Investigation of the Flotation Stability of a Helicopter After Ditching,” Proceedings of the 50th European Rotorcraft Forum, Marseille, France, 2024.