THE EVALUATION OF LIFEBOAT FORWARD VELOCITY CAPABILITY SUBJECT TO EXTREME CONDITIONS AT THE OFFSHORE INSTALLATIONS

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ABSTRACT

For the offshore installations, dropping lifeboats are employed as a last reserve evacuation method. Lifeboats normally rest on the skid, which is mounted on the mother vessel, until the hook holding the lifeboat rests. It is important that lifeboat diving is a safe method of evacuation. This study describes the capability assessment with respect to the forward speed of the lifeboats under extreme storm conditions. Hence, the aim of the analysis is to determine the limiting storm conditions where the lifeboats are still able to maneuverer away from the offshore installation. The findings of this work are in accordance with the simplified methods, where the North Sea is considered as the suitability of lifeboats under extreme storm conditions. The findings show that the lifeboats cannot propagate forward in storm conditions where the significant wave height is larger than 11 m. In addition, the net forward force for sea states with wave heights of 10 m and 11 m is rather small and hence the lifeboats may not be able to propagate forward with sufficient velocity.

Keywords: Lifeboat, offshore installation, wind force, storm condition, North Sea

1. Introduction

In extreme weather conditions, the evacuation of workers from offshore installations is usually assured by free-fall lifeboats. Using numerical simulations, their efficiency can be evaluated to predict acceleration loads on passengers, structural loads on the lifeboat hull, as well as forward velocity after water-out. Such parameters are highly dependent on the lifeboat's water-entry conditions, which in turn are very sensitive to the earlier launch phases that begin on the skid. Lifeboats are mostly mounted on bow skids on floating production, storage and offloading (FPSO) vessels in the Norwegian Sea, so that waves can cause large skid motions with typical extreme vertical amplitude of fifteen to twenty meters in a 100-year storm situation [1]. In addition, wave-induced movements can also trigger trim and skid listing, which activate more complex six-degree free-fall trajectories. In these situations, a proper modeling of the lifeboat trajectory on the moving skid is required in order to test the efficiency of the lifeboat with numerical simulations.

Prini et al. (2016) [2] provided a comparison of the results of numerical and experimental seakeeping movement experiments conducted on the Royal National Lifeboat Institution's (RNLI) Severn Class lifeboat. Previously, a numerical model was developed to predict the movements and loads that the vessel is likely to experience throughout its life of operation. Model-scale seakeeping tests were performed at the towing tank of Newcastle University to validate the numerical model. Two models were tested, one of which was designed and built to be segmented and held together by a strain-gauged backbone beam. Results are described in terms of Response Amplitude Operators (RAOs) and measured from hydrodynamic simulations against the motions. The results provide assurance that the numerical model forecasts the craft behaviour accurately at low speed.

Svendsen (2017) [3] investigated lifeboat diving using computational fluid dynamics (CFD), where the selected solver has been Star-CCM+. A sensitivity analysis and convergence study were conducted for the incompressible simulation, with focus on how the time step, number iteration and mesh discretization influenced the simulation.

Groth (2017) [4] used a simplified free-falling lifeboat geometry to investigate the physical phenomena connected with this evacuation method. The hydrodynamic results were obtained with a computational fluid dynamics (CFD) program, and the structural results from a finite element method (FEM) program, Abaqus. There has been conducted a sensitivity and convergence study of the CFD simulations, and a convergence check for the FEM model. Results from the initial conditions shows that the lifeboat experiences the same physical phenomena as a real lifeboat. For the parameter investigation, it was shown that the change in water entry velocity gave the largest difference on most of the results, with respect to the initial conditions. This included a variation of the air cavity closure time and peak magnitude, and water exit time.

Myrseth and Tronstad (2016) [5] presented the experience and lessons learned from lifeboat testing and analysis. Methods for analysis of FFLB output under different weather conditions have been identified. Established information and solutions can boost the protection and functionality of FFLBs which are used in harsh weather.

Fouques et al. (2013) [6] studied the strength and direction of the wind with respect to the lifeboats. The study focused primarily on the acceleration loads faced by the passengers during water-entry and was based on numerical simulations and model tests for simulation software and models validation.

Sauder et al. (2014) [7] provided a model explaining the launch of free-fall lifeboats under heavy environmental wind from offshore structures. Six-degree-of-freedom numerical simulations of the start of the lifeboat are carried out using the free-fall VARUNA lifeboat simulator with a full set of wind coefficients for the lifeboat. These wind coefficients are obtained by CFD simulations validated against wind tunnel tests. Simulations of the lifeboat launch are then tested against time-domain CFD simulations of the entire launch in air before the entry of water. Via numerical simulations it has been shown that wind-induced loads on the lifeboat have a strong effect on their kinematics before water entry, and consequently on the acceleration loads felt by the passengers, on the structural loads on the lifeboat, and on the forward speed after water departure. It was concluded that the impact of wind-induced loads on the efficiency of lifeboats should be studied in general when setting the operating limits for a given offshore installation.

Tregde and Nestegård (2014) [8] suggested a description and method for defining abnormal motions for A Free Fall Lifeboat (FFLB), and this description was used in the regression analysis as an indicator for motion. Using the proposed motion indicator, the regression analysis provided a percentage of acceptable versus non-acceptable motion paths for an intact or damaged host in a storm condition. The worst conditions have been identified and can be used for further analysis of the progress such as the ability of the FFLB to escape from the host after resurfacing.

Ji et al. (2015) [9] addressed the assessment of structural integrity of lifeboats launched from floating production, storage and offloading (FPSO) vessels. The research was based on long-term drop simulations of lifeboats, accounting for more than 50 years of metocean conditions hindcast data and corresponding FPSO motions. ABAQUS also modelled the finite element model (FEM) of the lifeboat's composite structure. Analysis of the quasi-static finite element (FE) is carried out for the selected cases of load. The cumulative stress and Tsai-Wu failure test were used to determine structural integrity. Furthermore, dynamic analysis is conducted with the time-varying pressure distribution for selected case and dynamic effect was examined.

Luxcey et al. (2014) [10] studied the impact of the wave-induced skid movement on the launch of floating host free-fall lifeboats. The paper defined the numerical skid model with six degrees of freedom that was used in the VARUNA lifeboat launch simulator. They then introduced two software research campaigns that aimed to verify the concept of numerical skid. The results of the test model were compared with those obtained from the numerical simulations. Finally, it addresses the effect of skid motion on the course of the lifeboat.

Mak et al. (2005) [11] focused on TEMPSC (Totally Enclosed Motor Propelled Survival Craft) performance in broken ice on the east coast of Canada, where various variables were discussed to assess TEMPSC performance in ice, including ice concentration, ice thickness, ice strength, ice floe size etc. The craft's speed and navigability is predicted to deteriorate with ice conditions worsening. Hence, investigating how the efficiency of lifeboats can be restricted by different ice conditions was important. If lifeboat performance was insufficient for the anticipated operating environmental conditions, consideration should be given to supplementing them with other means of evacuation.

Present study addresses the capability assessment with respect to the forward speed of the lifeboats under storm conditions. The findings of this study are based on simplified methods. The objective of this study is to determine the limiting storm conditions for which the lifeboats are still able to maneuver away from the offshore installation based on simplified methods. The results show that the lifeboats cannot propagate forward in storm conditions where the significant wave height is larger than 11 m. In addition, the net forward force for sea states with wave heights of 10 m and 11 m is rather small and thus the lifeboats may not be able to propagate forward with sufficient velocity.

2. Lifeboat Particulars and Basis for the Analysis

Free-falling lifeboats are a method of escaping hazardous events in open sea. They rest at a skid until released and launched into the water. The lifeboats MCF 28” have an overall length of 9.56 m and are equipped with a 90 HP engine capable of producing 6150 N of thrust.

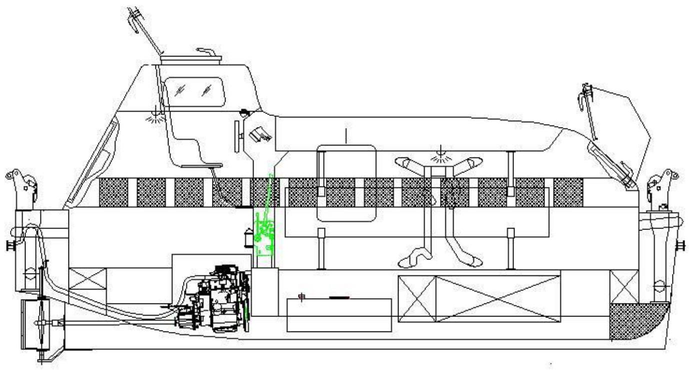

Figure 1. Lifeboat MCF 28”

The evaluation is conducted based on the following geometry and hydrostatic properties that are summarized in the Table 1 below.

Table 1. The geometry and hydrostatic properties

Property	**Value**
Draft, T	1.05 m
Length of the waterline, L_{WL}	8.25 m
Breadth, B	3.80 m
Block coefficient at midships, C_b	0.78
Displacement, Δ	16.89 m^3
Superstructure height above mean water line	1.95 m
Superstructure breadth	2.98 m

3. Assessment Methodology

In order for the lifeboat to propagate forward in storm conditions, the forward force exerted by the lifeboat propulsion system must be greater than the environmental forces opposing to the motion. These forces are defined as follows:

F_T = thrust force from lifeboat engine

F_{wind} = wind forces on the lifeboat superstructure

F_{wave} = wave forces on the submerged hull area

$F_{current}$ = current forces on the submerged hull area

For severe sea states typical of storm conditions the characteristic wavelength are much larger than the dimensions of the lifeboat. This implies that the lifeboat will more or less follow the waves and thus the motion of the lifeboat relative to the wave surface can be ignored. This also means that the submerged surface area of the lifeboat can be accounted as constant.

The lifeboat will be able to propagate against a given sea state (characterized by significant wave height H_s and peak period T_p) when:

$F_T > F_{wind} + F_{current} + F_{wave}$

If the sum of the environmental forces is greater than the engine thrust, the lifeboat will not be able to sail against the storm.

4. Relationship between Mean Wind Speed and Significant Wave Height

The sea states used in the assessment are assumed to be wind generated and co-linear in head seas (wind, current and waves in the same direction). The Beaufort wind speed is presented in Table 2 that can be used to obtain a relationship between the mean wind speed U_{10} (measured at a 10 m height above sea level) and the wave height H_s.

Table 2. Beaufort wind speed and wave height [1]

Beaufort number	Wind speed				Mean wind speed (kt / km/h / mph)	Description	Wave height	
	kt	km/h	mph	m/s			m	ft
0	0	0	0	0-0.2	0 / 0 / 0	Calm	0	0
1	1-3	1-6	1-3	0.3-1.5	2 / 4 / 2	Light air	0.1	0.33
2	4-6	7-11	4-7	1.6-3.3	5 / 9 / 6	Light breeze	0.2	0.66
3	7-10	12-19	8-12	3.4-5.4	9 / 17 / 11	Gentle breeze	0.6	2
4	11-15	20-29	13-18	5.5-7.9	13 / 24 / 15	Moderate breeze	1	3.3
5	16-21	30-39	19-24	8.0-10.7	19 / 35 / 22	Fresh breeze	2	6.6
6	22-27	40-50	25-31	10.8-13.8	24 / 44 / 27	Strong breeze	3	9.9
7	28-33	51-62	32-38	13.9-17.1	30 / 56 / 35	Near gale	4	13.1
8	34-40	63-75	39-46	17.2-20.7	37 / 68 / 42	Gale	5.5	18
9	41-47	76-87	47-54	20.8-24.4	44 / 81 / 50	Severe gale	7	23
10	48-55	88-102	55-63	24.5-28.4	52 / 96 / 60	Storm	9	29.5
11	56-63	103-119	64-73	28.5-32.6	60 / 112 / 70	Violent storm	11.5	37.7
12	64-80	120	74-95	32.7-40.8	73 / 148 / 90	Hurricane	14+	46+

The wind speed reduction from 10 m down to the sea level is assumed to follow a 1/7 power law such that;

$$U(z) = U_{10} \left(\frac{z}{10}\right)^{1/7}$$

Where z is measured in meters.

Table 3. Relationship between mean wind speed and wave height

Wind Speed, U_{10}		**Significant Wave Height, H_s (m)**
(km/h)	(m/s)	
0	0.00	0.0

4	1.12	0.1
9	2.52	0.2
17	4.79	0.6
24	6.77	1.0
35	9.78	2.0
44	12.27	3.0
56	15.98	4.0
68	18.94	5.6
81	22.56	7.0
96	26.78	9.0
112	31.19	11.7
148	41.31	14.0

The values in Table 3 are plotted in Figure 2 in order to obtain an algebraic relation between the wind speed and wave height based on a 2nd order best fit curve.

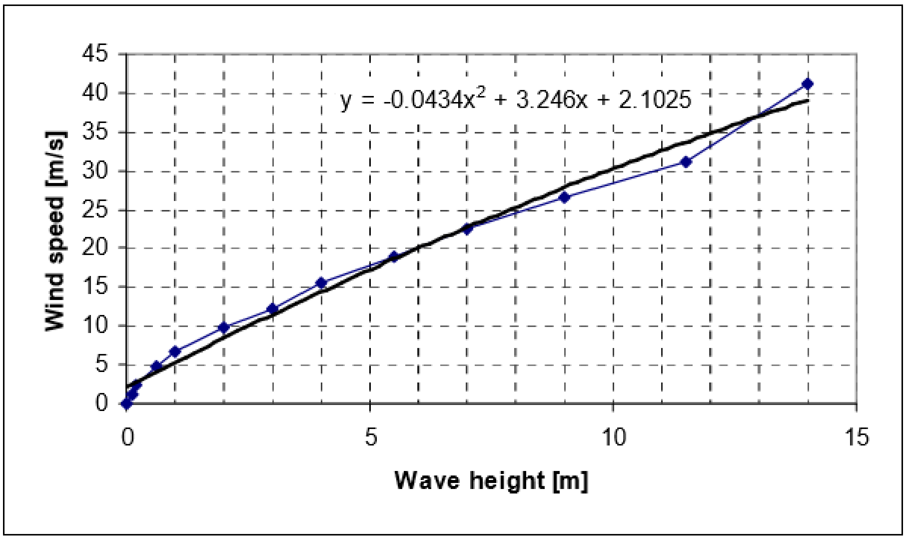

Figure 2. Wind speed vs. significant wave height from the Beaufort relationship. Solid line is the fitted 2nd order curve

The expression for U_{10} given below is used in the analysis to calculate the wind speed for a set of significant wave heights increasing in steps of 1 m.

$$U_{10} = -0.04343H_s^2 + 3.246H_s + 2.1025$$

It is noted that the fitted curve is not accurate for very small wind speeds.

5. Wind Forces on the Lifeboat Superstructure

The wind force on the lifeboat superstructure above of the waterline can be taken as follows,

$$F_{wind} = \frac{1}{2}\rho_a C_{Dw} S_w U_w^2(z_m)$$

$\rho_a = 1.225$ kg/m^3

$C_{Dw} = 0.72$ = drag coefficient for the structure

$S_w = 4.44$ m^2 = projected area of the lifeboat superstructure

$z_m = 1.21$ m = mean height of the superstructure

$U_w(z_m)$ = wind velocity at height z_m

6. Wave and Current Forces on Wetted Hull Surface

The force on the submerged hull of the lifeboat can be taken simply as the hydrodynamic drag due to relative velocity between the lifeboat and the water particles. The Stokes drift velocity can be added to the current velocity (assumed to be in the same direction) so that the total drag force on the submerged hull can calculated as:

$$F_{current} + F_{wave} = \frac{1}{2}\rho_w C_{Ds} S_s (U_c + U_s)^2$$

Where,

$\rho_w = 1025$ kg/m^3 is the density of seawater

$C_{Ds} = 0.02$, friction coefficient for submerged hull

$S_s = 28.9$ m^2, wetted area of the submerged hull

U_c = current velocity (m/s)

U_s = Stokes drift velocity (wave velocity component), (m/s)

The wetted area of the hull can be found by the formula

$$S_s = k\sqrt{\nabla \bullet L_{WL}}$$

$L_{WL} = 7.6$ m, ∇ is the displacement at the given draft in m^3 and k = 2.6.

6.1. Current velocity, U_C

The current velocity close to the sea surface can be taken as the sum of the wind generated current and a background current.

$$U_c = U_{bc} + U_{wc}$$

For this assessment the background current is to $U_{bc} = 0.3$ m/s and the wind generated current can be found as a function of the wind speed as given in DNVGL-RP-C205 [1].

$$U_{wc} = 0.03 \bullet U_{10}$$

6.2. Wave drift velocity, U_s

The resistance due to waves, F_{wave} , can be taken as drag force caused by the so called Stokes drift in waves. For regular waves with wave height H and wave period T, the Stokes drift velocity can be found using the formula given below,

$$U_s = \frac{2\pi^3}{g}\frac{H^2}{T^3}$$

For irregular sea states, the significant wave height H_s can be used as H and zero up-crossing period T_z as T.

6.3. Thrust reduction due to current and waves

The propeller thrust in still water is F_T = 599 kg • 9.81 m/s^2 = 5876 N. However, the efficiency of the propeller is reduced the lifeboat operates in current and waves, thus reducing the actual thrust.
It is assumed that the engine thrust is maximum (5876 N) without current and that it is reduced to 0 N for a current velocity of 10 m/s. Linear interpolation is applied to current velocities between 0 m/s and 10 m/s.

A constant thrust reduction factor due to waves is taken as η = 0.7 for all sea states.

7. Analysis Results

The net force on the lifeboat is found by

$$F_{NET} = F_T - (F_{wind} + F_{current} + F_{wave})$$

F_{NET} has been calculated for a set of sea states with defined significant wave height H_s and peak periods T_P assuming JONSWAP wave spectra.

For each significant wave height the net force is calculated for a low value of $T_{p,min}$ (steepest wave) and a max value $T_{p,max}$ defined by

$$T_{p,\,min} = 3.6\sqrt{H_s} \quad \text{and} \quad T_{p,\,max} = 5.0\sqrt{H_s}$$

The results are given in Table 4 as below:

Table 4. Sum of environmental forces and engine thrust

Wind Speed U_{10} (m/s)	**Wave Height (H_s) (m)**	**Wave Peak Period (min)** (s)	**Sum of forces* (N)**	**Wave Peak Period (max)** (s)	**Sum of forces (N)**
5.5	1.0	3.8	3098	5.0	3211
8.7	2.0	5.7	2812	7.1	3056
11.7	3.0	6.8	2488	8.7	2899
14.8	4.0	7.7	2201	10.2	2688
17.9	5.0	8.6	1899	11.2	2497

20.5	6.0	0.2	1579	12.2	2265
22.9	7.0	9.9	1223	13.2	2033
25.8	8.0	10.6	901	14.1	1787
28.1	9.0	10.9	542	15.0	1540
31.1	10.0	11.7	178	15.8	1281
33.1	11.0	12.3	-189	16.8	1017
35.8	12.0	12.8	-588	17.3	751
37.4	13.0	13.2	-969	18.0	478

**Sum of forces includes: wind forces on exposed boat area, current forces and wave forces on underwater hull area and engine thrust.*

In accordance with these results, the lifeboat cannot propagate forward in storm conditions where the significant wave height is larger than 11 m. It should also be noted that the net force for sea states with wave heights of 10 m and 11 m is rather small and thus the lifeboats may not be able to propagate forward with sufficient velocity.

8. Conclusion

In case of accidental scenarios, evacuation of personnel from the offshore platforms is generally ensured by falling lifeboats launched from the skids. Safe lifeboat launches occur at water entry for a limited range of pitch angles and flat-water impacts can result in hazardous acconal conditions for secure starting of lifeboats.

Present study addresses the capability assessment with respect to the forward speed of the lifeboats under extreme storm conditions, which are based on simplified methods. To perform an assessment of the forward speed capabilities of the lifeboats at the offshore installation, the North Sea is assessed as an extreme storm conditions. This study is to determine the limiting storm conditions for which the lifeboats are still able to maneuver away from the offshore installation. The findings show that the lifeboats cannot propagate forward in storm conditions where the significant wave height is larger than 11 m. In addition, the net forward force for sea states with wave heights of 10 m and 11 m is rather small and thus the lifeboats may not be able to propagate forward with sufficient speed. The results also show how the minimum peak period for a given wind speed results in steeper waves and therefore reducing the maneuvering capabilities of the lifeboat. The use of free-falling lifeboats is critical in ensuring safe evacuation.

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