POLISH MARITIME RESEARCH Special Issue 2018 S1 (97) 2018 Vol. 25; pp. 42-50
10.2478/pomr-2018-0021

SIMULATION OF LIFE RAFT MOTIONS ON IRREGULAR WAVE - AN ANALYSIS OF SITUATIONS LEADING TO RAFT CAPSIZING

Olga Kazimierska
Gdańsk University of Technology, Poland

ABSTRACT

Successful rescue action at sea is based on a. o. a correct choice of rescue means and their reliability. Operational characteristics of life-saving appliances determine their performance in a given water area. Therefore they affect duration time of rescue action and decide this way on survival time of shipwrecked persons. This paper presents impact of characteristics of circular inflatable life rafts on their dynamics in a given sea environment. Particular issues dealing with raft motion were analyzed and their solutions were then presented in the form of computer programs built into MATLAB environment. The programs operate on the open choice basis– the user is requested to introduce data of a raft to be investigated. The program clearly informs which units should be used for the data. The obtained results allow to limit survivours searching area and simultaneously form the basis for working out a model of searched object drift motion. In this work the use was made of the results obtained from the KBN research project No. 4T12C03827 in which an attempt was made to analyzing capsize probability of a raft at given sea states. The raft investigated in the project is also used as a reference raft in the computer programs developed in this work.

Keywords: life rafts, inflatable rafts, circular rafts , drift anchors, simulations of motions on irregular wave, raft dynamics, wave spectrum

INTRODUCTION

Maritime navigation has been always connected with a risk. In spite of scientific and technological developments , tragic accidents at sea which require to undertake search and rescue operations , still happen.

Success of a sea rescue operation depends not only on knowledge of hydro-meteorological conditions , proper choice and effectiveness of rescue means but first of all on used life saving appliances and - most importantly - their reliability.

In spite of a high resistance against loads and environmental factors of contemporary life rafts it happens that they capsize in extreme weather conditions. As a rule such situation ends with loss of all life raft crew. Though life raft construction is continuously under improvement, conducting research on their effectiveness in real conditions leads not only to a high cost but also constitutes a hazard for research team. This work is aimed at development of a software intended for the analyzing of situations which may lead to the capsizing of raft , i.e. investigations on its longitudinal and oscillating motions. The calculations would allow to verify and compare reactions against sea environment action of circular inflatable rafts of various dimensions .

Life rafts used on open water areas rarely float in still water , usually they are exposed to wave and wind action. Though during life rafts design there are taken into account also other environmental factors such as ice and icing, minimum and maximum temperature of air and water , the factors do not have such impact on raft motion as the factor which decides on its dislocation (translation) , namely wind-generated waves [1-4]. In this work attention was focussed on storm waving , called also irregular. For simulation of wave surface profile , Neumann spectrum was used. In the next chapter results obtained from the KBN research project No. 4T12C03827 [5] are referred to in order to be used for the software developed in this work , and subsequent chapters present own results of this author's work.

RESEARCH PROJECT AND REFERENCE LIFE RAFT

Results of this work were reached on the basis of measurements carried out in Ship Design and Research Centre (CTO) , Gdańsk, and Aviation Institute, Warsaw , where three life rafts for 6, 10 and 20 persons, respectively , were tested. The tests were conducted in the frame of the KBN research project No. 4T12C03827 [5].

All the computer programs presented in subsequent chapters operate by making comparisons between selected quantities and results of the above mentioned research project obtained for the 10-person life raft. There were utilized also results of raft resistance measured during towing tests with and without drift anchor in CTO towing tank and results of the tests of aerodynamic forces and moments performed in IL wind tunnel. Below, in Tab. 1 and 2 there are presented the selected results of the referred to research project , which were subsequently implemented in the computer programs.

Tab. 1. Resistance of the raft with and without drift anchor (V_{tr} - wind speed) [5]

Resistance of the raft without drift anchor	
Percentage of crew persons	Regression equation of raft resistance
100%	$Rt_{100\%} = 7,38776-30,4399 \cdot V_{tr} + 258,83 \cdot V_{tr}^2$
50%	$Rt_{50\%} = 3,02773 + 7,71107 \cdot V_{tr} + 237,813 \cdot V_{tr}^2$
10%	$Rt_{10\%} = 6,3795-35,6088 \cdot V_{tr} + 268,987 \cdot V_{tr}^2$
Drift anchor resistance	$Rd = 0,485404-63,3809 \cdot V_{tr} + 385,023 \cdot V_{tr}^2$

Tab. 2. Measurement results for aerodynamic forces and rolling moment (V_w - wind speed) [5]

Aerodynamic forces	
X0	$= 0,266556 + 1,66005 \cdot V_W + 0,795924 \cdot V_W^2$
Y0	$= 0,943574 - 3,21311 \cdot V_W + 0,0154846 \cdot V_W^2$
Z0	$= 7,37481 - 16,047 \cdot V_W + 1,57432 \cdot V_W^2$
Rolling moment	
MX0	$= - 0,893263 - 1,69975 \cdot V_W + 0,191677 \cdot V_W^2$

Tab. 3 shows dimensions of the 10-person life raft used as the reference raft in the worked -out computer programs.

Tab. 3. Dimensions of the 10-person life raft used as the reference raft [5]

Raft mass	m_T	85 kg
Raft total height	H_{TOT}	1,24 m
Raft diameter	D	2,9 m
Raft depth	H	0,58 m
Raft draught	T	0,144 m
Raft displacement	Δ	935 kg
Height of gravity centre over reference plane of the raft	ZG	0,313 m
Height of buoyancy centre	ZF	0,072 m
Block coefficient	C_B	~1,0

The movable raft-fixed coordinate frame OXYZ is so orientated that OX –axis is pointed towards raft motion under action of waves and wind and dragged by drift anchor; OY –axis - towards conventional left side of the raft , and OZ – axis – upwards [5]. The line connecting the drift anchor with the raft is placed in the OXZ plane on the odd side of OX - axis. The coordinate frame origin O is placed in the mid-point of the raft's bottom. The motionless coordinate frame $O_0X_0Y_0Z_0$ is located on the still water level . In the initial instance of raft motion the movable coordinate frame OXYZ coincides with the frame $O_0X_0Y_0Z_0$.

The experiment on raft model motions performed in CTO towing tank as well as respective observations in real conditions show that the raft in waves makes the following motions [1, 2, 5, 6]:

- vertical motion (heaving) following wave profile;
- oscillation motion (pitching) around OY- axis perpendicular to direction of wave propagation , following wave slope angle.

The raft with drift anchor moving in waves is placed in OXZ plane and makes very small yawing motions around OZ- axis.

The above presented observations allowed to make the following assumptions simplifying mathematical model to a time-dependent simulation of raft motion in irregular waves, namely:

- wind pressure force and Froude-Krilov buoyancy forces are the main forces exciting raft motion;
- in view of the very small draught (not exceeding 0,4 m at the raft side under heel), influence of wave pressure distribution on the forces exciting raft motion was not taken into account;
- the raft undergoes motions mainly in OXZ plane;
- wind and waves have the same directions;
- average wind force does not cause any heel of the raft;
- there is no correlation between heaving and pitching around OY- axis;
- the heaving is excited by irregular wave , wind and drift anchor;

- added water mass inertia moment is constant during heaving.

Heeling moments generated by drift anchor , wind pressure and resistance forces incline the raft by the angle θ, assumed positive for "bow" immersion [5]. Within the frames of the research project there was determined the righting moment arm of the 10-person raft , described by 5th order polynomial in respect to the pitching angle θ [°] (Tab. 4.). The curves were determined for the least favourable arrangement variant for different numbers of persons in the raft.

Tab. 4. Righting moment arm [5]

GZn	Righting arm
GZ10	$= -0{,}0160587 + 0{,}0794899 \cdot \theta - 0{,}0032757 \cdot \theta^2 + 0{,}0000625384 \cdot \theta^3 - 6{,}05361E\text{-}7 \cdot \theta^4 + 2{,}29939E\text{-}9 \cdot \theta^5$
GZ5	$= -0{,}637218 + 0{,}101485 \cdot \theta - 0{,}00487179 \cdot \theta^2 + 0{,}000110211 \cdot \theta^3 - 0{,}00000118823 \cdot \theta^4 + 4{,}85768E\text{-}9 \cdot \theta^5$
GZ1	$= -0{,}421806 + 0{,}11902 \cdot \theta - 0{,}00666039 \cdot \theta^2 + 0{,}000162703 \cdot \theta^3 - 0{,}00000183171 \cdot \theta^4 + 7{,}68054E\text{-}9 \cdot \theta^5$

In the computer programs there was taken into account a standard drift anchor recommended for floating units of up to 4,5 m in length (Fig. 1.). Its dimensions and masses are given in Tab. 5 [7]. For analyzing operation of the programs the use was made of LALIZAS firm catalogue which contains technical characteristics of LALIZAS OCEANO circular inflatable rafts produced in accordance with the latest recommendations of SOLAS convention (Tab. 6.)[8].

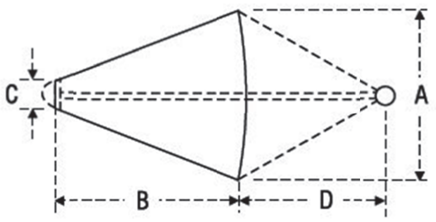

Fig. 1. Schematic diagram of the drift anchor [7]

Tab. 5. Dimensions and mass of the drift anchor used in the computer programs [7]

ØA	0,50 m
B	0,55 m
C	0,08 m
D	0,64 m
Mass:	0,26 kg
Volume:	2552 cm3

Tab. 6. Technical characteristics of LALIZAS circular inflatable rafts (M_T- raft mass, H_{TOT}- raft total height, H_N- raft tent height, D- diameter) [7]

A PACK version (for ships engaged in international shipping)				
Net capacity	6	8	10	12
MT [kg]	68	77	92	101
H_{tot} [m]	1,2	1,4	1,42	1,64
H_N [m]	0,742	0,875	0,88	1,014
H [m]	0,458	0,525	0,54	0,626
D_1 [m]	2,0	2,48	3,106	3,04
D_2 [m]	2,828	2,864	2,692	3,28
D average [m]	2,414	2,672	2,899	3,16
Net capacity	16	20	25	
M_T [kg]	129	150	173	
H_{tot} [m]	1,65	1,663	1,75	
H_N [m]	0,975	1,004	1,034	
H [m]	6,75	0,659	0,716	
D_1 [m]	3,622	3,622	4,25	
D_2 [m]	3,965	3,971	4,48	
D average [m]	3,7935	3,7965	4,365	

SIMULATION OF RAFT MOTIONS ON IRREGULAR WAVE

Wind generated waving may be considered as a superposition of many simple regular wave harmonic components every of which has its own amplitude, length, frequency , period and propagation direction [1-4, 9]. This concept allows to predict irregular phenomena on the basis of regular wave theory. As results, time stationary and uniform in space waving may be represented as a sum of elementary regular harmonic waves. For many practical issues a model of two-dimensional irregular waving based on the assumption that entire waving energy comes from one direction only, is satisfactory. In such case the 2D irregular wave propagating in the direction which coincides with X - axis may be approximated as a sum of of elementary harmonic waves and described in the form of Fourier series (1):

$$\eta(x,t) \approx \sum_{n=1}^{N} A(n) \cdot \cos[k(n) \cdot x - \omega(n) \cdot t + \varepsilon(n)] \tag{1}$$

where:

ε - phase shift of *n-th* harmonic wave [rad]; *A(n)*- amplitude [m]; *k(n)*- wave number [1/m]; *ω(n)*- circular frequency [rad/s].

Distribution of waving energy into particular harmonic components depends on squares of the harmonic amplitudes *A(n)* and may be represented by a function dependent on frequency of *n-th* harmonic wave . Below , the harmonic wave amplitude is presented in the form of a wave spectrum (6):

$$S_\eta\big(\omega(n)\big) \cdot \Delta\omega = \sum_{\omega(n)}^{\omega(n)+\Delta\omega} \frac{1}{2} \cdot A^2(\omega) \tag{2}$$

If there is assumed that the frequency increment $\Delta\omega$ approaches zero the frequency histogram will approach spectrum density function and Eq. (2) will take the form (3):

$$S_\eta(\omega) \cdot d\omega = \frac{1}{2} A^2(\omega) \quad (3)$$

Many of the worked out approximation function for wave energy spectrum usually concern the fully developed storm waving [1, 2, 4]. They assume the wave energy spectrum dependent on : the average wind speed V_W, the significant wave height H_s, and the characteristic wave period T_1. For angular motions calculation and accompanying phenomena there is recommended to use a wave energy spectrum density function obtained on the basis of measurements performed over water areas on which the raft in question will be used. To this work, Neumann spectrum , a direct function of wind speed , was applied (4):

$$S_{\eta N} = 1{,}525 \cdot \pi \cdot \omega^{-6} \cdot e^{-2 \cdot \left(\frac{9{,}807}{V \cdot \omega}\right)^2} \quad (4)$$

where : V stands for a set of wind speed values, and ω - a set of frequency values being random numbers.

In this work for simulating a wave profile two computer programs were prepared: Program No. 1 which contains the probability density functions (4) and constitutes an input function to the crucial program No.2 from which a function describing wave profile (based on the input data from Tab. 7) and its diagram are obtained. The program calculates also all wave heights as well as significant wave height.

Tab. 7. Input data to Program No. 2

Variable	Value	Description
V	25 m	Wind speed assumed constant
ω_0	0°	Initial value of wave frequency
ω_N	2°	Final value of wave frequency
N	50	Total number of frequency bands
t	1 s	Time instance
η_0	0	Iniial value of wave profile function
X	<0;300>; step = 0,1 m	Step in wave profile calculation

CALCULATION OF HORIZONTAL DRIFTING SPEED OF THE RAFT GENERATED BY WAVE AND WIND

Eq. (5) describes horizontal motion of the raft (along *OX* -axis) [1, 2, 5]:

$$m_{CD} \cdot \ddot{x} = -R_{dX} + R_W \quad (5)$$

It contains only the horizontal components: R_{dX} – resistance (drag) forces from drift anchor and immersed part of the raft, and R_W – wind pressure force , because during one wave cycle values of the averaged buoyancy forces components and mass forces resulting from raft sliding along wave slope are equal to zero. Assuming that accelerations in this motion are rather small compared with vertical one in heaving and angular in pitching , we are able to write the equation (6):

$$\frac{1}{2} \cdot \rho_w \cdot \dot{x}^2 \cdot (C_{Ddh} \cdot S_d + C_{DRh}(T) \cdot S_{R1}) = $$

$$= C_{DRa}(V_W) \cdot \frac{1}{2} \cdot \rho_a \cdot V_W^2 \cdot S_{R2}(z_W) \quad (6)$$

where:

ρ_w – water density [kg/m³];

ρ_a – air density [kg/m³];

dx/dt – instantaneous drifting speed, always positive even in case of very low speed of wind and wave;

C_{Ddh} – resistance coefficient of draft anchor against water;

$C_{DRh}(T)$ - resistance coefficient of immersed part of raft against water, depending on period – position on wave;

$C_{DRa}(V_W)$ - resistance coefficient of above-water part of raft against air, depending on wind speed in a given sea state;

S_d – cross-section area of drift anchor [m2];

S_{R1} – cross-section area of immersed part of raft [m2];

$S_{R2}(z_W)$ - cross-section area of above-water part of raft [m2], a function dependent on z_W –wave surface rise either above or below still water level (zero level).

To describe raft motion with the use of wave spectrum there is possible to take into account mass forces acting on the raft.. The equation which describes horizontal motion of the raft (along *OX*-axis) takes then the following form (7):

$$m_{CD} \cdot \ddot{x} = -R_{dX} + R_W + R_x \quad (7)$$

Its additional term R_x expresses just mass forces (8).

$$R_x = m_c \cdot g \cdot \sin(\alpha) \cdot \cos(\alpha) \quad (8)$$

The wave slope $tg(\alpha)$ can be expressed as a derivative of wave profile in respect of the translation x (9):

$$\tan(\alpha) = \frac{d\eta(x,t)}{dx} \quad (9)$$

From the partial derivative of the wave profile function $\eta(x,t)$ it is possible to get wave steepness (10):

$$\frac{d\eta(x,t)}{dx} = \frac{H_x}{\lambda} \cong \frac{H_s}{\bar{\lambda}} = \frac{H_s}{1{,}25^2 \cdot T_1^2} \quad (10)$$

which is the ratio of the wave height H_x in the point x to wave length λ, approximately equal to the ratio of the significant wave height H_s to the respective average wave length , and where T_1 stands for the characteristic wave period. Knowing Eq. (10) one can obtain the formula for α (11):

$$\alpha = arc\tan\left(\frac{H_s}{1{,}25^2 \cdot T_1^2}\right) \quad (11)$$

The remaining forces in Eq. (7) are described by the Eq. (12) and (13):

$$R_{dX} = -\frac{1}{2} \cdot \rho_W \cdot \dot{x}^2 \cdot C_{Ddh} \cdot S_d \quad (12)$$

$$R_W = \frac{1}{2} \cdot \rho_a \cdot (V_W - \dot{x})^2 \cdot C_{DRa}(V_W) \cdot S_{R2}(z_W) \quad (13)$$

It should be added that m_c – stands for mass of raft together with people in it, and the mass m_{CD} (14) is additionally enlarged by the drift anchor mass m_d:

$$m_{CD} = m_c + m_d \quad (14)$$

Program No. 3 calculates resistance forces during towing the raft with or without drift anchor (friction forces generated by water flowing around the raft) for raft crew percentage of 100, 50, 10%, as well as resistance of drift anchor itself , on the basis of a raft diameter set by the program's user. Input data to the program are given in Tab. 9. Based on geometrical similarity a new speed range for the investigated raft is established. In the calculations the regression equations from the CTO tests are used (Tab. 3.) Finally , we obtain diagrams of the forces resulting from the selected speed range V_{TT}.

Tab. 8. Input data to the program No. 3

Variable	value range	Comments
D_{Tod}	(see Tab. 3.)	Data concerns reference raft
V_{tr}	<0,5;1>; step = 0,01 m/s	Raft speed
$RT_{od100\%}$, $R_{Tod50\%}$, $R_{Tod10\%}$	(seeTab. 1.)	Resistance without drift anchor
R_{dTod}	(see Tab. 1.)	Drift anchor resistance

Program No. 4 calculates wind pressure force. It makes use of the relation $X0(V_W)$ which describes aerodynamic force acting on the raft along *OX* –axis direction, the formula comes from the tests in IL laboratory (Tab. 4.). The analysis is made for the raft with the maximum number of persons . It was assumed that the tested raft is placed on wave crest . This simplification was chosen in view of the quantity $S_{R2}(z_W)$ which appears in Eq. (13) describing forces acting onto the raft.

Tab. 9 contains the input data dealing with the reference raft and additional values necessary for the calculations.

Tab. 9. Input data to the program No. 4

Variable	Value range	Comments
m_{Tod}, D_{tod}, H_{Tod}	(see Tab. 3.)	Data concerns reference raft
$X0_{Tod}$	(see Tab. 2.)	Aerodynamic force
ρ_w	1025 kg/m3	Water density
m_{os}	80 kg	Assumed mean mass per person
N	50	Value partition number
V_w	<1; 34>; step = 0,5 m/s	Wind speed

After introducing , by the user , the data which describe a chosen raft the results' matrix $X0_{TT}(V_W)$ is produced and the diagram is formed showing the aerodynamic force in function of wind speed acting onto the reference raft as well as that investigated by the user.

In the program No. 5 there was used the working space of the preceding program (No. 4) - both the input data to it and its results – in order to determine a relation between raft drifting speed and wind speed.

After reading the data out of the file as well as the working space (Tab. 10) and making the respective calculations, the diagram illustrating the relation Vu(VW) was depicted.

Tab. 10. Input data to the program No. 5

Variable	Value range	Comments
D_d ($D_d/2=R_d$)	0,5 m	Drift anchor diameter (radius)
C_{DRh}	1,0	Water resistance coefficient of immersed part of the raft [10]
C_{Ddh}	1,5	Coefficient of drift anchor resistance to water [11]
T_{TT}, D_{TT}, $X0_{TT}$,	(Results of the program No. 4)	Data concerning the tested raft
ρ_w	1025 kg/m^3	Water density
V_W	<1; 34>;step = 0,5 m/s	Wind speed

In the program No. 6 there are verified - for the raft investigated in the program No. 4 - the relations of : relative speed versus time - *u(t)*, dislocation (translation) versus time - *x(t)*, as well as the attractor *u(x)*, by using the significant wave height from the program No. 2 , as well as values derived from the program No. 4. The use is made of a function which describes raft motion (along *OX* – axis) with taking into account mass forces affecting the raft.

The saved data concerning the drift anchor and those required for the subsequent calculations are contained in Tab. 11. After reading the significant wave height H_s obtained from Neumann wave spectrum, the user must put in its characteristic period T_1. Finally, the diagrams of the relations : *u(t), x(t), u(x)* are depicted.

Tab. 11. Input data to the program No. 6

Variable	Value range	Comments
D_d (D_d/2=R_d)	0,5 m	Drift anchor diameter, (radius)
C_{Ddh}	1,5	Drift anchor resistance coefficient [11]
m_d	0,26 kg	Drift anchor mass
$X0_{Tod}$, $X0_{TT}$, S_{R2TT}, M_{cTT}	(see Tab. 3. and results of the program No.4)	Data concerning the tested raft
H_s	(Result of the program No. 2)	Significant wave height
ρ_w	1025 kg/m^3	Water density
ρ_a	1,2 kg/m^3	Air density
V_W	25 m/s	Wind speed
T	<0; 100>; step = 1,0 s	Solving time range
Y=[X0; Y0]	[0;1], [m; m/s]	Vector of initial values

CALCULATION OF RAFT PITCHING MOTION ON IRREGULAR WAVE

The above described environmental forces acting onto the raft generate moments exciting its oscillations around *OY*-axis by the angle θ. Under their action the raft takes such inclination angle at which the inclination moment is in balance with the righting moment [12-15]. The larger the righting moment the greater the raft capability of keeping a given equilibrium position as well as recovering this position if the raft is led off the equilibrium. A quantity used for raft stability determination and assessment is the righting moment arm *GZ*.

To obtain the righting arm *GZ* (Tab. 6.), the relation (15) can be applied :

$$\frac{GZ}{GM} = \sin\theta \qquad (15)$$

where GM stands for the metacentric height.

The program No. 7 calculates the righting arm GZ for a selected raft in three different variants of crew occupancy percentage: 100, 50 i 10% for the least favourable variant of crew arrangement within the raft. At first, the input data to the program are read - Tab. 12. Into the program there are already written three polynomials of the gravity centre height *GZ* for the reference raft : *GZ10, GZ5, GZ1* (Tab. 4.) – corresponding to the above mentioned crew percentage. For the assumed angle range there are formed matrices of resulting *GZn* values for the reference raft. Next, the user puts in the data for a raft to be considered and in a few steps the function which calculates the height GZ_{TT} of the raft in the form of 5th order polynomial, is achieved.

Tab. 12. Input data to the progam No. 7

Variable	Value range	Comments
m_{Tod}, D_{Tod}, H_{Tod}	(see Tab. 3.)	Data concerning the reference raft
GZ100%, GZ50%, GZ10%	(see Tab. 4.)	Righting arm of the reference raft
ρ_w	1025 kg/m^3	Water density
m_{os}	80 kg	Assumed average mass per person
θ	<0;90°>; step = 1°	Pitching angle

All the calculations are carried out for different crew percentage occupancy - 100, 50 and 10%. After completing the calculations, from the achieved results the program forms a diagram.

RESULTS

Below is presented the diagram which shows the wave profile generated by the program No.2 (Fig. 2) for the input data of Tab. 7.

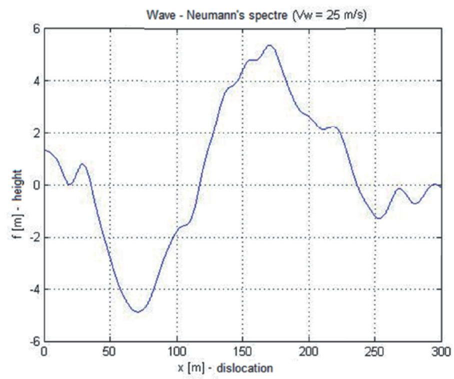

Fig. 2. The wave profile generated by the program No.2

Six values of wave height were achieved from the program (Tab. 13). The user is required to give height indices to calculate its mean value. As the significant height should be the mean calculated from 1/3 of the highest waves , two highest waves were selected to calculate it. As a result , the mean height H_s = 5,4034 m was obtained and then saved in the working space.

It should be stressed that the program does not calculate immediately a mean value because the generated wave is a random function – in case if the generated wave had only – for instance - three heights over sea level it would be not justified to select only one of them to be significant.

Tab. 13. Wave heights resulting from the program No. 2

H [m]					
0,7772	9,6740	0,5846	0,1020	1,1329	0,7420

In the program No. 3 , the diameters of the rafts accommodating 6, 8, 12, 16, 20 and 25 persons, respectively , were used for calculating resistance forces during towing the raft. An example diagram is presented below (Fig. 3.).

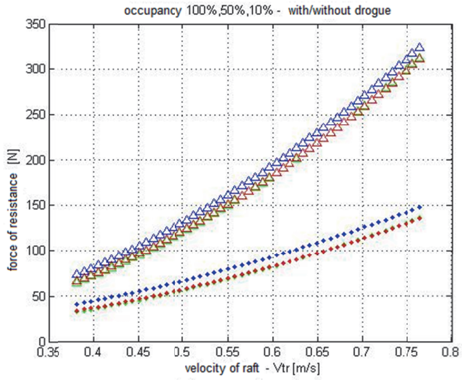

Fig. 3. Resistance forces during towing the 20-person raft with and without drift anchor , respectively ; (green colour stands for 100% crew occupancy, blue - 50%, red - 10%. Dots stand for resistance of the raft without drift anchor , triangles – for resistance of the raft with drift anchor.)

As the rift size is greater and greater , its speed and - consequently – the resistance force acting onto the rafts during towing decreases and only the range of diagrams is changed, that is especially visible when the results for 6-person raft and 20-person raft are compared to each other. On the both diagrams, at the speed of 0,7 m/s , the resistance force acting onto the raft without drift anchor amounts to abt. 130÷120 N (for the range of 100÷10% crew occupancy), and for the raft with drift anchor – to abt. 270÷250 N. The true is that the diagram showing relations between 6- person raft resistance force and its speed poses an extension of the respective diagram for 20-person raft. It's interesting, that the results for the raft with 100% crew occupancy coincide with those for that with 10% crew occupancy.

In the program No. 4 which calculates wind pressure force, the diameters of the rafts for 6, 8, 12, 16, 20 and 25 persons were used as previously. Below is presented the example diagram showing the obtained aerodynamic forces in function of wind speed values (Fig. 4.).

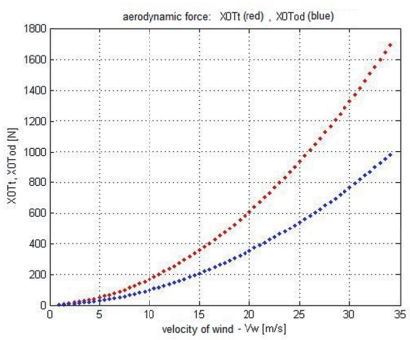

Fig. 4. Aerodynamic force acting onto 20-person raft compared with 10-person reference raft

Comparing subsequent diagrams to each other one can observe that along with growing size of the raft the wind pressure force acting onto the raft at a given wind speed increases. However, the results for 16 - and 20-person rafts do not differ significantly to each other – this probably results from the quantities describing the 20-person raft . This question may be solved by the next program where relations between raft drifting speed and wind speed can be mutually compared. For the calculations in the program No. 5 the use was made of the raft data introduced already into the program No. 4. The example diagram is presented below (Fig. 5.)

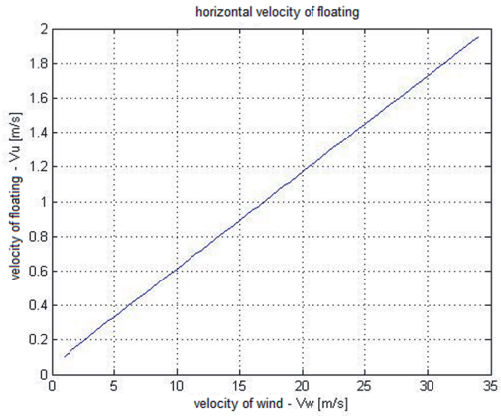

Fig. 5. Raft drifting speed in function of wind speed - relation for 20-person raft

As may be observed on the drawings which show relations for the rafts of 6, 8, 12, 16 - person capacity, along with increasing capacity of the considerd raft the linear function $V_u(V_W)$ becomes more and more " steep". The effect vanishes on the diagram for 20-person raft . The inclination angle of this function is clearly smaller than that for the preceding,16-person raft. It results from the dimensions of the raft. If we examine more thoroughly the catalogue data (Tab. 6.) it may be observed that inasmuch as diameter, tent height and mass of particular rafts increase along with their capacity, such correlation disappears just in case of the depth (pontoon height) of 20-person raft. Its depth as well as its total height is smaller than that of the preceding raft because , though the total cross-section area of 20-person raft is greater, the emerged part of this raft has smaller area than that of 16-person raft – and just on this area wind force acts. And, for this reason the inclination angle of the function $V_u(V_w)$ is smaller.

For the calculations in the program No. 6 there were used the raft data already introduced into the program No. 4. In the program in question the use was made of the significant wave height achieved on the basis of the wave spectrum from the program No. 2 ,namely : H_s = 5,3729 m. The user had to put in its respective period T_1 = 8 s (characteristic for the North Sea [15]). One of the drawings illustrating results of the calculations is shown below (Fig. 6.):

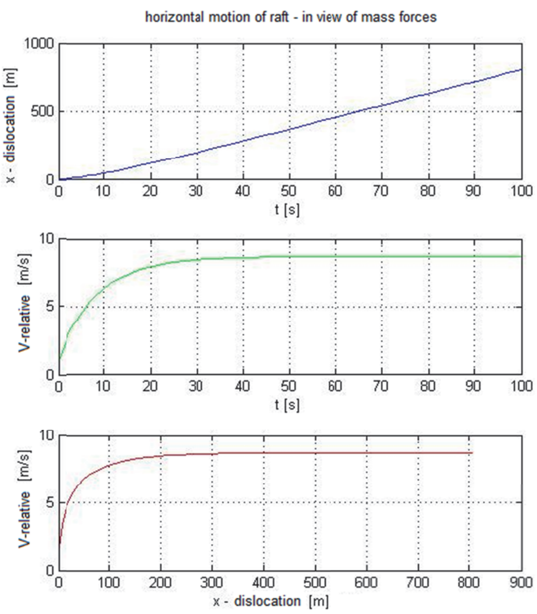

Fig. 6. Horizontal dislocation of the raft (relative speed , dislocation, attractor) reached with taking into account mass forces acting onto the raft – relations for 20-person raft

Examining the diagrams one may observe three unambiguous correlations resulting from size and mass of the rafts – the greater raft capacity the greater the inclination angle of the function of raft dislocation versus time, and the function of raft relative speed versus time as well as the attractor reach stable course at greater values. It should be stressed that in case of the dislocation- time function we have not to do really with an inclination" angle" of a linear function but rather an exponential function , while the diagrams concerning relative speed approach a definite value because the analysis was made for only one, constant value of wind speed.

For the calculations in the program No.7 there were used the same rafts as in the preceding programs, i.e. the rafts for 6, 8,12,16, 20 and 25-person, respectively. The achieved results are presented in the form of diagrams ; the examplary one is shown in Fig. 7, where green colour stands for 100% crew occupancy, cyjanide - 50%, magenta - 10%.

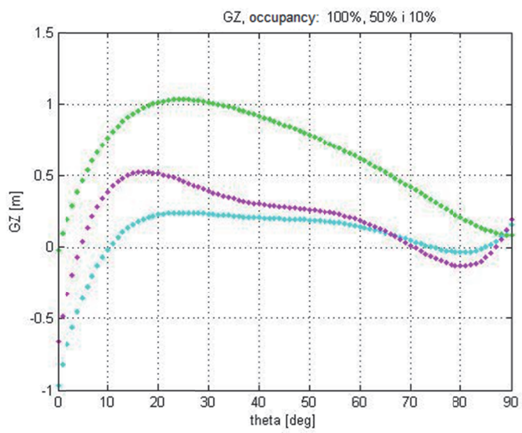

Fig. 7. The righting arm GZ in function of the heel angle theta for 20-person raft with 100, 50,10% crew occupancy

On the following diagrams as the rafts capacity increases the functions describing their righting arms are shifted towards greater and greater values. Additionally, the distances between particular functions at their points at GZ-axis for different percentage of crew occupancy, increase. The only exception from this relation is observed on the diagram for 20-person raft where the functions in question are located in the range of lower values , compared with that for the preceding raft of smaller capacity; the distances between the points of the functions at GZ –axis are also smaller. The limit angle of righting arms curve is not constant for all the rafts – for the rafts with 10 and 50% crew percentage it amounts to abt. 70^{o}, and for 100% - to abt. 90^{o}.

SUMMARY

The programs presented make it possible to show – in the form of diagrams – an influence of raft characteristics on raft performance in a critical situation as well as to compare to each other responses of various circular rafts against given environmental factors. In particular situations leading to raft capsizing its longitudinal and oscillation motions were examined. The investigations were conducted for given weather conditions in which at first wind speed and then - based on the generated wave spectrum - the significant wave height and characteristic wave period was determined. However , enough to modify somewhat the code to get similar analytical tool for selected hydrometeorological parameters – hence the programs may serve as a useful tool for inflatable raft designers , because they allow to select such raft dimensions as to assure the best effectiveness / highest reliability level for the raft in dangerous weather conditions possible to met in a given water area.

Effectiveness of a rescue action depends on action time of a search & rescue system as well as survival time of survivours. And, duration time of such action depends on an extent of area to be searched. Knowing operational characteristics of life saving appliances one is able to restrict search area and – consequently - to shorten duration time of a search & rescue action.

Determining search area one must take into acount not only wind drift generated along wind direction but also occurrence of wind drift components deflected right or left from the wind direction [6]. The deflections are caused a. o. by raft tent supporting bows [17], that results in a nonlinearity of aerodynamic coefficients. Knowledge of the following information: drift anchor usage (its application results in stabilization of wind drift direction as well as reduction in wind drift speed), size and form of the raft as well as its tent (change in their technical parameters affects drift parameters), raft occupancy (number of survivours also affects drift parameters) can significantly reduce fuzziness of a search area. The programs prepared within the frames of this work make it possible to use the above specified information for analyzing raft motion (prediction of its path); owing to this they may serve as an introduction to development of a drift model of to- be- searched object and contribution in shortening time to rescue of survivours.

BIBLIOGRAPHY

1. Cepowski T.: Numerical modelling of seakeeping qualities of selected types of ships in preliminary desige stage (in Polish). WNAM, Szczecin 2011.

2. Sobczyk K.: Stochastic differential equations (in Polish). WNT, Warszawa 1996.

3. Massel S.: Hydrodynamic problems of offshore buildings (in Polish). PWN, Warszawa 1981.

4. Sobczyk K.: Stochastic waves (in Polish). PAN, Warszawa-Poznań 1982.

5. Bielański J.: The probability analysis of the life raft capsizing on the rough sea, 16'th International Conference on Hydrodynamics in Ship Design, 3'rd International Symposium on Ship Manoeuvring, 7-10 September 2005, Gdańsk - Ostróda, Poland, pp. 219-227.

6. Burciu Z.: Life raft reliability in sea transport (in Polish). Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2011.

7. http://www.smart.gda.pl, (access date : 21.01.2016r.)

8. Krajewska, P.: Analysis and assessment of requirements for building and usage of life saving appliances in sea transport (in Polish). Logistyka 3/2014

9. Sawicki J. Free surface liquid flows (in Polish). PWN, Warszawa 1998.

10. White, F.: Fluid Mechanics (in English). 3rd edition, McGraw-Hill, Inc., International Edition 1994, p. 419.

11. Gryboś R.: A book of problems on technical mechanics of fluids (in Polish). PWN, Warszawa 2011.

12. Jeżowiecka-Kabsch K., Szewczyk K.: Fluid mechanics (in Polish). Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2001.

13. Pacześniak J.: Design of sea-going mercantile ship (in Polish). I,II,II vol., a course book. Gdansk University of Technology, Gdańsk 1984.

14. Szozda Z.: Stability of sea-going ship (in Polish). Akademia Morska w Szczecinie, Szczecin 2002.

15. Więckiewicz W.: Essentials of floatability and stability of merchant ships (in Polish) . Wydawnictwo Akademi Morskiej w Gdyni, Gdynia 2006.

16. Dudziak J.: Theory of ships (in Polish). Wydawnictwo Morskie, Gdańsk 1988.

17. Morawski, M.: Inflatable rafts in sea rescue (in Polish). WMG, Gdynia 1961.

CONTACT WITH THE AUTHOR

Olga Kazimierska

e-mail: olga.kazimierska@pg.gda.pl

Department of Hydromechanics and Hydroacoustics
Faculty of Ocean Engineering and Ship Technology
Gdańsk University of Technology
11/12 Narutowicza St.
80 - 233 Gdańsk
POLAND