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MODELING OF THE WIND GENERATED FORCE ACTING ON THE LIFERAFT

ABSTRACT The aim of this paper is to derive a mathematical model for estimating the wind forces and wind moments effects a life raft. The mathematical model based on data from laboratory experiments. Forces due to the action of wind are adequately described. The governing physical equations, however, contain characteristics of the environment that are often not well quantified. In the strong wind condition, when the wind speed is much larger than the current and body speeds, all wind-generated forces must be taken into account.
Friction and pressure forces exerted by the wind on the upper part of the floating body result in the wind force**,** which has a downwind component (drag) and a crosswind component (side force or lift), [1][2]. The drag component is always positive. The side force or lift component can be positive or negative[8]. The lift depends on the wind speed, body geometry, and strongly on the angle between the long axis of the floating body and the wind direction. In this paper the author presents models of wind forces acting at a life raft. Data from laboratory experiments (wind tunnel [5]) are used to build dynamical models.

INTRODUCTION

The stability of the liferaft shall be considered in the hull-borne, transitional and foil-borne modes. The stability investigation shall also take into account the effects of external forces. The following procedures are outlined for guidance in dealing with stability:

- relationship between the capsizing moment and heeling moment to satisfy the weather criterion
- heeling moment due to wind pressure.

The heeling moment M_V shall be taken as constant during the whole range of heel angles and calculated by the following expression [2]:

$$M_V = 0.001\ P_V\ A_V\ Z \qquad \text{(kNm)}$$

where: P_V - wind pressure (N/m^2),
A_V - windage area including the projections of the lateral surfaces of the raft, superstructure and various structures above the waterline (m^2)
Z - windage area lever (m) that is the vertical distance to the geometrical centre of the windage area from the waterline

LABORATORY EXPERIMENTS IN THE AERODYNAMIC TUNNEL

The aim of experiments was to determine the wind forces acting at a liferaft. Aerodynamic experiments of inflatable life rafts were performed in the Laboratory of Low Velocities in the Institute of Aviation [5].

Fig. 1. A ten- person raft in the aerodynamic tunnel

The research was carried out in the aerodynamic tunnel. The research concerned the range of speeds in the measurement space of the tunnel from 20 to 64 knots, V_w = 10-34 m/s.

The speed profile was transformed according to the formula [5]:

$$\frac{V_w}{V_{ref}} = \left(\frac{Z}{Z_{ref}} \right)^{\kappa}$$

where:

Vw	– wind speed on the height of raft measured from the sea surface (m/s)
V_{ref}	– reference speed- speed of undisturbed flow (m/s)
Z	– the raft height measured from the water (m) surface
Z_{ref}	– 1,5 m – the reference height that is the height at which in the aerodynamic tunnel conditions, the flow speed equals an undisturbed flow speed
$\kappa = 0{,}11$	– for the sea according to ISO standard.

To estimate a real wind pressure force F_N, for a certain wind speed a dynamic pressure q was modelled [5]:

$$q = \frac{\rho \cdot (V_w)^2}{2}$$

In standard conditions: surrounding temperature T = 15^o C, atmosphere pressure 1013.2 hP, air density ρ = 1.233 kg/m ^{3}. A wind pressure force F_N in real conditions is equal to [5]:

$$F_N = \frac{x}{q} \cdot \frac{\rho (V_w)^2}{2}$$

where x /q - reduced pressure force number in the stream system (modelled during the research)

Forces and moments presented in the fig.2 were measured in the laboratory. Measurements were performed in two coordinate systems:

wind direction system, XOY, with X - axis (OX) parallel to the wind speed vector;

liferaft main axis system, X_1OY_1.

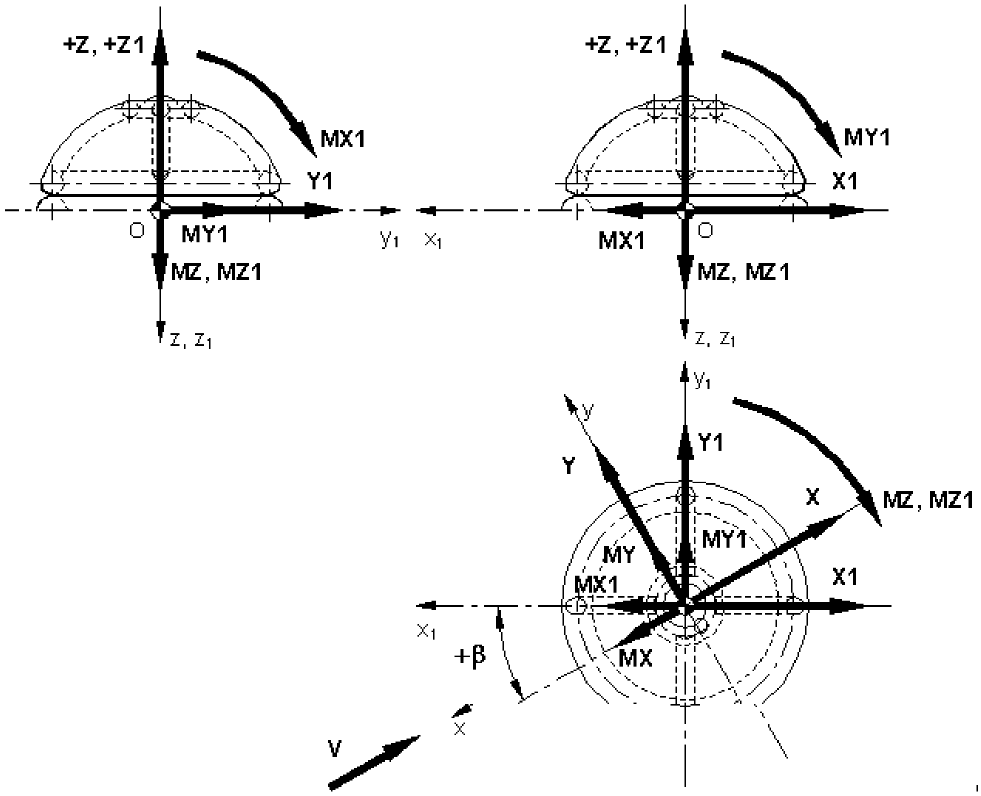

Fig. 2. Measured forces and moments

where: β angel between wind direction (axis Ox) and direction of axis Ox1 [deg];

- X - drag force in wind direction system [N];
- Y - side force in wind direction system [N];
- Z - lift force in wind direction system [N];
- MX - rolling moment in wind direction system [Nm];
- MY - pitching moment in wind direction system [Nm];
- MZ - yawing moment in wind direction system [Nm];
- X_1 - drag force in liferaft main axis system [N];
- Y_1 - side force in liferaft main axis system [N];
- Z_1 - side force in liferaft main axis system [N];
- MX_1 - rolling moment in liferaft main axis system [Nm];
- MY_1 - pitching moment in liferaft main axis system [Nm];
- MZ_1 - yawing moment in liferaft main axis system [Nm].

Relation between forces and moments in both coordinate systems are presented in table 1.

Table 1. Relation between forces and moments for wind direction system and liferaft main axis system

$X_1 = X \cdot \cos\beta - Y \cdot \sin\beta$	$Y_1 = Y \cdot \cos\beta + X \cdot \sin\beta$	$Z_1 = Z$
$MX_1 = MX \cdot \cos\beta - MY \cdot \sin\beta$	$MY_1 = MY \cdot \cos\beta - MX \cdot \sin\beta$	$MZ_1 = MZ$

The geometrical parameters of the 10-person liferaft are presented in the table 2.

Table 2. Geometrical parameters of the 10-person liferaft

Raft	Diameter [mm]			Rated altitude [mm]
	outer	lower float chamber	upper float chamber	
10 person	∅ 2907	∅ 288	∅ 272	1225

Relations between forces for different wind speed, 10 [knts], 15 [knts], 20 [knts] and 25 [knts], as a function of wind direction, are presented in the figures Fig. 3- Fig. 5

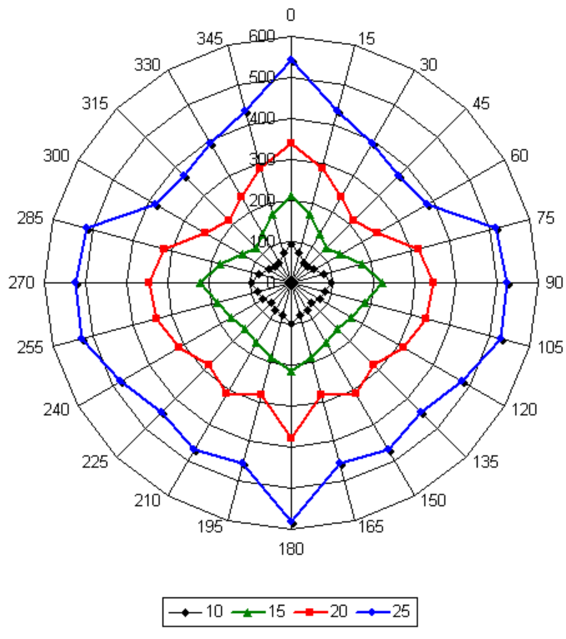

Fig. 3. Spatial distribiution of force X for different wind speed V_w (10, 15, 20, 25 knts)

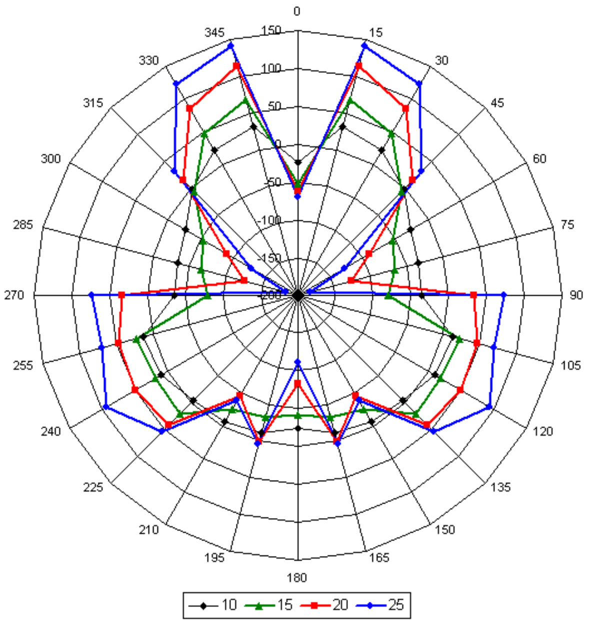

Fig. 4. Spatial distribiution of force Y for different wind speed V_w (10, 15, 20, 25 knts)

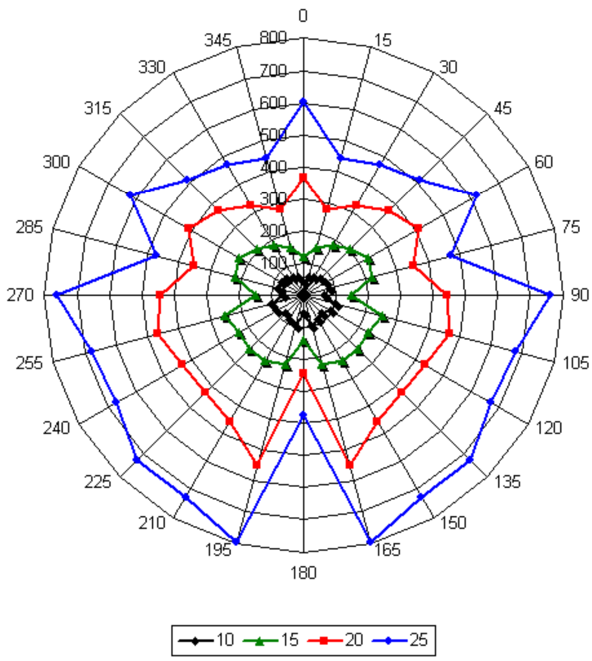

Fig. 5. Spatial distribiution of force Z for different wind speed V_w (10, 15, 20, 25 knts)

REGRESSION ANALYSIS OF WIND FORCES AND MOMENTS

Laboratory data were analysed by statistical program Statgraf. Regression models of dependency between wind velocity and measured forces and moments were obtained. Because of very small real value of forces and moments for low speed of winds and some mistakes in measurements for very low speeds of winds, obtained models do not cover situations for wind speeds less than 10 knots

Table 4. Regression models of wind forces for the 10 person pneumatic raft in liferaft main axis system

Force	**FITTED MODEL EVALUATION**	Correlation Coefficient	R-squared	Standard Error of Est.	P-Value
X_1	$X_{max} = 1,14871 \cdot V_w^{1,93674}$	0,999926	99,9853	0,011389	0,0001
	$X_{min} = 0,46576 \cdot V_w^{2,05983}$	0,998658	999,7317	0,051764	0,001
Y_1	$Y_{max} = \exp(6,0004-26,1466/V_w)$	-0,998876	99,7754	0,039959	0,0011
	$Y_{min} = 64,3943 - 9,77679 \cdot V$	-0,997376	99,4759	5,6101	0,0026
Z_1	$Z_{max} = 0,574729 \cdot V_w^{2,26198}$	0,997463	99,4932	0,078218	0,0025
	$Z_{min} = (-2,23534+ 0,872591 \cdot V_w)^2$	0,998987	99,7976	0,310679	0,0010

Table 5. Regression models of wind forces moments for the 10 person pneumatic raft in liferaft main axis system

Moment	**FITTED MODEL EVALUATION**	Correlation Coefficient	R-squared [%]	Standard Error of Est.	P-Value
MX_1	$MX_{max} = \exp(5,50614 - 27,4584/V_w)$	-0,988485	97,7103	0,135391	0,0115
	$MX_{min} = 1/(0,014145 - 0,524912/V_w)$	-0,998841	99,7684	0,000815	0,0012
MY_1	$MY_{max} = \exp(5,99381 - 21,7569/V_w)$	-0,999039	99,8079	0,0307457	0,0010
	$MY_{min} = 29,3407 - 2,19656 \cdot V_w$	-0,969228	93,9403	4,41047	0,0308
MZ_1	$MZ_{max} = \exp(4,87989 - 30,0794/V_w)$	-0,990655	98,1397	0,133395	0,0093
	$MZ_{min} = 44,4484 - 21,5017 \cdot \ln(V_w)$	-0,995642	99,1303	0,975781	0,0044

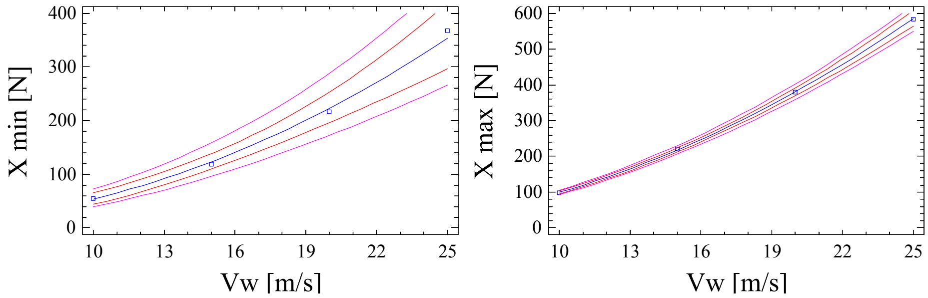

Fig. 6 Wind force X estimation curves

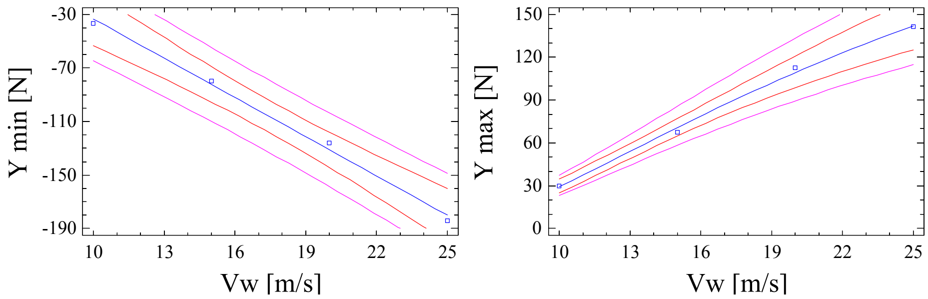

Fig. 7 Wind force Y estimation curves

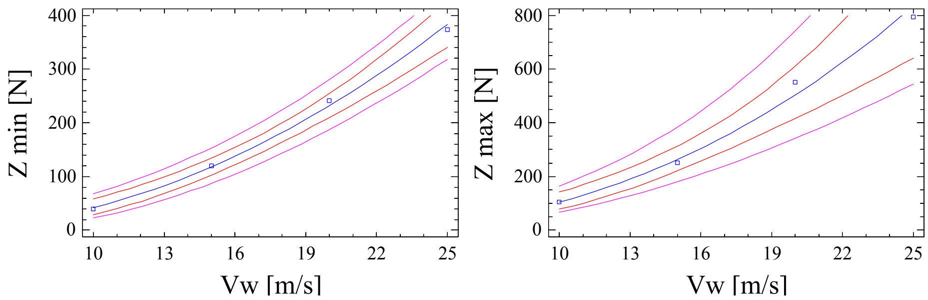

Fig. 8 Wind force Z estimation curves

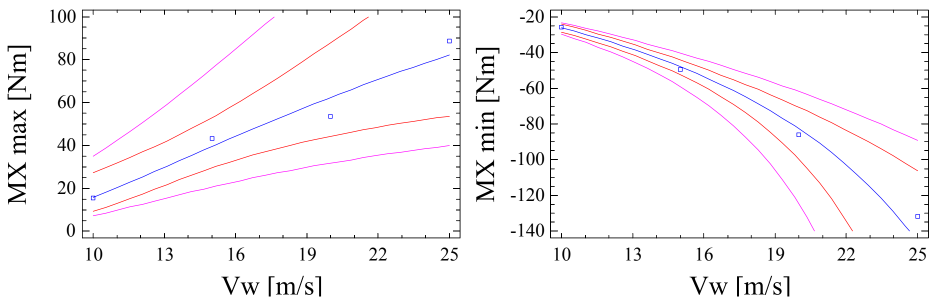

Fig. 9 Wind moment MX estimation curves

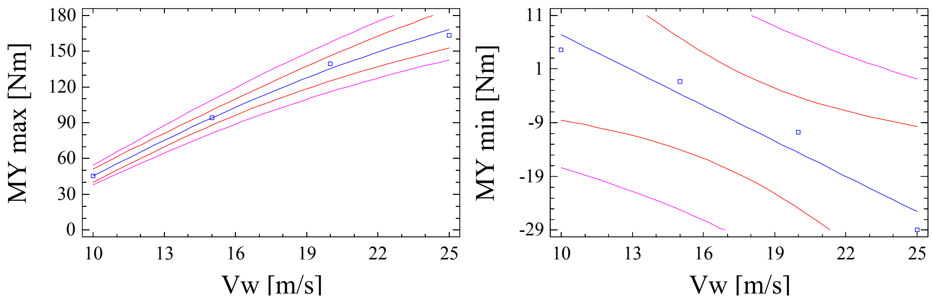

Fig. 10 Wind moment MY estimation curves

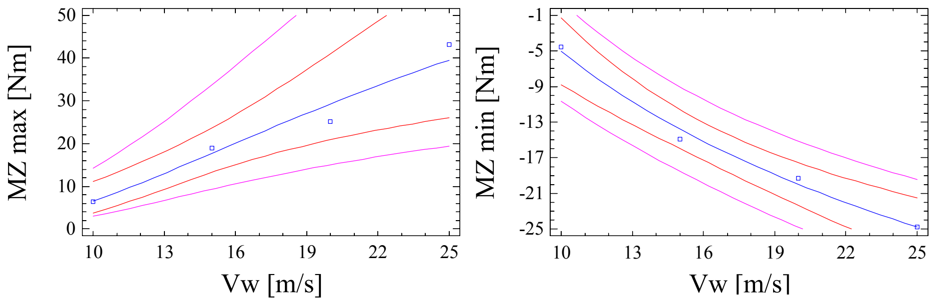

Fig. 11 Wind moment MZ estimation curves

CONCLUSION

The results obtained from laboratory experiments allow estimating life raft's real aerodynamic drag. This statement follows from lack of wind speed influence on flow character around raft. Results got from tunnel experiments

Application of wind forces and moments, estimated in the laboratory experiments for a particular raft size, will allow for more correct estimation of a raft wind heeling arm. As well they could be used in further investigations of raft modifications and designing especially drag force X, side force Y and yawing moment MZ.

The others aerodynamical loadings lift force Z, rolling moment MX and pitching moment MY have a less influence on raft stability.

The deformation of liferaft canopy disturbs all wind's forces and moments. Spatial distributions of wind's forces show that unexpected change of a wind direction affects the liferaft stability.

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