The wind gusts effects on human body based on cfd simulations

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Abstract: *In this paper, the impact of wind forces on human bodies is shown. Like many meteorological phenomena, the influence of wind energy applied to human bodies is inevitable which comes into the spotlight of the scientist only when the wind becomes violent and extremely disturbing. Based on weather and observations in February 2019, abnormal wind characteristics in Albania are evidenced. On February 23, 2019, a very special situation in the Northern part of Albania, the region of Puka, with extreme values of wind parameters causing the phenomenon of "wind gust", leading to a series of material damage and loss of human life, is evidenced. Researchers and predictors need scientific information on the impact of strong winds applied on the human body for specific conditions. Wind speed values in this region of the northern part of our country set records reaching extremely values (30 ÷ 35) ms^{-1} on the ground level. Taking a cue from this unprecedented situation, the effect of strong winds on the determination of aerodynamic forces acting on the human body using numerical simulations has been studied and so far, well investigated. For this study, we considered a human body with a height of 172cm. The investigation takes into account two different positions against the wind, frontal and lateral position traversed by wind speeds levels of 20m/s, 30m/s, and 40 m/s. The study concluded that strong winds can exhibit unimaginable and unaffordable forces, leading to fatal consequences for human life.*

Keywords: CFD, Forensic Science, OpenFOAM, Wind Drag, Wind Gust.

1. Introduction

On 23rd February 2019, the wind speed during that day was at moderate conditions reaching values of 11 m/s where at some point values up to 30 m/s is identified, so there was a sudden increase in speed [1]. Referring to an online site for the forecast and history of climate change of the weather, www.ventusky.com, it turns out that on February 23, 2019, at 14:00 (an approximate hour with the occurrence of several accidents causing loss of human life) wind gust with values as it is shown in the figure1 is observed:

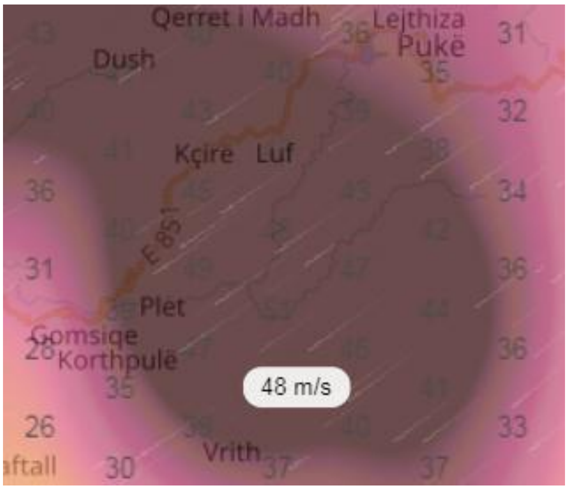

Fig. 1 *Wind gusts speed in the region of Puka [2]*

In the area where the accidents occurred, there were strong winds in the range of 20 ÷ 40m/s. In this case study, the velocities of the wind gust of 20m/s, 30m/s, 40m/s are assumed.

Referring to the documents in the event under investigation, it turns out that at the scene there was an ice hearth, which can be eliminated by simply throwing a quantity of salt in it, excluding the need for snow-clearing machinery.

Referring to the mechanism of the event, the worker, tends to get into the truck by placing his left foot on the rear tire of the vehicle and holding with his left hand the body of the vehicle, a position which is not very stable and as a result of wind force the worker loses his balance. The expert group asked to judge the impact of strong winds on the worker's body.

The phenomena of a sudden increase in wind speed, the duration of which is less than 20 seconds, are known as the "Wind Gust". This is a sudden and unidentifiable phenomenon and work process must be immediately interrupted.

2. The impact of wind in general

If the wind blows towards an object, it loses speed due to the obstacle that the object exhibits to the wind and according to Newton's second and third laws, equal opposites forces are exerted between the wind and the object. These forces, functions of wind speed are caused by two components [3]:

- Frictional forces usually occur between the wind and a stationary object, in contact with the body the wind speed is reduced to zero by the coefficient of friction of the object. This force component depends on the geometry, the roughness of the object surface and the nature of the flow.
- Pressure forces are generated and are a function of the shape and size of the object. Generally, bodies with large transverse surfaces generate a larger pressure force due to the Bernoulli effect.

Resistance forces consist of two components, the friction force component and the pressure force component. Both of these forces have their components in the direction of fluid flow motion. The coefficient of resistance is determined as follows [3], [4]:

$$C_D = C_{D\ Friction} + C_{D\ Pressure}$$

The components of the pressure and friction force perpendicular to flow's direction tend to move the body towards and the sum of these forces gives what is called the resistance force. The wind resistance force can be expressed by the following equation [5], [6]:

$$F_D = \frac{1}{2} \cdot \rho \cdot C_D \cdot S \cdot V^2$$

$\rho = 1.275\ kg/m^3$, calculated air density, referring to pressure 1.015 bar and temperature 5°C
C_D, the coefficient of resistance of the body
S, the surface of the cross-section of the body,
V, the wind speed
The power of this wind resistance force is given by equation [3]

$$P_D = F_D \cdot V = \frac{1}{2} \cdot \rho \cdot C_D \cdot S \cdot V^3$$

The same equations are used for the lifting force, given the lifting force coefficient:

$$P_L = F_L \cdot V = \frac{1}{2} \cdot \rho \cdot C_L \cdot S \cdot V^3$$

$$F_L = \frac{1}{2} \cdot \rho \cdot C_L \cdot S \cdot V^2$$

C_D, C_L, coefficients that are determined experimentally or in our study through numerical simulations.
To determine the strength of wind resistance on a body, the front surface on which the wind will strike must first be determined [7].

The values of the body's surface area as a function of the position and mode of action of wind force on the human body are given. In this case study, a human body with a height of 172cm (same length as the worker who loses his life) is considered.

Referring to the sketch of the scene, two positions of the worker's body as a function of wind direction is assumed. The first case, the frontal position, parallel to the direction of wind flow and the second is intended to be perpendicular to the direction of wind movement, lateral position.

The total body surface area of a person with a height of 172cm is 1,892 m^2. If the position of the human body against the wind is frontal, the frontal surface area is 0.555 m2. If the position of the human body against the wind is lateral, its lateral surface area is reduced to 0.325 m2.

Fig.2 *The body position of the person and the projected surface area*

3. Numerical analysis

To understand the impact that wind has on various objects, thus experiments employing wind tunnels is required. In our country, such tunnels are not available. In recent years computer programs have managed to study various phenomena of fluid flow in virtual environments, performing numerical simulations. The expert group owns a computational fluid dynamics software, OpenFOAM version 3.0.x [8], in which the effect that the wind exhibits on the human body can be verified. For this act of expertise, a virtual wind tunnel with length and width of 5x5m and 20m long is assumed.

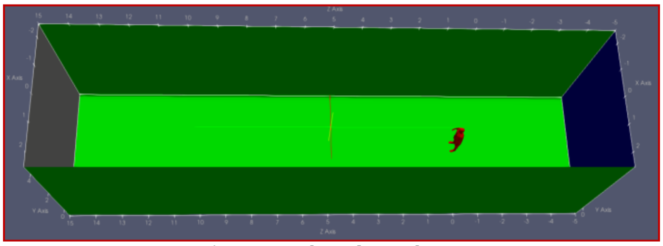

Fig. *3 Virtual wind tunnel overview*

In the center of this tunnel, a body with a height of 172cm, the same height as the worker, is placed. To get as close as possible to the circumstances of the event, the person's body was raised 0.8m from the ground, a deliberate position above the tire of the vehicle, in an attempt to catch the shovel and then throw salt on the ice hearth. In this way, the impact that wind has on a person's body by setting wind speed values is calculated. From the CFD simulation, the values of pressure forces and the level of drag and list forces acting on the body of the person are evaluated.

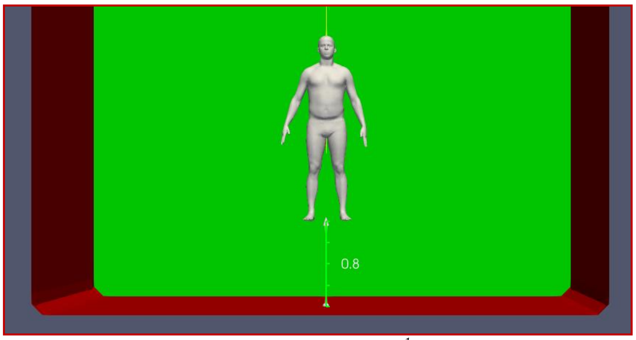

Fig. *4 The position of the person's body[1] to the wind tunnel*

4. CFD simulation results

4.1 Technical analysis No.1 - wind gust speed of 20m/s

a) Frontal position in parallel wind flow direction

From the numerical simulations, for a wind speed 20m/s, the following results for the frontal position: $F_D = 126.956$ N and $F_L = 2.818\ N$ are carried out.
By using these data the coefficient of drag force and the coefficient of lift force is determined, respectively:

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 126.956}{1.275 \cdot 0.555 \ \cdot 20^2} = 0.90$$

$$C_L = \frac{2 \cdot F_L}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 2.818}{1.275 \cdot 0.555 \ \cdot 20^2} = 0.02$$

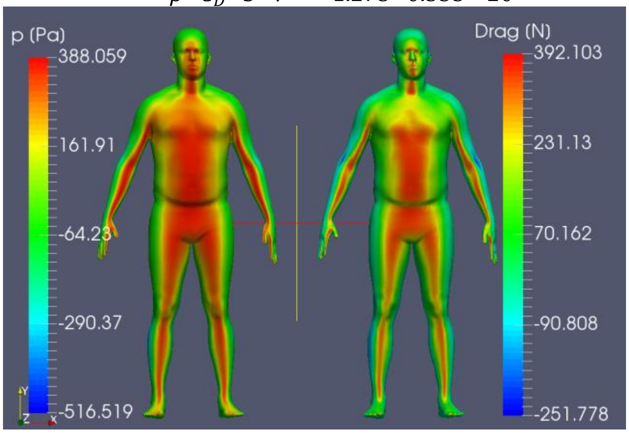

Fig. 5 *The pressure field and the Drag forces on the human body (frontal position)*

b) Lateral position with the direction of wind movement.

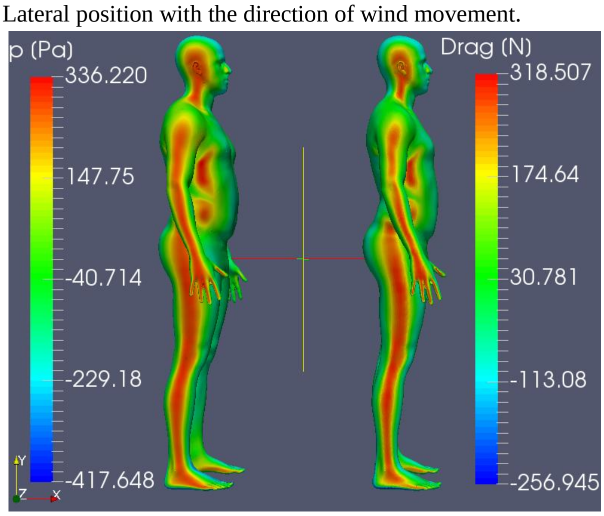

Fig. 6 *The pressure field and the Drag forces on the human body (lateral position)*

[1] https://free3d.com/3d-models/human

From the numerical simulations, for the assumed wind speed of 20m/s, by surface integration the following results are obtained:

$$F_D = 69.4322 \text{ N and } F_L = 5.35977\ N$$

Employing the above data the coefficient of resistance force and the coefficient of lifting force, is determined respectively:

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 69.4322}{1.275 \cdot 0.325 \cdot 20^2} = 0.840$$

$$C_L = \frac{2 \cdot F_L}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 5.35977}{1.275 \cdot 0.325 \cdot 20^2} = 0.065$$

Since the lifting force is very small compared to the strength of drag force resistance, it is excluded in the calculation.

4.2 Technical analysis No.2 - wind gust speed of 30m/s

a) Frontal position with the direction of wind movement.

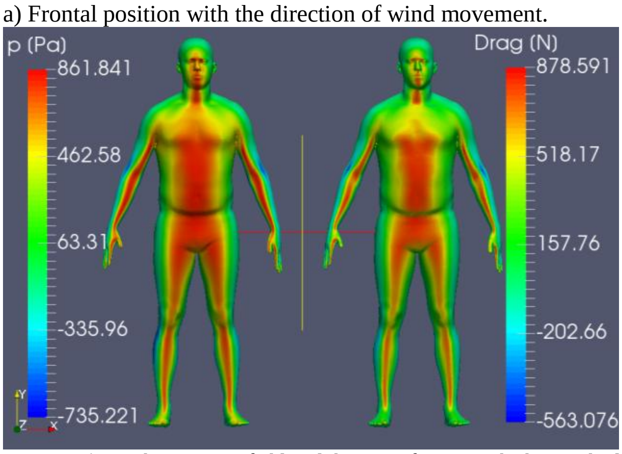

Fig. 7 *The pressure field and the Drag forces on the human body (frontal position)*

From the numerical simulations, for the assumed case of wind speed of the order of 30m/s, the following results are calculated:

$$F_D = 272.009 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 272.009}{1.275 \cdot 0.555 \cdot 30^2} = 0.857$$

b) Lateral position with the direction of wind movement.

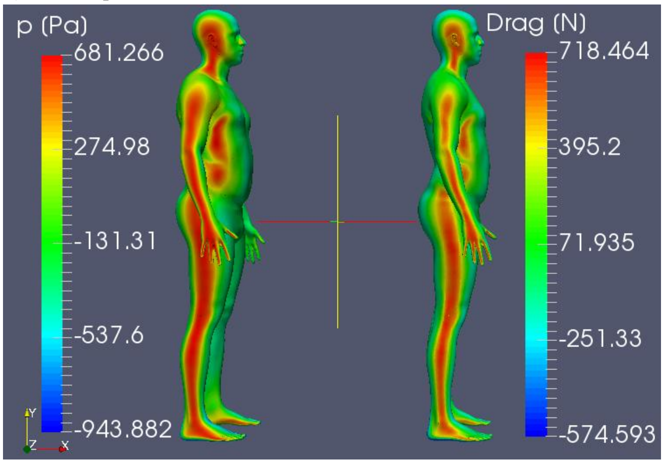

Fig. 8 *The pressure field and the Drag forces on the human body (lateral position)*

From the numerical simulations, for the assumed wind speed of 30m/s, the following results are obtained:

$$F_D = 155.612 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 155.612}{1.275 \cdot 0.325 \cdot 30^2} = 0.837$$

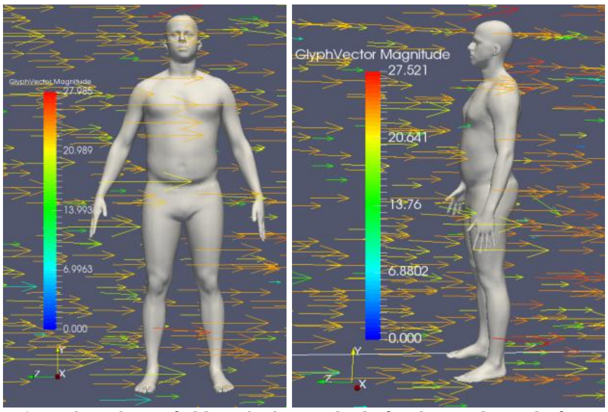

Fig.9 *The velocity field on the human body for the wind speed of 30m/s (frontal and lateral position)*

4.3 Technical analysis No.3 - wind gust speed of 40m/s

a) Frontal position with the direction of wind movement.

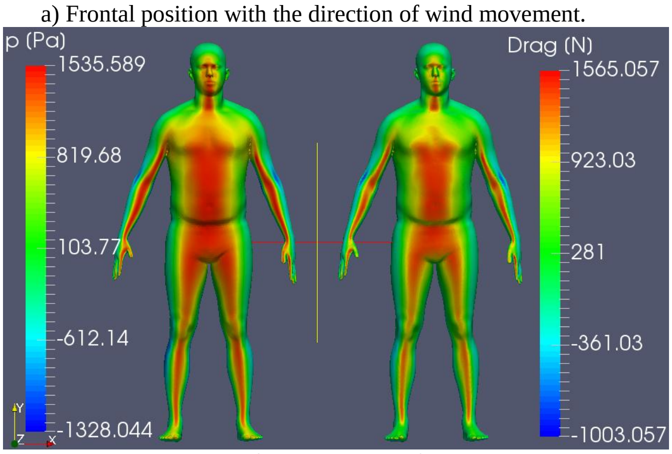

Fig. 10 *The pressure field and the Drag forces on the human body (frontal position)*

From the numerical simulations, for the assumed case of wind speed 40m/s, the following results are calculated:

$$F_D = 479.672 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 479.672}{1.275 \cdot 0.555 \cdot 40^2} = 0.85$$

b) Lateral position with the direction of wind movement.

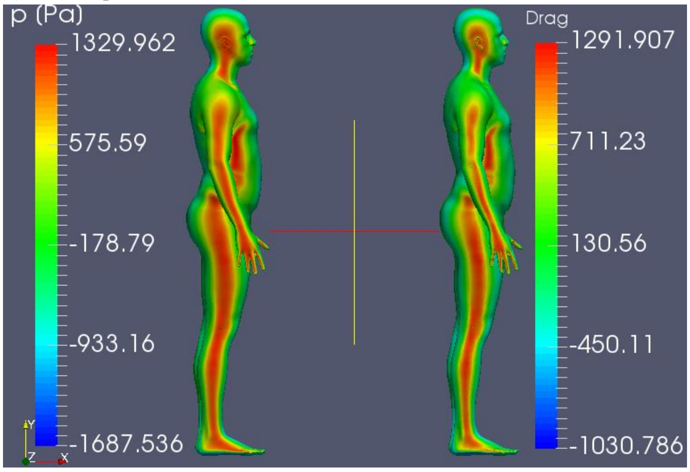

Fig. 11 *The pressure field and the Drag forces on the human body (lateral position)*

From the numerical simulations, for the assumed case of wind speed 40m/s, the following results are obtained:

$$F_D = 277.65 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 277.65}{1.275 \cdot 0.325 \cdot 40^2} = 0.84$$

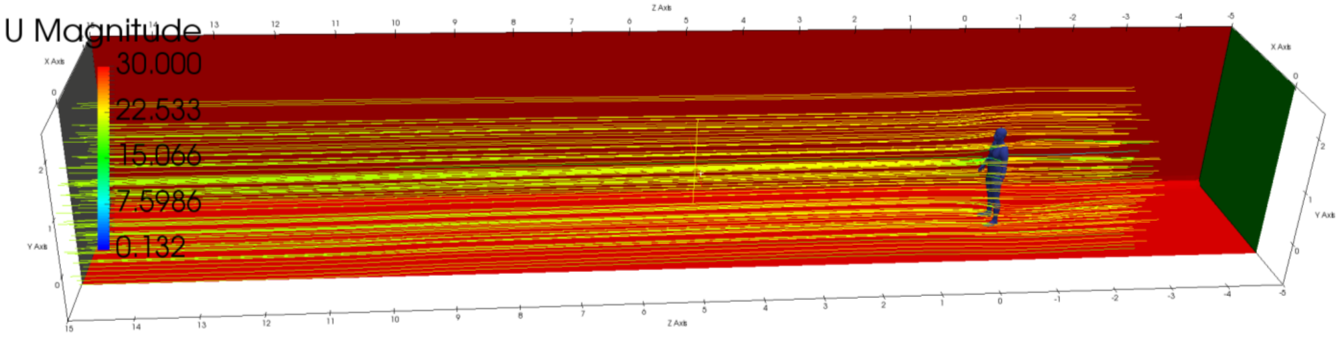

Fig. 12 *Wind streamlines in the wind tunnel for the wind speed velocity 30m/s*

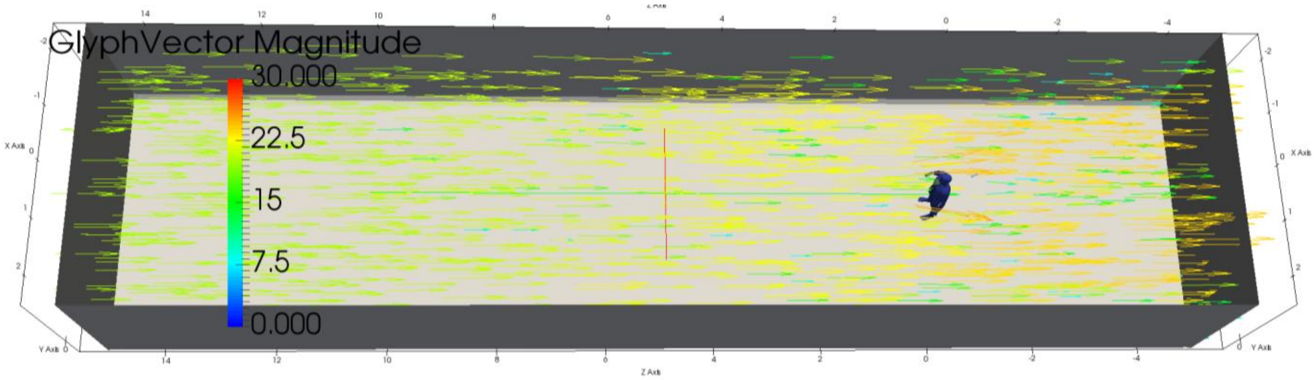

Fig. 13 *Wind glyph vector magnitude in the wind tunnel for the wind speed velocity 30m/s*

4. Comparison of the obtained results

The results from the numerical simulations should be verified at best by conducting experiments, which is not possible in our conditions, so the simulation results performed in this case study will be accepted as realistic values and validated to that of the analytical methods known for wind impact as well the results of experiments obtained from other studies [10], [11].

Table 1. Summary results from numerical simulations

The position of the human body against the wind	Wind speed [m/s]	Drag Force [N]	C_D [-]
Frontal position	20	126.956	0.9
	30	272.009	0.857
	40	479.672	0.85
Lateral position	20	69.432	0.84
	30	155.612	0.837
	40	277.650	0.84

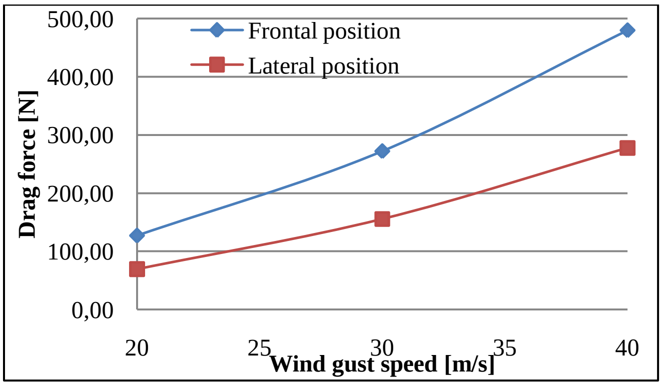

Fig. 12 *Drag force on human body function of wind speed*

According to (M. Kemal Atesmen) [9] are defined the minimum and maximum values of the drag forces by the wind on the human body referring to the frontal position. Values are given as a function of human body height in cm. In our case study, the worker has a height of 172cm.

Table 2. Wind speed scales [9]

V_{wind}	Min (km h^{-1})	Max (km h^{-1})	Min (m s^{-1})	Max (m s^{-1})	Min (mph)	Max (mph)
Storm	88.4	101.4	24.6	28.2	55	63
Violent storm	103.3	117.5	28.6	32.6	64	73
Hurricane cat 1	119.1	152.9	33.1	42.5	74	95
Hurricane cat 2	154.5	177.0	42.9	49.2	96	110
Hurricane cat 3	178.6	207.6	49.6	57.7	111	129
Hurricane cat 4	209.2	251.1	58.1	69.7	130	156
Hurricane cat 5	252.7	Above	70.2	Above	157	Above

The following graph in figure 13 shows the level of drag force exerted by the wind in storm conditions, for wind speed levels of 24.6 ÷ 28.6m/s. This is referring to a normal body weight, with a BMI of 22, of 65kg.

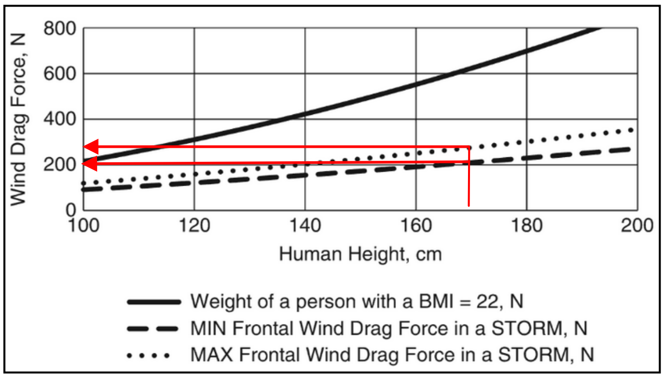

Fig.13 *Frontal wind drag force on a human body versus human height in a storm [9]*

The graph above shows that the values of wind forces are in the range 200÷280 N (for wind speed 24.6 ÷ 28.2m/s), for the body height of 172cm. Such values are comparable to the results obtained from numerical simulations (simulations are performed for wind speeds in the range of 20 and 30m/s).

5. Conclusion

From the numerical simulations, for the assumed wind speed of 20m/s, 30m/s and 40m/s, the following results for the frontal position are obtained:

The level of pressure on the human body can reach up to 1535 Pa and the drag force from the wind can reach the value respectively:

$$F_{D_{20m/s}} = 126.956 \text{ N}$$

$$F_{D_{30m/s}} = 272.009 \text{ N}$$

$$F_{D_{40m/s}} = 479.672 \text{ N}$$

From the numerical simulations, for the assumed wind speed of 20m/s, 30m/s and 40m/s, the following results for the lateral position are obtained:

The level of pressure on the body of the person can reach up to 1330 Pa and the drag force from the wind can reach the value respectively:

$$F_{D_{20m/s}} = 69.432 \text{ N}$$

$$F_{D_{30m/s}} = 155.612 \text{ N}$$

$$F_{D_{40m/s}} = 277.650 \text{ N}$$

From the results of numerical simulations performed in very scientific program, OpenFOAM version 3.0.x, there are observed the lifting forces, as a consequence of the influence of the wind, but these forces are incomparable to the strength of the drag forces and for this purpose have not been considered.

6. References

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