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THE USE OF MATHEMATICS IN INTENSITY ESTIMATION WIND FOR UNMANNED AIR VEHICLES

Dorin AFANAS, doctor, associate professor
https://orcid.org/0000-0001-7758-943X
Department of Algebra, Geometry and Topology

Abstract. There are various weather risks that the operators of unmanned aerial vehicles must take into account and which depend on the following properties of the atmosphere [1, p. 82]: • Altitude density; • Temperature; • Visibility; • Humidity and saturation; • The wind. In this article we will investigate the estimation of the wind speed at the requested height.
Keywords: unmanned aerial vehicle, wind intensity, height, anemometer, Beaufort scale, functional dependence, formula.

Rezumat. Există diverse riscuri meteo de care operatorii vehiculelor aeriene fără pilot trebuie să ţină cont şi care depind de următoarele proprietăţi ale atmosferei [1, p. 82]: • Densitatea altitudinii; • Temperatura; • Vizibilitatea; • Umiditatea şi saturaţia; • Vântul. În prezentul articol vom cerceta estimarea vitezei vântului la înălțimea solicitată.
Cuvinte cheie: vehicul aerian fără pilot, intensitatea vântului, înălțime, anemometru, scara lui Beaufort, dependență funcțională, formulă.

Due to the small size, during the flight of an unmanned aerial vehicle, an important factor in the stability of its handling is the environmental conditions. One of these factors is the intensity equivalent to the wind speed at the height where this flight will take place. That is why it is very important that before the start of the flight we can estimate the intensity of the wind at that height.

The device with which we can determine the wind speed is called an anemometer (fig. 1). To be able to estimate the wind speed at the required height, the formula is usually used:

$$V_1 = V_0 \cdot \left(\frac{H_1}{H_0} \right)^k ,$$

where V_1 is the wind speed at the requested height;
V_0 – wind speed at the measured height;
H_0 – the height at which the measurements take place (for weather stations, $H_0 = 10\ m$ is considered);
H_1 – requested height;
k is an empirical coefficient and can take one of the following values shown in the table below:

Figure 1. Anemometer

Landscape features	The values of the coefficient *k*
smooth water surface	0
completely open terrain, such as airport runways	0,12
open farmland with some individual buildings	0,245
agricultural land with separate buildings fenced with 8-meter fences at a distance of more than 1250 *m*	0,257
agricultural land with separate buildings and 8 meter fences at a distance of 500 *m*	0,3
agricultural land with groups of buildings fenced at a height of 8 *m* and located at a distance of more than 250 *m* from each other	0,335
villages, small towns, farmland with individual buildings and high fences, forest and rough terrain	0,37
big cities with tall buildings	0,405
very big cities with tall buildings and skyscrapers	0,44

Students should also be trained in visual assessment of wind intensity equivalent to speed at a height of 10 *m*.

For this purpose, Beaufort's scale is presented:

Wind intensity, degrees	The name of the wind	Wind speed, *m/s*	Wind speed, *km/h*	The effects produced by the wind	
				on objects on the earth's surface	on the surface of water bodies
0	calm	0 – 0,2 (0)	0 – 1 (0)	The smoke rises vertically or almost vertically, the leaves of the trees and the flag cloth are motionless	The smooth surface of the water – like a mirror
1	Perceptible wind	0,3 – 1,5 (1)	1 – 5 (3)	Some leaves are moving, the smoke is rising at an angle to the direction of the wind	Light wrinkling of water
2	Light wind	1,6 – 3,3 (3)	6 – 11 (8)	We feel the breeze on our face, the leaves rustle from time to time, the flag cloth moves slightly	Waves appear with not too big crests
3	Weak wind	3,4 – 5,4 (5)	12 – 19 (15)	Small leaves and branches are in continuous motion, grass and seeds are moving with small amplitudes, the flag cloth is in continuous motion	The small crests of the waves begin to roll over, and the foam is not white but glossy like glass
4	Moderate wind	5,5 – 7,9 (7)	20 – 28 (24)	The wind sets the small branches of the trees in motion, raises the dust from the earth's surface, waves	Small waves are well observed, the crests of some of them overturn,

				appear on the surface of the grains and tall grasses, the flag cloth is kept stretched	forming white foam in places
5	Significant wind	8,0 – 10,7 (9)	29 – 38 (33)	The branches and thin stems of the trees are swayed, the web of the great flag is kept stretched	The waves are more pronounced, they form foam everywhere
6	Strong wind	10,8 – 13,8 (12)	39 – 49 (44)	The thick branches of the trees sway, the forest trembles. Tall grass and grain bend to the ground. I want the telegraph conductors	The crests of large waves appear, their foaming winds cover large areas, the wind begins to break the foam from the crests of the waves
7	Very strong wind	13,9 – 17,1 (15)	50 – 61 (55)	Tree trunks sway, thick branches bend. It takes effort to move against the wind. You can hear the whistling of the wind around buildings and stationary objects	The crests outline the large waves formed by the wind, the foam broken by the wind on the crests of the waves spreads in stripes on the shores of the waves
8	Extremely strong wind	17,2 – 20,7 (19)	62 – 74 (68)	Big trees are swayed, thin branches and dry twigs are broken. It becomes very difficult to advance against the wind. The pounding of the shore can be heard at enormous distances	Long strips of foam, torn by the wind, cover the shores of the waves, in some places they merge with their base
9	The storm	20,8 – 24,4 (23)	75 – 88 (81)	Insignificant damage to buildings is reported. Big tree branches are broken. Light objects are moved	The foam covers the coasts of the waves, and their surface becomes white, only in places there are portions without foam
10	Strong storm	24,5 – 28,4 (27)	89 – 102 (95)	Destruction is reported. Some trees can be cleared	The surface of the water is foamy. The air is supersaturated with water powder and spray. Visibility is extremely reduced
11	Violent storm	28,5 – 32,6 (31)	103 – 117 (110)	The wind causes considerable damage, breaks tree trunks	The surface of the water is covered with a dense layer of foam. Visibility

					is considerably reduced
12	Hurricane	Over 33	Over 117	Catastrophic destruction is reported. The trees are cleared	The surface of the water is covered with a dense layer of foam. Visibility is considerably reduced

After the presentation of the above concepts, laboratory works are carried out, which elucidate the functional dependence $V_1 = f(V_0, H_0, H_1)$.

Below are various type dependencies $V_1 = f(V_0, H_0, H_1)$ for completely open terrain such as airport runways.

Estimated wind intensity equivalent to speed at 30 *m* height, based on speed measured at 2 *m* height, for fully open terrain such as airport runways:

V_0, (*m/s*)	H_0, (*m*)	H_1, (*m*)	$\frac{H_1}{H_0}$	*k*	V_1, (*m/s*)
1	2	30	15	0,12	1,38
2	2	30	15	0,12	2,76
3	2	30	15	0,12	4,14
4	2	30	15	0,12	5,52
5	2	30	15	0,12	6,9
6	2	30	15	0,12	8,28
7	2	30	15	0,12	9,66
8	2	30	15	0,12	11,04
9	2	30	15	0,12	12,42
10	2	30	15	0,12	13,8

Estimation of wind intensity equivalent to speed at heights between 10 *m* and 120 *m*, depending on speed $V_0 = 2$ *m/s* measured at a height of 2 *m*, for completely open ground such as airport runways:

V_0, (*m/s*)	H_0, (*m*)	H_1, (*m*)	$\frac{H_1}{H_0}$	*k*	V_1, (*m/s*)
2	2	10	5	0,12	2,42
2	2	20	10	0,12	2,63
2	2	30	15	0,12	2,76
2	2	40	20	0,12	2,86
2	2	50	25	0,12	2,94
2	2	60	30	0,12	3,0
2	2	70	35	0,12	3,06
2	2	80	40	0,12	3,11
2	2	90	45	0,12	3,15
2	2	100	50	0,12	3,2
2	2	110	55	0,12	3,23
2	2	120	60	0,12	3,26

Estimation of the wind intensity equivalent to the speed at heights between 10 *m* and 120 *m*, depending on the speed $V_0 = 4$ *m/s* measured at the height of 2 *m*, for a completely open terrain, such as airport runways:

V_0, (*m/s*)	**H_0, (*m*)**	**H_1, (*m*)**	$\frac{H_1}{H_0}$	***k***	**V_1, (*m/s*)**
4	2	10	5	0,12	4,84
4	2	20	10	0,12	5,26
4	2	30	15	0,12	5,52
4	2	40	20	0,12	5,72
4	2	50	25	0,12	5,88
4	2	60	30	0,12	6,0
4	2	70	35	0,12	6,12
4	2	80	40	0,12	6,22
4	2	90	45	0,12	6,3
4	2	100	50	0,12	6,4
4	2	110	55	0,12	6,46
4	2	120	60	0,12	6,52

In case we want to check the correctness of the formula:

$$V_1 = V_0 \cdot \left(\frac{H_1}{H_0} \right)^k$$

it is important that the measurements taken at the ground surface are taken at the same time as those at the requested height. For this purpose, a device that measures the wind intensity is placed on board the unmanned aerial vehicle, after which the vehicle is maintained at the respective height.

In the absence of such a device, one method would be to travel the same distance at a constant speed by the air vehicle against and in the direction of the wind timing the time, after which we can easily determine the required data. But this method does not always give us accurate data.

Another laboratory work can be done based on the displacement calculation formula:

$$S = \frac{v_A}{nD},$$

where v_A is the velocity of the axial current, and *nD* – the speed of the outer points on the propeller circle.

This being the abscissa of the free movement diagram, we can express it through the functions:

- $K_T(S) = \frac{T}{\rho n^2 D^4}$ – the value of Schube;
- $K_Q(S) = \frac{Q}{\rho n^2 D^5}$ – the torque value;
- $\eta_O(S) = \frac{T v_A}{2\pi n Q} = \frac{S}{2\pi} \cdot \frac{K_T}{K_Q}$ – vane angle measure value.

Conclusions

A small unmanned aerial vehicle is not recommended for flight:

- when the wind is strong;
- when the speed of the gusts can exceed the maximum speed of the unmanned aerial vehicle;
- less than 40 *km* from a storm, because hail can fall a long way from storm clouds
- near tornadoes;
- during freezing rain, which are the most unfavorable weather conditions. This is explained by the fact that ice can be stored on the surface of the unmanned aerial vehicle (icing) and therefore can change the aerodynamic characteristics of the propellers;
- in foggy weather, because it is more difficult to maintain visual contact with the unmanned aerial vehicle.

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