Optimization of AirHES mesh

(c) Andrew Kazantsev, inventor of Air HES, andrew@airhes.com

Abstract

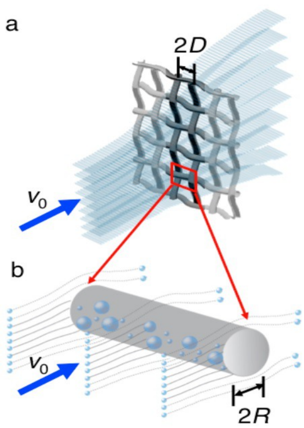
Surfaces of AirHES for receiving moisture (kites, sails, meshes) must perform several conflicting functions, these functions may vary for different designs of AirHES. In this article, I will continue to consider kite design, which was discussed in a previous article about the AirHES blow-by [1], where design calculations are based on aerodynamic coefficients obtained experimentally for the flow around an impenetrable flat plate. Since such a surface is hardly capable of receiving condensed moisture, then there is a problem to find an optimal level of permeability which will provide both acceptable capture of the drops and still sufficiently good aerodynamics to create a working prototype of AirHES.

Mesh simulation

Since I have no way to carry out laboratory experiments, I must first find and substantiate the possibility of theoretical and numerical simulation of such problem. I'll start from the well-known methodological studies to optimize meshes for collecting fog [2][3] performed at the Massachusetts Institute of Technology (MIT), as well as from previous field studies on the effectiveness of existing meshes for collecting fog [4][5][6].

Thus, this work will be divided into several stages:

1. selection of optimal parameters for numerical modeling (dimension, accuracy) for a sufficient correlation with the MIT research [2][3].
2. analysis of the results for compliance with field trials [4][5][6] and explanation of the causes of potential nonconformities.
3. obtaining numerical simulation data on aerodynamics and efficiency of the proposed kite surfaces by varying the parameters (thickness of yarn, weaving step, angle of attack, accuracy) and optimization of the selected criteria.
4. example of calculation of a real fabric for kite with the function of collecting condensed moisture.



For numerical simulation has been used a great CFD program XFlow. Wind tunnel, the location and mesh size correspond to the MIT lab setup described and shown in [2][3]. Initial calculations were performed under the same conditions: the flow velocity $v = 2\ m/s$ with radius of fog drops $r = 3\ \mu m$. All geometry of mesh is described using dimensional and dimensionless parameters adopted in the MIT and shown in the figure. From there we take also the parameters of tested meshes.

Example of three-dimensional calculation for the thinnest mesh $D^* = (R+D)/R \sim 3.5$, $R^* = r/R \sim 0.024$ ($\eta \sim 12\ \%$), which corresponds to the yarn radius $R = 127\ \mu m$ and weaving step $S = 2(R+D) = 889\ \mu m$, you can see in this video, which reproduces the movement of droplets through a mesh.

The results of some numerical three-dimensional calculations can be found in the following table, which shows the aerodynamic coefficient (**C_x**) gotten by CFD simulation and the proportion of drops passed the mesh (**P**).

C_x	P, %	η, %	X, %	η / X	Condition
3.012	85.88	11.14	14.12	0.79	3D0(156)O
3.012	90.16	11.14	9.84	1.13	3D0(156)[]
3.995	88.40	11.14	11.60	0.96	3D2(19)O
3.995	91.24	11.14	8.76	1.27	3D2(19)[]

Since XFlow has no mechanism of adhesion of the particles, I conventionally believed that a drop "stuck" in the mesh if its speed was less than 1 µm/s (in this case in this model, such drop "ejected" from the flow by using a huge lateral acceleration). Accordingly, the share of "stuck" drops (**X**) for the three-dimensional numerical model is (100 - P), and the magnitude of deviation from the calculated efficiency (**η**) on the model of MIT, is a ratio (**η/X**).

Condition of calculations in the table shown by code, where 3D is "three-dimensional", followed by a digit (here, 0 or 2) - double resolution limit of the computational grid (here, respectively, 156 and 19 µm) and "emitter" of drops: a circle (O) to the experimental model MIT or square ([]) for the calculation model of MIT. This code has a link on the appropriate image (screenshot XFlow for this calculation).

From this table it is clear that such numerical simulation gives results quite consistent with the calculated and experimental data MIT study [2][3].

Unfortunately, the three-dimensional calculations on my home computer can take weeks, making it impossible to carry out the optimization within a reasonable time. Therefore, further numerical experiments I carried out by using a two-dimensional approximation.

Now we can proceed to analyze the impact of the calculation accuracy on the results. The following table shows the two-dimensional calculations for the same MIT mesh with different resolutions computational grid. It should be noted that the percentage of "stuck" drops (initially in a one-dimensional model) is here multiplied by two-dimensional geometric factor 2(1-1/(2D*)), the same way as the coefficient SC in MIT study [2].

R, µm	S, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
127	889	1.342	92.80	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	12.34	0.90	HD0(156)
127	889	1.052	93.20	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	11.66	0.96	HD1(78)
127	889	1.012	94.00	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	10.29	1.08	HD2(19)
127	889	0.917	94.20	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	9.94	1.12	HD4(5)

It can be seen that the resolution of the computational grid for the MIT mesh does not strongly affect the capture of droplets and can be limited to a minimum to speed up calculations. Also I checked the effect of the accuracy of the calculations for other MIT meshes.

R, µm	S, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
127	889	1.342	92.80	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	12.34	0.90	HD0(156)
172	1204	1.083	94.30	0.017	3.50	0.49	2.24	0.21	1.37	0.47	9.58	9.77	0.98	HD0(156)
229	1603	0.879	94.40	0.013	3.50	0.49	2.24	0.21	1.03	0.40	8.14	9.60	0.85	HD0(156)
292	2044	0.855	95.30	0.010	3.50	0.49	2.24	0.21	0.81	0.34	6.98	8.06	0.87	HD0(156)
445	3115	0.581	96.10	0.007	3.50	0.49	2.24	0.21	0.53	0.25	5.18	6.69	0.78	HD0(156)

R, µm	S, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
127	889	1.052	93.20	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	11.66	0.96	HD1(78)
172	1204	0.870	95.70	0.017	3.50	0.49	2.24	0.21	1.37	0.47	9.58	7.37	1.30	HD1(78)
229	1603	0.762	98.20	0.013	3.50	0.49	2.24	0.21	1.03	0.40	8.14	3.09	2.64	HD1(78)
292	2044	0.709	97.60	0.010	3.50	0.49	2.24	0.21	0.81	0.34	6.98	4.11	1.70	HD1(78)
445	3115	0.557	99.70	0.007	3.50	0.49	2.24	0.21	0.53	0.25	5.18	0.51	10.08	HD1(78)

R, µm	S, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
127	889	1.012	94.00	0.024	3.50	0.49	2.24	0.21	1.85	0.54	11.14	10.29	1.08	HD2(19)
172	1204	0.758	97.10	0.017	3.50	0.49	2.24	0.21	1.37	0.47	9.58	4.97	1.93	HD2(19)
229	1603	0.688	98.30	0.013	3.50	0.49	2.24	0.21	1.03	0.40	8.14	2.91	2.79	HD2(19)
292	2044	0.641	99.10	0.010	3.50	0.49	2.24	0.21	0.81	0.34	6.98	1.54	4.52	HD2(19)
445	3115	0.518	99.70	0.007	3.50	0.49	2.24	0.21	0.53	0.25	5.18	0.51	10.08	HD2(19)

It is surprising, but from the tables we can see that the too high resolution of computational grid leads to an increase in errors for sparse meshes MIT. The most appropriate calculations for all meshes MIT correspond to the minimum resolution of the computational grid, roughly corresponding to the geometry of the thinnest mesh MIT. Physically, it can be interpreted as that the surface of the real meshes MIT has irregularities of the same order (which is not taken into account when modeling the "ideal" surface meshes with higher resolution).

Similar calculations for Raschel meshes with the MIT parameters *D* ~ 5.1, R* ~ 0.005 (η ~ 4.8 %)*, that used in the field conditions by volunteers of FogQuest, are presented in the following table. Note that since such meshes are predominantly linear (like fence) and not cross (woven) geometry, the proportion of "stuck" drops are here **not multiplied** by a two-dimensional geometric factor of 2(1-1/(2D*)).

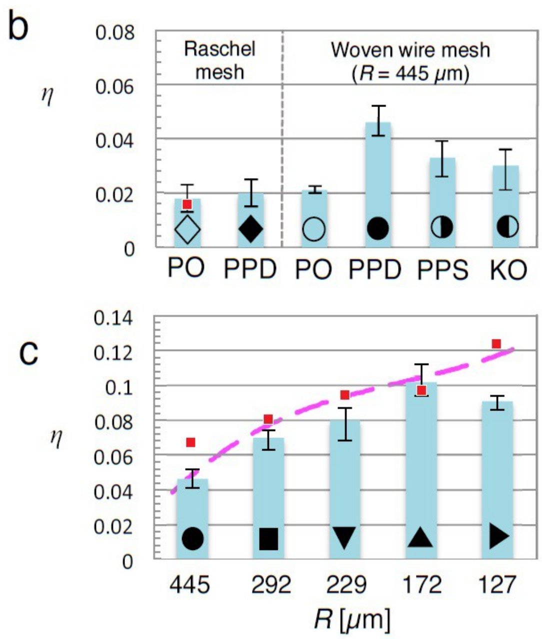
R, µm	S, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
600	6120	0.351	98.50	0.005	5.10	0.35	1.09	0.18	0.39	0.20	3.60	1.50	2.40	HD0(156)
600	3060	0.795	97.20	0.005	2.55	0.63	5.37	0.20	0.39	0.20	4.02	2.80	1.44	HD0(156)

The first line corresponds to a one-layered mesh used in the experiments, MIT, and the value obtained for the efficiency it is much closer to the experimental value than the corresponding values calculated by the method of MIT. It can be assumed that the large discrepancy with the calculation may be caused by incorrect use of the parameter SC by the method of MIT with woven geometry, while the real mesh in this case has an elongated triangular weaving that is closer to the one-dimensional fence. The second line corresponds to a double-layered mesh, which is just really used in the field conditions and for which values correspond better to calculation of MIT, because a crossing of two layer of triangular meshes is much closer to the square weaving in the wind projection.

Thus the use of two-dimensional numerical CFD simulation with the value of the computational cell ~ 50-80 µm gives quite an adequate description of the experimental and calculated data presented in the MIT study [2][3].

Analysis of field trials

Consider first the compliance of calculations and experiments in the original paper MIT [2][3]. On this chart taken from [2], I posted the results of numerical CFD simulation for the same conditions (red square). The figure shows that the CFD simulation gives similar values and similar behavior of chart.



At the same time, it appears that in MIT study the predicted calculated efficiency is overestimated in comparison with the experimental data. So for the thinnest mesh $D^* \sim 3.5$, $R^* \sim 0.024$ the efficiency is $\eta \sim 12$ %, although the actual calculation by the method of MIT gives the value ~ 11.14 %. For one-layered Raschel mesh with $D^* \sim 5.1$, $R^* \sim 0.005$ the efficiency is $\eta \sim 4.8$ %, although the actual calculation by MIT method gives only ~ 3.6 %, and the experiment on this graph yields the value ~ 1.7 %. The even greater difference is shown in the figure S6 in [3]. There predicted efficiency for the MIT mesh with R = 172 μm for our calculation mode 3 is ~ 14 %, whereas the calculation according to the MIT method gives ~ 9.58% (and ~ 10% shows the experiment), while for a double-layered Raschel mesh the predicted efficiency is ~ 6 %, whereas the calculation gives ~ 4 %.

We now consider the similar calculations and CFD simulation for more important mode for AirHES (**cloud**) with value of flow velocity $v = 8$ *m/s* and with a droplet of radius $r = 6$ *μm*. On already mentioned chart S6 in [3] the predicted efficiency for MIT mesh with R = 172 μm for this calculation mode 6 is ~ 21 % (although the calculation gives ~ 19.21 %), and for double-layered Raschel mesh the effectiveness is ~ 16 %. My calculations are presented in the following table.

R, μm	S, μm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	η/X	Condition
127	889	1.121	74.80	0.047	3.50	0.49	2.24	0.21	29.64	0.95	19.55	43.20	0.45	HD0(156)
172	1204	0.893	77.40	0.035	3.50	0.49	2.24	0.21	21.89	0.93	19.21	38.74	0.50	HD0(156)
229	1603	0.739	79.30	0.026	3.50	0.49	2.24	0.21	16.44	0.91	18.79	35.49	0.53	HD0(156)
292	2044	0.802	82.90	0.021	3.50	0.49	2.24	0.21	12.89	0.89	18.35	29.31	0.63	HD0(156)
445	3115	0.536	80.00	0.013	3.50	0.49	2.24	0.21	8.46	0.84	17.36	34.29	0.51	HD0(156)
600	6120	0.351	90.50	0.010	5.10	0.35	1.09	0.18	6.27	0.80	14.41	9.50	1.52	HD0(156)
600	3060	0.775	78.80	0.010	2.55	0.63	5.37	0.20	6.27	0.80	16.09	21.20	0.76	HD0(156)

These calculations were carried out for other resolutions of computational grid, but the result remained close to the effectiveness shown above. The table shows that the efficiency for MIT meshes in CFD simulation has increased approximately twice compared with the calculation by the method of MIT.

Let us compare the CFD simulation and calculation by the method of MIT with data for double-layered Raschel mesh shown in [4][5][6], which should correlate with the real values obtained in the field conditions.

In [4] we can find only estimates for maximum aerodynamic efficiency factor ~ 20-24.5 %, which is correlated with both η_a parameter in the calculations by the method of MIT, so with efficiency in CFD simulating double-layered Raschel mesh for the conditions clouds or high-mountain fog.

In [5] we can find a lot of interesting data on high-mountain fog, but unfortunately they are not compared with the conditions for the LWC and wind speed. The only thing that is important for the AirHES idea is given the maximum values of 160-300 L/m^2/day, which allow to assess the level of performance for feasibility study [7].

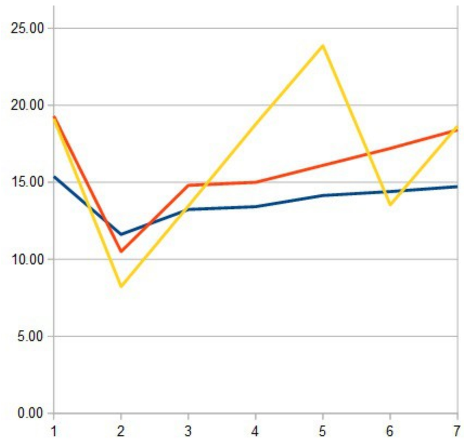
The most important data are provided in the work [6]. There are given actual measurement data required values: LWC, wind speed, measured performance, droplet size and concentration. These data we can use in our calculations by the method of MIT or CFD simulation to demonstrate the suitability of the numerical simulation. Combining in [6] the Tables 1 and 2, we can obtain the following table the initial data.

LWC front, g/m^3	Wind, (V), m/s	Flow rate measured, cm^3/s (or g/s)	*Real effectiveness (E), %*	MVD, (D), µm	Concentration, cm^{-3}	*Recalculated LWC, g/m^3*
0.31	6.50	18.50	*19.13*	12.0	231	*0.21*
0.68	1.90	5.10	*8.22*	14.4	477	*0.75*
0.72	2.60	12.10	*13.47*	14.6	435	*0.71*
0.73	2.60	17.10	*18.77*	14.9	419	*0.73*
0.66	3.20	24.20	*23.87*	14.6	408	*0.66*
0.73	3.10	14.70	*13.53*	15.3	384	*0.72*
0.68	3.40	20.70	*18.65*	15.2	366	*0.67*

The results of the simulation with indicated wind speeds (V), droplet size (D) and real efficiency (E) for a double-layered Raschel mesh are presented in the following table:

V, m/s	D, µm	C_x	P, %	R*	D*	SC	C_0	η_a	St	η_d	η,%	X, %	E, %	Condition
6.50	12.0	0.793	80.70	0.010	2.55	0.63	5.37	0.20	5.10	0.76	15.38	19.30	19.13	HD0(156)
1.90	14.4	0.783	89.50	0.012	2.55	0.63	5.37	0.20	2.15	0.58	11.62	10.50	8.22	HD0(156)
2.60	14.6	0.817	85.20	0.012	2.55	0.63	5.37	0.20	3.02	0.66	13.23	14.80	13.47	HD0(156)
2.60	14.9	0.817	85.00	0.012	2.55	0.63	5.37	0.20	3.14	0.67	13.42	15.00	18.77	HD0(156)
3.20	14.6	0.845	83.90	0.012	2.55	0.63	5.37	0.20	3.72	0.70	14.14	16.10	23.87	HD0(156)
3.10	15.3	0.819	82.80	0.013	2.55	0.63	5.37	0.20	3.95	0.72	14.40	17.20	13.53	HD0(156)
3.40	15.2	0.813	81.60	0.013	2.55	0.63	5.37	0.20	4.28	0.73	14.72	18.40	18.65	HD0(156)

The graph clearly shows that the measured values of the real effectiveness of meshes generally correspond to both the calculations by the method of MIT, and CFD simulation. For us, this means that the proposed method of CFD simulation can be quite applicable to other meshes or fabrics for creating AirHES kite type and calculating their aerodynamics and efficiency.



It is necessary to make some additional comments on the analysis of data in [6]. If to recount LWC before mesh by droplet size (MVD) and concentrations, it can be seen a serious mismatch with the initial measured value of LWC for some measurements. Such mismatches are shown by colored markers in the original data table above.

Another important remark is due to the big (~ 2.9-fold) deviation between the calculated efficiency obtained by direct measurements of LWC in front and behind the mesh, and the actual performance obtained by the measurement of the collected water. Since the numerical simulation showed quite reliable values for real effectiveness, I would venture to guess that it LWC value behind the mesh and made this stable deviation. I can not say for sure, but I assume that the device FSSP, designed to calculate and analyze the spectrum of particles in a uniform flow or still air, mistakenly could greatly reduce the number of particles behind mesh due to its specific design. Air intake in the device for particle counting is not designed for huge turbulence which is formed behind the mesh (see any example of CFD simulation for double-layered mesh). This turbulence means that water droplets that have passed the mesh moving with high transverse velocities and the device pipe, placed on the main flow, actually receives only a fraction of the particles of the chamfered flow that actually by entering with angle greatly reduces its cross section, and furthermore the drops are more likely to fall on the wall of the pipe instead of the tested flow. This is indirectly confirmed by the fact that the measured efficiency (and in fact, the value of this deviation) according to Table 1, was greater for the shorter test (flow did not have time to stabilize) and for higher speed of the original flow (and hence the greater turbulence at flow behind the mesh).

So that the efficiency of meshes ~ 50-70%, that was repeated many times from one publication to another, really is not true for the given conditions.

Aerodynamics and efficiency of kite

Let us now consider our main task - modeling kite surfaces and optimizing the terms of aerodynamics and efficiency. Obviously, I do not claim to solve this problem, but only demonstrate a technique that can be used for further research. Consider the most typical kite angle of attack (~ 15°), and will vary dimensionless parameters of mesh R* and D* under typical conditions of low cloud or high-mountain fog *v = 8 m/s* and *r = 6 µm*. Also the conditional efficiency of drop capture will be evaluated by flow from conditional source with the same wind projection that the inclined mesh-kite.

R*	D*	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.10	2.500	60.00	300.00	0.312	0.104	49.60	50.40	0.33	18.43	16.80	HD1(78)
0.10	2.000	60.00	240.00	0.294	0.316	57.60	42.40	1.07	47.07	45.57	HD1(78)
0.10	1.875	60.00	225.00	0.278	0.395	62.40	37.60	1.42	54.86	53.42	HD1(78)
0.10	1.750	60.00	210.00	0.261	0.522	71.20	28.80	2.00	63.43	57.60	HD1(78)
0.10	1.625	60.00	195.00	0.270	0.736	79.50	20.50	2.73	69.85	55.88	HD1(78)
0.10	1.500	60.00	180.00	0.334	1.014	81.80	18.20	3.04	71.77	55.25	HD1(78)
0.10	1.250	60.00	150.00	0.261	0.865	90.70	9.30	3.31	73.21	30.82	HD1(78)
0.10	1.000	60.00	120.00	0.208	0.743	99.00	1.00	3.57	74.36	3.57	HD1(78)

Here (L/D) = C_y/C_x – aerodynamic quality, which characterizes the ratio of lift and drift of the kite and the angle of inclination of kite rope (A) = *atan* (L/D).

Should specify that the two-dimensional simulation cannot adequately describe the aerodynamics of a mesh surface, ie the aerodynamic coefficients shall be checked by using three-dimensional modeling and experimentally. The same applies to drop capture because it is unclear what the geometric factor should be used here. Nevertheless, it is obvious that the actual values are proportional to (or at least correlated) the values, that we obtained in this simulation. Because we may use them in calculation of the relative optimization criterion.

Optimization criteria depend on the tasks that AirHES must solve and will be different, of course, for the giant power plant or for portative means of escape for getting water on the kite basis. In this case, I have conventionally taken as the optimization criterion the value of X*(L/D), that allows to maximize the conditional water supply from a maximum altitude with minimal drift. It is clearly seen that the criterion has a clear maximum for each given geometry. By changing the geometry, we can continue to optimize.

R*	D*	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.01	2.500	600.00	3000.00	0.348	0.125	36.10	63.90	0.36	19.76	22.95	HD0(156)
0.01	2.000	600.00	2400.00	0.356	0.157	47.00	53.00	0.44	23.80	23.37	HD0(156)
0.01	1.750	600.00	2100.00	0.376	0.106	50.00	50.00	0.28	15.74	14.10	HD0(156)
0.01	1.500	600.00	1800.00	0.399	0.063	51.90	48.10	0.16	8.97	7.59	HD0(156)
0.01	1.375	600.00	1650.00	0.378	0.247	51.40	48.60	0.65	33.16	31.76	HD0(156)
0.01	1.250	600.00	1500.00	0.300	0.481	70.20	29.80	1.60	58.05	47.78	HD0(156)
0.01	1.125	600.00	1350.00	0.331	1.106	93.20	6.80	3.34	73.34	22.72	HD0(156)
0.01	1.000	600.00	1200.00	0.290	0.995	96.20	3.80	3.43	73.75	13.04	HD0(156)

R*	D*	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.05	2.500	120.00	600.00	0.327	0.097	47.00	53.00	0.30	16.52	15.72	HD0(156)
0.05	2.000	120.00	480.00	0.307	0.270	55.30	44.70	0.88	41.33	39.31	HD0(156)
0.05	1.750	120.00	420.00	0.273	0.481	69.20	30.80	1.76	60.42	54.27	HD0(156)
0.05	1.625	120.00	390.00	0.271	0.704	77.70	22.30	2.60	68.95	57.93	HD0(156)
0.05	1.500	120.00	360.00	0.299	0.883	82.10	17.90	2.95	71.29	52.86	HD0(156)
0.05	1.375	120.00	330.00	0.256	0.757	85.40	14.60	2.96	71.32	43.17	HD0(156)
0.05	1.250	120.00	300.00	0.324	1.118	89.60	10.40	3.45	73.84	35.89	HD0(156)
0.05	1.000	120.00	240.00	0.254	0.859	98.40	1.60	3.38	73.53	5.41	HD0(156)

R*	D*	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.05	2.500	120.00	600.00	0.328	0.071	44.80	55.20	0.22	12.21	11.95	HD1(78)
0.05	2.000	120.00	480.00	0.342	0.074	51.10	48.90	0.22	12.21	10.58	HD1(78)
0.05	1.750	120.00	420.00	0.313	0.223	53.30	46.70	0.71	35.47	33.27	HD1(78)
0.05	1.625	120.00	390.00	0.297	0.328	59.30	40.70	1.10	47.84	44.95	HD1(78)
0.05	1.500	120.00	360.00	0.267	0.463	68.50	31.50	1.73	60.03	54.62	HD1(78)
0.05	1.375	120.00	330.00	0.276	0.827	85.10	14.90	3.00	71.54	44.65	HD1(78)
0.05	1.250	120.00	300.00	0.297	1.008	90.20	9.80	3.39	73.58	33.26	HD1(78)
0.05	1.000	120.00	240.00	0.196	0.649	98.70	1.30	3.31	73.20	4.30	HD1(78)

R*	D*	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.05	2.500	120.00	600.00	0.314	0.109	41.80	58.20	0.35	19.14	20.20	HD2(19)
0.05	2.000	120.00	480.00	0.352	0.073	45.80	54.20	0.21	11.72	11.24	HD2(19)
0.05	1.750	120.00	420.00	0.340	0.062	49.30	50.70	0.18	10.33	9.25	HD2(19)
0.05	1.625	120.00	390.00	0.327	0.128	51.60	48.40	0.39	21.38	18.95	HD2(19)
0.05	1.500	120.00	360.00	0.322	0.258	53.80	46.20	0.80	38.70	37.02	HD2(19)
0.05	1.375	120.00	330.00	0.297	0.494	65.10	34.90	1.66	58.99	58.05	HD2(19)
0.05	1.250	120.00	300.00	0.277	0.771	81.90	18.10	2.78	70.24	50.38	HD2(19)
0.05	1.000	120.00	240.00	0.218	0.771	98.40	1.60	3.54	74.21	5.66	HD2(19)

It is seen that the values of C_y and X are also strongly dependent on the accuracy of calculations. At the same time it also moves the conditional optimum of target function.

Interestingly, the last line in each such calculation corresponds to a substantially continuous surface, corresponding approximately to a flat plate with high AR, and can be compared to those values obtained with experimental data [1].

From all the above, we can get the interesting practical result, which relates to possible modernization of highland fog collection systems. Existing fog collectors are quite expensive, because they use the two pillars (posts) between which stretched mesh. These supports should be fixed by cables, and the process is quite time-consuming installation and should always be carried out in the field conditions in the mountains. In addition, the fixed position of mesh is not always optimal because the wind can change the direction.

In this sense, fog collector, built on the basis of a multi-tier kite would give a lot of benefits. Such kite collectors could be mass produced in advance in workshops by industrial way and transported to the installation site in the folded compact and light form. When mounting in the mountains it would be necessary to only one ground-support anchor. They automatically have always supported its optimal location against the wind, and in addition, they themselves could climb much higher and capture a greater flow of fog or clouds. For automatic opening in the wind they would simply have slight special wings (valves) on the top tier of the kite. In addition, these almost ground kites could have a low aerodynamic quality (ie the rope angle only ~ 20°), but a very high efficiency of water capture ~ 60 %.

Calculation of a real fabric for kite

In practice, we often can not order the fabric or mesh with pre-calculated optimal properties. Therefore, vice versa we must choose the existing fabric with the necessary characteristics for it to perform the necessary calculations of aerodynamics and efficiency.

Take for example the kite fabric:

TX-NY008 Taffeta 20D*20D 400T 36-42 gsm 58/60" Nylon Rip-stop Waterproof fabric

It is important for us to extract information on the physical parameters R and S, which we used in our earlier simulating. The main parameters of fabric - a structure of yarn (yarn count = 20D*20D) and the density of the weave (thread count = 400 TPI).

The first parameter indicates that the thread (yarn) layed of the two fibers, each at 20 (Denier), in terms of giving the fiber diameter $(20D/9000/1.15/0.7855)^{1/2}$ = 49.6 µm, where 1.15 g/cm^3 –

density of nylon. Since it is the double thread, then conditionally its radius is R ~ 50 µm.

The second parameter is the total number of yarns (in both directions) in a square with a side of 1 inch (2.54 cm). Accordingly, the step of weaving is S = 25400/(400T/2) = 127 µm.

In our case it is necessary to order the fabric without impregnation and without waterproof coating.

So, after creating a model of the fabric, we can simulate its aerodynamics and efficiency. First, make a calculation with the calculated grid of the same order as the holes in the fabric (19 µm).

t, sec	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.010	50.00	127.00	0.277	0.971	90.90	9.10	3.51	74.08	31.90	HD2(19)

After increasing the accuracy of up to 5 µm, we obtain a calculation for the whole week... Below are the results of calculations of the dynamics, through every msec.

t, sec	R, µm	S, µm	C_x	C_y	P, %	X, %	L/D	A, °	X*(L/D)	Condition
0.001	50.00	127.00	0.332	0.861	71.00	29.00	2.59	68.91	75.21	HD4(5)
0.002	50.00	127.00	0.324	0.864	72.00	28.00	2.67	69.44	74.67	HD4(5)
0.003	50.00	127.00	0.296	0.769	74.00	26.00	2.60	68.95	67.55	HD4(5)
0.004	50.00	127.00	0.302	0.782	75.00	25.00	2.59	68.88	64.74	HD4(5)
0.005	50.00	127.00	0.328	0.858	71.00	29.00	2.62	69.08	75.86	HD4(5)
0.006	50.00	127.00	0.333	0.864	73.00	27.00	2.59	68.92	70.05	HD4(5)
0.007	50.00	127.00	0.287	0.708	76.00	24.00	2.47	67.93	59.21	HD4(5)
0.008	50.00	127.00	0.316	0.807	74.00	26.00	2.55	68.62	66.40	HD4(5)
0.009	50.00	127.00	0.326	0.829	74.00	26.00	2.54	68.53	66.12	HD4(5)
0.010	50.00	127.00	0.272	0.672	76.60	23.40	2.47	67.96	57.81	HD4(5)

Unfortunately, the three-dimensional calculation on my computer is completely impossible, so that the actual values will be available only experimentally to correlate and correct the two-dimensional CFD simulations.

So, I have shown that the problem can be solved in principle by numerical simulation. Moreover, on the basis of this approach, we can create high-altitude kites that can collect water from the low clouds that (in contrast to the existing collection systems fog) can universally operate almost worldwide and solve one of the major problems of the Third World - the lack of high-quality drinking water. Even without energy function of AirHES, such kites can be used as emergency rescue equipment, as well as to supply the fresh water in many uninhabited areas, such as, for example, small islands in the ocean, where there are no high mountains and its own sources of fresh water.

Appendix: CFD calculations for a double-layered Raschel mesh

V, m/s	Attack, °	C_x	C_y^*	P, %	X, %	Condition
5.000	90.000	0.834	*0.188*	82.600	17.400	HD0(156)
10.000	90.000	0.772	*0.006*	77.400	22.600	HD0(156)
15.000	90.000	0.699	*0.130*	73.100	26.900	HD0(156)
20.000	90.000	0.664	*-0.007*	71.900	28.100	HD0(156)
5.000	15.000	0.364	*0.227*	53.800	46.200	HD0(156)
10.000	15.000	0.320	*0.101*	15.400	84.600	HD0(156)
15.000	15.000	0.424	*-0.081*	23.500	76.500	HD0(156)
20.000	15.000	0.346	*0.040*	16.200	83.800	HD0(156)
5.000	30.000	0.671	*0.021*	77.300	22.700	HD0(156)
10.000	30.000	0.600	*-0.225*	74.700	25.300	HD0(156)
15.000	30.000	0.511	*0.197*	66.400	33.600	HD0(156)
20.000	30.000	0.531	*-0.065*	63.600	36.400	HD0(156)
5.000	45.000	0.731	*0.264*	71.000	29.000	HD0(156)
10.000	45.000	0.698	*-0.135*	60.100	39.900	HD0(156)
15.000	45.000	0.551	*0.139*	52.900	47.100	HD0(156)
20.000	45.000	0.609	*-0.127*	52.600	47.400	HD0(156)
5.000	60.000	0.767	*-0.028*	88.800	11.200	HD0(156)
10.000	60.000	0.687	*-0.168*	84.600	15.400	HD0(156)
15.000	60.000	0.687	*-0.063*	81.000	19.000	HD0(156)
20.000	60.000	0.566	*-0.096*	78.800	21.200	HD0(156)
5.000	75.000	0.715	*-0.046*	93.000	7.000	HD0(156)
10.000	75.000	0.694	*-0.096*	90.100	9.900	HD0(156)
15.000	75.000	0.665	*-0.005*	90.100	9.900	HD0(156)
20.000	75.000	0.593	*-0.016*	89.900	10.100	HD0(156)
5.000	90.000	0.784	*0.046*	82.700	17.300	HD0(156)
10.000	90.000	0.745	*-0.187*	74.000	26.000	HD0(156)
15.000	90.000	0.682	*-0.036*	71.100	28.900	HD0(156)
20.000	90.000	0.540	*-0.039*	71.600	28.400	HD0(156)

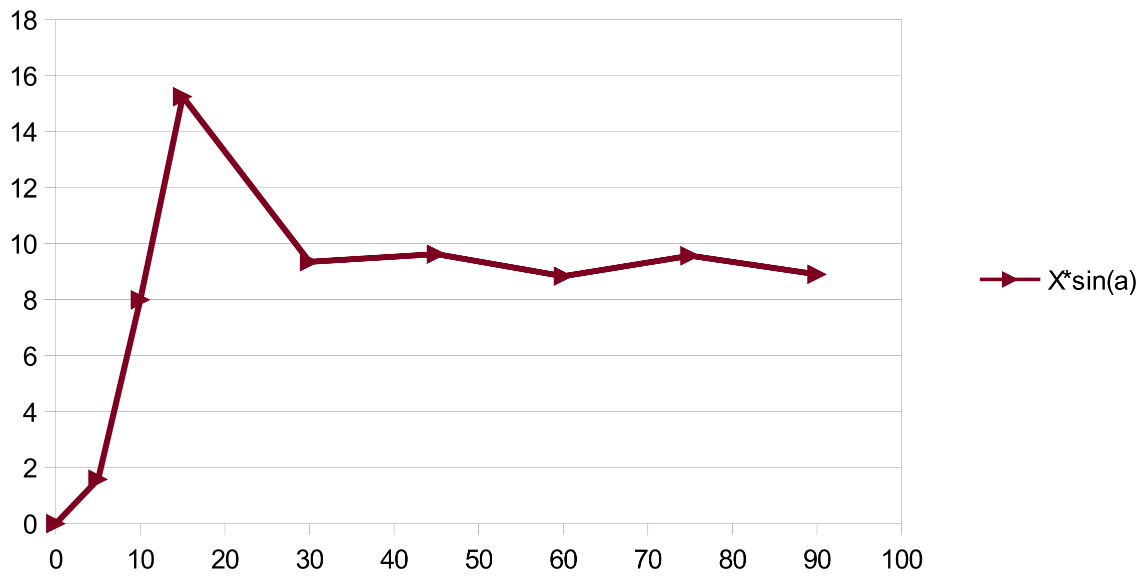
C_y^* is not a valid value, as the graphs show the lack of asymptotic stability of this parameter for the mesh. It is recommended to use a zero value. Calculations are performed for micro drops of a cloud with a radius of 6 μm.

CFD calculations for a single-layered Raschel mesh (V = 8 m/s)

Attack, a, °	C_x	C_y^*	P, %	X, %	X*sin(a)	Condition
0.0	0.164	*0.068*	*0.000*	*100.000*	*0.000*	HD0(156)
5.0	0.136	*0.036*	81.900	18.100	1.578	HD0(156)
10.0	0.160	*0.070*	54.000	46.000	7.988	HD0(156)
15.0	0.186	*0.092*	41.100	58.900	15.244	HD0(156)
30.0	0.290	*-0.042*	81.300	18.700	9.350	HD0(156)
45.0	0.317	*0.005*	86.400	13.600	9.617	HD0(156)
60.0	0.328	*0.066*	89.800	10.200	8.833	HD0(156)
75.0	0.371	*-0.068*	90.100	9.900	9.563	HD0(156)
90.0	0.351	*-0.040*	91.100	8.900	8.900	HD0(156)

C_y^* is not a valid value, as the graphs show the lack of asymptotic stability of this parameter for the mesh. It is recommended to use a zero value. Calculations are performed for micro drops of a cloud with a radius of 6 µm.

The graph below shows that as long as there is no overlapping of the mesh elements (for sufficiently large angles of attack, > 15°) the mesh efficiency in the wind projection ***X*sin(a)*** is practically constant, since the mesh elements are practically aerodynamically independent.

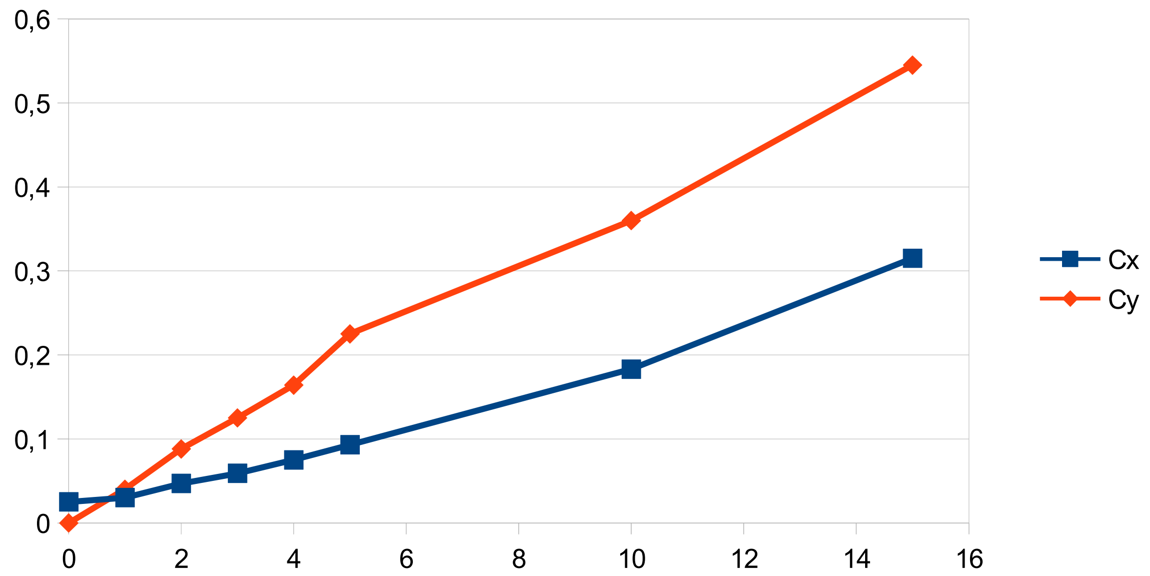


CFD calculations of permeable kite fabric (sail) with V = 8 m/s

R* = 0.05	D* = 1.250	R = 120.00 µm	S = 300.00 µm

Attack, a, °	C_x	C_y	P, %	X, %	Condition
0.0	0.025	0.000	*0.000*	*100.000*	HD2(19)
1.0	0.030	0.040	54.000	46.000	HD2(19)
2.0	0.047	0.088	51.900	48.100	HD2(19)
3.0	0.059	0.125	55.500	44.500	HD2(19)
4.0	0.075	0.164	55.200	44.800	HD2(19)
5.0	0.093	0.225	56.300	43.700	HD2(19)
10.0	0.183	0.360	60.800	39.200	HD2(19)
15.0	0.315	0.545	62.200	37.800	HD2(19)

The graph below shows that the aerodynamic coefficients can be approximated by the dependences $Cx \sim Cx0 + Kx*a^2$ and $Cy \sim Ky*a$ for small angles of attack, and the efficiency of ***X*** can be approximately assumed constant.



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