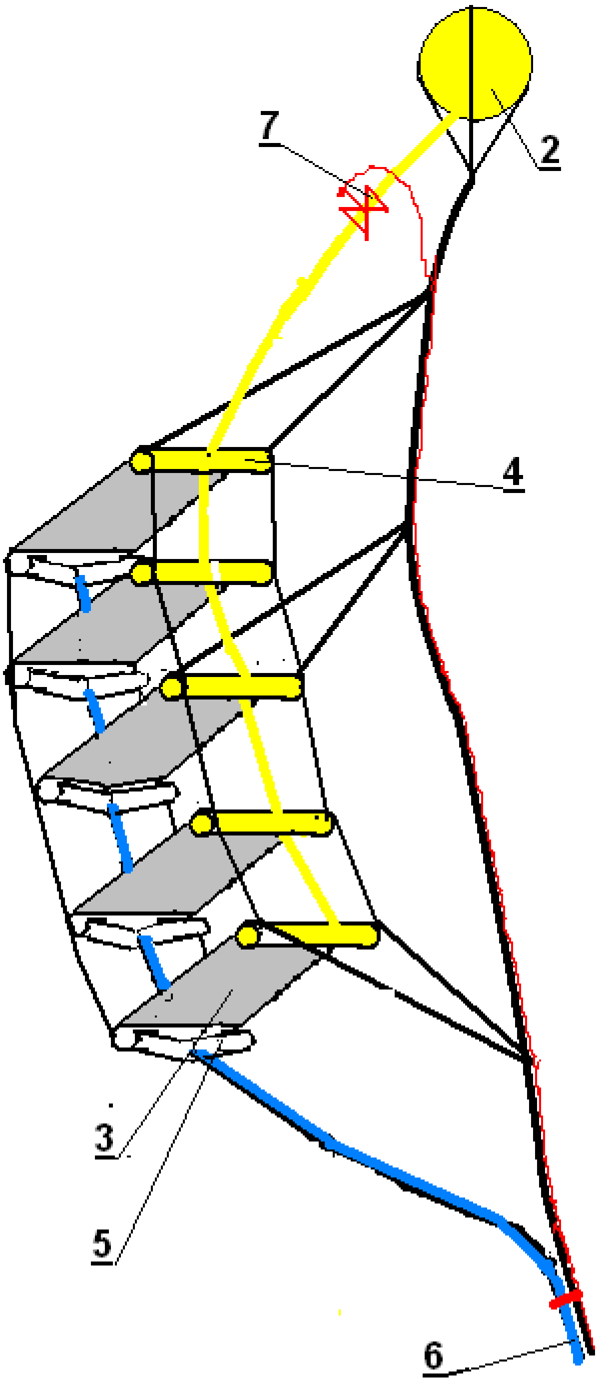
Appendix: Example of calculation for the pilot unit with power of 27 kW



Construction and energy calculations

The balloon 2 rises to level of cloud one or more meshes 3 with total area A of about 15000 m2 (most appropriate variant is 5 meshes with size of 100 m * 30 m). Meshes are deployed on the ground or better on altitude by filling the gas cylinders 4 attached to the upper edges of the mesh. These cylinders are connected to the balloon 2 by using hoses with the pinch valve 7. The lifting force of the cylinders also helps to maintain the upper edge of the mesh. Supercooled cloud moisture is concentrated and deposited on the surface of meshes. Under the influence of gravity and wind the water flows into the collector (the gutter 5), fixed to the bottom edge of the mesh. The trough has a curved shape to drain the water down to the middle of it. The collected water is drained from all the meshes through the holes in the centers of the gutters into the hose 6. According to published data for the fog collectors, such a way to collect moisture by using meshes provides from 2 to 300 liters of water per day from m2. Let's use for calculation a pretty conservative estimate q = 10 l/m2/day. Thus, from these meshes the following average flow of water can be collected

Q = q*A =10*15000 = 150000 l/day = 6.25 m3/h (1)

With an average altitude of the clouds H = 3000 m, this has the potential power

N= ρ * g * Q * H / 1000 / 3600 = 51 kW (2)

where ρ - density of water, g - acceleration of gravity.

To deliver this amount of water on the surface of the earth is used the hose (standpipe) with an internal diameter d = 40 mm. Pressure losses in such tube with length l = 3000 m are

$\Delta h=\lambda*l/d*Q^2/(0.785*d^2)^2/g/2=0.015*3000/0.04*6.25^2/(3600*0.785*0.05^2)^2/9.8/2=110$ m (3)

where λ - coefficient of hydraulic friction (Darcy friction factor).

The losses can be significantly reduced if the inner surface of the hose will be coated the superhydrophobic coating, that repels water molecules.

On reaching the ground, the water with a pressure of about 3000 m from the hose can be used in the active Pelton turbine. Static pressure in the nozzle is converted to its speed

V = φ*sqrt(2*g*(H-Δh)) = 0.98*sqrt(2*9.8*(3000-110)) = 233 m/s, (4)

where φ - the speed factor of the nozzle unit (= 0.98).

Accordingly, the diameter d of the nozzle at such a flow rate and velocity

d = sqrt(4/π * Q/V) = sqrt(4/π * 6.25/3600 /233) = 0.003 m = 3 mm (5)

The required circumferential speed of the periphery of the impeller

U = ψ*V = 0.45*233 = 105 m/s, (6)

where ψ - speed factor (ψ_{opt} = 0,44-0,47)

The outer diameter of the impeller at a speed of n = 12000 rev/min

D=60*U/(π*n) = 60*105/(π * 12000) = 0.167 m = 167 mm (7)

Specific speed n_s of a single-stage turbine is equal to 4.5 (significantly less than the optimum 13-18). Therefore efficiency η_t of a turbine with such nozzle is less 0.6, and a reduction gear is required for connection to a standard electric generator or a high-frequency generator with a frequency converter. Due to the low (equal to the atmospheric pressure) internal pressure, the turbine housing can be made thin-walled and light. Thus, electrical power of unit is

Np= η_t * η_g * N *(H-Δh)/H = 0.6*0.92*51*2890/3000 = 27 kW, (8)

where η_g – efficiency of generator with gear.

Significantly higher efficiency (up to 0.85) with n = 3000 rev/min and pressure at the inlet 2890 m can be obtained by using a screw machine type or hydraulic drilling screw due reversibility standard screw pump operating in the turbine mode. For example, with minimal alterations in turbine mode, you can use a screw pump A13B 4/160 of "Livgidromash" with nominal parameters Q = 5.8 m3/h, H = 1600 m, n = 2900 rev/min, Ndv = 37 kW, weighing up to 450 kg. However, due to high internal pressure, the housing and entire unit is substantially heavier than the turbine drive.

Assessment of material capacity and the forces acting on the main flight parts

To estimate the required lifting force of the balloon we should determine weights of the major system components. At a weight of 1 m2 of the mesh 10 g the total weight of meshes is

M_c = 0.01 * A = 0.01 * 15000 = 150 kg (9)

Mass of cladding boundary cylinders from aero tissue with thickness δ=0.09 mm, 80 g/m2, a diameter d_c 0.25 m with a total length of l_c 150 m can be determined

M_{bg} = 0.08 * π * l_c * d_c = 0.08 * π * 0.25 * 150 = 9.5 kg (10)

Hose consists of several parts. The upper part (l_t ~ 300 м) can be made of aero tissue. Taking in account the area of external surface (with a double margin to enhance the strength of the bottom part), this part weighs

M_t = 0.08 * 2π * d * l_t = 2π * 0.04 * 300 * 0.08 = 6.5 kg (11)

The hose of ultrahigh-molecular polyethylene ($\sigma_в$ = 2,4 GPa) with a diameter d = 40 mm wall thickness δ = 0.5 mm withstands a margin pressure corresponding to the pressure

$H_в = 2\delta*\sigma_в/(g*d) = 2*0.0005*2.4*10^9/(1000*9.8*0.04) \approx 6000$ m (12)

Therefore, the lower part of the hose can be made of this material (ρ_b = 970 kg/m^3) with weight

M_b = π * d * δ * ρ_b * (H - l_t) = π * 0.04 * 0.0005 * 970 * 2700 = 165 kg (13)

The hose must be attached to a tethered rope, going to a lifting balloon, which takes most of the weight and the aerodynamic loads acting on the hose.

We can use a rope, produced by many companies, from ultrahigh molecular weight polyethylene with a diameter d_c = 14 mm, a maximum load of 173 kN and a linear mass of 0.089 kg/m. The weight of the rope (length 3000 m) can be calculated

M_{ca} = 0.089 * H = 0.089 * 3000 = 267 kg (14)

Additional cordage of meshes and the lifting of the balloon can be made much smaller rope diameter 5-8 mm. Its weight (with a maximum total length of 500 m) and the additional hoses with pinch valve M_{cr} can be estimated at 15 kg.

Thus, the weight of the structure, which is necessary to lift by balloon

$M_к = M_c + M_t + M_b + M_{ca} + M_{cr}$ = 150 + 6.5 + 165 + 267 + 15 ≈ 600 kg (15)

For the lifting of the structure can be used balloon filled by inhibited hydrogen (the hydrogen with 15% helium for displacement of explosive ratio of air) with specific buoyancy f = 11.06 N/m3, and the theoretical load capacity of F = 700 kg (6860 N). The corresponding volume of 620 m3 balloon, the radius of 5.3 m and weight of the shell of aero tissue M_o = 30 kg. Consequently, the lifting force is M_a = 670 kg (6570 N).

After lifting to a predetermined height and filling with light gas cylinders, supporting meshes, lift force is slightly increased. After the start of the collection of moisture and filling the hose, the structure adds the weight of water in the hose, which can be defined as

$M_w = 0.785 * d^2 * H * 1000 = 0.785 * 0.04^2 * 3000 * 1000$ = 3770 кг (16)

When the hose in upright position (ideally in the absence of wind) the weight of the water is taken by the ground base. However, when the hose is tilted by the wind (which, on the other hand, increases the lifting force, see below), the part of it, which is proportional to the cosine of tilt to the horizontal, is to be taken by using lifting force.

Significant additional lift and drag forces are created by a wind that almost always blows at altitude. Considering the mesh as a flat plate that deviate from the horizontal direction by 15 degrees (close to the optimum value) at standard atmospheric conditions at mid latitudes at altitude 3000 m, wind speed $v_a = 7.1$ m/s, and density $\rho_a = 0.943$ kg/m^3 we can estimate the aerodynamic drag F_x and lift F_y force

$F_x = c_x*0.5*\rho_a*v_a^2*A$ = 0.2*0.5*0.943*7.1^2*15000 = 71305 N (7276 kg) (17)

$F_y = c_y*0.5*\rho_a*v_a^2*A$ = 0.77*0.5*0.943*7.1^2*15000 = 274520 N (28012 kg) (18)

where c_x (=0.2) and c_y (=0.77) – drag and lift coefficients of the plate with this angle of inclination by measured data of Goettingen Institute. *(For information: when tilted 80 degrees F_x = 406400 N, F_y = 8913 N, at an inclination of 45 degrees $F_x = F_y$ = 250000 N).* It should be noted that the mesh rather than solid surface reduces the aerodynamic drag and lift force by several times depending on the ratio of the areas between the filaments and the total area. On the other hand, the cylindrical balloon, acting as the curvature of the leading edge of the plate, increases lifting force and reduce the sensitivity of the plate to the angle of attack with the non-optimal flow direction. In addition, the mesh curving by the wind slightly increases the lifting force. Thus, lift force of meshes in the operating position may hold the weight of water in the hose and weight of all unit.

Wind also affects the hose (tethered rope of smaller diameter than the hose is secured and stored in the wind shadow of the hose). By using the mean parameters standard atmospheric conditions along the hose in a vertical position, we can estimate the aerodynamic resistance of the pipe

$F_{xca} = c_x * 0.5 * \rho_a * v_a^2 * d * H = 1.2 * 0.5 * 1.07 * 4.2^2 * 0.04 * 3000 \approx 1400$ N (138 kg) (19)

(Given the changing parameters by altitude, a more accurate value 1560 N)

When hose is tilted, aerodynamic drag is reduced.

Lifting force can be adjusted by tilting meshes, depending on the wind speed. With the rapid descent in an emergency, gas resets from the cylindrical balloons, the mesh is freed, and the rope winch is pulled to the ground.

Assessment of material capacity of the ground parts and the whole installation

To assess the material capacity of the main ground parts, we should calculate the power required for the winch. Taking the time T to descent of the flight parts for one hour from a height of 3000 m and the necessary force of winch as a lifting force with 1.5 factor to compensate for wind gusts, we can obtain the necessary power

$N_h = 1.5 * F * g * H/3600/1000 = 1.5 * 700 * 9.8 * 3000/3600/1000 = 8.5$ kW (20)

Such electric winch with a pulling force of 10,000 N, used, for example, drilling rigs, has the mass M_h about 300 kg.

It should be noted that the it is required modernization of the rope reel with hose and proper compounds. Of course, the weight of the winch can be reduced at least by half.

Standard synchronous generator with power of about 30 kW at a speed of 3000 rev/min, has a mass of about 200 kg. Taking in account the hydraulic turbine and gear or screw motor, the total weight of the unit M_e can be estimated, respectively, in 300 or 450 kg.

Thus, the total consumption of materials will be

$M = M_h + M_e + M_к + M_o$ = 960 or 1110 kg (21)

Overall specific consumption of materials per unit of power may be defined as

$m_y = (M_h + M_e + M_к + M_o) / Np$ =35…41 kg/kW (22)

For comparison, a typical stationary diesel generator at the same power with a fuel consumption of 10 liters/hour (without the tank weight) has a mass of about 1100 kg.

The possibility of using the unit for energy storage

Such unit can supply a village with 100 inhabitants with electricity and clean water at positive temperature in the warmest areas, and in temperate latitudes in the warmer months.

For energy storage during the overproduction of electricity you can use a similar unit with a ballonet balloon of variable volume, an additional hose of a hydrogen between ground and the balloon, an electrolyzer, a small water collector (upstream) and an automatic system of balancing the lifting force and load. Excess electricity is thus used in the electrolytic decomposition of water. The resulting hydrogen is supplied by hydrogen hose into the ballonet balloon of variable volume. Simultaneously the meshes accumulate condensed water in the small water collector, in accordance with amount of the incoming hydrogen that reduces the load on the main rope. The energy stored both in the form of reserve ecological fuel - hydrogen with calorific value 120.9 MJ/kg, and the potential energy of water - 0.02 MJ/kg, which can be used at peak loads. Under the terms of explosion safety, the hydrogen balloons of variable volume can be positioned at a sufficient distance from the main balloon, and also these balloons can be directly used for the transport of hydrogen and water to the other areas of consumption.