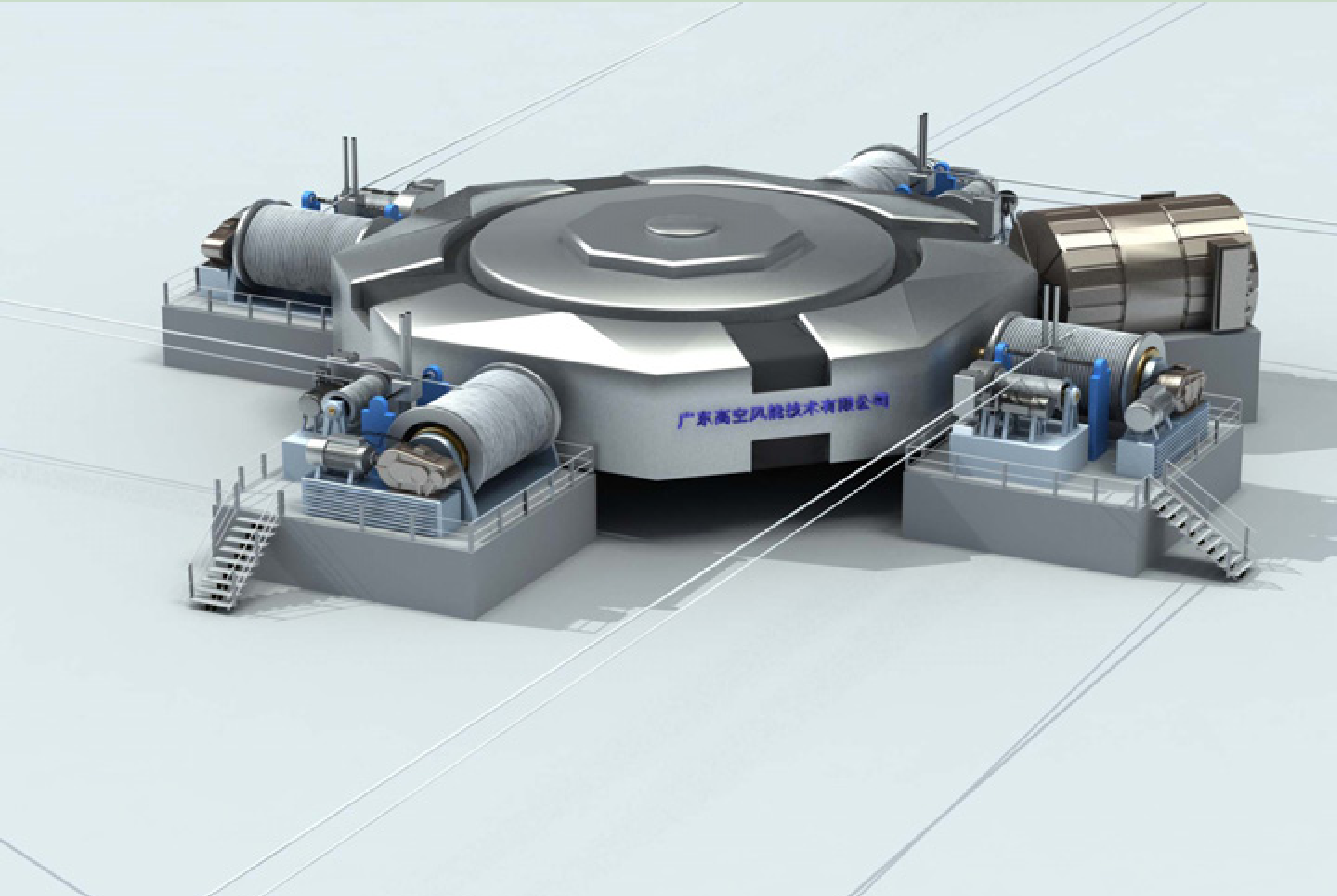
2MW Industrial Prototype of High Altitude Wind Power System

Guandong High Altitude WindPower Technology Ltd.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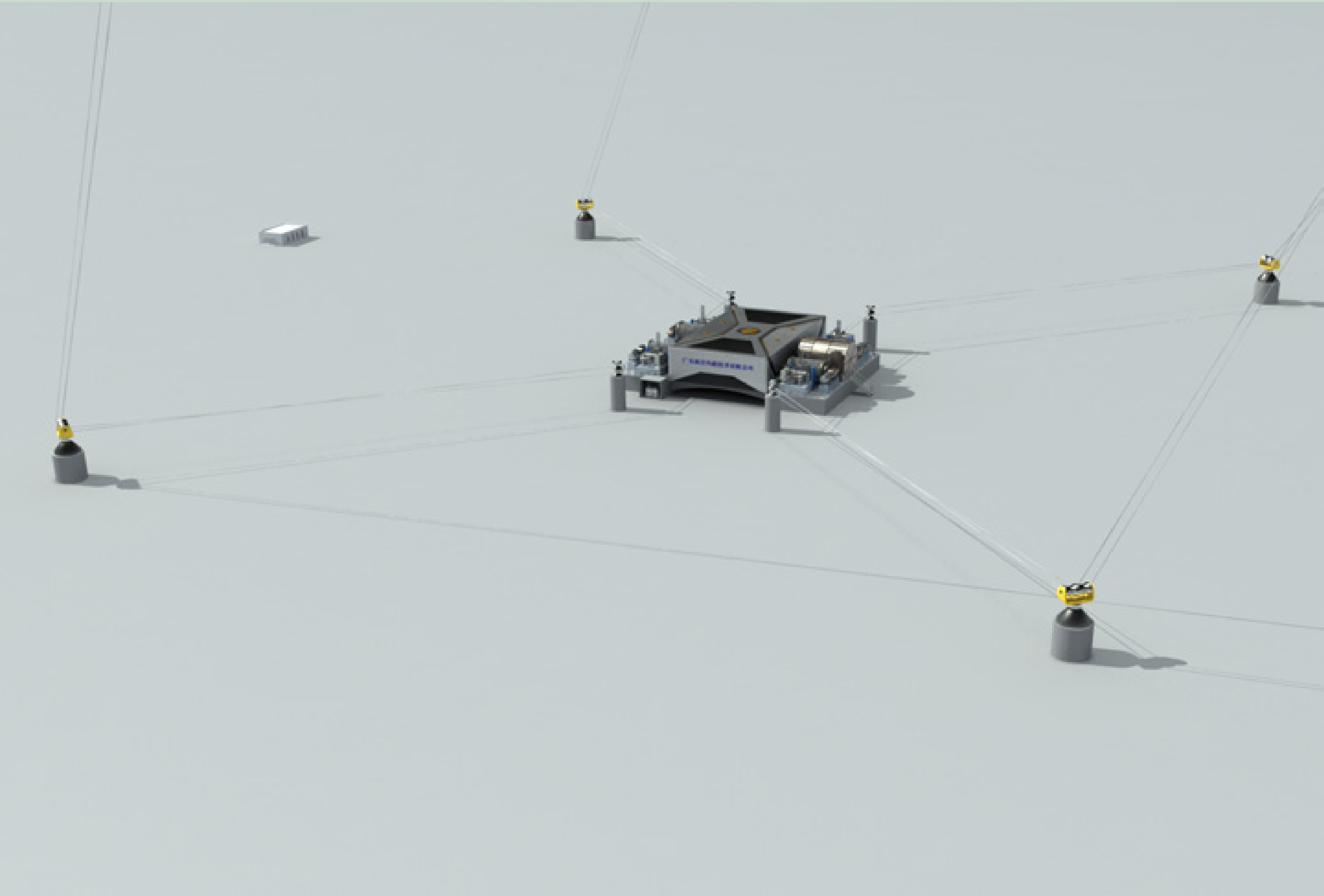
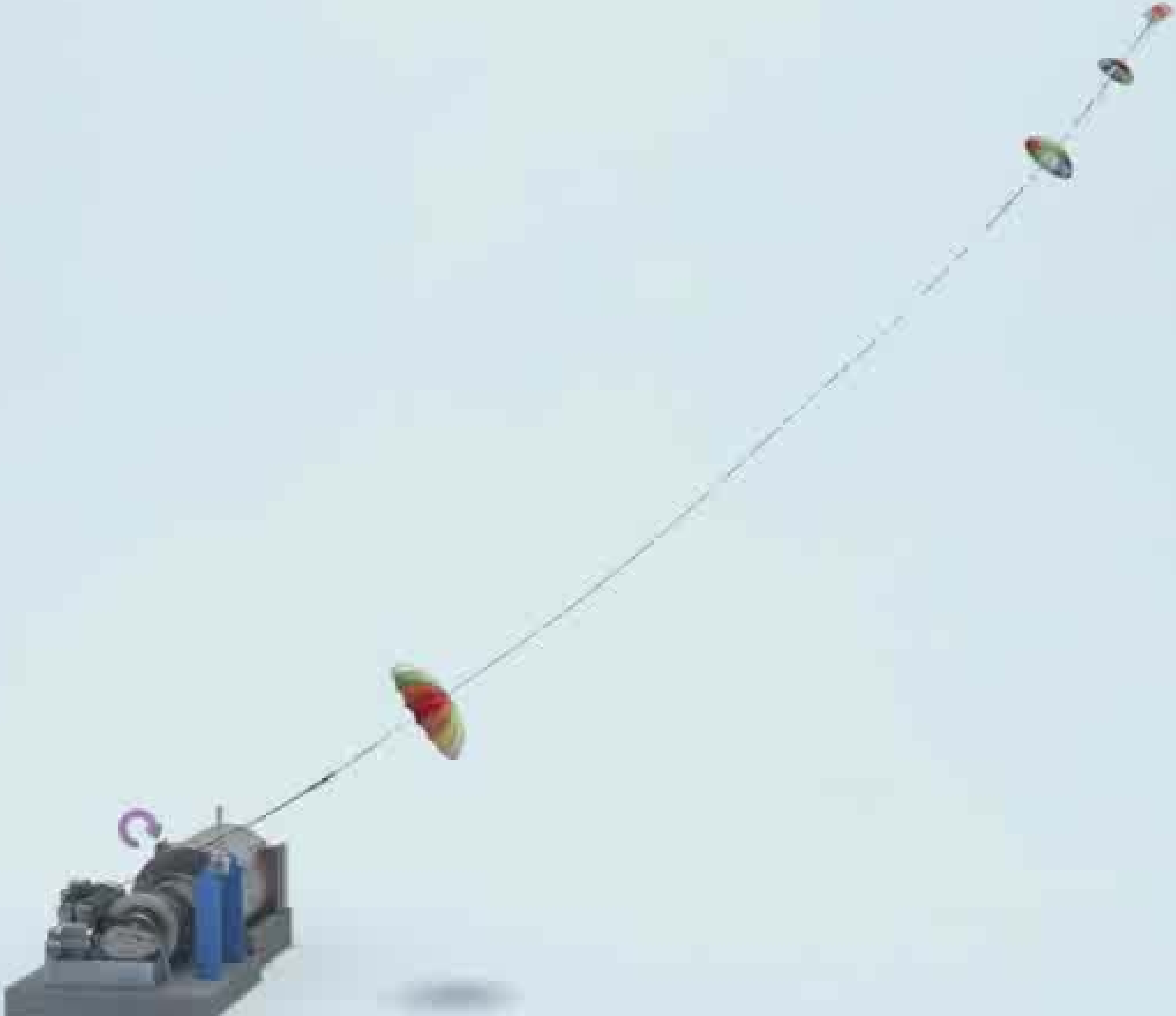
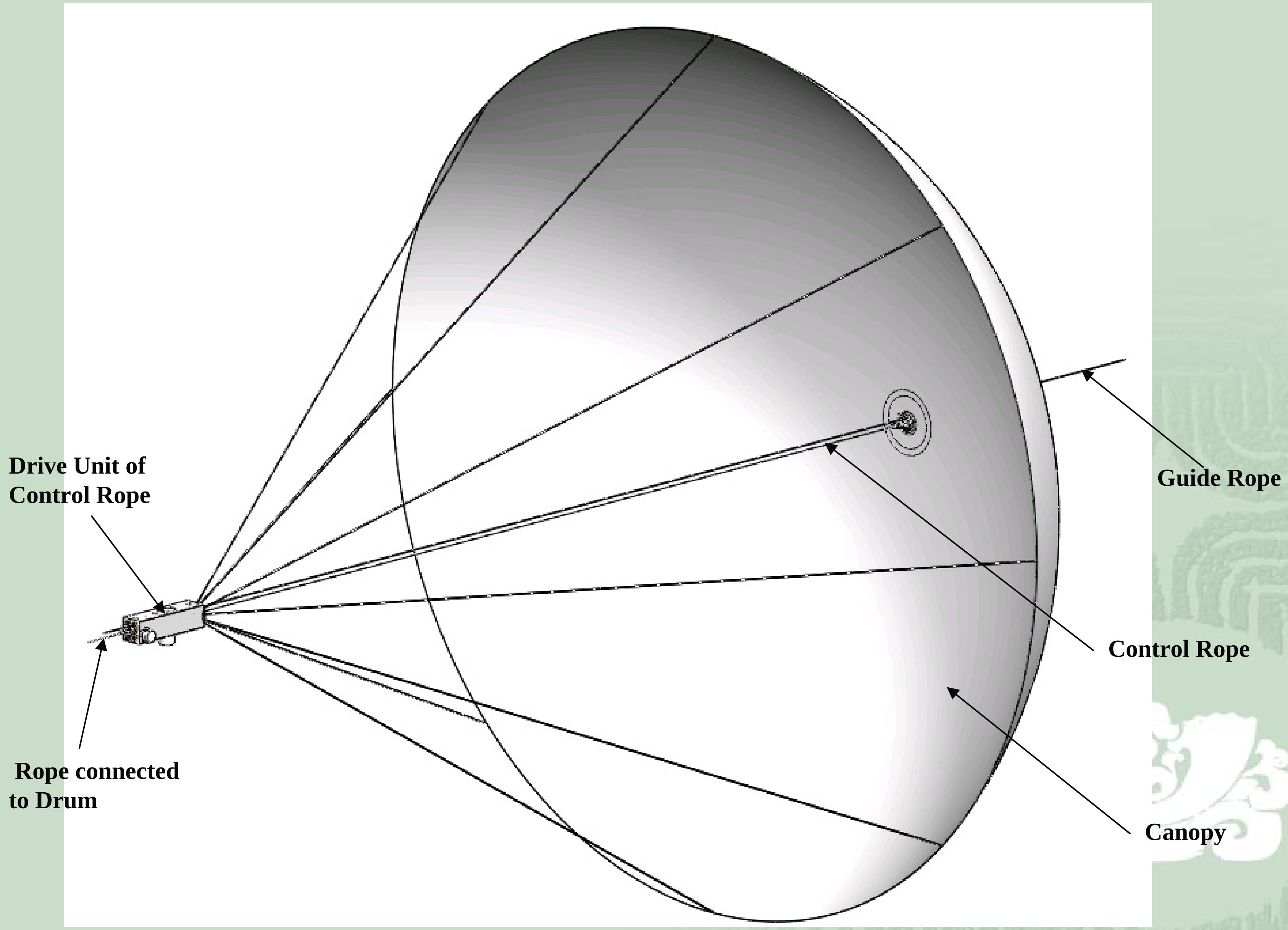


Umbrella ladder based high altitude wind power system

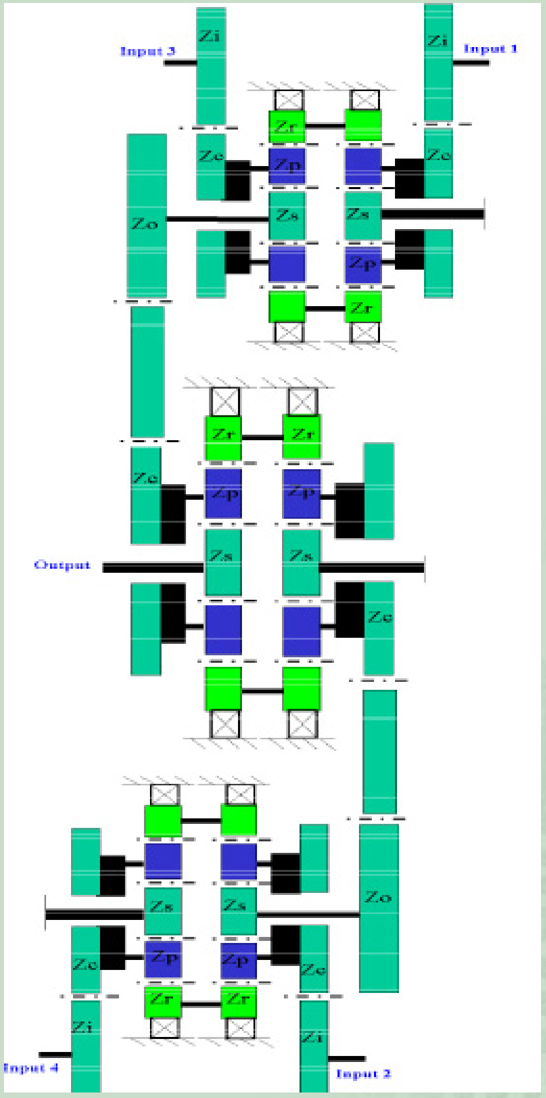


Structure of Working Umbrella



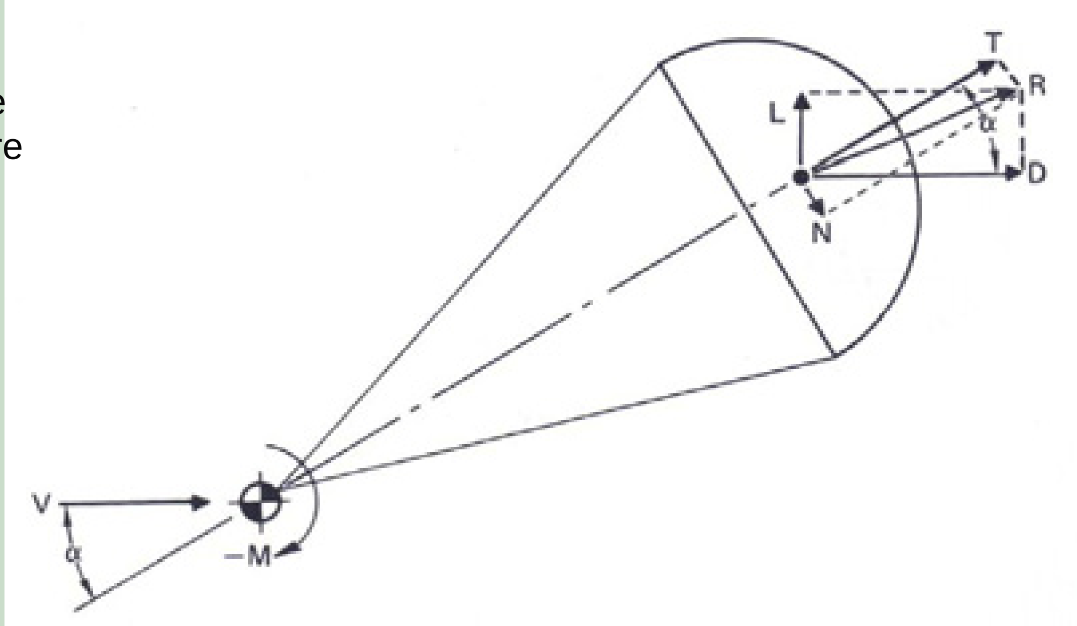
Transmission System

Use planetary gear



Parachute Aerodynamics

Aerodynamic force for parachute has two components: tangential force T (along the axe) and normal force N. Both T and N are proportional to the surface area of the canopy, and the air dynamic pressure q:



$$T = C_T(\alpha)\,Sq$$
$$N = C_N(\alpha)\,Sq$$

C_T is tangential force coefficient

C_N is normal force coefficient

$q = \frac{1}{2}\rho V^2$ ρ air density， V – relative wind velocity

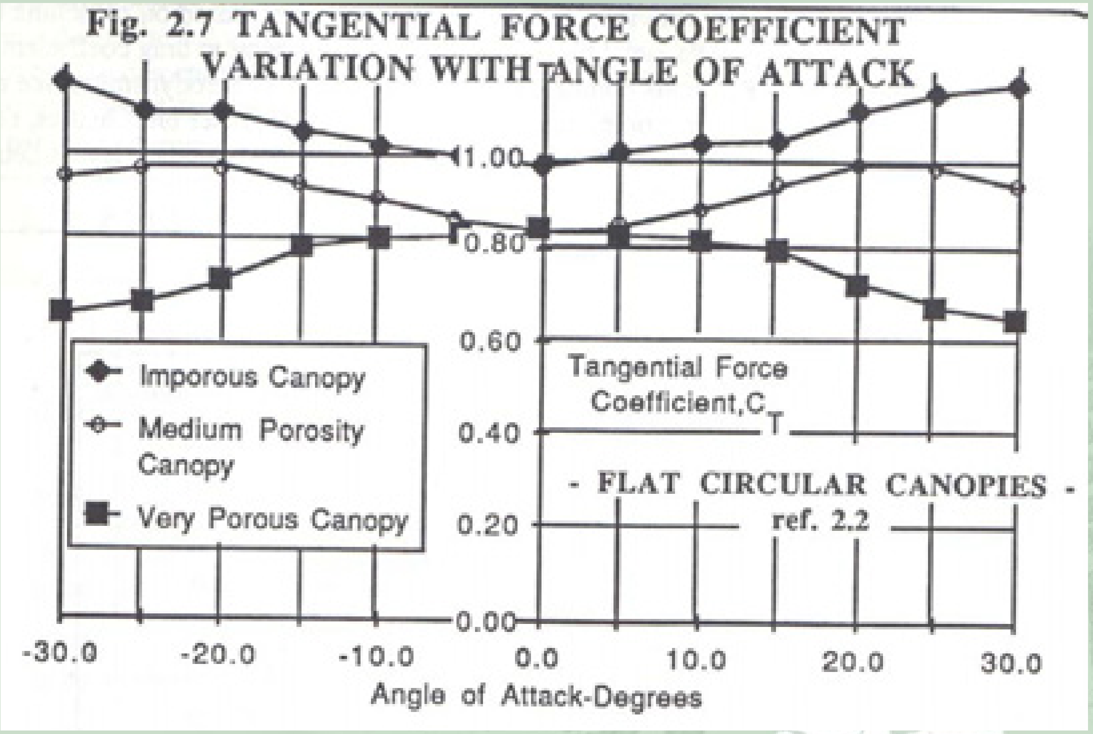
Moment

$$M = C_M(\alpha)\,Slq$$

C_M is the moment coefficient

Tangential force coefficient VS Angle of attack α

For imporous canopy, the tangential force coefficient increases as the angle of attack α increases



Wind tunnel result

Normal force coefficient VS Angle of attack α

$C_N/C_T < 0.01$

$N/T < 0.01$

The required lifting force to keep an opened umbrella's angle of attack constant is very small compared with the polling force it generates

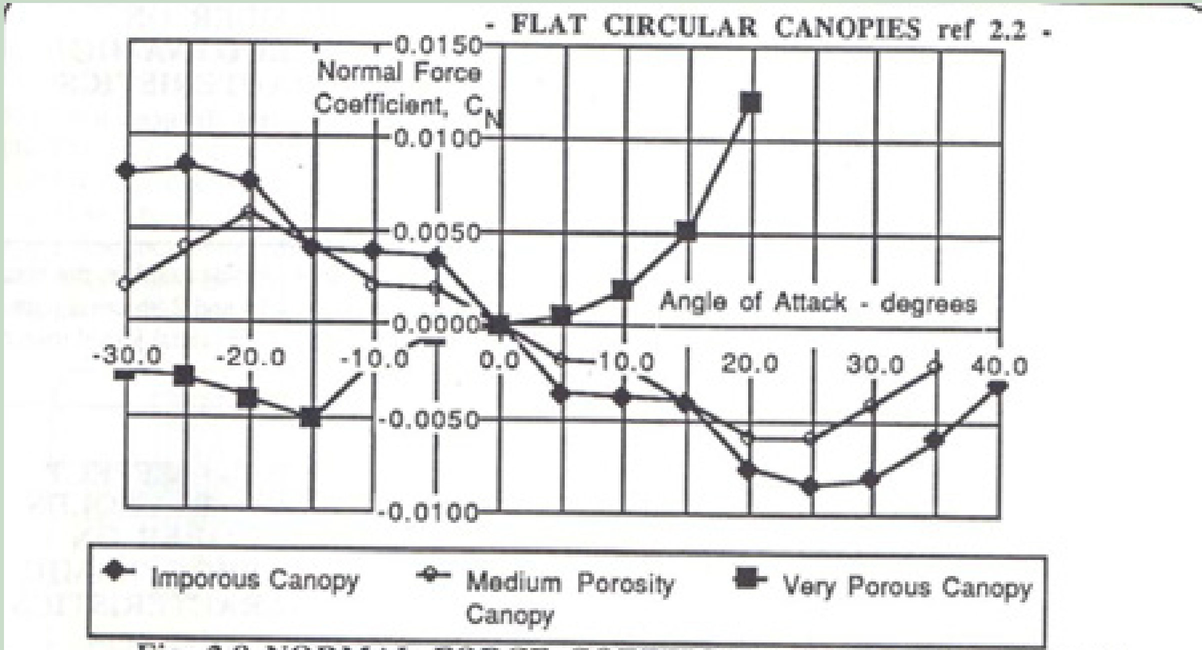


Fig. 2.8 NORMAL FORCE COEFFICIENT VARIATION WITH ANGLE OF ATTACK

Wind Tunnel Result

Moment coefficient VS Angle of attack ɑ and system stability

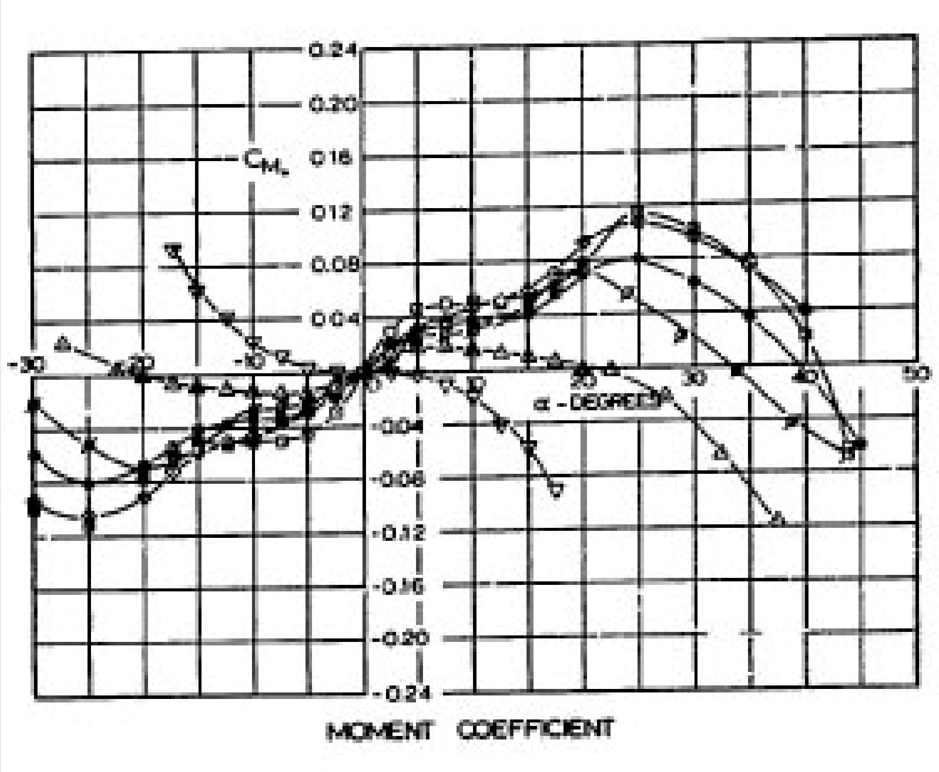
If parachute is in equilibrium state, the condition for it to be stable state is：

when ɑ increases C_M decreases (dC_M / dɑ 〈 0）

-25° 〈 ɑ 〈 25° ，equilibrium state not stable, parachute will oscillate

But if ɑ 〉 25° ， the equilibrium state is stable.

We always keep the working umbrella’s angle of attack larger then 30° . The system is very stable



Wind Tunnel Result

Power Generation

When the working umbrella is opened and traveling up, the mechanical power it generates is

$$P = (T_O - mg \sin \alpha) V_{UP}$$

T_O -- the tangential force when umbrella is opened
V_{UP} -- is the umbrella's velocity

This mechanical power is transferred to the transmission system and electricity is generated

When the working umbrella is closed and pulling down, the electricity power it consumes is

$$P = (T_C - mg \sin \alpha) V_{DOWN}$$

T_C -- the tangential force when umbrella is closed
V_{DOWN} -- is the umbrella's velocity

Total work for the whole cycle $W = (T_O - T_C) L$ L -- traveling distance

For the system with four groups

Control: at any time, the working umbrellas of three groups are traveling up, one is traveling Down

The total mechanical power transferred to the transmission system is constant at any time

$$P_{TOTAL} = 3 (T_O - mg \sin \alpha) V_{UP}$$

So the electricity output from the generator is constant

Equation of Motion for Parachute-Air System

The general form of the equation is：

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial \boldsymbol{V}}\right) + \boldsymbol{\Omega} \times \left(\frac{\partial T}{\partial \boldsymbol{V}}\right) = \boldsymbol{F}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial \boldsymbol{\Omega}}\right) + \boldsymbol{\Omega} \times \left(\frac{\partial T}{\partial \boldsymbol{\Omega}}\right) + \boldsymbol{V} \times \left(\frac{\partial T}{\partial \boldsymbol{V}}\right) = \boldsymbol{M}$$

After applying appropriate apparent mass tensor, the motion of equation appears as follow：

$$\boldsymbol{F} = \begin{bmatrix} (m+\alpha_{11})(\dot{u} - vr) + (m+\alpha_{33})wq + (K+\alpha_{15})(\dot{q} + rp) \\ (m+\alpha_{11})(\dot{v} + ur) - (m+\alpha_{33})wp - (K+\alpha_{15})(\dot{p} - qr) \\ (m+\alpha_{33})\dot{w} - (m+\alpha_{11})(uq - vp) - (K+\alpha_{15})(p^2 + q^2) \end{bmatrix}$$

$$\boldsymbol{M} = \begin{bmatrix} (I_{xx}+\alpha_{44})\dot{p} - (K+\alpha_{15})(\dot{v} - wp + ur) - (I_{yy} + \alpha_{44} - I_{zz} - \alpha_{66})qr + (\alpha_{33} - \alpha_{11})vw \\ (I_{yy}+\alpha_{44})\dot{q} + (K+\alpha_{15})(\dot{u} + wq - vr) + (I_{yy} + \alpha_{44} - I_{zz} - \alpha_{66})pr - (\alpha_{33} - \alpha_{11})uw \\ (I_{zz}+\alpha_{66})\dot{r} + (I_{yy} - I_{xx})pq \end{bmatrix}$$

Where ***I*** is inertia tensor， α is apparent mass tensor.
F is the combined force，including T，N，polling force P of the string and G：***F*** = **T + N + P + G**
M is the moment.
With this equation we can calculate the steady state and the motion of the working umbrella

Advantage of the umbrella ladder based system

- **Simple**

  During power generation only the working umbrellas traveling up and down along the guide rope, the control is relatively simple and easy to implemented

- **Stable**

  Except the working umbrellas all the other air parts are in static states, as long as the working umbrella's angle of attack is large, the system is very stable

- **Scalable**

  The system capacity can be increased by adding new group of umbrella ladder

- **Innovative**

  This is a new technology invented by our company and protected by patent law.