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S1_5 Space Tether Wind Analysis

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Abstract
An investigation into how wind conditions could affect a space tether. The results show that with proper construction and materials then any problems from a hurricane strength wind could be overcome.

Introduction

A space tether is a structure connecting the Earth's surface to a satellite in orbit. Due to the nature of its construction, it would have to be constructed in the equatorial regions. However, some areas are prone to high speed winds caused by hurricanes, which could affect the tower. This must be investigated in order to determine what could be done about the problem.

Assumptions and constants

It assumed that the space tether is a free standing structure that is made of solely carbon Nano-tubes and is cylindrical in shape and of uniform density ρ_c and of uniform cross-sectional area, A_c = (π*Diameter^2/4) (although it is suggested that a tapered tower would be most viable construction option, this investigation will only consider a relatively small 1km length of the tether, where the value of A_c would not change by much.) The winds are assumed to have a constant velocity and direction.

Constants used:

Shear modulus of Carbon Nano-tubes **(G)** = 1 GPa [1],
Drag coefficient of a cylinder, $C_{d(c)}$ = 0.07 [2]
Diameter of cable, d = 5 cm [3]
Diameter of single strand, d = 10 microns [2]
Density of air, ρ_a = 1.3 kg/m³ [4]
Viscosity of air
Surface Area under the effect of the winds, A_s = 0.5*π*Diameter*Height

For Hurricane force winds, wind velocity is taken to be 78 m/s (upper limit for hurricane force winds) [5]

The Reynolds number is calculated, taking the tether as the characteristic length, to be much greater than 2300 (of order 10^9), so therefore the flow of air is turbulent, so the drag force equation may be used.

Investigation

The force exerted on the tether will be proportional to the force of drag upon the tether.

Drag force on an object:

$$F_D = \frac{1}{2}\rho_a v^2 C_{d(c)} A_s \quad (1)$$

Rearranging for velocity:

$$v = \sqrt{\frac{2F_D}{\rho_a C_{d(c)} A_s}} \quad (2)\ [4]$$

The force needed to break a cable is the shear stress of the cable multiplied by the cross-sectional area of the cable.

For the case of a single strand made of Carbon Nano-tubes, taken to have a diameter, d = 10 microns, m^2, F_D= 7.85*10^{-2} N/m

Using these values shows that the tether will break when v equals 10.55 m/s.
(Calculated using equation (2))

So for a single strand there is a strong chance that it will break in a moderate breeze [5].

But it is unlikely that the tether will be constructed as a single strand. More likely, it will be composed of several strands connected together (like conventional cabling). However this would help bind the cabling together, so this can still be considered to act as a homogenous unit.

For the total cable of diameter, d = 5cm, the value F_D= 1.96*10^6 N/m²
So wind speed needed to break the tether, which has been calculated using equation (2), is **740.59 m/s.**
So there is no danger for a homogeneous cable from the winds alone.

Another thing to consider is that there is not only a danger from the winds themselves, but also from any debris that could be picked up by the hurricane striking the tower.
(We assume that the debris has a mass of one metric ton and is a single object)
This may be represented by the following equation:

$$\text{Shear stess (T)} = 2\left(\frac{\text{dU} * \text{G}}{\text{Vol}}\right)^{\frac{1}{2}}$$

G = 1 Gpa, Vol. = 1.96 m^3, dU =3.04*10^6 J
(dU in this case will just be the kinetic energy of the debris, as the tether is taken to be at rest (assuming that it is moving at the same speed as the wind)).

Thus Sheer stress from a one tonne impact is calculated from (3) to be 7.88*10^7 Pa
To break the cable, the maximum shear stress must equal or be greater than the shear modulus (T=G). But the force of the impact will be in addition to the force of the winds.
So factoring the result of the above equation (3) into equation (2) for the whole cable, we find the new critical wind speed for breaking the tether to be **710.9 m/s**

So the tether would still be intact even when it has been struck by debris.

Conclusions

Provided that the properties for Carbon Nano-tubes remain around the given estimates, there should be few problems with such atmospheric phenomena, but it should be borne in mind that this is modelled as a perfect system without turbulence.

It should be noted that this only considers the best case values for Carbon Nano-tubes, as an unproven technology, it's possible that these calculations will prove unfeasible, for example some research has shown that some of the estimates of Carbon Nano-tube properties may have been overly optimistic. [6]

It may be possible to reduce the drag on the tether by changing the shape of the region affected by winds, for example the drag coefficient of a plate parallel to the flow (edge on) is 0.005 – 0.001, an order of magnitude less than the value for a cylinder. [7]

It should also be noted that it may prove too expensive to produce Carbon Nano-tubes in sufficient quantities needed (due to high quality standards required for their manufacture [6]), so it may prove necessary to construct the tether out of a composite material that may have inferior properties like a reduced shear modulus.

Also, even if the tether itself is immediately unaffected by the hurricane, an impact may damage the structure, causing fractures that could worsen over time.

In addition any surrounding infrastructure, such as the transportation network that brings cargo to the tether, could still be damaged, interrupting the smooth flow of operations. For this reason it would be wise to consider constructing the tether in an equatorial region not prone to such winds. [2]

References

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[7]http://web.archive.org/web/20070715171817/http://aerodyn.org/Drag/tables.ht