Tethers for Aerial Drones

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Introduction

The use of aerial drones has proliferated in the last few years. The US Federal Aviation Administration estimates that the number of small hobbyist drones will increase from 1.1 million in 2016 to more than 3.5 million in 2021. The commercial drone fleet in the US is predicted to increase at an even faster rate from 42,000 in 2016 to 442,000 by 2021, over a tenfold increase in use in the US[1]. Worldwide, Business Insider predicts that the number of hobbyist drones will be on the order of 29 million, while commercial drones will reach 805,000[2].

Presently, the most mature drone markets are government related drones. These fall into either the category of public safety or military. Traditionally, drones have been thought of as a fixed wing aircraft that will travel at high speeds and be controlled from anywhere in the world, such as Northrup Grumman's Global Hawk shown in Figure 1.

Figure 1. Global Hawk is the largest drone mainly used for surveillance.
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In recent years the development of the quad-rotor drones have opened up new uses for drones including border control, temporary towers and low-altitude satellite surveillance and photography. Even most novices are familiar with the Phantom from DJI, shown in Figure 2.

Figure 2. DJI's Phantom Drone, © DJI

Since the moment drones were introduced, flight time has been a ubiquitous concern. Although there are some hybrid drones, operating on both gas power and batteries, most are solely battery powered. The longest documented autonomously powered drone flight on record is held by Spider Drone of Hungary who operated a muilticopter for 2 hours, 6 minutes and 7 seconds[3]. A hybrid drone called HYBRiX.20 from Quanternium in Spain is claimed to have flown for 4 hours and forty minutes.[4] Even with these impressive and increasingly long flights by battery and hybrid powered drones, those drones that intend to perform similar functions to that of an aerostat will need continuous power.

For more permanent aerial vehicles one typically employees an aerostat, like the one shown below in Figure 3 can remain afloat for long periods of time and are used for surveillance or communications. A kite based vehicle is another option. This can be flown in areas of sustained wind, or off of the back of a moving vehicle similar to TALONS (Towed Air-borne Lift of Naval Systems) being developed by MAPC for DARPA. TALONS is shown below in Figure 4. These vehicles remain airborne through passive means (i.e. helium or wind power), and although they are tethered with an electrical cable, the power is for the electronics on the payload.

Figure 3. Linden Photonics Hybrid Tether[5]

Figure 4. TALONS Kite with Linden Photonics Hybrid Tether

In order to keep a quadcopter in flight for more permanent uses, one must bring power to the vehicle. Heavy lift quadcopters can currently carry a payload of up to several hundred pounds, but the more weight that is used by a powered tether, the less useful payload the drone can hold. Additionally, there is a problem with altitude. The higher the drone needs to be, the longer the tether. The longer the tether is, the more weight the drone must support. Furthermore, the higher the drone is, the larger the copper conductor gauge needs to be…and copper is heavy.

This need for a lightweight drone tether has spawned a new "micro tether" industry. These small tethers are designed to have maximum performance while minimizing the complexity and weight found in designs used for other applications such as subsea communications.

Development of these specially designed cables involves a balance of performance characteristics that must consider the requirements of the platform and the requirement for low weight, in order to maximize payload, is almost always the primary concern.

Cable Design

The primary weight driver for a cable designer is typically the electrical conductors. Copper has a density of 0.324 lb/in^3 (8.96 g/cm^3). For nickel plated copper the density is effectively the same since nickel has a density of 0.320 lb/in^3 (8.90 g/cm^3). The lower the gauge of the conductor, the more copper and the higher current carrying capacity. In Figure 5, below, we compare the weight of conductors from 28 gauge to 14 gauge (including the weight of the wire's insulation – in this case standard low temperature PVC and 300V capacity). We see that the weight of the conductor rises from about 1.4 lb/1,000 ft. (2.08 g/m) for a 28 gauge wire to 15.6 lb/1,000 ft (23.21 g/m) for a 14 gauge conductor. If the voltage capacity is increased, thus the insulation increased, we see that the weight of increasing to a 600V conductor can be over 50% more depending on the gauge. Other factors that will effect conductor weight include flexibility and temperature rating. A more flexible conductor that is comprised of multiple strands, will weigh more than an equivalent solid conductor. High temperature insulators are generally more dense than low temperature insulators.

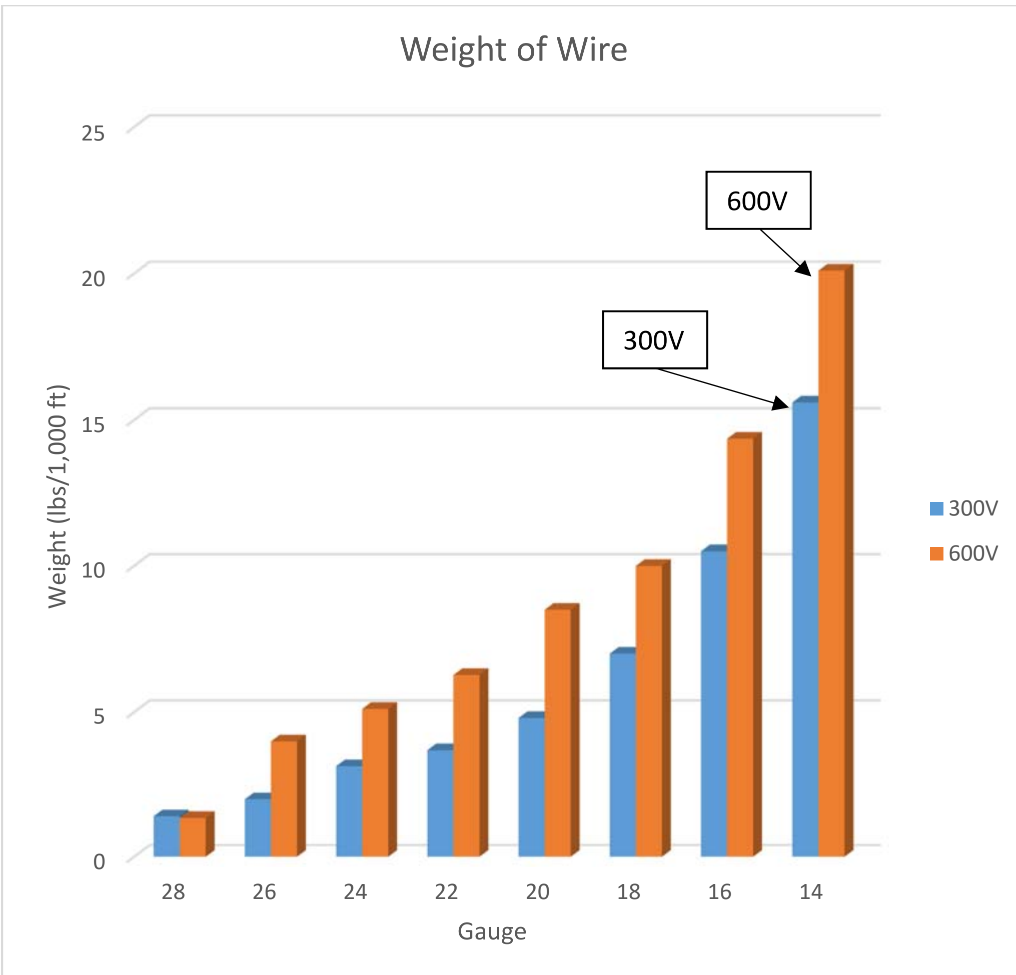

Figure 5. Weight of Wire (lbs/1,000 ft)

The other critical component of electrical cable design that we touched upon before is voltage drop. The longer the cable, the more voltage drop occurs. And as the voltage drops so too does power as

Power (Watts) = Amps x Volts

The actual voltage drop can vary depending on for basic causes. The first is the choice of material used for the conductor. Copper is a better conductor than aluminum and will have less voltage drop for a given length and wire size.

Wire size is another important factor in determining voltage drop. Larger wire sizes (those with a greater diameter) will have less voltage drop than smaller wire sizes of the same length.

Still another critical factor in voltage drop is wire length. Shorter wires will have less voltage drop than longer wires for the same wire size (diameter).

Lastly, the amount of current being carried can affect voltage drop levels. Voltage drop increases on a wire with an increase in the current flowing through the wire.

As an example; if we have a 20 AWG conductor 100m in length operating at 300V and 1 amp, the voltage drop along the length will be roughly 2.2%. If we want to increase the length of the cable to 200m but keep the voltage drop the same, we will have to increase the gauge size to 18 AWG. This will increase our linear weight of the single conductor from 4.8 lb/1,000 ft (7.29 g/m) to 7.0 lb/1,000 ft (10.4 g/m). For a pair of conductors we are talking about increasing the total weight from 729g to 2,080g, almost a threefold increase in weight of the conductors.

Fiber

Most cables for tethered drones include one or more fiber optic elements for communications. Fiber communication is a secure form of data transfer not susceptible to physical hacking or Electro Magnetic Interference. Although the fiber elements are not nearly as heavy as their copper counterparts, they still add weight to the overall design and while the actual bare fibers - 250µm in diameter and 0.044 lbs/1,000 ft. (0.066 g/m) – are extremely lightweight, it is the reinforcing and mechanical protection of these fibers that adds weight to the design. Typically, a bare fiber can be protected at a minimum by applying a thin jacket layer of Hytrel to 900µm, but this would be for a cable used in a stationary installation and usually indoors. For something that will be subjected to the mechanical rigors of a drone tether, one would need to include strength members, traditionally Kevlar, to protect the fiber from longitudinal strain and an outer jacket to protect the fiber from things like compressive forces and even moisture. A traditional 2.0 mm reinforced fiber optic cable that includes Kevlar and an outer jacket of PVC will weight approximately 3.02 lbs/1,000 ft (4.5 g/m).

Typical aerospace cables have requirements either for high temperature operation or radiation resistance. Jacket materials that meet these requirements are often things like fluoropolymers, which are very dense. Teflon, for instance, has a density of 2.15 g/cm^3. However, in these aerial drone tether applications, the fiber optic element does not usually need the high temperature characteristic of a Teflon.

To find materials that are strong, but lightweight and appropriate for drone tethers we can look to a vastly different industry – the subsea cable industry. Subsea cables are required to be strong, rugged, moisture resistance and often times have low density either to float or to be neutrally buoyant and match the density of sea water (1.02 g/cm^3).

Exploiting the properties of certain materials with a density of <1 g/cm^3 one is able to build a fiber optic element with very low density, while not sacrificing mechanical strength. It is possible by using these cables to build a high strength fiber optic element with tensile strength >50 lbs

(22 kg) and a weight of only 0.4 lbs/1,000 ft. (0.6 g/m)[6].

In a 200m long hybrid tether, the weight from the fiber optic element alone would be almost 2 lbs (0.9kg) for a traditional Kevlar reinforced cable, whereas with a new high strength low weight element, the weight can be reduced to 0.25 lbs (0.11kg) as illustrated below in Figure 6.

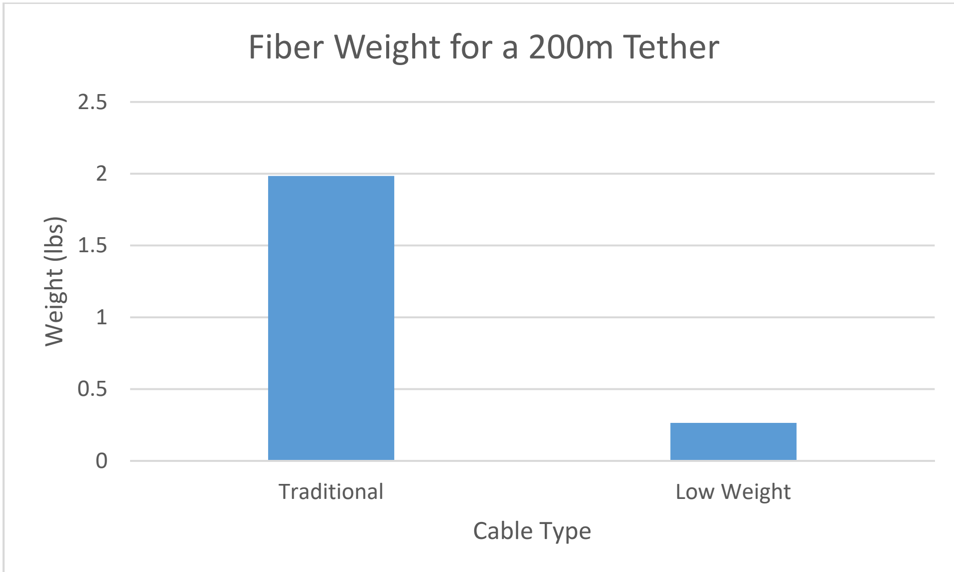

Figure 6. Weight of Fiber optic Element in a 200m Long Tether

Strength Members

Many times, tethers for drones will need some strength members to take any strain in the cable above and beyond what one might get from the conductors and fiber elements. The use of steel strength members is not an option due to the weight of such strength members. A synthetic option that is traditionally used in cable design is Kevlar 0.052 lb/in^3 (1.44 g/cm^3). This is a strong material (20 time that of steel with the same diameter) and lightweight as compared to steel strength members.

While strength members may not be a necessity in all tethered drone applications, particularly in the case of the smaller quadcopters that are able to hover in place, strength members are a requirement in any aerostat like that shown in Figure 3 or a kite aerostat – see Figure 7. The tether for this vehicle is shown in Figure 8.

Figure 7. Kite Aerostat Using Tether with 2 Kevlar Strength Members in Parallel.

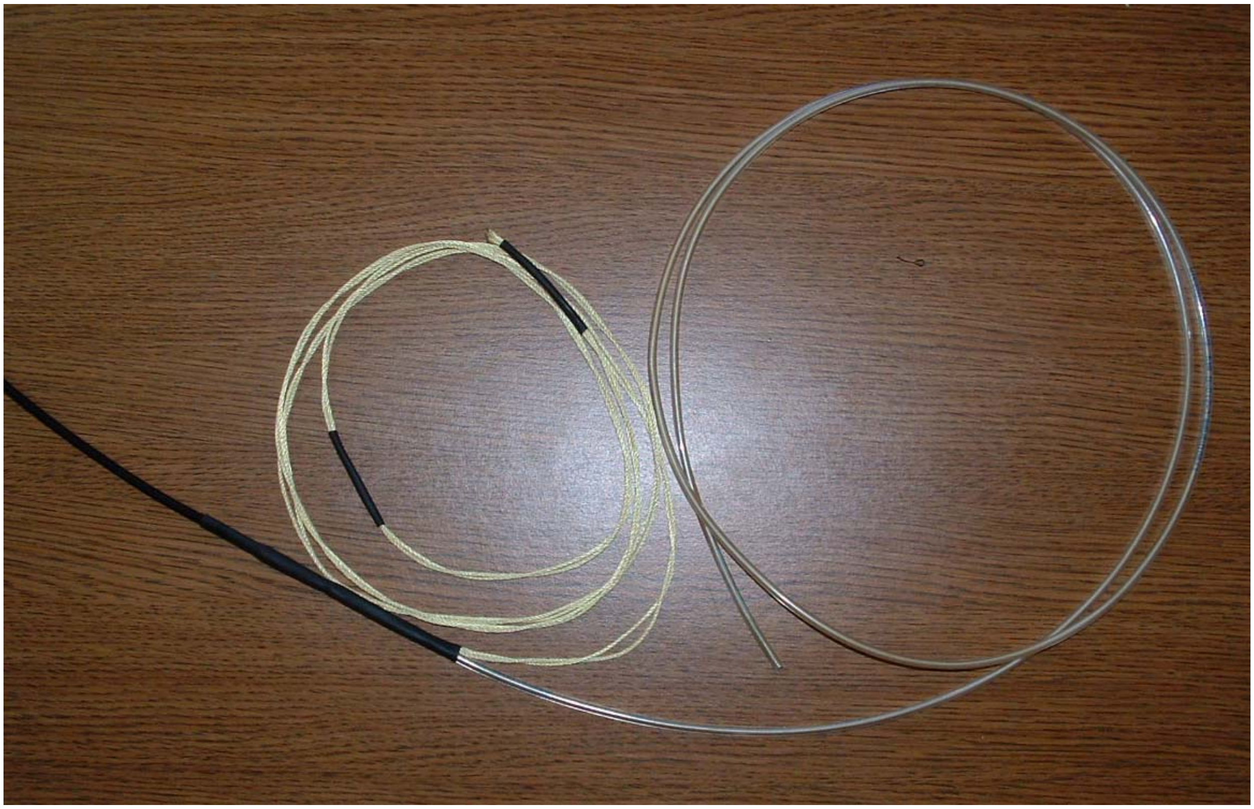

Figure 8. Linden Photonics Tether with Two (2) Kevlar Strength Members and One (1) Fiber Optic Element.

As a practical example, if one wants a cable with a break strength of approximately 250 lbs. the design would include eight (8) strands of 1,000 denier Kevlar. The linear weight of the strength member in this case is 0.7 lb/1,000 ft. (1.06 g/m).

Other Synthetic Strength Members

Vectran is a material similar to Kevlar in terms of tensile strength and density/weight, but it does have improved resistance to moisture and high temperature. This alternative strength member might be chosen for a tether that has little protection from the elements inherent in the outer jacket design.

Spectra and Dyneema fall under the classification of ultrahigh molecular weight polyethylene. These low weight strength element are 33% lighter than Kevlar at a density of 0.035 lb/in^3 (0.97 g/cm^3).

Outer Jacketing

The two main jacket types for these cables are either a traditional extruded jacket which encapsulates the inner elements or as an alternative, a braided outer jacket made from a light material. An example of each is shown in Figure 9. The pros and cons of each are discussed below.

Braided

This ultra-lightweight jacketing serves the purpose of holding the multiple inner elements together into a single cable. It is extremely lightweight, but it is porous, can be susceptible to abrasion and adds to the stiffness of the cable. If an internal drain wire with aluminum/mylar tape wrap is required in the design, the stiffness of this cable may be prohibitive to some applications.

Extruded

The extruded jacket is a continuous jacket that will protect better from the elements, be more resistant to abrasion and be more flexible than the braided outer jacket. However, it is heavier. Even for small cables with a diameter in the range of 0.120” (3 mm) the use of an extruded jacket will add roughly 1 lb/1,000 ft. (1.49 g/m) to the weight of a tether as compared to the braided jacket.

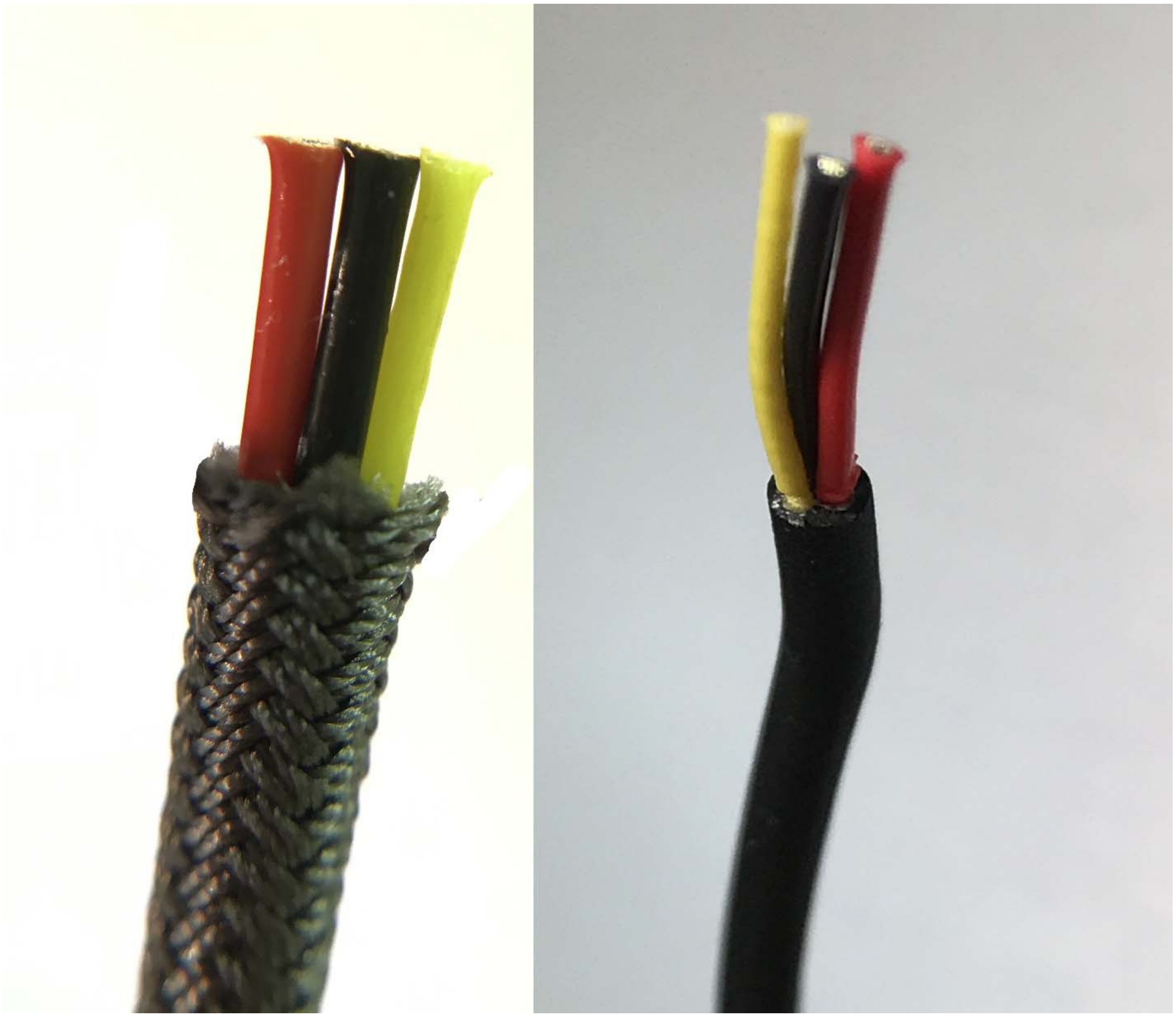

Figure 9. A Hybrid MicroTether with Braided Jacketing (left) and Extruded Jacketing (right).[7]

Conclusion

Tethers for aerial drones is a new and emerging market. The design of these cables can call on lessons learned in other industries like aerospace, terrestrial robotics and even subsea ROVs. Various factors such as weight, communications, power requirements and mechanical performance must be considered in relation to each specific application.

References

[1] https://www.reuters.com/article/us-usa-drones/u-s-commercial-drone-use-to-expand-tenfold-by-2021-government-agency-idUSKBN16S2NM

[2] https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts-2017-7

[3] http://www.guinnessworldrecords.com/world-

records/longest-rc-model-multicopter-flight-(duration)

[4] https://uavcoach.com/drone-record-time/

[5] Photo Courtesy of Airborne Industries, Ltd.

[6] http://www.lindenphotonics.com/specification_sheets/STFOC/LINDEN-SPE-7034%20STFOC.pdf

[7] http://www.lindenphotonics.com/documents/Linden%20-%20MicroTethers.pdf