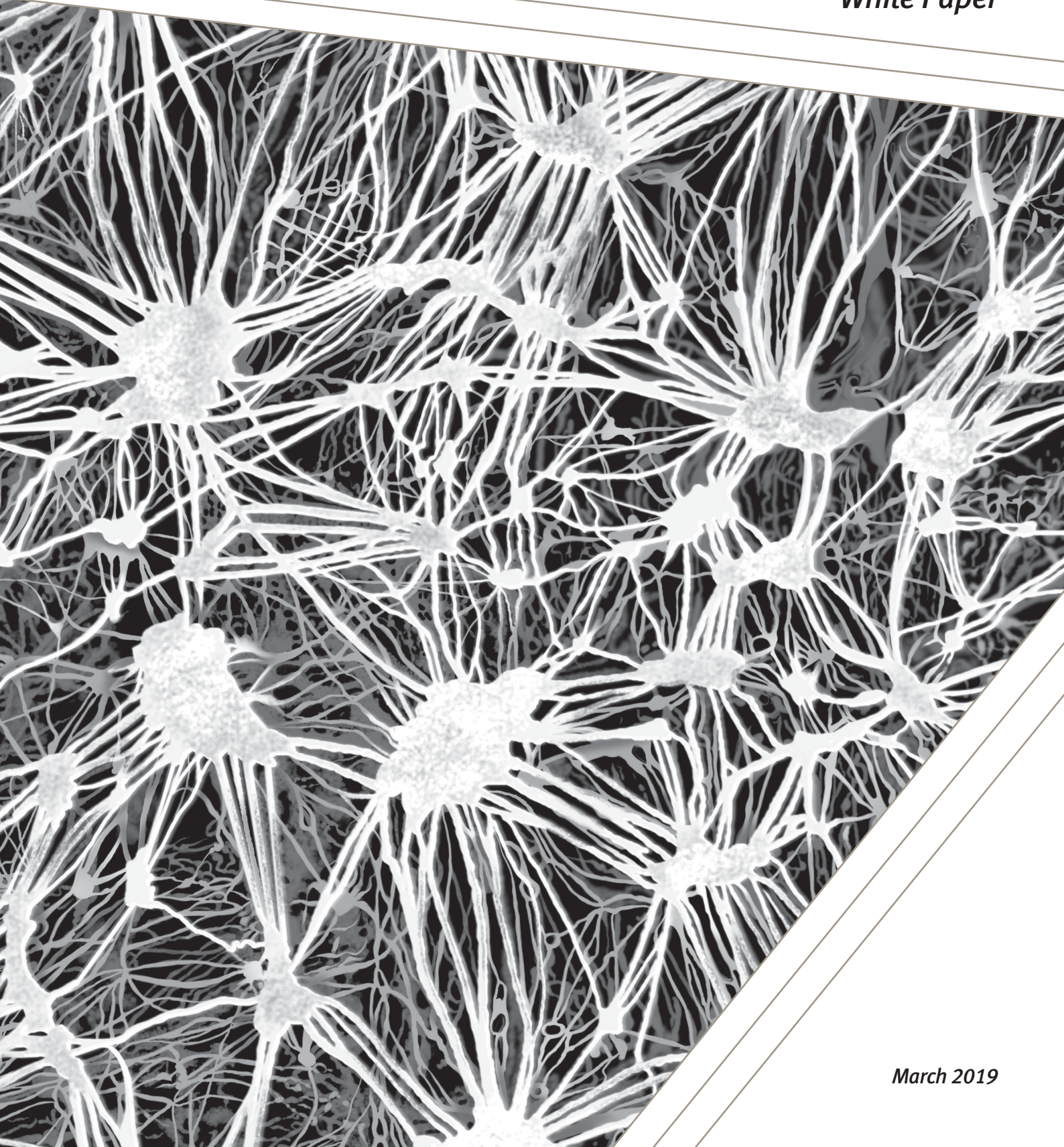




Understanding and Maximizing Tethered Drone Cable Performance in Harsh Operating Conditions

White Paper



March 2019

Abstract:

As the commercial and military industries rely more on drone technology, high-performance tether cables offer new capabilities for many applications. Therefore, it is necessary to fully understand the tethered drone system, power and data transmission needs, and the environmental effect on cable materials to ensure reliability and longevity. Current carrying capacity and weight limitations should also be considered for specific applications. In addition, thorough testing should be performed to validate the tether cable will operate reliably in the intended application.

W. L. Gore & Associates (Gore) evaluated the strength and durability of its hybrid solution compared to a standard tether cable. This testing showed the importance of choosing the right tether cable that delivers continuous power and data transmission in harsh operating conditions to extend flight time while minimizing weight to increase payload options for operational success.

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Introduction

The use of unmanned aerial vehicles, commonly known as UAVs or drones, continue to grow at a fast pace across commercial and military industries globally. Package delivery, sporting events, concerts, news coverage, search and rescue operations, and military surveillance are examples that use this evolving technology.

However, the recent introduction of tethered drones has enabled power management systems to shift from using high energy density batteries with limited flight time to high-performing cables using a battery backup with unlimited flight time. This shift in drone technology requires a better understanding of a tethered drone system, power and data transmission needs, cable survivability in harsh operating conditions, and payload options to determine the right tether cable for a specific application (Figures 1 and 2).

Figure 1: Tethered Drone for Military Surveillance



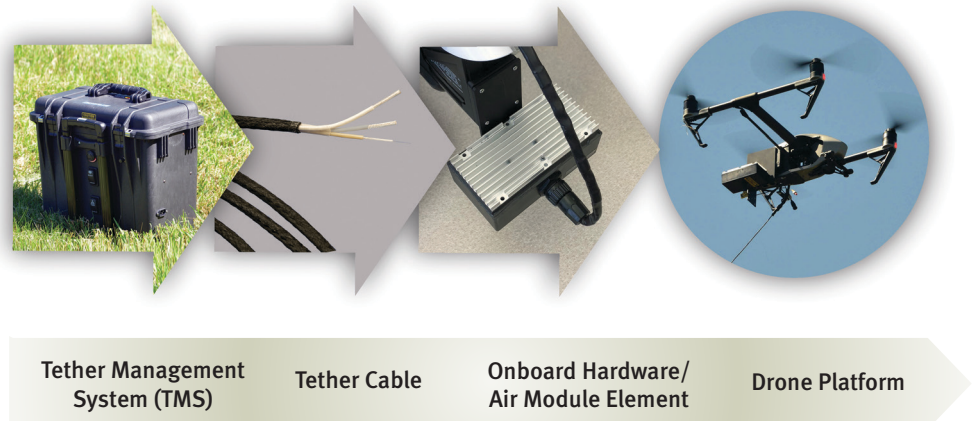
Figure 2: Tethered Drone for Commercial Use



Tethered Drone System

Fundamentally, a tethered drone system includes the Ground Support Equipment (GSE), Tether Management System (TMS), and onboard hardware also known as air module element (Figure 3).

Figure 3: Components of a Tethered Drone System



Mechanical Design

The GSE equipment is usually powered by an AC generator or fixed power that provides 110 or 220 volts to the TMS. In turn, the TMS converts the AC power to high-voltage DC. High-voltage power is more efficient than low-voltage power to transmit over long distances. Once the power reaches the drone, a DC-to-DC Converter Module (DCM) is required to down convert the high-voltage DC on the cable to the operating voltage of the drone or motors. Drone firmware and battery controls can be very complex due to safety measures. As a result, a drone system modified for tethered use often requires additional components to support uninterrupted flight. Finally, a battery backup must be used to ensure operational safety in case of a power source disturbance.

Electrical Design

The tether cable serves as the backbone for drone operation by delivering high-voltage DC power, data and video via optical fiber, as well as optional hardwired controls up to the drone. The overall length of the tether cable based on altitude above ground level (AGL), desired operating radius, and power supply voltage determine the amount of power (voltage/current) received by the drone. A small amount (higher than normal) of voltage drop is inevitable and can be determined based on the cable's American Wire Gauge (AWG) size. The tether cable often carries around 1 amp, which is much smaller than the typical current in the drone at 12 amps; however, caution is necessary when handling either system. Depending on the application, the tether cable can be used to transmit sensor, video, and communications data to the GSE over a single-mode optical fiber. This versatile cable can be used in multiple ways to merge power and data functionality.

Power and Data Transmission

The military, in particular, has struggled with using conventional battery-powered drones to fulfill operational needs and requirements. Lithium polymer (LiPo) batteries provide high energy density, deliver fast discharge rates, and are relatively low cost. However, the expected flight time is approximately 20 to 30 minutes for an off-the-shelf battery, which is insufficient for drone missions that demand longer flight times. Alternatively, higher capacity batteries can be used for longer missions, but the additional weight requires larger motors.

Typically, there are trade-offs when converting battery-powered drones to a TMS. The type of operation usually determines the path for system designers — short flight time with maximum maneuverability (battery) or unlimited flight time with minimal mobility (TMS). Customers overcome these trade-offs using rotary-wing tethered drones for continuous power. However, the need for continuous power has increased with new and emerging drone applications.

The most common commercial drones are the DJI Inspire, DJI S900, Flydeo, Walkera, and Yuneec to name a few. Each drone offers a unique advantage such as the Inspire's speed and maneuverability and the S900's payload versatility. However, the power consumption of these drones is vastly different. The Inspire requires approximately 300 watts to operate continuously, while the S900 requires approximately 2,000 watts. This substantial difference in wattage means that system designers must carefully consider power consumption when choosing a tether cable for a new drone platform.

What if there were a better power and data transmission solution that could increase design options and payload, enable drones to fly higher, expand the line of sight or coverage, and perform reliably in harsh conditions over the drone's lifetime?

Striking a Balance with Gore's New Hybrid Design

Gore combines a power pair and fiber optic cable with rugged materials in a small-scale hybrid construction that eliminates these challenges and trade-offs. GORE® Tethered Drone Cables includes a power pair with a 6-mil engineered fluoropolymer insulation that delivers continuous high-voltage rated at 600 volts, and a rugged fiber optic element that provides secure, high-bandwidth data transmission with low optical loss. Gore's fiber can serve as a low-loss coaxial cable for applications that transmit and receive data such as temporary cell towers, rural network connectivity, mesh drone networks, and line-of-sight communications. Gore's 900-micron jacketed, single-mode optical fiber can also be used as a downlink for continuous video streaming to provide situational awareness and coverage for emergency response, news and events, aerial photography, and border patrol.

The power rating of Gore's tethered drone cables depends on three key factors — operating current, temperature limitations, and heat dissipation. In general, Gore's standard size 24 AWG can operate at 2 kilowatts. However, the heat generated by the tether cable during operation can affect its overall performance and reliability. Heat can also become an issue for the remaining cable on the reel due to the proximity of wires carrying current and lack of cooling inside the TMS. As a result, Gore specifies the voltage rating at 600 volts based on industry conventions to give system designers more flexibility. System designers can determine the power rating and acceptable trade-off of current versus temperature. Gore tests the power primaries at 2500 Vrms using jacket and insulation materials comfortably rated at 200°C and fiber optic rated at 85°C.

Table 1 shows the expected performance of the power pair in GORE® Tethered Drone Cables for a system operating at 600 volts direct current (V_{DC}).

Table 1: GORE® Tethered Drone Cables for a 600 V_{DC} System

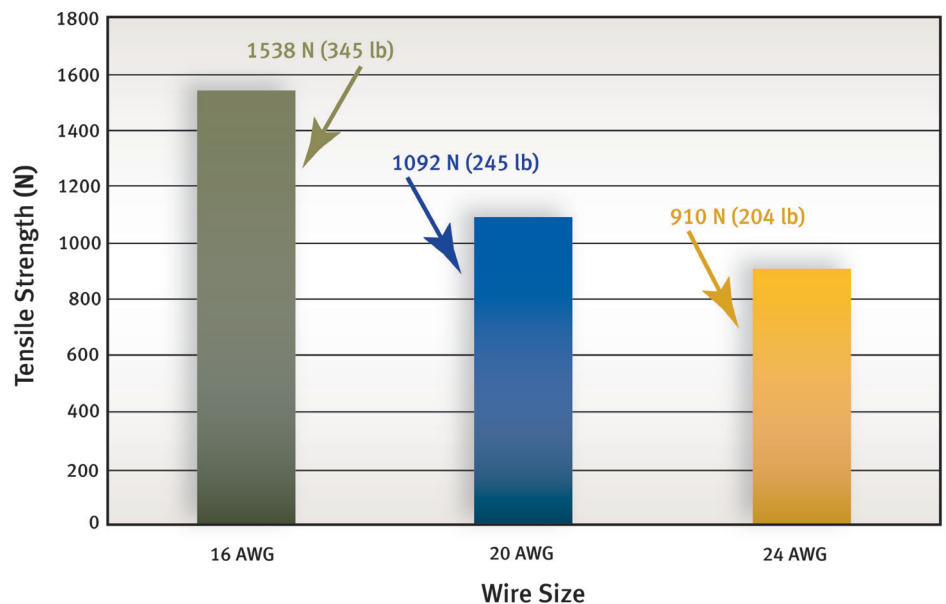
AWG Size (Stranding)	Watts	Expected Performance
16 (19/29)	2,000	Minimal to no heat generated
20 (19/32)	2,000	Moderate heat generated and warm to touch
24 (19/36)	2,000	Maximum heat generated. Cable should not be touched at or above 60°C Cable on reel should be minimized or actively cooled

Cable Survivability

The environment in which tethered drones operate can significantly impact system performance and reliability, and tether cables struggle to find the right balance between durability and less weight. Even though drone technology is relatively new, there are many well-known industry specifications and standards for testing tether cables for mechanical durability such as ARINC 802-2 and AS4373. These standards outline the requirements for evaluating tensile strength and resistance to humidity, harsh fluids, and crushing.

For instance, tensile strength refers to the maximum load or force that can be applied to the tether cable before a rupture occurs. Typical industrial engineering convention for wire or rope uses safety factors between 8 and 9 times the expected force. Therefore, the maximum thrust of the drone minus the expected take-off weight can be multiplied by 8 or 9 to determine a safe tensile strength level. However, the physical limitations of a drone to create thrust beyond its rating may lead system designers to settle for a safety factor less than 5 times the thrust of the drone. Figure 4 shows the tensile strength of Gore's tethered drone cables.

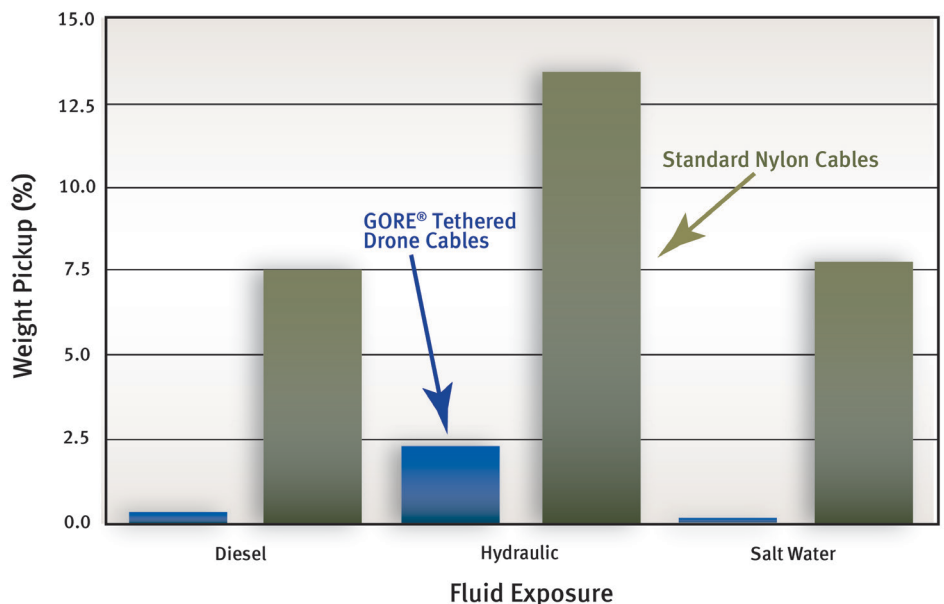
Figure 4: Tensile Strength of GORE® Tethered Drone Cables



In addition, there are concerns around fluid resistance and weight stability as tether cables are exposed to surrounding conditions. Every gram of weight saved on a drone and tether allows for more payload flexibility, increased AGL during operation, and greater drone responsiveness. Therefore, the tether cable must prevent weight pickup after exposure to harsh contaminants and fluids such as hydraulic oil, diesel fuel, and salt water.

Gore compared its cable to a standard nylon cable using AS4373 Method 601 to determine weight stability after immersion in harsh fluids. Results showed that the initial weight of the nylon cable increased significantly by 13 percent in hydraulic fluid and more than 7.5 percent in salt water. However, Gore's tethered drone cables showed a significant reduction in weight pickup in these harsh fluids. For example, **Gore demonstrated only 1 percent weight pick up in salt water, which translates to 90 percent less weight pickup than a standard nylon cable** (Figure 5).

Figure 5: Fluid Resistance Comparison of Tethered Drone Cables



Choosing the Right Tether Cable

Power, Temperature, Material & Weight Trade-offs

System designers should consider the maximum operating voltage and operating length when choosing a tether cable for a specific drone system. The operating current determines the target weight per 100 feet (30 meters) that the drone can tolerate. The typical weight is around 2 pounds per 100 feet (30 grams/meters). Once the cable length is determined, the voltage drop can be calculated based on the cable's resistance and expected current.

For example, a 2,000-watt drone running a 400-V_{DC} power supply requires 5 amps on the tether. Selecting a size 24 AWG cable with a conductor resistance of 2.48 ohms per 100 feet to minimize weight means the voltage drop would be 12.4 volts per 100 feet (2.48 ohms times 5 amps). The voltage drop can easily be accounted for by adjusting the GSE power supply. However, the 5-amp current on the size 24 AWG cable causes another challenge for the drone system. The temperature of the cable in ambient air will increase by approximately 30°C, which then causes the cable to heat up to 60°C. Furthermore, the cable on the reel during take-off and landing will experience hotter temperatures due to the proximity of the current carrying the wires and lack of heat dissipation, which can quickly melt everyday jacket and insulation materials.

Also, system designers should consider using the smallest AWG size that supports the desired power delivery needs and temperature limitations to help minimize weight. However, as power wires decrease in size, conductor resistance increases. This resistance creates heat during operation and increases the temperature of the wires, which then causes an additional increase in resistance. In steady state operation, the temperature of the cable will be high causing wire and insulation materials to degrade and the cable to possibly fail. The solution is to use power wires that have insulation with a high-temperature rating allowing smaller conductors to deliver power reliably.

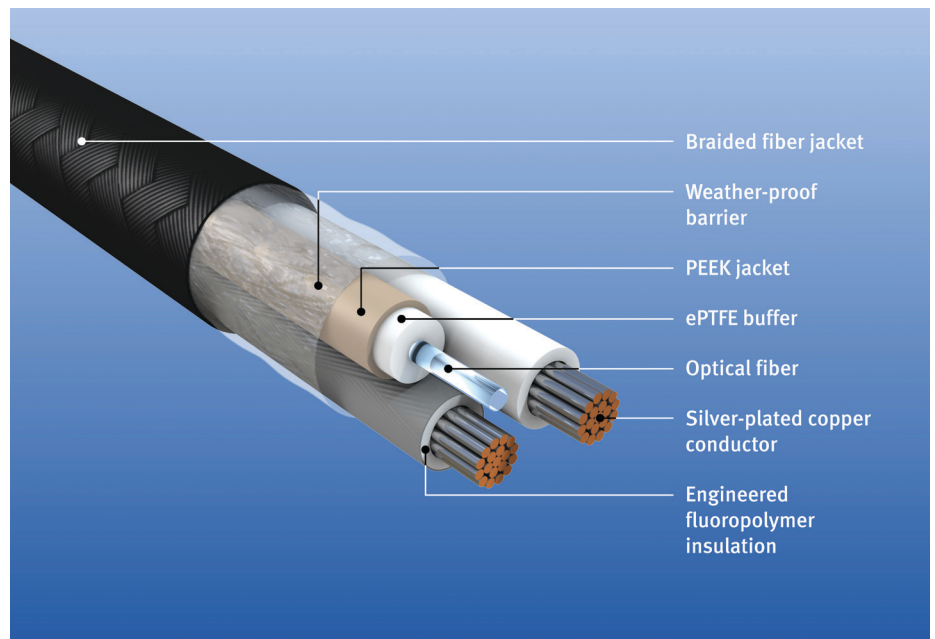
All of this means that the temperature rating of the jacket and insulation materials are critical to overall cable performance and longevity. Therefore, system designers need to choose a tether cable with durable materials that can withstand challenging environments and ensure the success of any drone operation.

Material Selection

Cable materials such as polytetrafluoroethylene (PTFE) with high-temperature ratings can maximize weight savings without impacting overall cable performance. There is a wide range of PTFE materials available on the market today. However, not all of these materials are equal in durability, weight and voltage withstanding. This is where Gore's expertise in engineering PTFE can make a big difference.

GORE® Tethered Drone Cables include a patent-pending fiber braid jacket along with thinner insulation that make them smaller, lighter weight, and more durable (Figure 6). These unique materials are designed specifically to survive the harshest conditions such as extreme temperatures, humidity, rain, snow, tough terrain, crushing, and repeated reeling. The fiber braid jacket is also low friction and resists abrasion induced by the TMS or during operation. Gore's low weight cable materials also enable tether drones to operate at longer lengths and higher elevations. For instance, the military can deploy a tethered drone using a Gore cable quickly at AGL up to 400 feet (122 meters), expanding the line of sight by up to 25 statute miles (40 kilometers).

Figure 6: High-Strength, Lightweight Construction of GORE® Tethered Drone Cables



Conclusion

As the commercial and military industries rely more on drones, shifting from high-energy density batteries only to high-performing tether cables with battery backup can provide continuous power and more flight time. However, this shift in drone technology requires a deep understanding of the TMS, power and data transmission needs, and cable survivability in harsh operating conditions. System designers must also consider current carrying capacity, high-temperature material performance, and weight limitations to determine the right tether cable for a specific application. In addition, comprehensive testing should be completed to ensure the tether cable will perform reliably in the intended application.

Gore's testing shows that not all materials are created equal and choosing the right tether cable with durable protection is essential to long-lasting performance in demanding drone environments. Gore's unique hybrid solution combines power wires and fiber optics in a rugged, low-weight construction that offers exceptional benefits to system designers and end users. GORE® Tethered Drone Cables are built with high-strength, weather-proof materials proven to tolerate harsh fluids, fluctuating temperatures, abrasion, repeated reeling and more. They deliver continuous high-voltage power, secure signals (more than radio links), and reliable data and video transmission to ensure the success of every drone operation.

Ultimately, GORE® Tethered Drone Cables maximize TMS availability and drone capability, increase design and payload options, allow drones to fly higher, expand line of sight or coverage, enable longer flight times, and last over the drone's lifetime.

Proven Track Record

For decades, Gore's products have been used successfully in many aerospace and defense applications — from the first moon landing to today's International Space Station, commercial airliners, fighter jets, combat vehicles, and naval platforms. Gore has been a trusted partner to the aerospace industry and many branches of the military, delivering cables and materials with an optimal blend of durability, reliability, and flexibility.

Application Notes



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