The Impact of Wiring on Network Reliability in the Aviation Industry

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Abstract— Advancements in networking and embedded systems have played a crucial role in transforming the inflight entertainment and avionics industries over the past few decades. Inflight entertainment relies on various networking applications via these embedded devices like live streaming, video and music streaming from a central server, payment for services, and passenger and crew communications. To understand the network complexity in these aircraft, we need to look at some of the commonly used networking protocols in these applications: ICMP, IP, UDP, TCP, IGMP, ARP, DHCP, and HTTP. A typical commercial aircraft contains many wires, around 150,000 to 500,000, depending on the airline type and size of the aircraft. A lot of modern aircraft use fiber optic cables for high-speed communication. However, copper cables still exist in these aircraft for various reasons. This paper examines the various types of cables used in aircraft and their specific applications. It also highlights potential issues that may impact these cables, focusing on how they can affect network performance. Finally, as a case study, we explore strategies for identifying and addressing problems related to cable bend radius, ensuring a smooth and reliable in-flight entertainment (IFE) experience for passengers.

Keywords— Embedded systems, Networks, Network reliability, Cables, Bend radius, Copper, Coaxial, STP, UTP, Fiber optic, Signal integrity, ARP, ICMP, Signal degradation, EMI

I. INTRODUCTION

In the complex and demanding field of aviation, the reliability of avionics systems is paramount to ensuring safety and operational efficiency. One of the most overlooked issues in aircraft systems is cabling, which results in unreliable networks. The intricate maze of wires within an aircraft is more than just a medium for power and data; it is a vital element that sustains the functionality and reliability of avionics networks. These wires ensure connectivity and communication within onboard systems and passenger safety. This paper investigates some of the common issues faced in aircraft related to cables and how faulty wiring and issues like bend radius can adversely affect performance and network reliability. This study also dives deep into the bend radius issue, offering insight into early detection and improvements in the process to capture these issues.

Understanding these factors is vital not only for aircraft manufacturers and maintenance engineers but also for policymakers who aim to set robust standards in aviation safety. The hope is that this study will delve into an overlooked issue and significantly contribute to the current body of knowledge while providing practical recommendations to address some of the complexities leading to network issues.

Through a detailed analysis of existing problems, the study seeks to lay the groundwork for future improvements in aviation network reliability caused by wiring issues.

II. CABLES USED IN COMMERCIAL AIRCRAFT

- Coaxial Cable: The coaxial cable contains several layers of conductive and insulating materials to transmit video, audio, and data signals without signal interference and loss. It consists of four layers: inner conductor, insulation, outer conductor, and outer insulating layer. The outer layer, known as a sheath, helps protect the cable from physical damage. The outer conductor made of metal protects the cable from any external interference, and the insulation layer protects the conductor, which is the core of the coaxial cable.

- Shielded Twisted Pair Cable: STP cables consist of colored wires twisted around one another, forming pairs. They incorporate additional Shielding around the pairs of wires to reduce electromagnetic interference (EMI) and crosstalk between adjacent pairs. It has three layers: Twisted pairs, Shielding, and Outer jacket. STP cables consist of pairs of insulated copper wires twisted together. This twisting helps eliminate or reduce interference by causing the electromagnetic noise to be picked up equally by both wires in a pair, which causes the signals to cancel. The inner shield layer acts as a preventive barrier protecting it from external electromagnetic interference (EMI), which can affect the signal while also helping to prevent signals from leaking out of the cable. The outer jacket protects the entire assembly from physical damage and environmental factors

- Unshielded Twisted Pair Cable: UTP cables are the same as STP cables without the shielding layer. Instead, it contains a plastic insulation layer to protect the cable from short circuits and other essential environmental factors. They are a more cost-effective solution without the additional interference protection.

- Fiber Optic Cables: These cables contain either a glass or a plastic core, shielded by a cladding, a buffer and a jacket. These layers protect fiber optic cables from potential damage and external interference. This networking cable is the perfect choice for carrying data around long distances and the standard cable for connecting networks in different locations. [6]

III. APPLICATION OF CABLES IN AVIONICS

Table 1 below describes how all the different cables are used in avionics. It gives an overview of potential issues if a cable is damaged. Figure 1 shows the approximate percentage breakdown of cables used in commercial aircraft.

FIGURE 1 CABLE TYPE USAGE BREAKDOWN IN AIRCRAFTS [8]

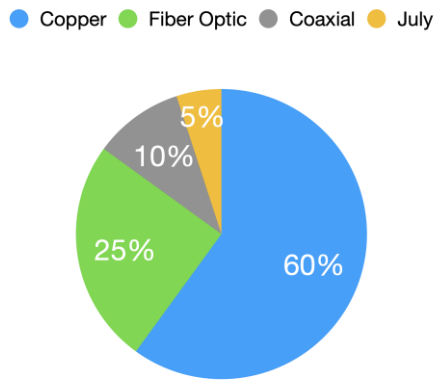


TABLE I. CABLE TYPW AND USAGE [6]

Cable Type	Usage in Avionics

Copper	Power distribution, low-speed signal transmission, avionics equipment, lighting systems, cockpit controls.
Coaxial	RF signal transmission (radio, radar), analog video transmission (older systems, cockpit displays).
Fiber	High-speed data communication (IFE, communications, flight control systems), radar, video signals, data buses.
UTP	Ethernet networks, passenger information systems, non-critical cockpit systems.
STP	Data communication in noisy environments, avionics data buses, control systems requiring noise immunity.

IV. POTENTIAL WIRING ISSUES

It is important to understand how to wire all systems correctly in avionics. This can be complex and challenging. Existing research provides a foundational understanding of the technical challenges associated with wiring. Various studies have investigated the implications of aging electrical components and other factors on system performance, pointing to the increasing vulnerability of avionics systems as aircraft continue to operate beyond their expected lifespan [1,2]. Here, we will look at some wiring issues that could affect the aircraft's performance.

- Aging electrical components: Wires and Cables used in aircraft are prone to degradation over time due to various issues like humidity, radiation, vibration, and obsolesce of parts. Short circuits, electrical arcing, and signal interference are common problems due to the insulation on wires becoming fragile or broken. This can lead to fires and complete electrical failures and adversely affect avionics systems, which rely on a continuous, regular supply of power and signal transmission. [1,2]

- Electromagnetic Interference: Aircraft cables distribute critical signals and power to various avionics components like flight instruments, communication systems, navigation equipment, and flight control systems. Due to avionics cables being in a dynamic environment consisting of vibration, high-temperature fluctuations, and electromagnetic fields are present, they must be designed and shielded to minimize the impact of EMI. Potential issues of EMI in avionics include signal degradation, communication failures and complete system failures.

- Weight and Fuel Efficiency: Excess weight from cables can directly influence the total weight of the aircraft. The higher the number of cables and the heavier the weight, the larger the fuel consumption will be. Lighter cables with lower resistance can also help improve overall power efficiency by minimizing energy losses. Cable type and insulation material also play a huge role in fuel efficiency.

- Signal Integrity: Signal integrity refers to the quality and accuracy of signals transmitted through these cables. Any degradation or distortion of the signal can have serious consequences for the performance of avionics equipment, which relies on accurate, reliable transmission of data, power, and control signals. Noise, attenuation, crosstalk, and EMI are common issues. Some of these can be mitigated by properly routing cables, proper grounding, and using shielded and twisted pair cables wherever necessary.

- Environmental Factors: Aircraft are designed to operate in environments with significant temperature fluctuations. The cables can face high heat from the engines, electrical equipment, and sunlight on the surface, as well as the extreme cold at cruising altitude, which can cause the materials used (such as insulation, Shielding, and conductors) to expand and contract. This can lead to insulation cracking and thermal cycling, leading to worn-out conductors. There is also fatigue damage and microfractures caused by constant vibration. Moisture and humidity also have an effect that can lead to corrosion and insulation breakdown. Pressure variations are another important factor that can lead to outgassing, where some cable materials can release certain gases

- Retrofitting compatibilities: Many aircraft rely on retrofitting to adapt to newer technologies since rewiring an entire aircraft could be tedious. That said, we could run into issues like component mismatch or components could have gone EOL (End of Life). Comprehensive Shielding, training, testing, and frequent cable routing management maintenance can alleviate some of these issues.

- Routing issues: Proper cable routing is essential to ensure reliable signal transmission, preserve system integrity, and reduce the risk of interference, short circuits, and mechanical damage. Incorrect routing can compromise avionics systems' performance, safety, and long-term reliability. This can cause issues like improper bend radius on cables, signal integrity issues, crosstalk and physical damage due to improper cable management. Mapping out paths in advance, securing cables properly, leaving enough spacing and regular maintenance are some of the ways to alleviate this issue

V. NETWORK RELIABILITY IN AVIATION

Network reliability in aviation refers to the ability of avionics systems to consistently perform without failure, ensuring smooth communication, navigation and control throughout a flight. This is crucial to ensure flight safety and operational efficiency. For a network to be trusted in avionics, it must withstand various environmental factors discussed above to provide uninterrupted data for routine and emergency operations. Aviation networks encounter industry-specific challenges that demand they remain reliable in harsh environmental conditions. Moreover, the complex integration of numerous systems requires a sophisticated network design capable of managing high data volumes while adhering to stringent safety standards. Overcoming these challenges is key to ensuring network reliability and supporting the safe, effective operation of the aircraft. The functioning of avionics networks is directly tied to the current condition and setup of aircraft wiring.

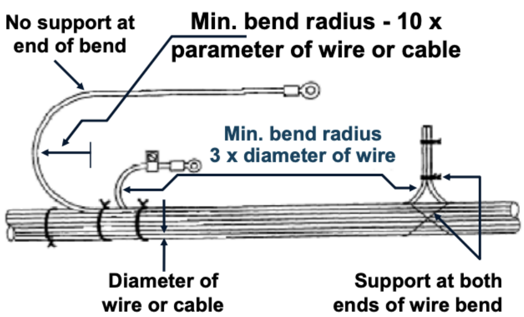
These wiring systems must be carefully maintained to avoid issues like insulation breakdown, conductor fatigue, and violations of proper bend radius, all of which can degrade network performance. Ensuring network reliability means taking more proactive care.

VI. CASE STUDY - BEND RADIUS ON NETWORK RELIABILITY

This study significantly focuses on the technical constraint of cable bend radius. Cable bend radius refers to the minimum radius at which one can bend a wire without causing damage.

- What is the bend radius of cables: The cable bending radius is the smallest radius by which a cable can be bent without damaging it. It is influenced by factors such as the cable size, construction, conductor type, and the materials used for sheathing and insulation. It is usually expressed as a multiple of the cable's outer diameter, for example, 6 times the diameter. Figure 2 represents a diagram depicting the same [3,4]

FIGURE 2 CABLE BEND RADIUS [7]



- Different cables used in avionics, including their bend radius and potential impact: Table 2 represents all the different cable types used in avionics and its maximum allowed bend radius

TABLE 2 CABLE TYPE BEND RADIUS ALLOWED[3,4]

Cable Type	Bend Radius	Example
Copper Cables	10 times the outer diameter of the cable	40 mm for a 4 mm diameter copper cable
Fiber Optic Cables	20 times the outer diameter (non-armored) / 10 times (armored)	120 mm for a 6 mm fiber optic cable (non-armored)
Coaxial Cables	4 to 6 times the outer diameter	32 mm to 48 mm for an 8 mm coaxial cable
STP Cables	8 to 10 times the outer diameter	56 mm to 70 mm for a 7 mm STP cable
UTP Cables	4 to 6 times the outer diameter	24 mm to 36 mm for a 6 mm UTP cable

- Current methodologies to detect bend radius: By industry standards mentioned in SAE AS50881 and the Aircraft manufacturer's wiring practices manual, the following best practices are recommended:
  - Understand the minimum bend radius: Each cable type has a specified minimum bend radius, which is critical to prevent damage from excessive bending.
  - Check the cable specifications: Refer to the cable manufacturer's data sheet for the recommended minimum bend radius.
  - Proper cable routing: Plan cable runs to avoid sharp bends, using gentle curves with sufficient space to maintain the required bend radius.
  - Support systems: Utilize cable ties, clamps, and other support mechanisms to maintain the proper bend radius throughout the cable run.
  - Select appropriate cables: Choose specialized cables designed to withstand repeated bending without damage.
  - Understand the minimum bend radius: Each cable type has a specified minimum bend radius, which is critical to prevent damage from excessive bending.
  - Select appropriate cables: For high-flex applications, choose specialized cables designed to withstand repeated bending without damage [3,4]

- Potential Improvements to Process: Most of the methods described in the previous section require extensive manual inspections and planning. In a data-centric modern world, providing field engineers and technicians with ample data is important to help them identify and debug routing issues. The following proposal should be implemented during flight taxiing when high-throughput video samples are being streamed as part of tests.
    - Maintain an Active Inventory of Network Addresses:
        - Create and maintain a comprehensive list of all network addresses associated with In-Flight Entertainment (IFE) equipment. This list should be regularly updated to reflect the network topology.
        - Implement a software service that routinely pings all network addresses. Any instances where a ping fails or is delayed beyond acceptable thresholds should trigger an investigation to diagnose potential cabling issues.
    - Monitor Network Traffic for ARP Anomalies:
        - Monitor network traffic for requests for missing or incomplete ARP (Address Resolution Protocol). A lack of ARP responses may indicate issues with network connectivity or misconfigured devices that could impact video data flow.
        - Utilize Network Diagnostic Tools: Use diagnostic tools such as Iperf, Wireshark, and other network monitoring utilities to evaluate key network parameters, including:
            - Jitter: Monitor variations in packet arrival times to detect potential issues with video streaming stability.
            - Delay: Track latency across the network, ensuring minimal delays in the video signal.
            - Throughput Loss: Assess data throughput to ensure no bottlenecks or packet loss affect the video stream quality.

        These tools will help identify any network issues caused by wiring issues that could lead to degradation in video quality or streaming interruptions.

VII. LIMITATIONS OF STUDY

While the case study above offers useful insights, it does have some limitations. One key limitation is its focus on commercial aircraft, which means the findings may not necessarily apply to other sectors, such as military or private aviation.

VIII. AREAS OF FUTURE RESEARCH

Future research could build on this study by looking at how aging wiring systems affect various types of aircraft and different operating conditions. Exploring new technologies and materials that could improve the durability of wiring and the overall resilience of avionics systems would also be a valuable area for further investigation. Additionally, long-term studies tracking the effectiveness of updated maintenance practices and design upgrades could provide more insights into the best ways to maintain network reliability. These research efforts will help advance aviation safety and efficiency, particularly as the industry faces the challenges of an aging infrastructure.

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