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A Brief Analysis of Innovative Management of Electrical Systems in New Propulsion Aircraft Based on a Certain Model Failure

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ABSTRACT

The new power aircraft possesses capabilities such as rapid response, strong penetration, and high survival rate. To fundamentally improve the response speed and accuracy of the aircraft, the electrical system is required to enhance the rates of control information, data processing, and transmission, as well as to reduce the assembly volume. This paper briefly explains the definition and function of the new cyclic power engine and conducts analysis and research from two aspects: cable network design for cable miniaturization and highly integrated bus design. It proposes a bus design scheme for the electrical system and offers suggestions for promoting the lightweighting and integration of new power aircraft.

KEYWORDS

New powered aircraft; Electrical system; Cable; Lightweight and miniaturization; Bus design

Since the 1960s, research on rocket-based combined-cycle engines in foreign countries has targeted reusable transport systems as the ultimate application goal. Typical research programs in the United States include NASP, ASTP, GTX, CCE, JAXA, etc. In terms of turbine-based combined-cycle engines, foreign countries have never ceased research in this area, exemplified by the SR-71 Blackbird reconnaissance aircraft and X-43B. The air-breathing combined-cycle engine is an ideal propulsion system for Single-Stage-To-Orbit (SSTO) vehicles, with a typical program being the British Skylon spaceplane project. Currently, new propulsion projects are experiencing explosive growth, effectively expanding the flight speed range and airspace of traditional aircraft and cruise missiles, enabling aircraft to possess cross-domain flight capabilities. These can be applied to reusable transport systems, high-speed aircraft, and high-speed missile weapons. To equip new propulsion aircraft with rapid response, strong penetration, high survivability, and other capabilities, it is necessary for the aircraft to adopt an electrical solution that is easy to use and maintain, improve the rate of control information, data processing, and transmission, reduce assembly volume, and fundamentally enhance the aircraft's response speed and accuracy. This paper analyzes two aspects: lightweight and miniaturized cable network design and highly integrated bus system design, and proposes suggestions for promoting the lightweighting and integration of new propulsion aircraft.

1 Definition and Role of New Cycle Propulsion Engines

The new cyclic power engine (hereinafter referred to as "new power engine") refers to a novel wide-envelope multi-mode power plant formed through the organic integration of two or more single-type engines (typically turbine engines, ramjet engines, rocket engines, etc.) via thermal cycling and structural layout. Compared to single-type engines, the new power engine leverages the technical advantages of different engine types within their respective operating ranges, featuring a wide operating range and superior overall economy. It represents an ideal power plant for future wide-speed-range, large-airspace near-space, and aerospace missile weapons. The primary reason for proposing the concept of new power technology is to accommodate the full-speed-range and full-airspace flight conditions encountered in accessing aerospace [1].

As a high-performance power plant, the new power engine will play a pivotal role in the future development of the aerospace industry. Through the organic integration of thermal cycling and structural layout, it integrates the technical advantages of various single engines, such as turbines, ramjets, and rocket engines, enabling flexible maneuverability across wide speed and airspace ranges. The design goal of the new power engine is to achieve high-performance operation under full-speed-range and full-airspace flight conditions. By adopting the organic integration of thermal cycling and structural layout, it can switch operating modes under different flight conditions to optimize performance. This multi-mode power plant not only has the potential to break through aerospace flight performance limitations but also provides critical technical support for the development of future intelligent weapon systems. The advent of the new power plant will undoubtedly drive significant breakthroughs in aerospace vehicles, substantially enhancing their flight performance and combat capabilities, and injecting new impetus into the leapfrog development of the aerospace industry. Currently, this technology is undergoing a transition from theoretical exploration to engineering practice, urgently requiring in-depth research and innovation in multiple fields such as materials and control to facilitate the application and promotion of the new power engine.

2 Concept of Lightweight and Miniaturization for Missile-borne Cable Networks

Missile-borne cable networks are fabricated from a certain quantity and specification of electrical connectors and wires. Serving as the information flow carrier of the entire missile, missile-borne cable networks constitute a vital component of the aircraft's electrical system. Additionally, they serve as the bridge for coordinated operation of the entire missile, enabling power supply delivery, measurement, and control signal transmission through the cable network. The fundamental approach to lightweight and miniaturization design for missile-borne cable networks involves adopting optimized design methods for traditional cable networks while concurrently applying optical fiber transmission methods to reduce the number of traditional cables. This aims to achieve lightweight and miniaturization of the cable network while meeting electromagnetic compatibility (EMC) requirements. The crux of lightweight and miniaturization design for missile-borne cable networks lies in optimizing the structural layout and material selection of the cable network. By utilizing lightweight materials for cables and connectors and optimizing the cable routing, the weight of missile-borne cable networks can be effectively reduced.

2.1 Optimization of Traditional Cable Network Design

The optimization of traditional cable networks necessitates enhancements in their fundamental components, including cables and connectors, to achieve weight reduction. Meanwhile, where feasible, new technologies, devices, and materials should be fully utilized.

(1) Selection of Electrical Connectors: Electrical connectors are a crucial part of cable networks, and the quantity used in missile systems significantly impacts the overall weight of the cable network. Assuming there are approximately X electrical connectors in the cable network, a reduction of 1g per connector translates to a total reduction of Xg. Therefore, optimal selection of electrical connectors is essential. However, the choice of electrical connectors not only affects the cable network itself but also all electrical equipment within the system [2]. Thus, the selection should be considered jointly by the missile's electrical system in coordination with other missile-borne equipment. Based on the characteristics of all electrical signals on the missile, electrical connectors should be chosen that are small in size, lightweight, have a high contact density, reliable contacts, good electromagnetic compatibility, and are resistant to shock, vibration, and centrifugation, while meeting their respective specifications.

(2) Selection of Conductors: The selection of conductors is a primary factor determining the miniaturization and lightweighting of cable networks. Typically, electrical systems incorporate four main signal types: power transmission signals (including missile power supply, telemetry power supply, and isolated/converted electrical power transmission signals), analog transmission signals (including electrical control signals and analog measurement signals for telemetry), digital transmission signals (missile-borne control bus signals, missile-to-ground communication signals, and switching signals for guidance and control systems), and pulsed analog signals. Currently, there are commonly used wire specifications for each of these four signal types, as shown in Table 1. When selecting conductors for the cable network, appropriate lightweight materials can be chosen based on the actual project situation to reduce the weight of the cable network.

Table 1 Recommended commonly used wire types for four signal types

Signal type	Tin-plated copper core Teflon-coated wire	Tin-plated copper core polytetrafluoroethylene shielded cable	Tin-plated copper core polytetrafluoroethylene (PTFE) twisted shielded pair cable
Power supply transmission signal	Low-current power supply signal	Pulsed or high-current power supply signal	External sampling signal of power supply
Analog transmission signal	Telemetry measurement signals or ground-based simulated measurement signals	Low-current measurement circuit signal	It is generally not adopted
Digital transmission signal	It is generally not adopted	It is generally not adopted	Switching signal or 485 communication signal
Pulse analog signal	It is generally not adopted	Impulse or high-current power supply signal	Pyrotechnic activation signal

2.2 Application of Optical Fiber Transmission Technology

Currently, optical fiber transmission technology has matured and been widely applied in the field of communications.

Based on the characteristics of optical fibers, optical fiber transmission technology is primarily used for transmitting signals with high isolation requirements, signals with large data volumes, microwave signals, and so on. Missile-borne optical fiber cable transmission technology refers to the integration of necessary digital or analog optical modulators within the equipment of aerial vehicles, in accordance with the characteristics and technical specifications of aerial vehicle information transmission, enabling transmission through optical fiber connectors and cables. This technology facilitates rapid and stable optical signal transmission among various devices within aerial vehicles, significantly enhancing the reliability and anti-interference capabilities of signal transmission. Furthermore, optical fiber cables are lightweight and compact, contributing to the reduction of the overall mass and structural complexity of aerial vehicles. With the continuous development of optoelectronic devices, missile-borne optical fiber cable transmission technology is poised for broader application in the aerospace industry in the future.

A comparison between traditional metal cables and optical fibers is shown in Table 2. If optical fiber transmission technology can be applied to new propulsion aerial vehicles, it could represent a significant breakthrough in the miniaturization of missile-borne cable networks.

Table 2 Comparative (Reference) Data Between Optical Fiber Transmission and Metal Wire Transmission

Content	optical fiber	metal wire
Transmission loss	low	high
Transmission bandwidth	10GHz/km	10MHz/km
Cable diameter	extremely thin	relatively thick
Material	fused quartz or quartz glass	Tin-plated copper core

3 Bus Design for Electrical Systems

MIL-STD-1553B, also known as the "Multiplex Data Bus for Digital Command and Control in Military Airborne Systems," was published by the U.S. military in the 1970s, employing a multi-redundant bus topology [3]. The bus can accommodate up to 31 Remote Terminals (RTs) for connecting payloads and enabling data communication [4]. The bus boasts excellent reliability and stability. However, the 1553B bus features high power consumption, stringent transmission matching requirements (necessitating the use of matching transformers), and demanding wiring specifications.

3.1 Optimizing Bus Network Design

Typically, in the bus design of new propulsion aircraft, the flight control computer serves as the Bus Controller (BC), responsible for the communication and management of the bus system. The various Remote Terminals (RTs) are illustrated in Figure 1 below.

Due to the large number of remote terminals and the complex structure of the new power aircraft, the following two aspects should be fully considered when arranging the cable network and equipment layout:

(1) Optimizing Equipment and Cable Network Layout: Intelligent algorithms can be utilized to generate and optimize

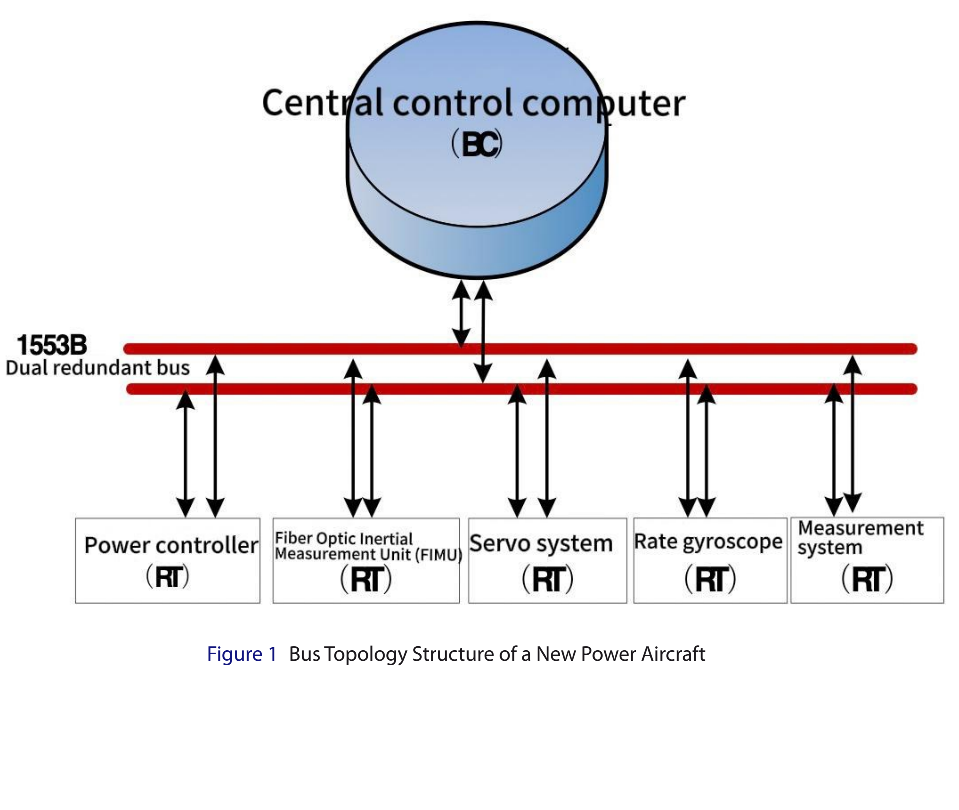

Figure 1 Bus Topology Structure of a New Power Aircraft

the network structure, simplifying the cable network while enhancing communication performance.

(2) Unified Software and Hardware Interface Circuits for System Bus Interface Equipment: To eliminate the need for bridging electronic components or adding adapters on cables due to inconsistent designs or inadequate considerations, unified software and hardware interface circuits should be employed for all system bus interface equipment. This will ensure reliability while shortening the instruction and data transmission cycles, thereby improving response speed.

3.2 Optimization of Timing Design

The structure of the new propulsion aircraft is complex, consisting essentially of a propulsion system, an integrated electrical control system, a measurement system, a servo system, a guidance and control system, structural and thermal protection systems. With multiple bus access terminal nodes, a wide variety of data types, and a vast amount of data, its complexity is significant. Data can be classified by function into onboard control bus signals, aircraft-ground communication signals, guidance and control system switching signals, telemetry signals, etc. From the perspective of real-time performance, data can be divided into three categories: periodic real-time data, aperiodic real-time data, and data with no real-time requirements. Since the various subsystems on the aircraft need to work in coordination based on the communication bus, the performance of the communication bus will directly affect the stability and control performance of the aircraft's control system. Data transmission on the communication bus may incur random or deterministic time costs due to various factors, such as physical signal encoding and hardware system latency. These time delays can impact system performance, cause coupling among multiple loops, and even lead to system instability [5]. Therefore, the following two aspects should be fully considered in bus design:

(1) Adequately optimize the timing design to maximize decoupling among subsystem loops and achieve efficient bus control.

(2) Through timing optimization design, achieve uniform bus data loading, effectively reduce the maximum burst volume of the bus, and ensure the reliability of bus data acquisition.

4 Conclusion

In summary, based on standardized and modular design, combined with new methods and technologies, the design of the missile-borne cable network has been simplified to achieve lightweight and miniaturization. Simultaneously, through the missile-wide bus design, and continuous optimization of bus design and timing, data transmission rates and processing speeds have been improved. As a result, the optimization of the electrical system is achieved in terms of both assembly volume and information transmission and processing efficiency, ultimately benefiting the response speed and combat capability of the new-type powered aircraft fundamentally. This design optimization scheme not only enhances the overall performance and combat capability of the new-type powered aircraft but also significantly reduces the overall weight and structural complexity of the entire aircraft. The adoption of advanced broadband multiplexing transmission technology can further improve the reliability and real-time performance of data transmission, ensuring the rapid transmission of critical information.

About the Author

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