MIL-STD-1553B in Avionics: Where Data Networking Has Been and Where It's Going

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The landscape of avionics architectures has shifted through the decades from analog to digital system implementations with increased software complexities. As the subsystems of the aircraft grow, so do the complexities in the communications between them. Speed, reliability, safety, cost, and quality of service are all factors that are taken into consideration when choosing a particular data networking standard. The present evolution in technology and data networking--of which, MIL-STD-1553B has and is still a major component--offers a wide variety of options for modern day aircraft.

However, increased data throughput requirements for high definition video and camera services far exceed what MIL-STD-1553B theoretically maximums are-- approximately 200 Mbps. Efforts have been made to provide enhanced speed MIL-STD-1553B, which may still serve some purposes on commercial aircraft. Moreover, technologies such as Ethernet, are more likely to succeed in meeting the latest throughput demands commercial, and possibly, military avionics.

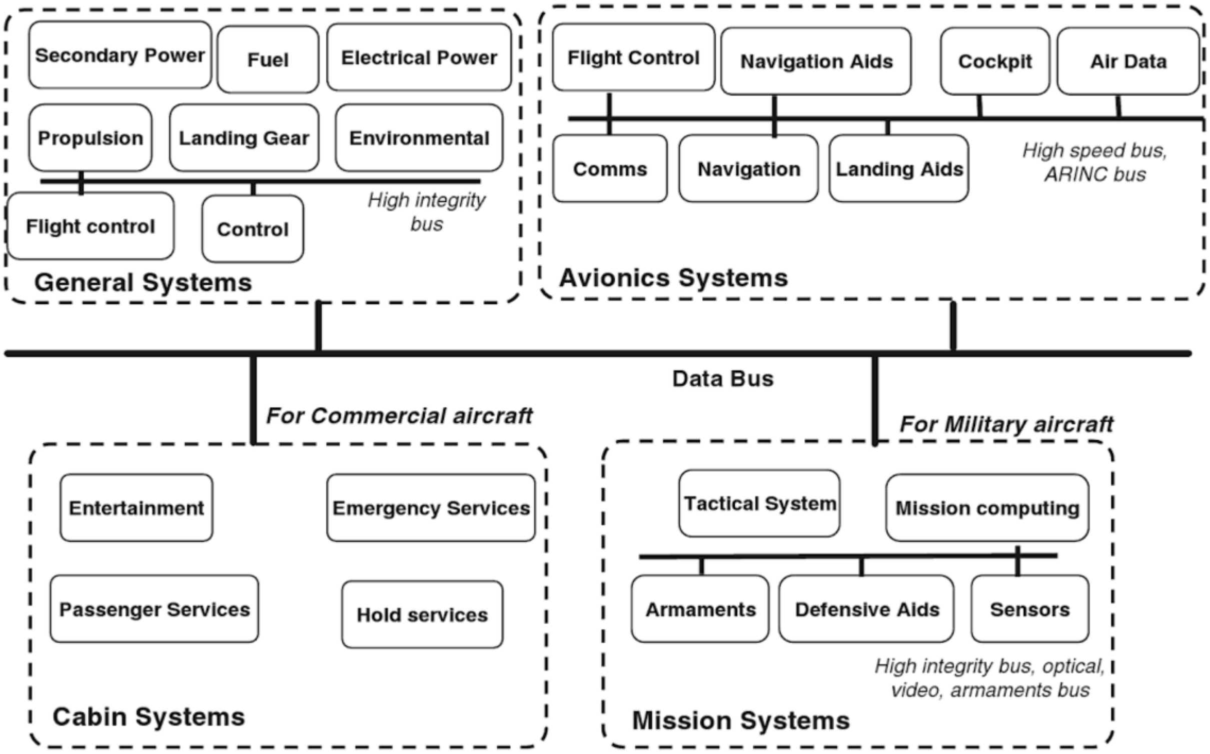
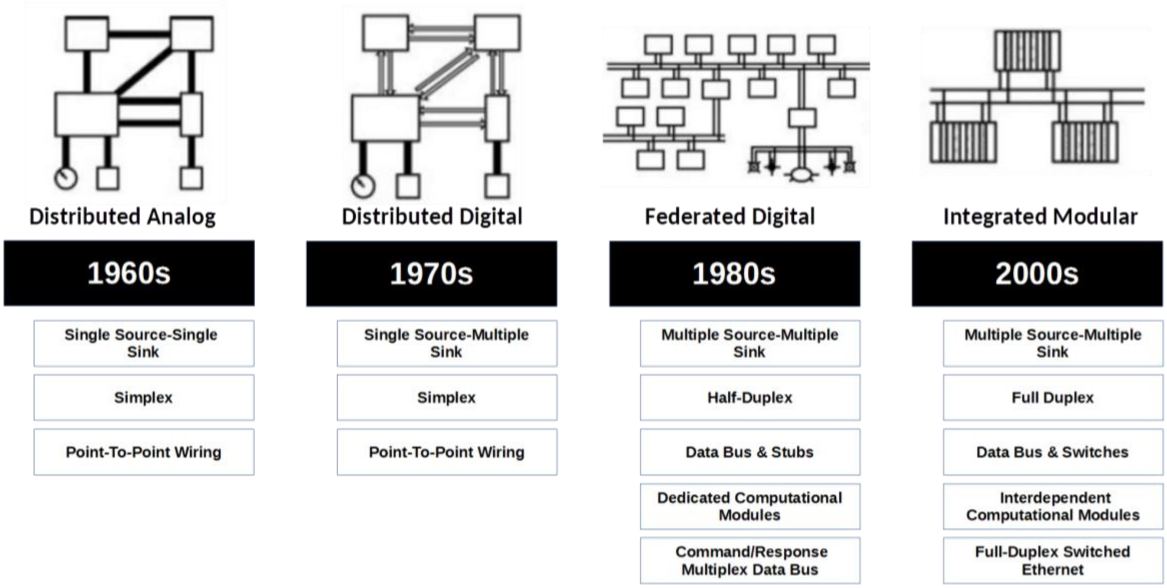


Figure 5.4 Aircraft systems.

Caption: As the complexity of subsystems grows so do data networking standards for both military and commercial avionics.
Source: Design and Development of Aircraft Systems
https://books.google.com/books?id=kD_ZC5GzqeIC&pg=PA98&dq=distributed+digital+architecture+arinc+429&hl=en&sa=X&ved=0ahUKEwiK0Y2L0MnSAhUj4oMKHRZ_DPYQ6AEIKTAC#v=onepage&q=distributed%20digital%20architecture%20arinc%20429&f=false

A Timeline of Avionics Architectures

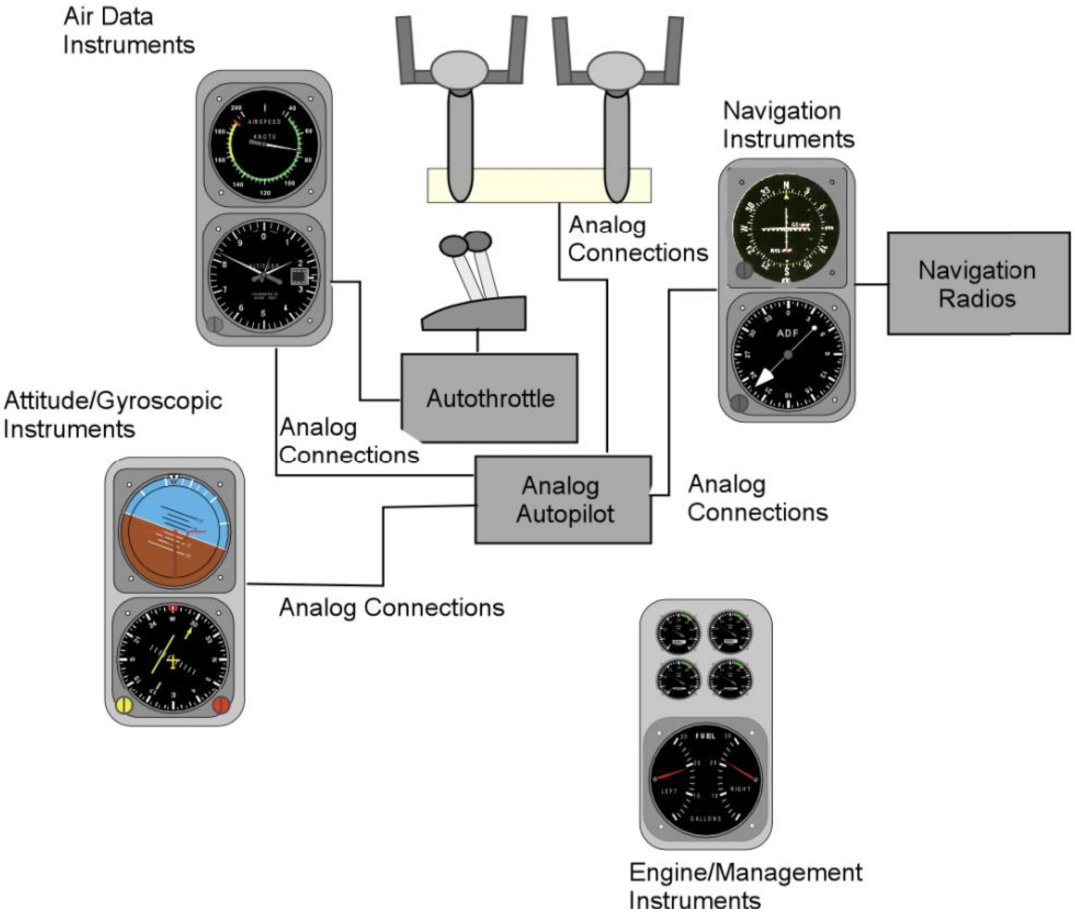


Distributed Analog	Distributed Digital	Federated Digital	Integrated Modular
1960s	1970s	1980s	2000s
Single Source-Single Sink	Single Source-Multiple Sink	Multiple Source-Multiple Sink	Multiple Source-Multiple Sink
Simplex	Simplex	Half-Duplex	Full Duplex
Point-To-Point Wiring	Point-To-Point Wiring	Data Bus & Stubs	Data Bus & Switches
		Dedicated Computational Modules	Interdependent Computational Modules
		Command/Response Multiplex Data Bus	Full-Duplex Switched Ethernet

Caption: Timeline of avionics architectures.
Source:https://de.slideshare.net/ostroumov/avionics-digital-data-buses

Distributed Analog

In the 1960s, the initial distributed analog avionic systems were of a single source-single sink application where a single computer could send commands to a single piece of equipment. This type of dedicated linking with simplex transmission, or a transmission that can only go in one direction, could be used in earlier aircraft with minimal subsystems. As the complexity of avionic data systems increased, so did the interdependency between equipment. This architecture rapidly presented limitations as aircrafts gained more subsystems, and the original analog system proved very difficult to modify as there were no buses and only wires and bulky electromechanical parts.

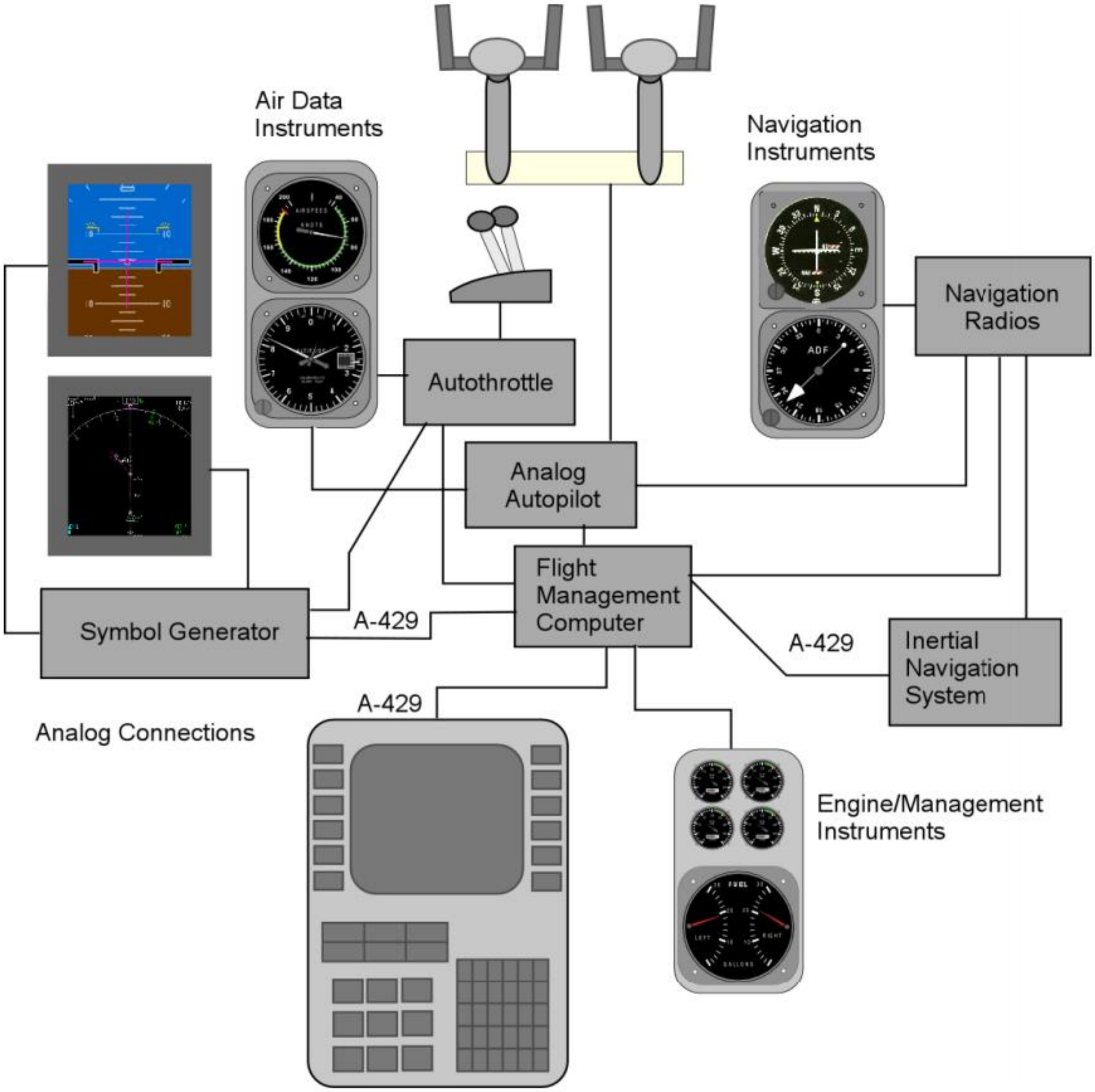


Caption: Schematic of a sample electromechanical flight deck implementing a distributed analog architecture.
Source: [https://acast.grc.nasa.gov/files/acast/2007/09/28/multi-modal_digital_avionics_for_commercial_applications.pdf]

Distributed Digital

In the late 1960s and early 1970s, the advent and maturation of digital computing led to distributed digital architectures with single source-multiple sink data transmission. This was practiced with standards such as ARINC 429, or Mark33 Digital Information Transfer System (DITS), as a serial unidirectional digital data bus. This technique enables one piece of transmitting equipment, or source, to communicate with 1-20 subsystems, or sinks. Still, this standard relies on a simplex transmission on one twisted shielded pair data line, and bi-directional data transfer necessitates two lines. This data protocol was adopted primarily in commercial aircraft as the point-to-point wiring structure provides highly reliable data transfer at a speed of approximately 100 kbs/s.

There are a limited number of topologies to leverage when designing an ARINC 429 system. Every transmitting line replaceable unit (LRU) must be connected to up to 20 receiving LRUs, such as radar altimeters, radios, and GPS sensors in various formations. Upgrades on this type of aircraft are very difficult considering the wiring challenges, as each subsystem was dedicated in function. Also, much of the equipment required custom design with almost no commercial off-the-shelf (COTS) hardware options. Sample aircraft with an ARINC 429 installation includes the Airbus A310/A320 and A330/A340, Bell Helicopters, Boeing 727, 737, 747, 757, and 767, and McDonnell Douglas MD-11.



Caption: Advancements in computerized components allows for the addition of ARINC 429 digital components such as Flight Management System (FMS).
Source: https://acast.grc.nasa.gov/files/acast/2007/09/28/multi-modal_digital_avionics_for_commercial_applications.pdf

Federated Digital

The military standard MIL-STD-1553, or Digital Internal Time Division Command/Response Multiplex Data Bus, was first released in 1973 and solidified the federated digital avionic architectures for the military while multiple ARINC 429 buses were still leveraged more often in the commercial arena. This multiple source-multiple sink system is a type of half-duplex serial data transmission between critical components, or subsystems, on an aircraft. Since its inception in 1973 this standard has proven robust and highly modular. MIL-STD-1553 has been implemented in wider range of applications including commercial aircraft, submarine, and space avionics systems. The high reliability of the 1553 standard stems from several factors which enable the bus controller (BC) to detect errors and recheck to see if any components, or remote terminals (RT), are malfunctioning. The addition of an extra bus (dual-redundant bus), and a backup BC in critical instances. Helped to avoid failure if the primary BC crashed. MIL-STD-1553 exhaustively lists design and implementation methods of an avionics system, from message commands to RT layouts, which has simplified the adoption of the standard across platforms and technologies through the decades. The federated digital architecture allows for a more interrelated functionality between systems that were previously independent in architectures of the past. Data transmission via buses drastically cut down on the weight and cost that traditional point-to-point systems typical required. For instance, the United States Air Force saved approximately 1,200 pounds in wire for the B-52 [8]. The 1553 system has become so prevalent over the decades that close to 30,000 aircraft leverage the standard with nearly 1 million total 1553 terminals implemented [9].

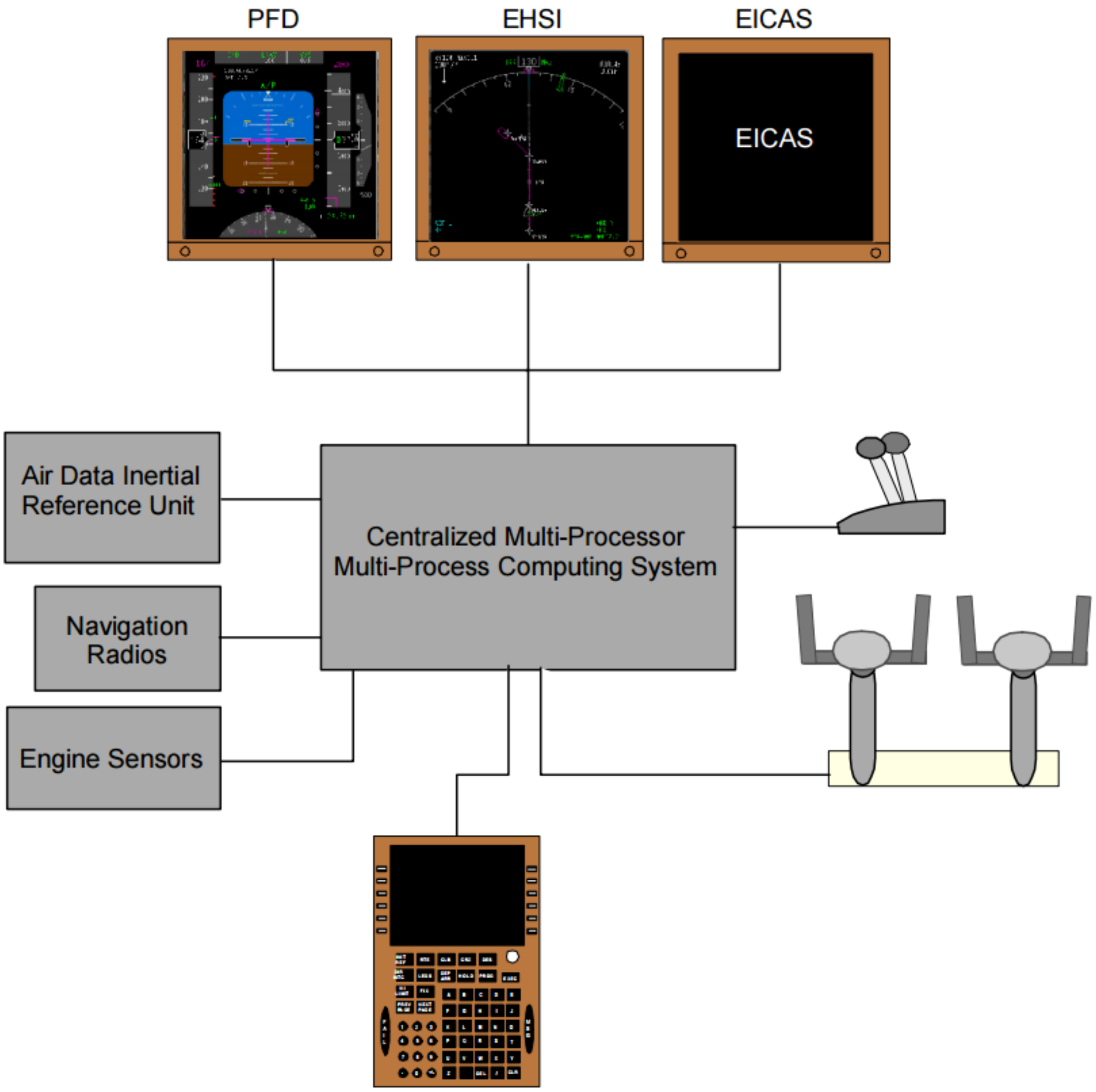
Caption: F-105 Thunderchief with LRUs laid out. Federated architectures mitigated the amount of wiring between discrete components and streamlined aircraft controls.
Source: https://en.wikipedia.org/wiki/Avionics#/media/File:Republic_F-105B_with_avionics_layout_060831-F-1234S-046.jpg

Integrated Modular

While the military standard MIL-STD-1553B’s system modularity and redundancy ultimately allowed for swift upgrades to subsystems as technology evolved—ARINC 429 was rapidly becoming outdated, expensive, and bulky for commercial airliners. Commercial aircraft did not need the level of upgrades military aircraft call for, this way a highly specialized and integrated system is a feasible option for many years.

However, the desired for increased data rates on aircraft led to the development of the ARINC 653 standard, which was developed in 1996 after a slow evolution from the widely used ARINC 429. This standard outlines the general purpose hardware and software for an IMA architecture. The data network development of fourth generation jet fighters (e.g.: F-22, F-35, etc.) led to the early phases of IMA concept, but was eventually more readily adapted by commercial industries.
Where components in federated networks generally function with independent operating systems per hardware module, integrated modular networks allow for a layer of abstraction between the hardware and software, in order to more swiftly allocate resources to and from any subsystem of the aircraft. These highly integrated systems often leverage the avionics full-duplex switched Ethernet (AFDX) data network with the APEX application program interface (API), as specified in ARINC 664 part 7 for data communications.

This data networking essentially replaced the point-to-point connections of ARINC 429 with virtual links (VL) over a highly integrated physical network of avionics. The AFDX network leverages twisted pair or fiber optic cables to accomplish full-duplex Ethernet transmission with two separate pairs for the transmit and receive paths. This approach prevents transmission collisions. Switches are a core component of this system and establish a distribution network of all information packets. The IMA system has already been implemented in a number of aircraft including the Airbus A350/A380/A400M, Boeing 777/787, Dassault Falcon 900, BAE Hawk, and the ATR 42/72.



Caption: Modern day aircraft feature a complex FMS with a centralized processing system.
Source: https://acast.grc.nasa.gov/files/acast/2007/09/28/multi-modal_digital_avionics_for_commercial_applications.pdf

1553B: Looking Forward

155B Strengths

Characteristics such as scalability, determinism, maturity, and interoperability give MIL-STD-1553B system an edge over many alternatives. This standard has had decades to steadily absorb into applications across industries. Thus, allowing for agile design capabilities, while established software and GUIs provide ease of simulation. Moreover, COTS components come available with the dual-bus system built into their specifications, thereby easing the design process. Vehicle or aircraft upgrades can be developed in parallel as opposed to linearly, as subsystems with 1553B are not tightly integrated.

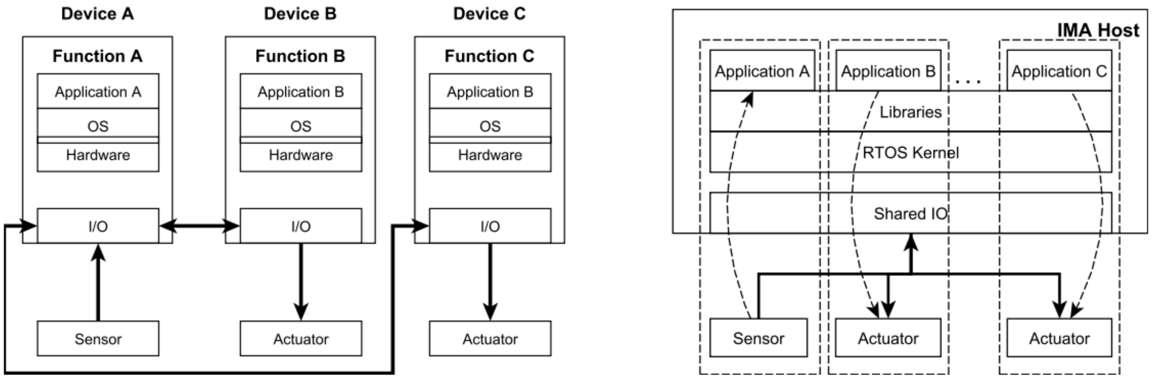
One cornerstone trait of MIL-STD-1553B is transmission reliability, that culminates as vastly less risk and cost in implementing it versus other avionic standards. The bit error rate (BER) with 1553B is a low 10^{-12}, so only a minimum bus bandwidth is used for retransmission. Ultimately, the low BER enables higher system throughput. There are many buffers to prevent a catastrophic failure in this architecture, such as the fail-safe timer, which prevents any transmission on the bus longer than 800us that may render the bus unusable for other transmissions. Also, the use of coupled transformers isolates subsystems, preventing power surges or electromagnetic interference (EMI) from disrupting system performance. These features allow for a graceful degradation and a longer lifespan of the aircraft.

1553B Areas for Improvement

While a centralized bus control facilitates predictability, this design can limit software modularity and the reconfigurability of resources. The increasing number of complex subsystems and the possible necessity to stream vast amounts of information on military aircraft, may cause challenges in relying on MIL-STD-1553B's in the future. System throughput via this architecture is limited to a maximum single-command size of 32 words. It is also not possible to access the BC and RT simultaneously, as the data bus operates asynchronously with a half-duplex transmission. The 1553B bus uses a shared path, which can accommodate one subsystems to communicate and there is no parallel processing in this regard.

IMA Drawbacks

Much of the obstacles in deploying a 1553B system comes down to throughput. Comparing 1553B with the IMA architecture, IMA boasts a higher maximum data rate, with the AFDX protocols reaching speeds up to 100 Mbit/s. The 1553B architecture provides high reliability with a real-time deterministic system and a series of redundancies for mission-critical scenarios. While there are many major improvements over previous technologies, implementing an IMA system can be very involved due to the complexity in partitioning off the wide variety of applications with AFDX data networking. The 1553B system specifies that the BC send commands to the RTs at predetermined times and monitors message requests according to a set of fixed instructions. The instructions can be manipulated to be able to respond to periodic or intermittent signals in wide array of circumstances, which gives 1553B the deterministic quality. Hence, a 1553B system can be pre-programmed for precise command/response timings—this cannot be done in the IMA architecture. While the IMA architecture has become a highly desirable alternative in commercial aerospace, it has yet to become common enough in military applications for wide deployment and to benefit from infrastructure advantages.



(a) Federated Network Layout (b) Integrated Modular Avionics

Caption: A side-by-side comparison of the (a) federated network architecture versus the (b) integrated modular avionics (IMA) architecture. The integrated system improves speed and latency of the network but can create complexity in upgrades and retrofits.
Source: https://www.net.in.tum.de/fileadmin/TUM/NET/NET-2012-08-1/NET-2012-08-1_09.pdf

1553B: Increasing Throughput

The 1553B system has proven a robust and effective method to realize communication and the integration of avionics equipment. Since the first release in 1973 (MIL-STD-1553A), the shift to MIL-STD-1553B in 1978 was to more strictly outline networking protocols to have consistency across all military embedded applications. There were only minor adjustments to this standard from 1978 onwards with six different change notices that primarily altered wording in the original document to imply use across applications beyond military.

In 2006, Edgewater Computer Systems of Canada took successful steps towards increasing 1553B data bus speeds to 200 Mbits/s with minimal retrofits and alterations to the currently incorporated systems, under a grant from the military. This system was in its early phases and was flight-tested in an Air Force F-16 jet fighter with promising results. The program has since been terminated due to a cut of funding, but the project illuminated the high speed potential of the 1553 topology.

DDC, a Bohemia, NY based 1553 technology company, also developed high-speed 1553B options in 2006, including ‘Turbo-1553’ and ‘HyPer-1553’ that accomplished comparable speeds to Edgewater Computer Systems. HyPer-1553 was flight tested on a Boeing F-15E Strike Eagle jet fighter-bomber. Using augmentations to the MIL-STD-1553B architecture, without generating a complete paradigm shift from 1553B system design, may allow for less complex and costly installations and maintenance for retrofits and new aircraft designs, increasing the longevity of MIL-STD-1553B. More likely, however, is that high throughput demands will continue to promote the development and implementation of other high speed avionics communications equipment, where needed.

Conclusion

Data networking architectures have experienced drastic shifts with the exponential technological advancements. Currently, there are trade-offs between choosing a highly integrated system with low latency and a high throughput with a more discrete system with high determinism, low risk, and interoperability. MIL-STD-1553B is a tremendous reliable communications architecture that may still serve for years to come. The IMA architecture offers great advantages in commercial aircraft, but has yet to find true practical implementation. However, newer technologies built for the digital age, such as Ethernet and IP-based networking, may be adapted to the reliability and performance standards of commercial and military avionics.

Resources:

1. http://www.milestek.com/s-145-mil-std-1553b.aspx
2. http://www.milstd1553.com/resources-2/desginers-guide/designers-notes/
3. http://www.ijarcce.com/upload/2016/august-16/IJARCCE%2021.pdf
4. Alta Data Technologies ‘MIL-STD-1553 Tutorial and Reference’
5. https://en.wikipedia.org/wiki/Integrated_modular_avionics
6. https://www.net.in.tum.de/fileadmin/TUM/NET/NET-2012-08-1/NET-2012-08-1_09.pdf
7. https://de.slideshare.net/ostroumov/avionics-digital-data-buses
8. http://www.aviationtoday.com/2000/12/01/product-focus-1553-still-a-key-standard/
9. http://www.militaryaerospace.com/articles/print/volume-19/issue-2/features/technology-focus/death-taxes-and-1553.html
10. http://oatao.univ-toulouse.fr/198/1/Mifdaoui_198.pdf
11. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2107&context=smallsat
12. http://www.aviationtoday.com/2006/11/01/product-focus-high-speed-1553-technology-advances-boost-performance/

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