Distributed Computing in Aircraft Controls

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***Abstract*—Aircraft Avionics has evolved significantly since the development of the A320 aircraft. The federated architecture in the airliner, assumed one computer for each function. Due to the cost, space and weight issues, a new architecture came into picture namely "Distributed Integrated Modular Avionics Architecture". It consisted of shared hardware resources for different functions. Satisfying the disadvantages of the earlier approach, new problems of dependencies, unpredictable behavior, troubleshooting and system modifications emerged. This paper focuses on presenting a fully distributed approach to the flight control systems, its advantages and disadvantages.**

***Index Terms*—Flight Control System, Distributed Computing, Avionics Architecture, Fly-By-Wire, Integrated Modular Avionics**

I. Introduction

"Avionic architectures" (for "aviation electronic architecture") are commonly used to describe electronic sets used on aircraft. Since the 1970s, avionic architectures, which are made up of digital processing modules and communication buses, have been supporting an increasing number of avionic applications including flight control, flight management, and so on. As a result, avionic architectures have become a crucial component of aircraft design. They must meet a wide range of important criteria, including protection, equipment robustness, determinism, and real-time. Avionic systems account for 40

Modern aircraft rely heavily on avionics architecture. Processing modules and communication buses make up the majority of the architecture. Its main functions are flight control and management, Navigation, Communication, Weather systems, Collision, avoidance systems and Aircraft health monitoring systems.

II. Flight Control System and Architecture

In the 1940s, the first avionic instruments to be integrated into aircraft were radios for contact and navigation. The analog and digital electronic controllers have overpowered the mechanical aircraft functions and equipment since then.

Flight Control System is one of the most well-known examples of digital embedded systems. According to the pilot's navigation instructions, it immediately guides the aircraft's trajectory.

The flight control system is made up of flight control surfaces, cockpit sensors, and connecting linkages. Since they adjust the speed of the aircraft, engine controls are often called flight controls. The Fly-by-wire (FBW) Flight Control System uses transducers, wires, and actuators to replace mechanical linkages.

A. Fly-By-Wire

The term "fly by wire" refers to a device that uses computers to pass various flight control surfaces.

As shown in Fig 1 and Fig 2, it refers to electrical transmission of commands given by pilot to the flying control actuators.

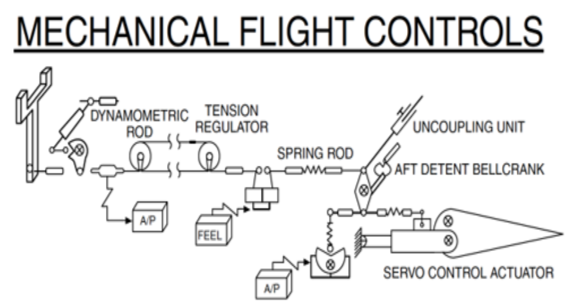

Figure 1. The mechanical linkages are driven by specific computers and actuators, which restore the pilot's feel on the controls and relay the autopilot commands.

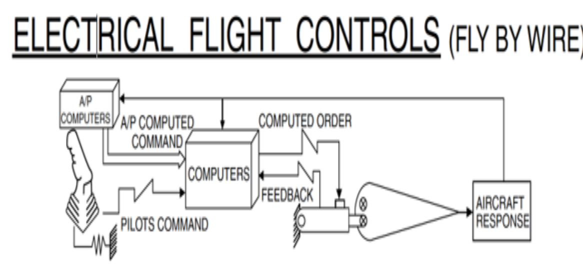

Figure 2.

The deflection of key control surfaces such as the elevator, rudder, and aileron as shown in Fig.4 are usually accomplished

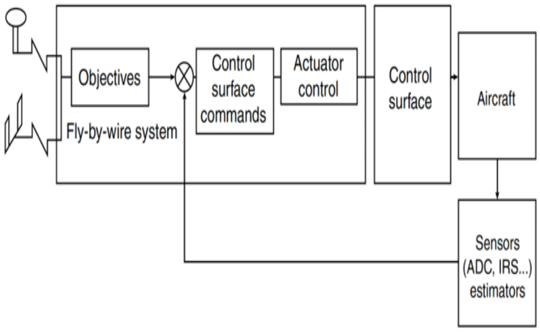

Figure 3. Control systems for the A320, A321, A330, and A340 take advantage of the potential of fly-by-wire for the application of control laws that offer comprehensive stability augmentation and flight envelope limiting in the configuration of the aircraft.

with Fly-By-Wire. It can also be used to power secondary flight controls including flap spoilers, slats, and trimmable stabilizers. A collection of mechanical elements, such as wires, cords, pulleys, and so on, transmits the pilot instructions to the servo-controls.

Specific computers and actuators, driving the mechanical linkages restore the pilot feels on the controls and transmit the autopilot commands.

Figure 4. Fly By Wire

B. Flight Control System Performance Specifications and Requirements

Flight stability augmentation, flight guidance, and envelope safety are only a few of the essential applications that Flight Control System performs. It must meet performance standards as well as safety and dependability criteria. The aircraft Flight Control System must transmit the correct commands to the control surfaces at the appropriate time and in a coordinated manner. When one component of a system fails, the rest of the system must operate in degraded mode to keep the system running. Communications Network During the device design, latencies must be taken into consideration. Unforeseen events, such as a breakdown of one of the flight control computers or a communication system failure, must not have a devastating effect on the system's performance. Advisory Curricular AC25.1309 must be followed before doing a safety review. The requirement of AC25.1309 is that the airplane structures must be configured in such a way that the existence of any malfunction condition that would prohibit the airplane from continuing to fly and land safely is highly unlikely. The software for the Flight Control System computers is well designed, but it should not be used on various computers. Since using different software reduces the likelihood of a single mistake, which may cause all computers to underperform or malfunction under bizarre circumstances. This concept is referred to as “Similar Redundancy”. Dependability, Safety and Real-time Constraints must be considered while designing the Flight Control System.

There are 2 approaches for Avionics Architecture design. Federated Avionics Architecture and Integrated modular avionics architecture (IMA):

C. Federated Avionics Architecture

Federated avionics architecture was used on commercial aircrafts until 1990s. As shown in Fig.5, it is characterized by the one function – one computer concept. Each aircraft system is run on separate dedicated hardware resources connected to its sensors and actuators. The key benefit here is that dependencies between systems are easily identified and Troubleshooting of federated systems is simplified. One of the drawbacks of a federated system is that a huge number of different line replaceable units containing the system. From the operator standpoint, this causes difficulties since large number of components need to be stored on stock for replacement purposes. From the manufacturer standpoint, each new subsystem adds weight to the aircraft, reducing passengers and cargo capacity. Airlines have needed more and smarter features since the 1990s, such as precise flight control capabilities, on-board repair services, bigger passenger entertainment systems, and so on. The principle of ”one function = one dedicated subsystem” was no longer valid.

D. Integrated Modular Avionics

In order to achieve reduced weight and optimize power, the integrated modular avionics (IMA) architecture is used, which allows optimizing the airframer avionics. The architecture can be seen in Fig.6. The benefits of IMA have overcome some of the shortcomings of the federated avionics architectures. The Integrated modular avionics concept is based on sharing hardware resources namely integrated modular avionics processors that are running on separate software modules for each system. The integrated modular avionics architecture provides a common I/O, communication line and computing resources, that is shared among the various avionics' functions. Reduced number of computer and communication data cabling

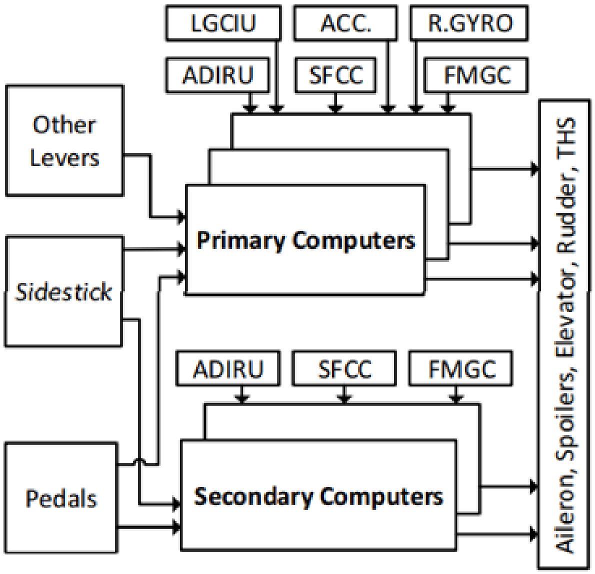

Figure 5. Federated Architecture

are the key benefits of it. Some of the disadvantages of this architecture includes issues regarding troubleshooting, dependencies arising because of shared hardware resources and data channels.

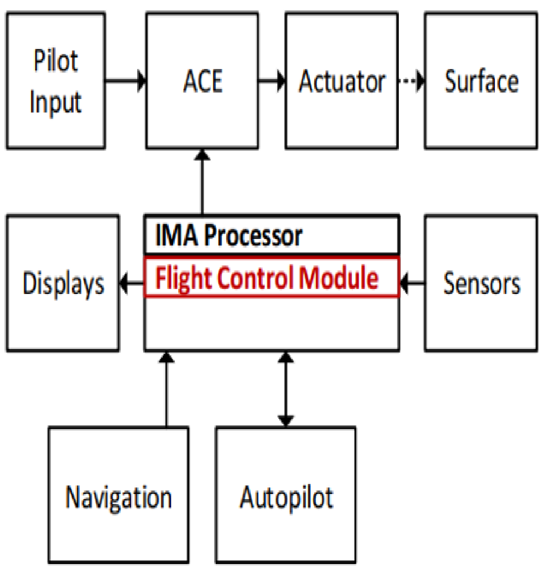

Figure 6. Distributed IMA

III. Fully Distributed Flight Control System

The sky is much more populated now than it was in 1903, thanks to all those jets zipping about. So, how do we share the skies productively, A fully distributed flight control system distributes flight control roles and functions over a network of embedded control units. A machine that moves or controls a device or structure is known as an actuator. Control units need to be placed and networked in a secure and reliable environment for the system to operate safety. Control unit is a part of the central processing unit which guides the operation of the processor and informs the computer memory, Arithmetic and Logic Unit (ALU) and I/O devices on responding to the instructions of the processor.

We will identify how the Controller Area Network (CAN) can be used to promote safety and maintenance of certification standards. It is what the central nervous system is to the human body. The CAN bus connects the control units, allowing them to communicate without the need for complicated dedicated wiring. It is low-priced, centralized, robust, efficient and flexible. As shown in Fig.7, in this architecture, two separate CAN networks are used in this architecture which can be used as redundancy which assures that no part of the system is left unconnected during communication break. Additionally, during connection loss, provisions need to be made within the control units to ensure minimal intermission of the disconnected unit to the operation of the rest of the system which can be achieved by automatic passivation.

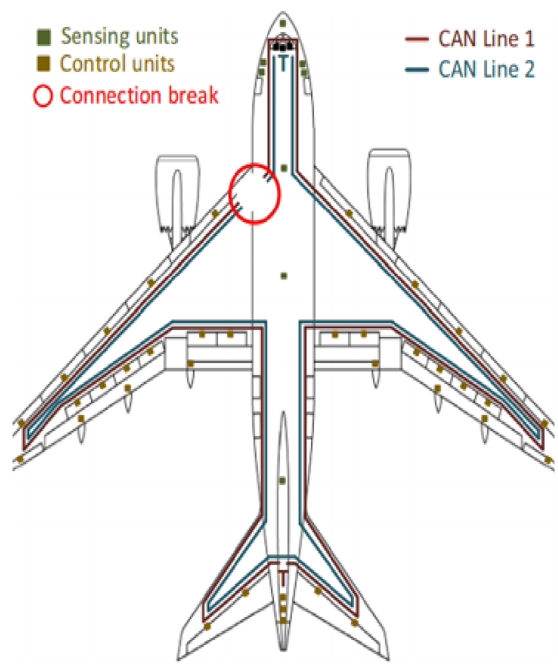

Figure 7. Fully Distributed Flight Control System's CAN Network

A. *Proposed Architecture Design*

Referring to the Fig.8, the architecture consists of three embedded systems namely the Flight Control Unit (FCU), External Override Unit (EOU) and the Actuator Control Unit (ACU). First, the FCU performs the flight control system functions and roles. Second, the EOU serves the purpose of overriding certain events and allowing the remote control of the corresponding actuator. The ACU, also called as the Executive Unit, which manages the actuators connected in a way ordered by the FCU and by the EOU when overridden. This unit uses both the power provided by FCU and EOU to assure it has power even if single unit is not operational. There are two power regulator units in this architecture. In the airspace technology, MEMS sensors are very promising due to their small size, low power consumption, high reliability and low cost. But, it lacks accuracy and hence cannot be the only serving input for positioning data.

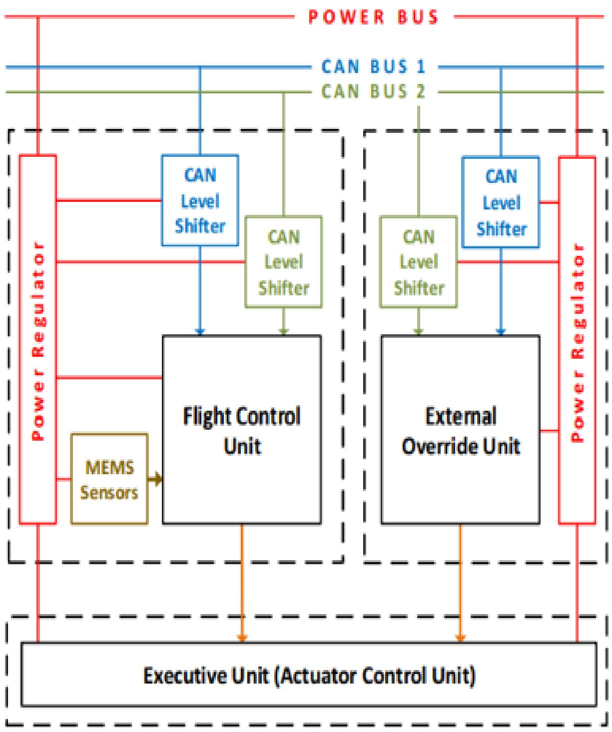

Figure 8. FDFCS Proposed Architecture

B. Flight Control System- Transmission, Broadcasting, Normal Mode and Emergency

Control Systems should not only be time triggered but event triggered also. Sensors like GPS receivers should broadcast data on the network on regular intervals so that all units have positioning data updated at certain intervals of time. Similarly, control units should communicate with other units on specific events only. There should be two types of data which should be transmitted, data request and data send. Data should be able to be requested and sent between units. Consider, for example the positioning data which assigns functions of one unit to other during a fault. The EOU machine should be operational until a certain number of units malfunction. The degraded mode of service should be available in an emergency. Standard mode, on the other hand, can increase the aircraft's stability and secure the flight envelope. Flight envelope is for example, when a plane is pushed due to high speeds, it is said to be flown outside the envelope which is dangerous.

IV. Emerging Technologies related to Flight Control System

1) Airbus Architecture
   The requirements of aircraft and its safety are continuously increasing shifting the focus to distributed computing. Airbus proposed an architecture in which control laws were placed between flight control computers and actuators. For example, consider the example of cruise control system, the control laws in it compares the reference speed to the current speed and uses this difference error in an algorithm to determine steps to reduce the difference between the actual and required. This method is very helpful in fault tolerance.

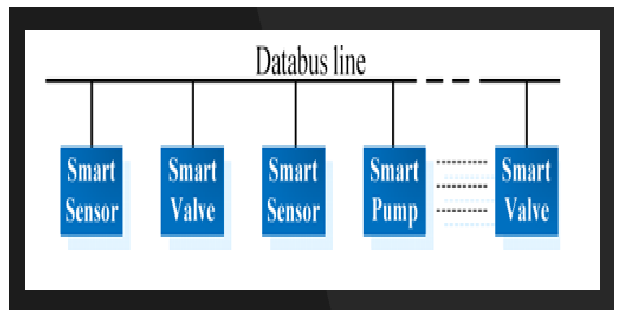

Figure 9. Fly By Wire

2) Fault Detection and Isolation (FDI)
   In this, the FDI takes information from neighboring FDI's. Each FDI consists of a fault detector and estimator who manages the local subsystem under normal conditions and isolated on detecting fault.
3) Distributed Optimization
   Collective Intelligence framework is another promising technique. For example, there are two aircrafts flying from the same airport and sharing same airspace. Consider an aircraft experiences difficulties, there is a concept called as Pilot Report (PIREP) in which pilot reports difficulties, important information and weather conditions to the flight service station which helps the flights following the same route or future flights.

V. Future Work and Challenges

Embedded control units will be designed to run the FCS and the control laws concept. MEMS sensors are continuously modified to improve accuracy. HIL Simulator will be emulated based on the proposed architecture.

Some of the challenges were as follows:
First, in order to develop a distributed control system design, the designer needs to identify the whole control structure, its subsystems and interconnections beforehand. Second, the control of large scale complex system require efficient design methods and algorithms. Example there is an ongoing debate over the wireless and wired networks. The recent growth of communication networks has only intensified the problems. Lastly, approach to timing is an important concept and needs to be addressed properly.

VI. Conclusion

Distributing the Flight Control System logic to actuators removes the need for any sophisticated computers performing Flight Control System function in the avionics bay. Routing of sensory and data wiring is unnecessary, resulting in reduction of aircraft weight. The complexity of the system reduces significantly especially because of integrating micro-electromechanical systems sensors into the Control Units. Fitting Control Units directly on or near the actuators surely reduces latencies caused by usual over the network control of actuators. The ease of troubleshooting of the system is expected by introduction of fault detection and self-testing functions.

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