

Multi-Axis Serially Redundant, Single Channel, Multi-Path FBW Flight Control System

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ABSTRACT

A multi-axis serially redundant, single channel, multi-path FBW (FBW) control system comprising: serially redundant flight control computers in a single channel where only one “primary” flight control computer is active and controlling at any given time; a matrix of parallel flight control surface controllers including stabilizer motor control units (SMCU) and actuator electronics control modules (AECM) define multiple control paths within the single channel, each implemented with dissimilar hardware and which each control the movement of a distributed set of flight control surfaces on the aircraft in response to flight control surface commands from the primary flight control computer, and a set of (pilot and co-pilot) controls and aircraft surface/reference/navigation sensors and systems which provide input to a primary flight control computer and are used to generate the flight control surface commands in accordance with the control law algorithms implemented in the flight control computers.

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INTRODUCTION

FBW technology has provided a major advance in aircraft flight control systems. Mechanical flight control systems had been prevalent where the flight control surfaces on an aircraft were controlled using a system of cables, linkages and mechanical controls as the primary and usually only control paths. Only limited, basic mechanical failure mode contingency was possible in such systems.

With the advent of electronics and computer-aided flight controls, mechanical systems were given enhanced controllability through augmentation with, e.g., electrical drive assist and controls. An example is shown in Fig. 1, a lateral control system, with a primary flight control system (typically a conventional mechanical cable/linkage system) coupled with Automatic Flight Control System (AFCS) and Electrical Flight Control System (EFCS) with multiple redundant electronic control channels to achieve fail safe and fail operational controls on the ailerons and spoilers.

Such improvements allowed for the development of advanced control laws that, among other things, improve and increase aircraft controllability and performance. These control laws can be complex and their implementation in a mechanical control system, even those with electronic

assistance, is difficult and often results in significant increase in aircraft weight.

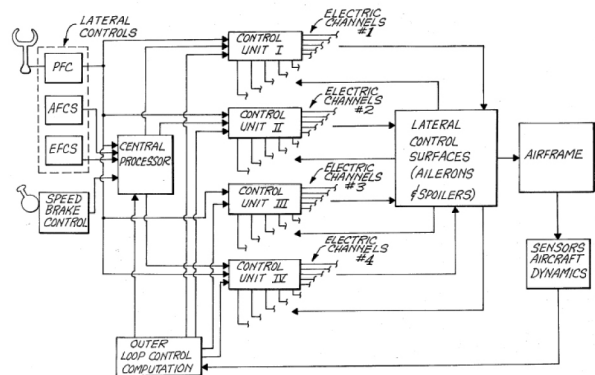


Figure 1. Example of EFCS Lateral Control System

As the next step in relevant technological evolution, mechanical linkages (cables, linkages, etc) were replaced by motors, actuators and drives with associated wiring as so-called “fly-by-wire” (FBW) technologies were developed.

A simplified diagram of a known FBW system is shown in FIG. 2. In such a FBW system, there is no direct mechanical coupling between the pilot controls 10 and a flight control surface 20. Known FBW systems include for

example, a set of pilot controls 10 which provide electrical signals to aircraft electronics 24, where they are combined with other airplane data to produce flight control surface commands. Instead of mechanical linkages and their attendant displacement/translation, the commands are transmitted across wires 38 to electrically control the movement of actuator/motors 26 that move the flight control surfaces 20.

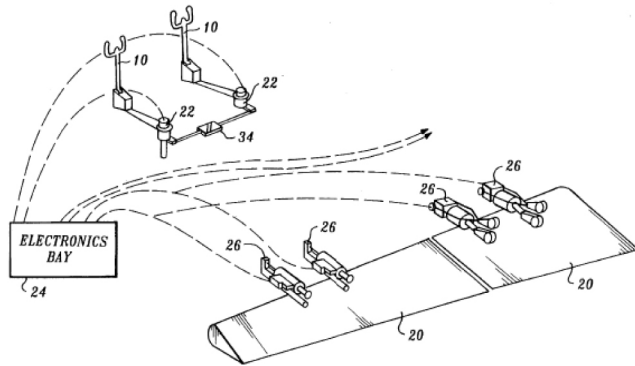


Figure 2. A simplified FBW System Diagram

As an improvement to such systems, redundant multi-channel, multi-axes, FBW control systems such as shown in Fig. 3 were introduced, in which the FBW system is divided into a series of parallel independent control channels, each capable of flying the aircraft. Each control channel is substantially isolated from the other control channels such that the channels operate in parallel and provide redundancy where in the event of a malfunction in one channel, the continued operation of the remaining channels is not affected and multi-axis controllability is maintained.

With reference to Figures 3, one such prior FBW system includes three isolated identical control channels - a left flight control channel 60, a center flight control channel 80 and a right flight control channel 90- each channel having its own dedicated primary flight computer (like 64) and actuator control electronics unit (ACE) (like 62) and a set of associated flight control surfaces (like 66).

In this prior FBW control system, the ACE in each channel receives transducer signals that are indicative of the position of the pilot controls and the primary flight computer coupled to the ACE generates flight surface commands based on the transducer signals received from the ACE. The ACE in each isolated flight control channel receives the flight surface commands from the corresponding primary flight computer and sends the commands to a set of servo loops that control the movement of a set of flight control surfaces on the aircraft.

Each of the redundant flight control channels is an independent, isolated, control channel with identical configuration, and all of the redundant channels operate in parallel, with redundancy incorporated through the parallel operation.

The set of flight control surfaces controlled by each isolated flight control channel is selected so that operation of a single isolated flight control channel is sufficient to fly the aircraft in the event that the remaining isolated flight control channels fail, further characterizing the independent, isolated and redundant nature and aforementioned structure of this known flight control channel.

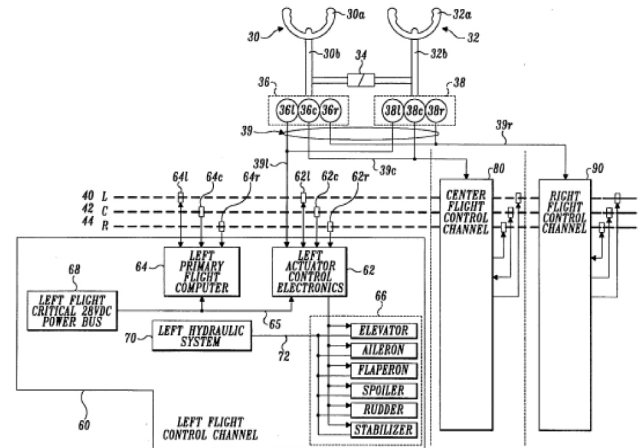


Figure 3. Multi-channel Axis FBW System Diagram

This described prior FBW systems is describe in more details in Reference 2.

Such parallel structure requires that all independent channels are active and operate in a synchronized (e.g., real-time) fashion. Failure mode monitoring requires flight control commands to be constantly compared between the simultaneously operating redundant control channels. In the failure operation of these types of systems, if one primary flight computer fails, the remaining ones continue to operate and control the aircraft.

While the above prior FBW system provides redundant control channels such that the aircraft can be controlled safely by one channel in case of failures of other channels, one drawback of the prior FBW system is that a generic fault at the ACE level (e.g., hardware design error, batch failure - manufacturing defects) could affect all ACEs, which could degrade the controllability of all surfaces. Another drawback is the need for duplicative components to achieve functional operation of such prior redundant system.

The present FBW flight control system proposed by this paper is a FBW multi-axis flight control system that is fault-isolated, fault tolerant to generic fault, fail-safe and fail-operational. Its architecture and operational details are discussed in detail in the following section.

DESCRIPTION OF THE PRESENT FBW ARCHITECTURE

The present FBW architecture is a multi-axis serially redundant, single channel, multi-path FBW flight control system (FCS) which includes a single control channel architecture based on serially redundant flight computers and

comprising multiple control paths each with dissimilar hardware controllers, which paths together, in the single channel, provide manual and automatic control of the aircraft in each of the pitch, roll and yaw axes through a matrix of complementary distributed control surfaces responsive to commands generated by the flight computers in accordance with predetermined control laws.

The present FBW FCS has two operation modes: Normal mode and Direct mode. The Normal mode is the system default operation mode and provides fully augmented flight control capability with flight envelope and structural protections. The Direct mode is command by wire, i.e. the pilot commands surface position. Stability augmentation and command limiting in pitch and yaw axes are provided in Direct mode. A block diagram of the present FBW architecture is shown in [Fig. 4](#).

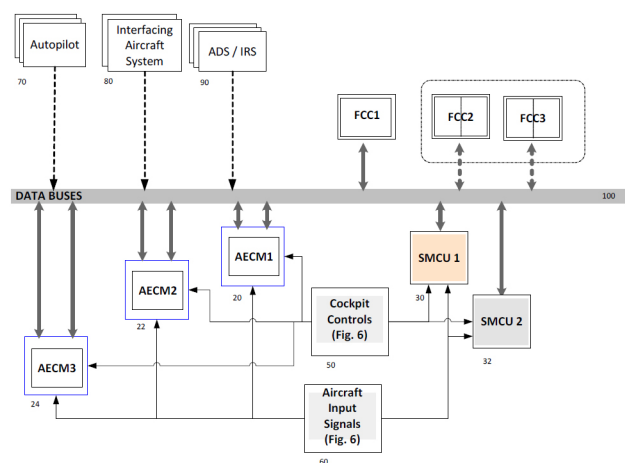


Figure 4. Schematic of Single Channel, Multi-path FBW System

With reference to [Figure 4](#), the FBW FCS comprises multiple flight control computers FCC1, FCC2 and FCC3, actuator electronics control modules (AECM) 20, 22, 24, stabilizer motor control units (SMCU) 30 and 32, cockpit controls 50 and aircraft sub-systems which provide aircraft input signals 60 and additional data from avionics (e.g. autopilot or navigation systems) 70, aircraft systems 80 and Air Data System (ADS)/Inertial Reference System (IRS) 90.

The signals from the various cockpit controls 50 and aircraft inputs 60 are received and processed by the AECMs and transmitted to the FCCs via data bus 100. The signals from the various cockpit controls 50 and selected aircraft inputs 60, in the current FBW system Flap/slat discrete data, are received and processed by the SMCUs and transmitted to the FCCs via data bus 100. Other systems e.g., avionics 70, aircraft systems 80 and ADS/IRS 90, also interface to data bus 100. In the present FBW system, the data bus architecture will include an ARINC 429 digital communication link, which is standard in the aircraft industry, and each FCC communicates with each AECM and SMCU through a dedicated ARINC 429 data bus; however, other types of data

communication links could be used. For illustrative purposes, a single data bus 100 is shown. Other bus configurations can be implemented, such as for example, using different bus protocols or multiple data buses.

Triple serial redundant Flight Control Computers FCC1, FCC2 and FCC3 perform Normal mode control/monitoring functions. The FCCs each receive input from the AECMs and other above mentioned sources, via data bus 100, and calculate command signals based on control law algorithms implemented in the FCCs. Autopilot system 70 ([Fig. 4](#)) can provide computer control of the aircraft without the need for direct pilot or copilot input. Upon engagement of the autopilot system 70, the FCCs generate the flight surface commands based on signals received from the autopilot system 70 instead of the pilot control signals received from the AECMs.

While any single FCC (FCC1, FCC2 or FCC3) is capable of providing full control functionality in all aircraft axes, the three FCCs operate independently in an active/standby configuration, with no output command voting/comparison. In this active/standby scheme, while the three FCCs operate in synchronous fashion for failure mode operation, only one FCC is active at any given time: one FCC (FCC1) is designated the default active “primary” FCC, and the other 2 FCCs (FCC2 and FCC3) each operate independently in a passive “standby” mode to serially come on-line as the “new” primary FCC in the event of failure of the prior active primary FCC.

With reference to [Fig.5](#), the cockpit controls 50 and AECM and SMCU are described in further detail.

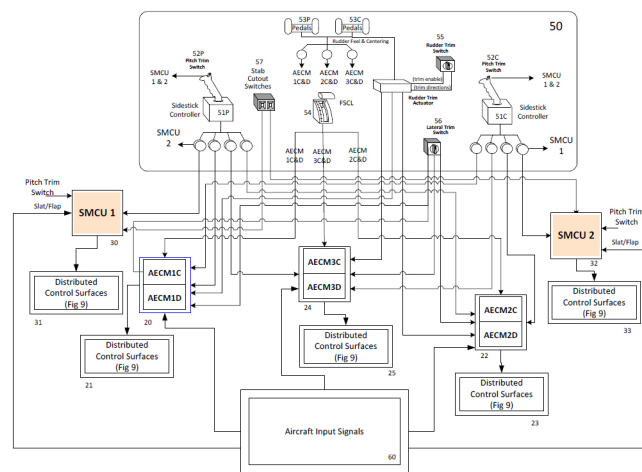


Figure 5. Cockpit Control/AECM/SMCU Interfaces

Cockpit controls 50 include a pilot and co-pilot sidestick controller (51P and 51C) for inputting pitch and roll commands through transducers (which translate mechanical displacement to an electrical signal). The sidestick controllers are coupled to each of the AECMs and SMCUs as shown. Each sidestick controller has a pitch trim switch (52P and 52C), which are coupled to each SMCU as shown.