The fly-by-wire system

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Abstract: *This report shows the execution and evolution of airplane flight control systems. The report describes the development of airplane flight control systems and gives a survey of the principal phases of the flight control systems that assure the finding and execution of the fly-by-wire system. The development of flight control systems, from human control with mechanical links to a wire-driven computer, is a remarkable representation of the development of aeronautical technologies. The fly-by-wire system constitutes a fast-forwarding in aircraft design, from mechanical linkage to large hydraulic actuators to computer-assisted fly-by-wire system. The use of the fly-by-wire system has generated huge satisfaction for the aircraft industry by lessening the weight of the flight control system, by creating multiple redundancy flight control systems, which increases the flight safety of all aircraft equipped with the fly-by-wire system. The passage from analog to digital is another fast-forwarding in the development of fly-by-wire systems.*

Key Words: *Fly-by-wire, flight control, analog, digital, fly-by-light, airplane*

1. FLIGHT CONTROL SYSTEMS

The flight control system of an airplane is determined by the control surfaces installed on the airplane body that are balanced movements coordinated by a flight control system that drives an airplane around the three axes of motion: Yaw, Pitch, and Roll as shown in Figure 1 [12], [14], [20], [26].

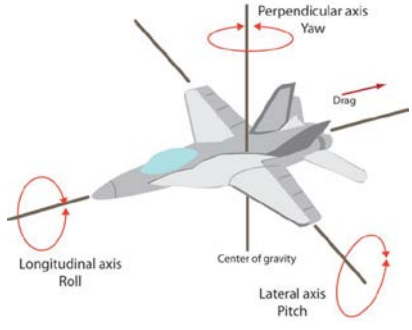

Fig. 1 Airplane axes of motion [27]

The fly-by-wire system with an electronic interface of an airplane replaces the old human-controlled system with mechanical links (see Figure 2). The displacements of flight controls are transformed into electric signals which are then transmitted via electric wires (hence the name of fly-by-wire) to the flight control computers establishing how and when to move the actuators of each control surface to supply the movement imposed by the pilot. Generally, it uses full fly-by-wire controls [5].

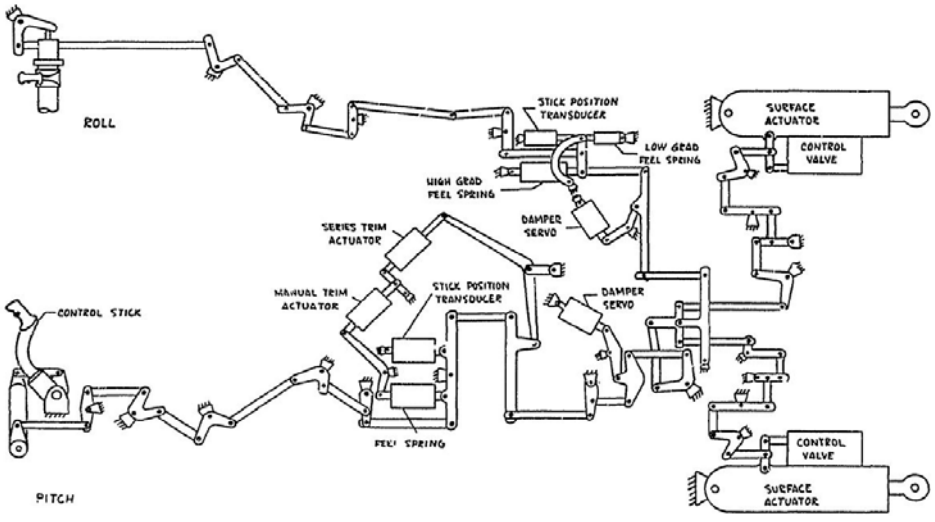

Fig. 2 Pitch and roll mechanical control system [5]

The fly-by-wire is the generally accepted name for the flight control systems which process the flight control inputs made by the pilot or autopilot using computers and submit suitable electrical signals to each actuator of the flight control surfaces. The fly-by-wire system means that the pilot inputs do not directly move the control surfaces as explained above. Instead, the inputs are read by a computer in turn determines how to move the control surfaces to perform the pilot's maneuvers as well as possible, in accordance with the active Flight Control Laws implemented on it (see Figure 3) [24].

Another definition for fly-by-wire is: a flight control system of an aerospace vehicle in which information is completely transmitted by electrical means [7].

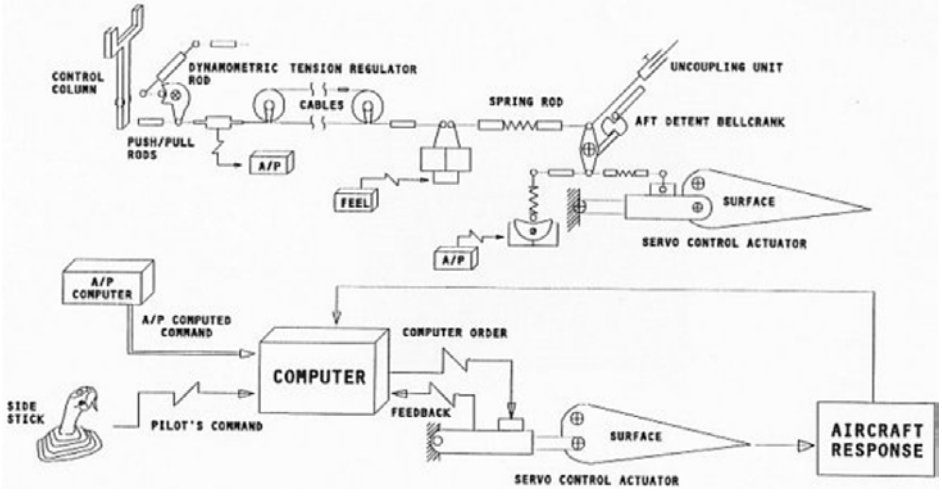

Fig. 3 Fly-By-Wire system [28]

A fly-by-wire system is a computer driven system that reads the pilot control inputs, various parameters such as the airspeed, the altitude and the angle-of-attack and orders the displacements of flight control surfaces such that the airplane remains within its designated flight envelope.

The flight control computer evaluates electrical signals via pilot control and sensor input and sends electrical signals to actuate the adequate control surface such that to obtain the desired airplane orientation [20].

The flight envelope relates to the safe operating characteristics of an aircraft. It is designed to fly at given altitudes, different speeds and other variables. The turn on of a fly-by-wire system is indeed the same for all of these systems; videlicet, the system uses electrical signal inputs to create electrical signal outputs. Nevertheless, these systems can be implemented with a variety of design elements or algorithms with control laws that decide the response of the system in a given situation, as well as the entity, man or computer, which has superior control of the aircraft to a given time [20].

2. THE FLY-BY-WIRE SYSTEM DEVELOPMENT

The evolution of FBW is summarized below [1], [19], [21]:

- **1958**- Avro Canada CF–105 is the first non-Experimental airplane with fly-by-wire controls.
- **1964**- Apollo Lunar Landing Research Vehicle is the first fly-by-wire airplane without a mechanical backup. It also almost killed Neil Armstrong when the attitude control system failed during his training in 1968.
- **1969**- The first flight of Concorde controlled by a Power Flying Control unit (PFCU) as Fly-By-Wire system took place, so it became the first aircraft to be fitted with Fly-By-Wire system.
- **1972**-NASA flies an F–8 with digital fly-by-wire, the system in use today.
- **1976**-General Dynamics (now Lockheed-Martin) flies an F16 with fly-by-wire system.
- **1987**- Airbus A320 is officially unveiled, the first airliner with digital fly-by-wire.
- **2005**-Dassault's Falcon 7X becomes the first business jet certified with digital fly-by-wire.

First major step in the development of Fly-By-Wire system has been made by NASA's Digital Fly-By-Wire (DFBW) Development Program [4], [6], [18], [20], [22], [25].

In 1972, at NASA's Dryden Flight Research Center, the first digital fly-by-wire flight control system without a mechanical back up was successfully utilized.

Neil Armstrong, a former research pilot at Dryden, played an important role after his historic Apollo 11 lunar landing. NASA's DFBW program consisted of 210 flights and lasted 13 years [4], [6], [20], [23].

The Dryden DFBW program has changed the way engineers design and pilots fly commercial and military aircraft. Aircraft equipped with Fly-By-Wire systems are safer, more reliable, easier to fly, more maneuverable and more fuel efficient, while having lower maintenance costs [4], [6], [20], [23].

The second major step in the development of Fly-By-Wire system is the F-16 Fighting Falcon, originally developed by General Dynamics (now Lockheed-Martin), is a proven compact, single-engine, multi-role fighter airplane and the World's first Fly-By-Wire Combat Airplane [3], [4], [9] (see Figure 4).

Fig. 4 F-16 fighting falcon fly-by-wire system [4]

Since the F-16A's first flight in December 1976, this highly maneuverable air-to-air combat and air-to-surface attack airplane has provided mission versatility and high-performance for the U.S. and allied nations at a relatively low-cost. The F-16 pilot maintains excellent flight control through the airplane's Fly-By-Wire system. The pilot sends electrical signals via a side stick to flight computers and then to the actuators of flight control surfaces, such as ailerons and rudder. The flight computers constantly adjust the inputs to enable stability in level flight and high maneuverability in combat, inside the flight envelope. The side stick allows the pilot to easily and accurately control the airplane during high G-force of combat maneuvers [3], [4], [9].

The F-16 was the first production airplane to use fly-by-wire technology. To improve maneuverability the F-16 was designed to be aerodynamically unstable, or to have relaxed static stability (RSS). To make the flight of this lightweight fighter airplane smoother, the F-16 has a Flight Control Computer (FLCC) that manages the flight control system [4], [13].

3. THE ADVANTAGES OF THE FBW SYSTEM

The main advantages of Fly-By-Wire system are:

- reduced weight.
- improved reliability.
- damage tolerance.
- more effective control of a necessarily highly maneuverable airplane.

All the advantages listed above were first recognized in military airplane design. The fast turbojet fighters are unstable aircrafts in order to provide high maneuverability. Fly-By-Wire system provides the ability to keep the aircraft inside of the flight envelope [2], [8], [24].

A brief list of FBW advantages is presented below [15], [29]:

- The protection software included in Flight-Envelope automatically prevent any unsafe actions of pilots and help them to stabilize the airplane.
- FBW ensures suppression of air disturbance and as a consequence reduces the fatigue loads and increases the comfort of passengers.
- FBW ensures an optimized trim setting and as a consequence, drag reduction.

- FBW ensures an easier interfacing to other automatic flight control systems and to auto-pilot.
- FBW ensures reduction of maintenance operations.
- FBW ensures reduction of costs for pilot training, because the flight operations becomes very similar for a whole airplane family.
- Flight-control computers continuously fly the airplane, so the demand for pilots is greatly reduced.
- FBW system makes the flight more economic because FBW system is usually lighter, covers less space and is less complex and more reliable.

Feedback control parameters such as airspeed, attitude, angle of attack and Mach Number are used to ensure that the airplane with Fly-By-Wire system remains within its implemented flight envelope. The Airbus strategy has a flight envelope with hard limitations: the control laws have total command control except if the pilot selects Direct Law. The Boeing strategy has a flight envelope with flexible limitations, so the pilot can overrule Flight Control Laws and so the pilot has the ultimate control over the operation of the airplane [24], [25], [29].

4. CONCLUSIONS

Using of fly-by-wire flight control systems has created huge benefits for the aerospace industry, reducing the weight of the flight control system, creating multi-redundant flight control systems which ultimately increases the flight safety for all airplane equipped with fly-by-wire systems. The leap from analogue fly-by-wire to digital fly-by-wire is another great step forward in the evolution process of fly-by-wire systems [24].

The present generation airplane is equipped with FBW systems, but in future the new design will migrate to the fly-by-light (FBL) system for airplane control system.

As the FBL system has light weight, large bandwidth, compact size, resistance to EMI & HIRF, it is expected to become the next generation of flight control systems. The FBL systems offer immunity to the new more hostile military environments. The intrinsic features are the motivator to achieve the technological advances to make Fly-by-Light systems a successful replacement airplane control system technology for the future. The FBL with optical fiber used in aviation guarantees a successful decision that solves airplane controls and all problems regarding airplane stability [10], [11], [16], [17], [18].

This document represents a documentary research about the fly-by-wire system and it will be used as basis for further research in the field.

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ABBREVIATION

DFBW: Digital Fly-By-Wire
EMI: Electro-Magnetic Interference
FBW: Fly-By-Wire
FBL: Fly-by-Light
FLCC: Flight Control Computer
HIRF: High Intensity Radiation Fields