

# EVOLUTION OF AIRCRAFT FLIGHT CONTROL SYSTEM AND FLY-BY-LIGHT FLIGHT CONTROL SYSTEM

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*Abstract— In past, the aircraft control systems were based on conventional methods of mechanical and hydro-mechanical system. The present generation aircraft are using fly-by-wire (FBW) and in future likely to migrate to fly-by-light (FBL) method for aircraft control system. Mechanical & Hydro-mechanical flight control systems have been replaced by Fly-By-Wire due to increasing speed of modern aircraft. Due to inherent characteristics of FBL like light weight, compact size, large bandwidth, immunity to EMI & HIRF FBL, it is expected to be ideal futuristic flight control system. Fly-by-Light control systems offer inherent resistance to the new generation more hostile military environments. The inherent features are the motivator to achieve the technological advances to make Fly-by-Light systems a successful replacement aircraft control system technology for future. The application of optical fiber in aviation promises to be very exciting study, covering highly complex aircraft stability and controls.*

*Keywords—Mechanical flight control system, Hydro-mechanical flight control system, Fly-By-Wire flight control system, Fly-By-Light flight control system.*

## I. INTRODUCTION

Aircraft flight control was traditionally accomplished through mechanical & hydraulic systems. Subsequently, “Fly-By-Wire” through electronics has been widely used. Application of fibre optics in aircraft offers considerable advantages for flight control system. The military driver for fly by light is the increased use of composite materials in aircraft which provides less protection for control systems against EMI. As fibre optics are not affected by EMI, are

lighter and has high bandwidth, it offers potential edge over FBW. This paper gives an overview of conventional (mechanical and hydro-mechanical), present (FBW) and futuristic (FBL) aircraft flight control systems.

## II. FLIGHT CONTROLS

### A. Airplane flight controls

Whenever an airplane changes its flight attitude or position in flight, it turns on one or more of its three axes, which are imaginary lines that pass through the airplane’s centre of gravity.

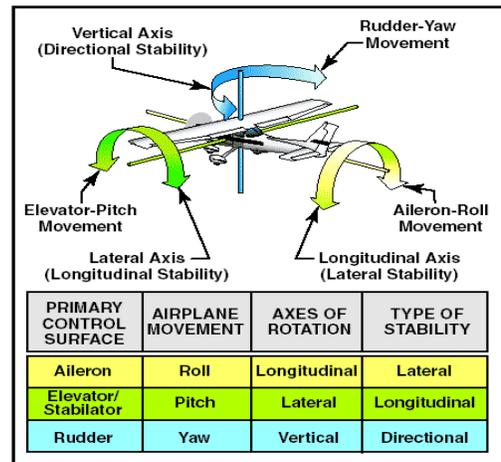


Fig 1: Airplane controls, movement, axes of rotation, and type of stability. [1]

At the point where all three axes intersect, they are mutually perpendicular. The axis that extends lengthwise through the fuselage from the nose to the tail is called as longitudinal axis, the axis which extends crosswise from wingtip to wingtip is known as lateral axis, and the third axis, is vertical axis passing through the through the centre of gravity.[1]

### B. Flight controls in the cockpit

Cockpit controls consist of the control column or the control yoke. The control column or control yoke is used for roll and pitch of aircraft by movement of elevators and the other flight components, which allows the plane to manoeuvre. The third controller is rudder pedals which move the rudder left or right. Finally, throttle controls are provided to control the engine's power and give the aircraft thrust. [2]

### III. MECHANICAL FLIGHT CONTROL SYSTEM

In this system, the control devices with the pilot are connected directly to the control surfaces of the aircraft by a system of rods, levers, cables and pulleys.[3] The levels of stick and rudder-pedal forces to steer and manoeuvring an aeroplane were constrained by the physical capabilities of the pilot, which have not changed since the times of Lilienthal and the Wright Brothers.[4] The aircraft in those days usually possessed natural aerodynamic stability.[3] Two types of mechanical systems were employed: push-pull rods and cable-pulley.[5][6]

Many aircraft use a combination of push pull rod and wire pulley arrangement as depicted below:

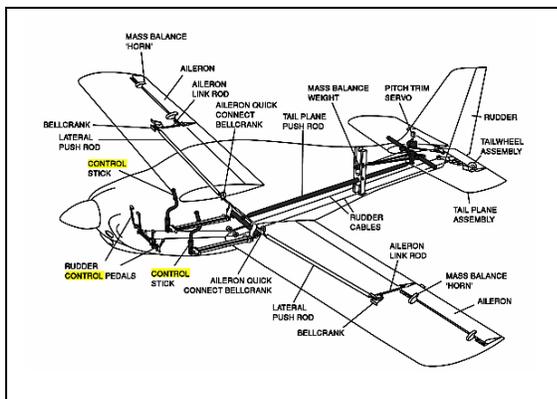


Fig 2: Mechanical Flight Control System [6]

TABLE I  
PURPOSE OF CONTROL SYSTEM COMPONENTS

Sl No	Item	Purpose
1	The cable	To transmit the power
2	Cable connector	To connect the cable
3	Turnbuckle	To adjust the cable length
4	Fairlead	To guide the cable
5	Pulley	To guide the in radial direction
6	Push pull rod	To go for aft as per requirement
7	Control stick	To make orders for the remaining circuit

In a push pull rod system, the linkage must be stiff, to avoid any unwanted deflection during flight and due to fuselage elasticity. The axial instability during compression must be excluded; the instability load P for a rod is given by:

$$P = \pi^2 EI / \lambda^2$$

Where:

E = Young modulus;

I = cross-section moment of inertia;

$\lambda$  = reference length. [5] [6]

The problems of the wire pulley system are largely overcome by the use of the push pull rods to move the control surfaces. In general this mechanism is slightly heavier but it is worth installing for the ease of maintenance.[8] This kind of flight control system was used in early aircraft and is still used in current light aircrafts like Cessna Skyhawk.[8]

### B. Limitations of mechanical flight control system

The complexity and weight of mechanical flight control systems increase considerably with the size and

performance of the aircraft. Hydraulically powered control surfaces help to overcome these limitations.

#### IV. HYDRO-MECHANICAL FLIGHT CONTROL SYSTEM

Due to ever increasing size and flight envelope of aircraft, mechanical flight control systems were found inadequate. With increasing speed of aircraft, it became more difficult to move the control surfaces due to high aerodynamic forces. This led to application of hydraulic power.[9] Hydraulics with high power and high stiffness is ideal as a medium for the operation of flight controls. [9] Hydro mechanical controls have two parts: [2] [8]

- A *mechanical circuit*: It is similar as in mechanical flight control system[2] [8]
- A *hydraulic circuit*: When a pilot moves the hydro mechanical controls, the circuit operates and the servo valve in the hydraulic circuit opens. This type of control is often used in older jets as well as high performance airplanes. [2]

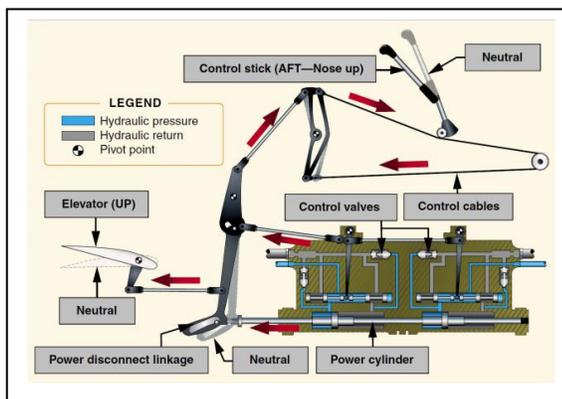


Fig 3: Hydro-Mechanical Flight Control System [2]

##### A. History of Hydro mechanical flight control system

After the commencement of jet age for civil transport aircraft after World War II, De Havilland Comet 1 (first flight 27 July, 1949) and the Boeing 707 (1954) were initial hydraulically controlled aircraft. The second generation aircraft were developed in 1960s and early 1970s (e.g. Boeing 727 and 737, Lockheed L1011 and McDonnell Douglas DC9, DC10 and Airbus A300) used hydro mechanical flight control systems. Boeing 747 was the first aircraft in Boeing series to have fully powered actuation

system. [4][8] Trident, Caravelle also had such a flight control system. [9]

#### V. FLY-BY-WIRE FLIGHT CONTROL SYSTEM

Fly-by-wire (FBW) control system replaced the conventional manual flight controls of an aircraft with an electronic interface. [10]

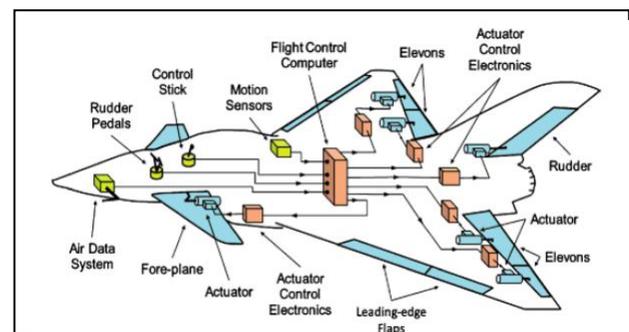


Fig 4: Basic elements of a Fly by wire Flight Control System [11]

The movements of flight controls are converted to electronic signals and transmitted by wires (hence the fly-by-wire term). Flight control computers determine how to move the actuators at each control surface to provide the ordered response. The fly-by-wire system also allows automatic signals sent by the aircraft's computers to perform functions without the pilot's input, as in systems that automatically help stabilize the aircraft. [10] The whole system in FBW act as a closed feedback loop.

Aircraft with FBW flight control systems first came into service in the late 1970s using analog implementation. Digital FBW systems have been in service since the late 1980s. [11]

The current generation of civil airliners exploit FBW control. (e.g. Airbus A319, A320, A330, A340, A380 and Boeing 777 and 787.[10]). A320 (1987) is the pioneering aircraft of Fly By Wire technology.[5][12] Millions of flying hours have now been accumulated by aircraft with digital FBW flight control system and their safety and integrity have been established. [12]

The FBW has a large number of advantages over the mechanical system such as: lighter weight, easier maintenance.

A demerit however is susceptibility to Electromagnetic Interference (EMI) and High Intensity Radiated Field (HIRF). To address this problem, one approach is to use

shielded electrical cables, but it increases the cable weight. A better way to avoid EMI and HIRF problems is to use optical fibre cables instead of electrical cables and to use optic sensors instead of electrical sensors, this introduces fly-by-light concept. [13]

## VI. FLY-BY-LIGHT FLIGHT CONTROL SYSTEM

A flight control system using optical fibre and optical sensors is called Fly-By-Light (FBL) system. Its benefits include not only immunity to EMI and HIRF but also large data bandwidth and light weight. [13]

The figure below shows the FBL system at a glance:

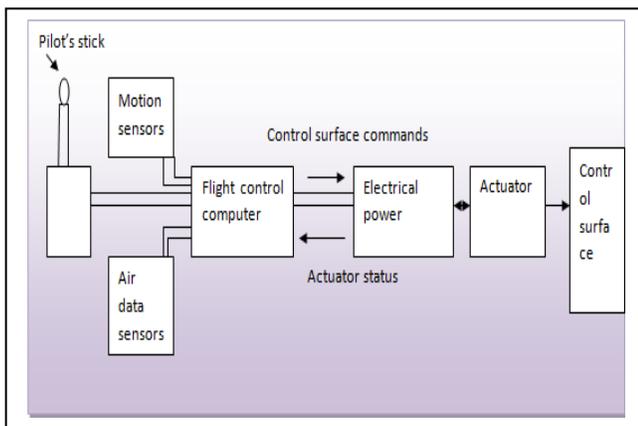


Fig 5: Fly By Light flight control system [12]

### A. Advantages of FBL

- Light weight
- Large bandwidth
- EMI shielding

The fibre optic cable is much lighter than the equivalent screened cables it replaces. The weight saved on equipment installation is geared up by a factor of about 10 on the overall aircraft weight.

### B. Requirement of higher bandwidth

As the speeds of the aircraft have increased, the need to increase data transmission rate from the pilot control panel to the control surface of the aircraft has also increased significantly. Higher data transmission rate necessitates higher bandwidth. Bandwidth is the amount of data that can

be carried from one point to another in a given time period (usually a second). In aircraft higher bandwidth ensures higher data transfer rate, therefore pilots command passes rapidly from aircraft cockpit to control surfaces (like aileron, elevator, rudder) which ensures smooth aircraft manoeuvring. The higher the bandwidth, the larger the aircrafts safety margin in high gain tracking tasks.

### C. Uses of composites in aircraft

Increasingly, aircraft designers have been turning to composites in order to make their vehicles lighter, more fuel-efficient and more comfortable for passengers.

Composites offer very high stiffness-to-weight ratio. Very stiff fibres (usually carbon or glass) are embedded in a matrix (usually some sort of plastic). Because of this, new aircraft with composite fuselages, such as the Boeing 787, can provide some additional passenger comfort amenities not available on a metal aircraft. [14]

Half of the Boeing 787 and the Airbus A350, for example, are made of composite materials and other manufacturers like Bombardier, are adopting composites for a variety of aircraft sections. Strength is higher per pound than steel, have ability to be shaped to any contour. This means aircraft will not need any rivets sticking out which would cause drag. [15]

The increasing use of composite materials in aircraft structures has decreased EMI shielding previously provided by metal structures. Consequently, FBW are subjected to greater electrical interference which can degrade performance. But optical pulses transmitted by FBL system are unaffected by the much lower frequency electromagnetic waves that characterize the EMI threat. [12]

### D. Signal processing

In FBL, pilot command comes to the actuator as an electrical signal and this signal is converted into optical signal, then passed through optical fibre and converted again into optical to electrical signal to which the control surface is subjected.

### E. Present status

Though, the research in the field of FBL application to aviation is going on for more than three decades, not much of progress has been made.

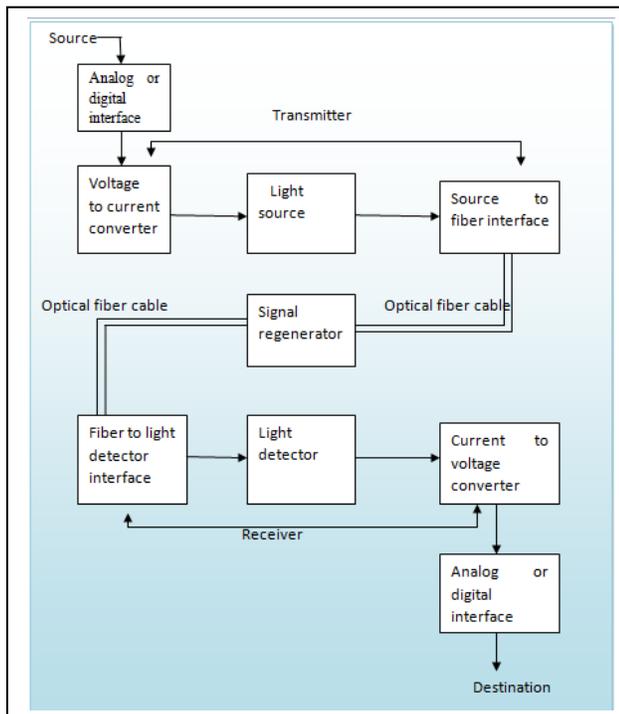


Fig 6: Optical fibre communication link

Still there are no production aircraft in service with FBL flight control system. Fibre optic connectors and passive couplers are not readily available and are relatively expensive. [12]

The application of fibre optic for flight control systems began in 1974 with the use of a simplex fibre optic data link to transmit pilot commands sensed in aircraft motion, the resulting surface commands (elevator, aileron, rudder) on an Air force NC-131H. An example of benefits of fibre optics, the FBL optical aileron Trim (FLOAT) flight test conducted on MD-87 (McDonnell-Douglas) test aircraft in the mid-1990s demonstrated the validity of a FO system on a production aircraft. [14] NASA have performed tests on F-18 fighter with FBL control and are planning tests on a Boeing 757. The sky ship 600 airship has had FBL controls since 1988. [17]

## VIII. SUMMARY OF FLIGHT CONTROL SYSTEM EVOLUTION

Wright brothers, the aircraft flight control systems have evaluated in last 110 years. A summary of various flight control systems along with some prominent examples are:

TABLE III  
EVOLUTION OF FLIGHT CONTROL SYSTEM

Generation	Name of aircraft	Control System of Aircraft
First Generation Aircraft	De Havilland Comet -1(1949)	Hydro mechanical
	Boeing 707 (1954)	
Second Generation Aircraft	Boeing 727 (1963) Boeing 737(1967) Boeing 747(1969) Lockheed L1011(1970) McDonnell Douglas(1967) DC9 (1965) DC10 (1970) Airbus A300(1972)	Hydro mechanical
Current Generation Aircraft	A319(1995) Airbus A320(1987) Airbus A330(1992) Airbus A340(1991) Airbus A380(2005) Boeing 777(1994) Boeing 787(2009)	Fly-By-Wire

## IX. CONCLUSION

Fly-by-light [flight control based on a fibre optic infrastructure] has been discussed for years but will become a reality primarily due to the experience with unmanned aircraft systems. As commercial communication/network systems move to totally fibre-

based systems, the military will have to move to these systems, and copper will be a thing of the past. Multi-fibre and mechanical transfer pull-off connector technology has been used on major fighter systems and will become the norm. [18]

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