

FLIGHT CONTROL SYSTEMS

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Abstract

The development of basic aircraft systems has not stood still. We can check this simple fact by looking at the wing size of a modern passenger aircraft and see that its size is reducing while the lifting power of the wing is still increasing. This is a measure of improvements now capable of being made in wing design which in turn are dependent on 'Systems' capable of developing the maximum performance from the minimum of weight, hence fly by wire. There is nothing new in all this: aircraft performance has ever been about the relationship between power and weight. Indeed, until adequate power at the right weight was available, sustained manned flight was not possible.

Key words: Aircraft systems, flight control, Flight control surfaces, Experimental Aircraft Programme (EAP)

1 INTRODUCTION

Flight controls have advanced considerably throughout the years. In the earliest biplanes flown by the pioneers flight control was achieved by warping wings and control surfaces by means of wires attached to the flying controls in the cockpit. Such a means of exercising control was clearly rudimentary and was usually barely adequate for the task in hand. The use of articulated flight control surfaces followed soon after but the use of wires and pulleys to connect the flight control surfaces to the pilot's controls persisted for many years until advances in aircraft performance rendered the technique inadequate for all but the simplest aircraft. When top speeds advanced into the transonic region the need for more complex and more sophisticated methods became obvious. They were needed first for high-speed fighter aircraft and then with larger aircraft when jet propulsion became more widespread. The higher speeds resulted in higher loads on the flight control surfaces which made the aircraft very difficult to fly physically. The Spitfire experienced high control forces and a control reversal which was not initially understood. To overcome the higher loadings

powered surfaces began to be used with hydraulically powered actuators boosting the efforts of the pilot to reduce the physical effort required. This brought another problem: that of 'feel'. By divorcing the pilot from the true effort required to fly the aircraft it became possible to undertake manoeuvres which could overstress the aircraft. Thereafter it was necessary to provide artificial feel so that the pilot was given feedback representative of the demands he was imposing on the aircraft. The need to provide artificial means of trimming the aircraft was required as Mach trim devices were developed.

A further complication of increasing top speeds was aerodynamically related effects. The tendency of many high-performance aircraft to experience roll/yaw coupled oscillations – commonly called 'dutch roll' – led to the introduction of yaw dampers and other auto-stabilization systems. For a transport aircraft these were required for passenger comfort whereas on military aircraft it became necessary for target tracking and weapon aiming reasons.

2 PRINCIPLES OF FLIGHT CONTROL

All aircraft are governed by the same basic principles of flight control, whether the vehicle is the most sophisticated high-performance fighter or the simplest model aircraft. The motion of an aircraft is defined in relation to translational motion and rotational motion around a fixed set of defined axes. Translational motion is that by which a vehicle travels from one point to another in space. For an orthodox aircraft the direction in which translational motion occurs is the direction in which the aircraft is flying, which is also the direction in which it is pointing. The rotational motion relates to the motion of the aircraft around three defined axes:

- pitch,
- roll,
- and yaw.

This figure shows the direction of the aircraft velocity in relation to the pitch, roll and yaw axes. For most of the flight an aircraft will be flying straight and level and the velocity vector will be parallel with the surface of the earth and proceeding upon a heading that the pilot has chosen. If the pilot wishes to climb the flight control system is required to rotate the aircraft around the pitch axis (O_x) in a nose-up sense to achieve a climb angle. Upon reaching the new desired altitude the aircraft will be rotated in a nose-down sense until the aircraft is once again straight and level.

In most fixed wing aircraft, if the pilot wishes to alter the aircraft heading then he will need to execute a turn to align the aircraft with the new heading. During a turn the aircraft wings are rotated around the roll axis (Oy) until a certain bank angle is attained.

In a properly balanced turn the roll altitude will result in an accompanying change of heading while the roll angle (often called the bank angle) is maintained. This change in heading is actually a rotation around the yaw axis (Oz). The difference between the climb (or descent) and the turn is that the climb only involves rotation around one axis whereas the turn involves simultaneous co-ordination of two axes. In a properly coordinated turn, a component of aircraft lift acts in the direction of the turn, thereby reducing the vertical component of lift. If nothing were done to correct this situation, the aircraft would begin to descend; therefore in a prolonged turning manoeuvre the pilot has to raise the nose to compensate for this loss of lift. At certain times during flight the pilot may in fact be rotating the aircraft around all three axes, for example during a climbing or descending turning manoeuvre.

The aircraft flight control system enables the pilot to exercise control over the aircraft during all portions of flight. The system provides control surfaces that allow the aircraft to manoeuvre in pitch, roll and yaw. The system has also to be designed so that it provides stable control for all parts of the aircraft flight envelope; this requires a thorough understanding of the aerodynamics and dynamic motion of the aircraft. As will be seen, additional control surfaces are required for the specific purposes of controlling the high-lift devices required during approach and landing phases of flight.

3 FLIGHT CONTROL SURFACES

The requirements for flight control surfaces vary greatly between one aircraft and another, depending upon the role, range and agility needs of the vehicle. These varying requirements may best be summarized by giving examples of two differing types of aircraft: an agile fighter aircraft and a typical modern airliner.

The Experimental Aircraft Programme (EAP) aircraft is shown in Fig. 1 and represents the state-of-the-art fighter aircraft as defined by European manufacturers at the beginning of the 1990s. The EAP is similar to the European fighter aircraft (EFA) being developed by the four nation Eurofighter consortium comprising Alenia (Italy), BAE SYSTEMS (UK), CASA (Spain) and Daimler Chrysler (Germany).

Primary flight control

Primary flight control in pitch, roll and yaw is provided by the control surfaces described below. Pitch control is provided by the moving canard surfaces, or foreplanes, as they are sometimes called, located either side of the cockpit. These surfaces provide the very powerful pitch control authority required by an agile high-performance aircraft. The position of the canards in relation to the wings renders the aircraft unstable. Without the benefit of an active computer driven control system the aircraft would be uncontrollable and would crash in a matter of seconds. While this may appear to be a fairly drastic implementation, the benefits in terms of improved manoeuvrability enjoyed by the pilot outweigh the engineering required to provide the computer controlled or 'active' flight control system.

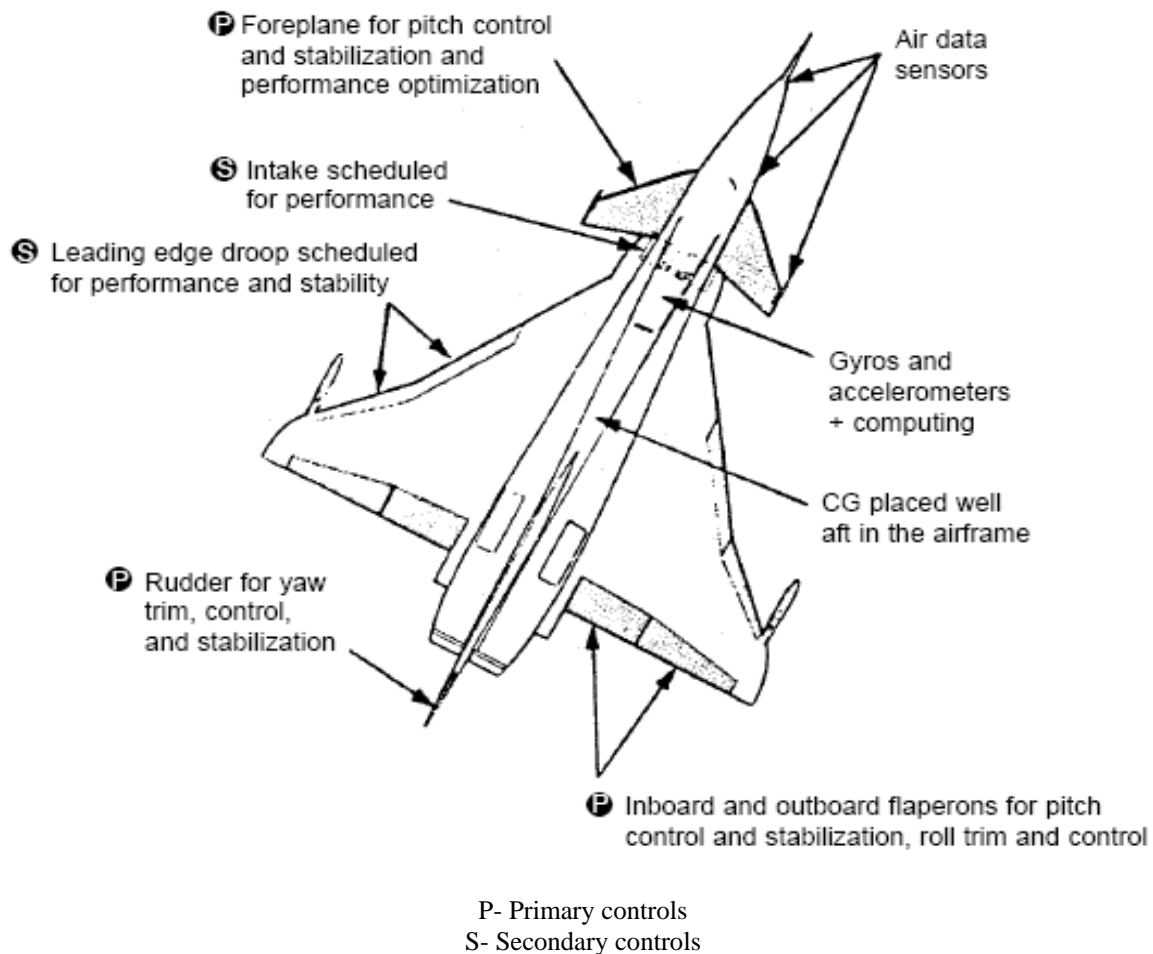


Fig. 1 Example of flight control surfaces – EAP (BAE SYSTEMS)

Secondary flight control

High-lift control is provided by a combination of flaperons and leading-edge slats. The flaperons may be lowered during the landing approach to increase the wing camber and improve the aerodynamic characteristics of the wing. The leading-edge slats are typically extended during combat to further increase wing camber and lift. The control of these high-lift devices during combat may occur automatically under the control of an active flight control system. The penalty for using these high-lift devices is increased drag, but the high levels of thrust generated by a fighter aircraft usually minimizes this drawback.

The EAP has airbrakes located on the upper rear fuselage. They extend to an angle of around 30 degrees, thereby quickly increasing the aircraft drag. The air brakes are deployed when the pilot needs to reduce speed quickly in the air; they are also often extended during the landing run to enhance the aerodynamic brake effect and reduce wheel brake wear.

4 COMMERCIAL AIRCRAFT

An example of flight control surfaces of a typical commercial airliner is shown in Fig. 2. Although the example is for the Airbus Industrie A320 it holds good for similar airliners produced by Boeing or other manufacturers. The controls used by this type of aircraft are described below.

Pitch control is exercised by four elevators located on the trailing edge of the tailplane or horizontal stabilizer. Each elevator section is independently powered by a dedicated flight control actuator, powered in turn by one of several aircraft hydraulic power systems. This arrangement is dictated by the high integrity requirements placed upon flight control systems. The entire tailplane section itself is powered by two or more actuators in order to trim the aircraft in pitch. In a dire emergency this facility could be used to control the aircraft, but the rates of movement and associated authority are insufficient for normal control purposes.

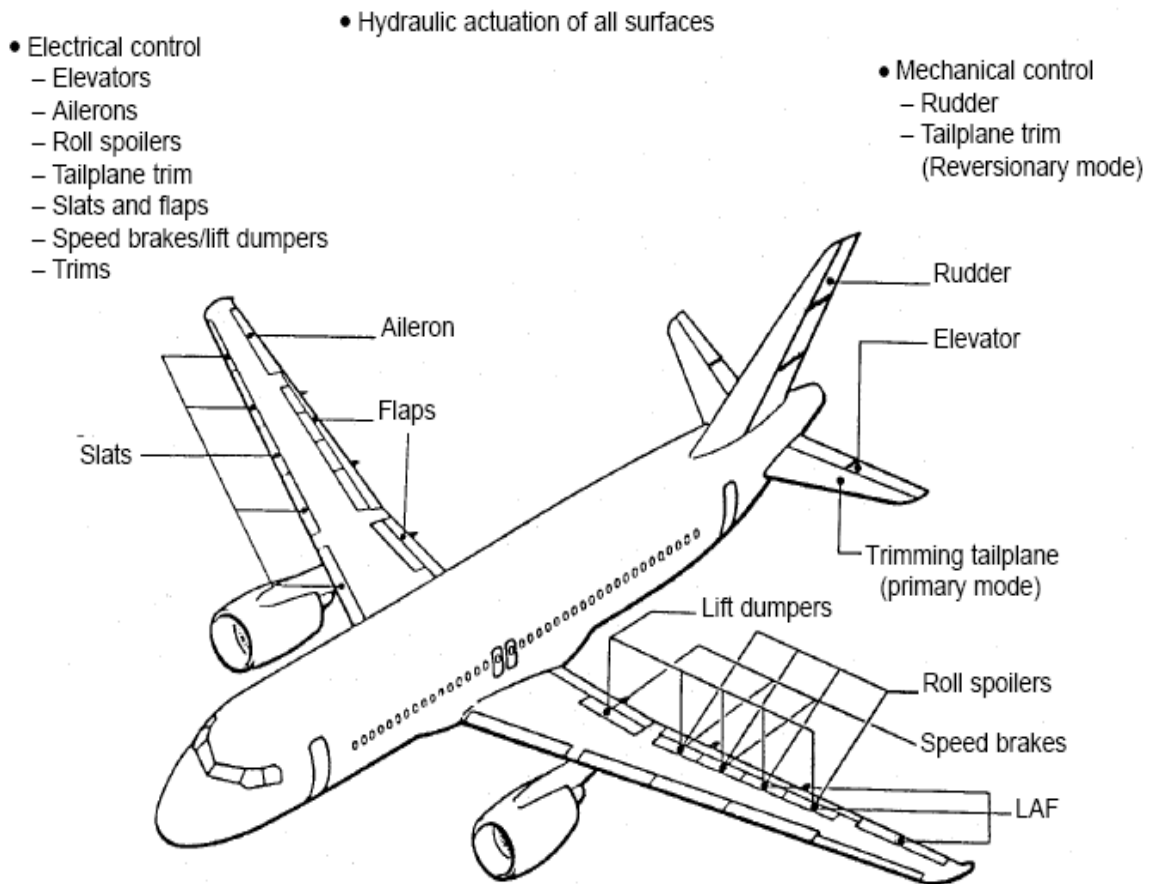


Fig. 2 Example of flight control surfaces – commercial airliner (A320) (BAE SYSTEMS)

5 FLIGHT CONTROL LINKAGE SYSTEMS

The pilot's manual inputs to the flight controls are made by moving the cockpit control column or rudder pedals in accordance with the universal convention:

- Pitch control is exercised by moving the control column fore and aft; pushing the column forward causes the aircraft to pitch down, and pulling the column aft results in a pitch up,
- Roll control is achieved by moving the control column from side to side or rotating the control yoke; pushing the stick to the right drops the right wing and vice versa,
- Yaw is controlled by the rudder pedals; pushing the left pedal will yaw the aircraft to the left while pushing the right pedal will have the reverse effect. There are presently two main methods of connecting the pilot's controls to the rest of the flight control system. These are:

- Push-pull control rod systems.
- Cable and pulley systems.

An example of each of these types will be described and used as a means of introducing some of the major components which are essential for the flight control function. A typical high-lift control system for the actuation of slats and flaps will also be explained as this introduces differing control and actuation requirements.

Push-pull control rod system

The example chosen for the push-pull control rod system is the relatively simple yet high performance Hawk 200 aircraft. Figure 3 shows a simplified three-dimensional schematic of the Hawk 200 flight control which is typical of the technique widely used for combat aircraft. This example is taken from BAE SYSTEMS publicity information relating to the Hawk 200. The system splits logically into pitch/yaw (tailplane and rudder) and roll (aileron) control runs respectively.

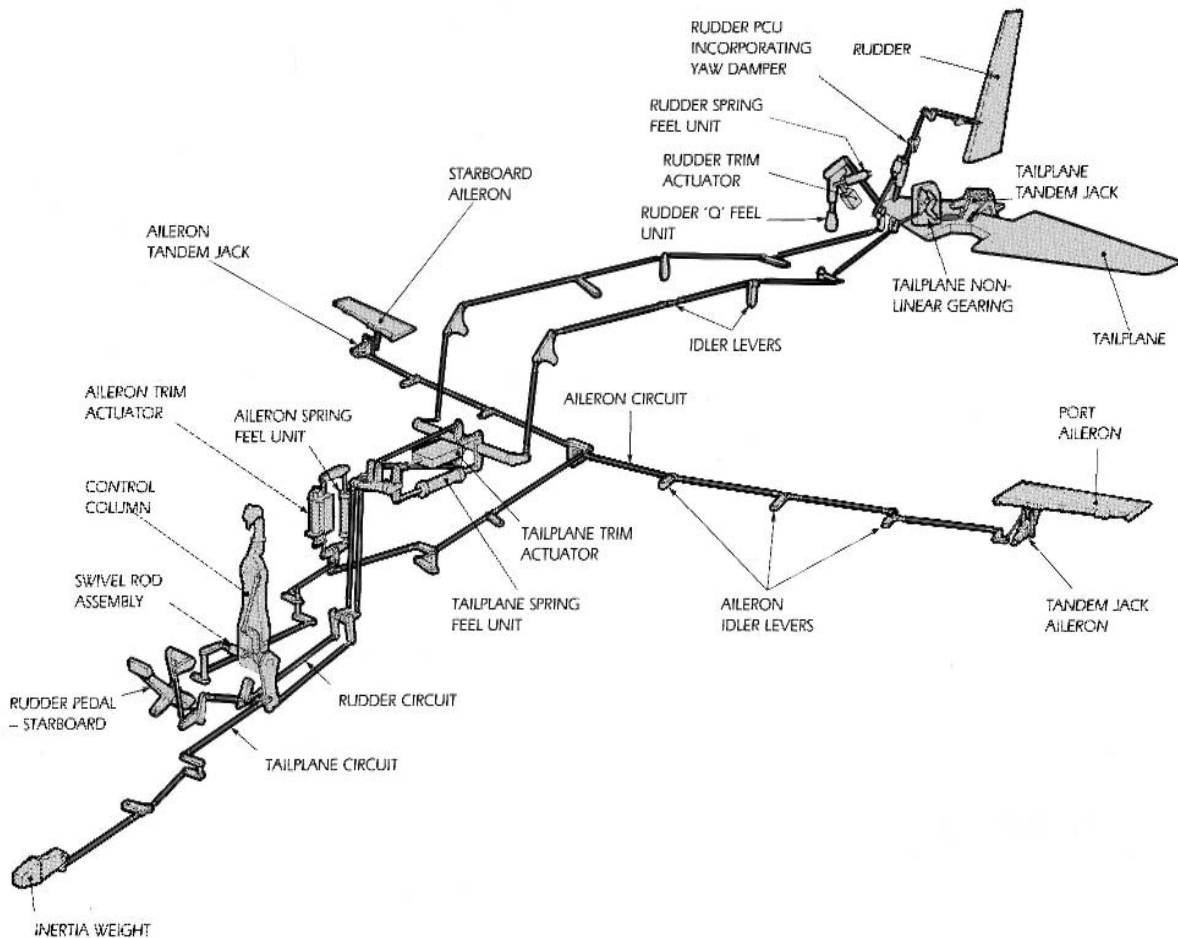


Fig. 3 Hawk 200 push-pull control rod system (BAE SYSTEMS)

Cable and pulley system

The cable and pulley system is widely used for commercial aircraft; sometimes used in conjunction with push-pull control rods. It is not the intention to attempt to describe a complete aircraft system routing in this chapter. Specific examples will be outlined which make specific points in relation to the larger aircraft. Manual control inputs are routed via cables and a set of pulleys from both captain's and first officer's control yokes to a consolidation area in the centre section of the aircraft. At this point aileron and spoiler runs are split both left/right and into separate aileron/spoiler control runs. Both control column/control yokes are synchronized. A breakout device is included which operates at a predetermined force in the event that one of the cable runs fails or becomes jammed.

Control cable runs are fed through the aircraft by a series of pulleys, idler pulleys, quadrants and control linkages in a similar fashion to the push-pull rod system already described. Tensiometer/lost motion devices situated throughout the control system ensure that cable tensions are correctly maintained and lost motion eliminated. Differing sized pulleys and pivot/lever arrangements allow for the necessary gearing changes throughout the control runs. Figure 4 shows a typical arrangement for interconnecting wing spoiler and speed brake controls. Trim units, feel units and PCUs are connected at strategic points throughout the control runs as for the push-pull rod system.

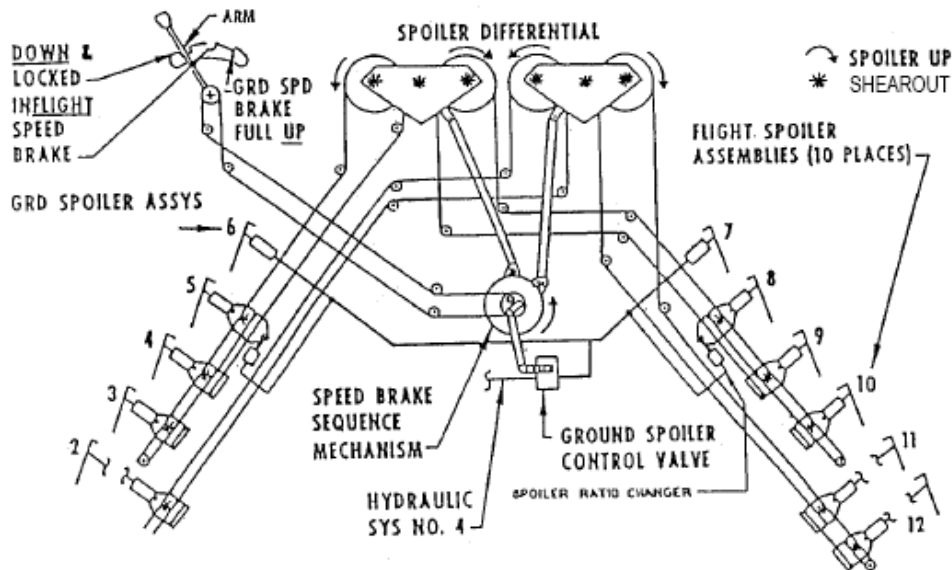


Fig. 4 Spoiler and air brakes control system

5 CONCLUSION

Aircraft Systems – mechanical, electrical, and avionics subsystems integration describes the nature of these systems in detail, giving both military and civil examples. In addition, the article describes the unique nature of helicopter systems and some of the more advanced systems concepts that are being developed or have recently reached fruition. Finally – given the magnitude and scope of the development of aircraft systems – the development methodologies and avionics technology typically used in the implementation of aircraft systems are also outlined.

There is another world of aircraft systems that are required to enable the aircraft to fly and function – the ‘general’ or ‘utilities’ systems. These are less glamorous than the classical avionics systems, but are nevertheless essential for the aircraft to operate, since without them the aircraft will not leave the ground. They are associated with flight control; engine control; and the control of fuel, hydraulics, electrical, pneumatic, environmental, and emergency systems. These systems have, in recent years, increasingly adopted electronics technologies in order to improve system control and diagnostics. Therefore, without exception, these systems are today also ‘avionic’ in nature.

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