

AEROSPACE

Donald McLean

Southampton University, UK

Keywords: aircraft, stability, automatic flight control systems, control, sensors

Contents

1. Introduction
 2. Control of Aeronautical Vehicles
 3. Aircraft Flight Control Systems
 - 3.1. General
 - 3.2. Air Traffic Control
 - 3.3. Flight Phases
 - 3.4. AFCS Reliability
 4. The Principles of Flight Control
 5. Primary Flying Controls
 6. AFCS Modes
 7. “Fly-by-Wire” and “Fly-by-Light” Systems
 8. Flight Control Functions
 9. Future Flight Control Systems
 10. Conclusions
- Glossary
Bibliography
Biographical Sketch

Summary

The article gives an account of how aeronautical vehicles are controlled. It explains the principles of manual and automatic flight control systems (AFCS) and indicates how a flight proceeds through phases that require particular modes of AFCS operation. The new technologies of “fly-by-wire” and “fly-by-light” are described and some indication of the future development of flight control systems is given.

1. Introduction

Aerospace is a portmanteau word that has been coined to cover all aspects of manufacturing, operating, and maintaining aerospace vehicles. These vehicles can be considered to belong to several different classes or types of categories. However, the chief distinction to be made between them is whether they belong to the group of vehicles that fly in the atmosphere (up to a height of 26 000 m (about 85 000 ft) above the earth’s surface), propelled by air-breathing engines, and supported in their flight by aerodynamic lifting surfaces; or to the group that are propelled beyond the atmosphere to orbit using rocket propulsion.

The majority of aerospace vehicles belong to the former group; vehicles used for military offense, space exploration, or satellite missions, are in the second group. Since

vehicles in the latter group do not yet operate in traffic systems, this article will be concerned only with vehicles in the first group, which are further distinguished by using predominantly aerodynamic control surfaces as the means of controlling the motion of the vehicle. There is some occasional use of thrust deflection. These aeronautical vehicles are usually considered as being either fixed-wing aircraft (airplanes) or rotary-wing aircraft (helicopters).

2. Control of Aeronautical Vehicles

Rotary-wing vehicles are characterized by a relatively short-range, low-speed, and, in general, limited lifting capacity. The sole means of sustaining flight by generating sufficient lift in a helicopter is the rotation of the blades of the main rotor. (In some helicopters there are two main rotors; they are called twin-rotor helicopters.) When the main rotor rotates in the air a thrust force is developed perpendicular to the plane in which the rotor rotates. If that plane is horizontal then the direction of the thrust force is upwards, and vertical flight can be achieved.

If the thrust force equals the weight of the helicopter it will remain stationary in the air. If the thrust exceeds the weight, then the helicopter ceases to be stationary and starts a vertical climb; if the thrust is less than the weight, then a vertical descent results. If it is intended to change the angular orientation of the helicopter with respect to the ground then it is required that the plane of rotation of the rotor be varied to align its normal with the required direction of thrust force. The rotor control of a single main rotor/tail rotor configured helicopter can be summarized as in Table 1:

Motion	Control action
Vertical	Main rotor thrust
Longitudinal	Tilting of main rotor (fore/aft)
Lateral	Tilting of main rotor (lateral)
Pitch	Tilting of main rotor (fore/aft)
Roll	Tilting of main rotor (lateral)
Yaw	Tail rotor thrust/engine torque

Table 1. The rotor control of a single main rotor/tail rotor configured helicopter

All single main rotor helicopters use either a tail rotor, a fenestron, or jet nozzles, chiefly to counter the torque of the counterclockwise rotating main rotor. (This is the usual direction of rotation in US and British helicopters. French helicopters use clockwise rotation.) Some of the tail rotor thrust is used for controlling yawing motion.

In fixed-wing vehicles, the lift is generated principally by the wing when the aircraft is in motion. Conventional aircraft generally have four controls (see Figure 1):

- elevator for pitch control (around the transversal axis)
- ailerons for roll control (around the longitudinal axis)
- rudder for yaw control (around the vertical axis)
- thrust, mainly in the longitudinal direction

In many modern aircraft there are, however, many additional control surfaces including flaps, leading edge slats, canards, nose strakes, spoilers, speed brakes, and so on; the use of these is often restricted to particular speed regimes of the aircraft. The principle of flight control remains the same, however, no matter how many control surfaces are used.

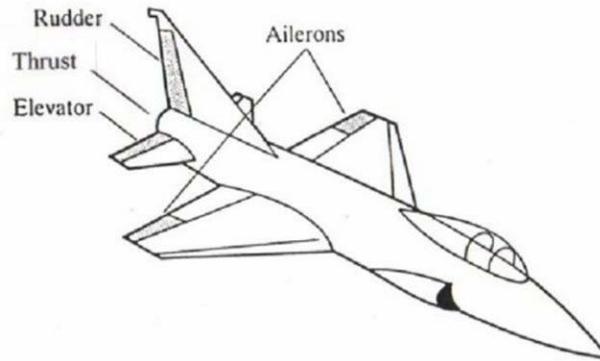


Figure 1. Conventional aircraft

3. Aircraft Flight control Systems

3.1. General

Flight control systems are used in commercial transport, general aviation (that is, light aircraft typically flown by private owners, business, as taxis and so on), and military combat aircraft. Of these classes general aviation is by far the largest, but relatively few such aircraft are equipped either with automatic flight control systems (AFCS) or with more than rudimentary avionics. Although few in relation to the total, there are, however, a number of general aviation aircraft, particularly twin-engined types, that are capable of being operated in instrument meteorological conditions (IMC) and, consequently, are well equipped with AFCS and avionics. Military combat aircraft usually operate over more extended flight envelopes and are equipped extensively with specialized avionics, AFCS, and weapons systems.

Their AFCS provide a number of functional modes not usually found on commercial transport or general aviation aircraft. This article aims to provide an account of flight control systems that relates to all classes of aircraft since military aircraft sometimes operate in regions of airspace under air traffic control.

3.2. Air Traffic Control

The purpose of air traffic control is to provide a system that ensures the safe and efficient flow of aircraft through regions of airspace and at airports. With high traffic density and in poor visibility it is essential that there should be a centralized system of ground control to maintain safe separation and to expedite the progress of individual flights. The system involves surveillance, communications, meteorological services, navigational aids, and rules and procedures. One of the chief requirements for any

aircraft operating under ATC rules is that its height, speed, and location can be accurately controlled. To achieve the precision required involves the use of AFCS.

3.3. Flight Phases

Usually the flight of any aircraft under ATC can be regarded as being composed of eight distinct phases, which are represented in Figure 2. The percentages shown represent the fraction of the total flight time spent in each phase. The profile shown is representative of a typical short-haul flight of stage length about 1500 km (about 930 miles). In each of those phases the aircraft will be under ATC.

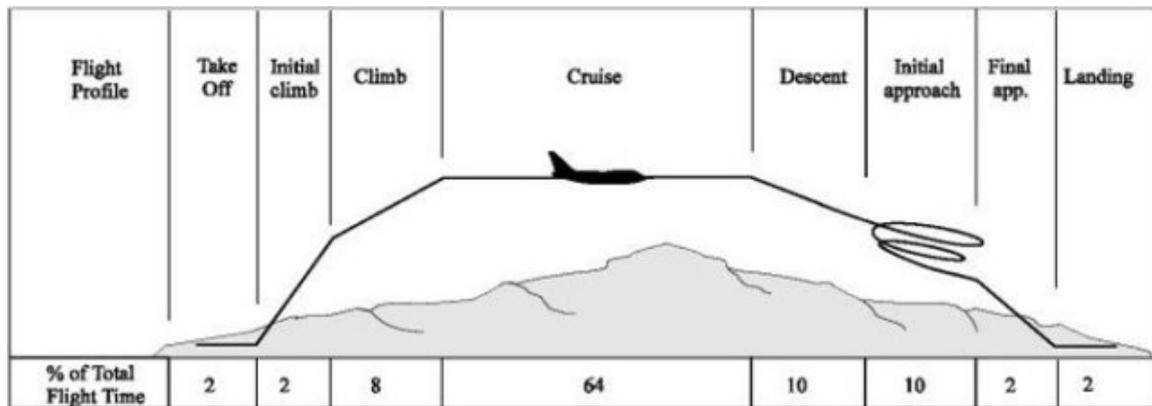


Figure 2. Flight phases shown as fractions of flight time

3.4. AFCS Reliability

Operating in the ATC system requires that the AFCS must be reliable. The reliability required is usually expressed as one failure in 10^7 flying hours, or, if it is assumed that an aircraft operates for as little as 3000 flying hours per year, one failure in every 3000 years of flying. (Modern, long-haul, commercial jet-transport aircraft can regularly achieve as many as 4500 flying hours per year.

Regional turbo-prop or jet aircraft usually achieve about 2700, and the corresponding figure for military combat aircraft can be as low as 300.) To achieve a reliability of 10^{-7} requires the use of redundancy, that is, the use of several channels of identical equipment simultaneously carrying out the same functions, with the individual channels being continuously monitored for any disparity from the other channels. Such an application makes the system both more expensive and heavier than if it had been possible to use only a single channel.

Although safety is of paramount importance in all aviation, in commercial aviation regularity of service is another important consideration. The need to operate safely in adverse weather is essential for the economic well-being of an airline. It has been estimated that each year in the United States some 24 000 commercial flights are diverted or delayed by bad weather.

With an average delay in that situation of about six hours, and with the average number of passengers involved in each flight being about 200, the total passenger hours involved in these delays is estimated to be about 30×10^6 . The annual cost of such delays to US airlines is estimated at US\$1.5 billion. The cause of about 60% of these delays has been directly attributed to severe weather conditions, with the cause of another 35% being attributed to the limited capacity of airports.

However, such capacity-limit delays are partly caused by the knock-on effects of earlier weather delays. In Europe, there are about 3.3×10^5 estimated hours of delay each year. Although three-quarters of those European delays were less than 25 min, it is evident that, for commercial airlines at least, AFCS and the associated avionics systems, which assist aircraft to operate in all weather conditions, are essential for operational efficiency.

-
-
-

TO ACCESS ALL THE 17 PAGES OF THIS CHAPTER,
[Click here](#)

Bibliography

Draper C.S. (1959). Flight control. *Aeronautical Journal* **59**(6), 451–477. [This paper outlines the fundamentals of flight control systems.]

Hollister W.M. (1993). Air traffic control systems. *Concise Encyclopedia of Aeronautics and Space Systems*, pp. 33–38. Oxford: Pergamon Press. [This article provides a clear explanation of how air traffic is controlled in Europe, the United States, and throughout the world.]

Hughes D. (1994). Raytheon/Beech pursue low cost fly-by-light. *Aviation Week & Space Technology*, May 2, 51–55. [This brief article reports on the engineering implementation of a flight control system.]

McLean D. (1990). *Automatic Flight Control Systems*. Hemel Hempstead, UK: Prentice Hall. Pp. 1–15, 63–101, 151–173, 270–449. [This textbook provides extensive coverage of aircraft dynamics and the design and use of automatic flight control systems.]

Nordwall B.D. (1994). HIRF threat to electronics less than expected. *Aviation Week & Space Technology*, February 14, 52–54. [A brief report on US tests relating to an assessment of the vulnerability of electronic and fiber-optic systems to high intensity r.f. radiation.]

Speyer J.J., Blomberg R.D., and Fonsilloc J.P. (1993). Cockpits: impact of new technology. *Concise Encyclopedia of Aeronautics and Space Systems*, pp. 78–84. Oxford: Pergamon Press. [This article provides a good account of cockpit displays based on cathode ray tubes, the so-called “glass” cockpits.]

Biographical Sketch

Professor Donald McLean was educated in Paisley, Scotland, UK. He joined British European Airways as a Student Radio Apprentice in 1952, and in 1958 was commissioned in the Technical Branch of the Royal Air Force (RAF). He retired in 1974 with the rank of Squadron Leader, having spent six years as a Research Officer at RAF College, Cranwell, UK, attended the Advanced Control Course at Cambridge University in 1968/1969, and been RAF Exchange Professor at the United States Air Force Institute of

Technology at Wright-Patterson Air Force Base, Dayton, Ohio, USA, from 1972 to 1974. He completed his Ph.D. at Loughborough University, UK, in 1974 and joined the Department of Transport Technology of Loughborough University as a Lecturer in 1974. He left Loughborough as a Reader in Flight Control Systems in 1985 and took the Westland Chair of Aeronautics at Southampton University, UK, in the same year. He has been Director of the Master of Engineering Courses, Public Orator, Head of the Department of Aeronautics and Astronautics, and is currently Director of the M.Sc. Aviation Management Course and Professor of Flight Control in the School of Engineering Sciences at Southampton University. He has written over 120 technical papers and is the author of the standard European textbook on automatic flight control systems. He is, at present, a member of the editorial panel of the *Aeronautical Journal of the Royal Aeronautical Society* (RAeS), and member of the editorial advisory board of the *Transactions of the Institute of Measurement and Control* (Inst.MC), of which he was President in 1985. He currently serves on the Learned Society Board, the Scientific and Technical Committee, the Journal Editorial Committee, and is Chairman of the Aviation Panel of the Institute. He has won the Honeywell Prize twice from the Inst.MC and the Simms Prize from the RAeS.

UNESCO – EOLSS
SAMPLE CHAPTERS