Advanced Aircraft Components

Colten Grissom

First Edition, 2012

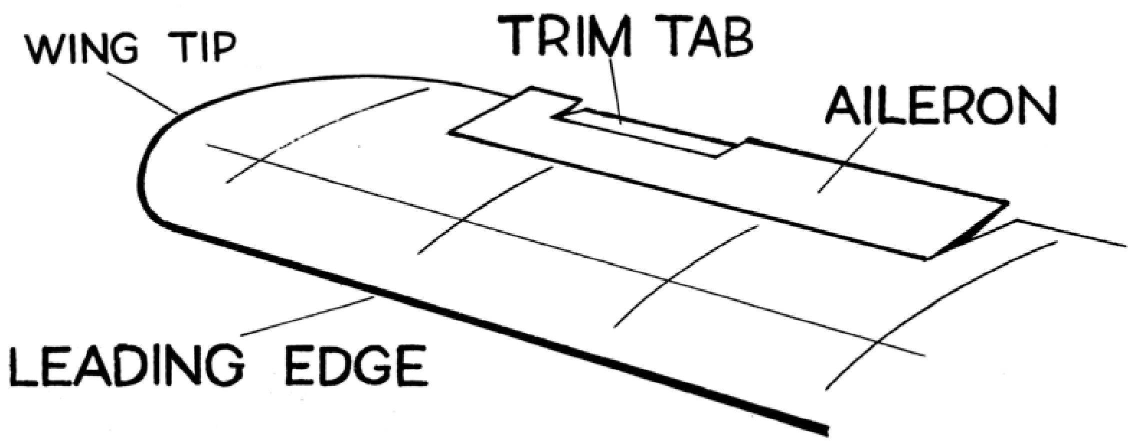
ISBN 978-81-323-2702-8

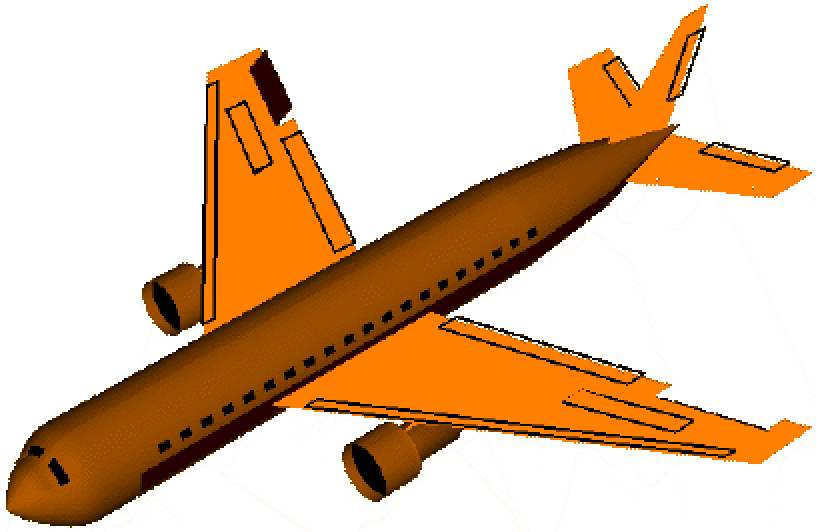
Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter- 1

Aileron





An aircraft rolling with its ailerons

Ailerons are hinged control surfaces attached to the trailing edge of the wing of a fixed-wing aircraft. The ailerons are used to control the aircraft in roll. The two ailerons are typically interconnected so that one goes down when the other goes up: the downgoing aileron increases the lift on its wing while the upgoing aileron reduces the lift on its wing, producing a rolling moment about the aircraft's longitudinal axis. The word *aileron* is French for "little wing".

An unwanted side effect of aileron operation is adverse yaw—a yawing moment in the opposite direction to the roll. Using the ailerons to roll an aircraft to the right produces a yawing motion to the left. As the aircraft rolls, adverse yaw is caused primarily by the change in drag on the left and right wing. The rising wing generates increased lift which causes increased induced drag. The descending wing generates reduced lift which causes reduced induced drag. The difference in drag on each wing produces the adverse yaw. There is also often an additional adverse yaw contribution from a difference in profile drag between the up-aileron and down-aileron.

Adverse yaw is effectively compensated by the use of the rudder, which results in a sideforce on the vertical tail which opposes the adverse yaw by creating a favorable yawing moment. Another method of compensation is *differential ailerons*, which have been rigged such that the downgoing aileron deflects less than the upgoing one. In this case the opposing yaw moment is generated by a difference in profile drag between the left and right wingtips. *Frise ailerons* accentuate this profile drag imbalance by protruding beneath the wing of an upward-deflected aileron, most often by being hinged slightly behind the leading edge and near the bottom of the surface, with the lower section of the leading edge protruding slightly below the wing's undersurface when the aileron is deflected upwards, substantially increasing profile drag on that side. Ailerons may also be designed to use a combination of these methods.

With ailerons in the neutral position the wing on the outside of the turn develops more lift than the opposite wing due to the variation in airspeed across the wing span, and this tends to cause the aircraft to continue to roll. Once the desired angle of bank (degree of rotation on the longitudinal axis) is obtained, the pilot uses opposite aileron to prevent the angle of bank from increasing due to this variation in lift across the wing span. This minor opposite use of the control must be maintained throughout the turn. The pilot also uses a slight amount of rudder in the same direction as the turn to counteract adverse yaw and to produce a "coordinated" turn where the fuselage is parallel to the flight path. A simple gauge on the instrument panel called the slip indicator, also known as "the ball", indicates when this coordination is achieved.

Ailerons are the trailing-edge control surface nearest the wing tip (although on some airliners they can also be found at the wing root). On this parked Piper Cherokee, the left aileron has deflected downwards, and the right, upwards.

History

Since the need for roll control on aircraft was not as obvious as the need for heading and pitch control, the aileron came into widespread use well after the rudder and elevator. The Wright Brothers used wing warping instead of ailerons for roll control, and initially, their aircraft had much better control in the air than aircraft that used movable surfaces; however, as aileron designs were refined, and aircraft became larger and heavier, it became clear that they were much more effective and practical for most aircraft.

There are conflicting claims over who first invented the aileron. In 1868, before the advent of powered aircraft, English inventor M.P.W. Bolton patented the first aileron-type device for lateral control. New Zealander Richard Pearse may have made a powered flight in a monoplane that included small ailerons as early as 1902, but his claims are controversial (and sometimes inconsistent), and even by his own reports, his aircraft were not well controlled. The aircraft 14 Bis by Santos Dumont was modified to add ailerons in late 1906, though it was never fully controllable in flight, likely due to its unconventional wing form. Ailerons were also developed independently by the Aerial Experiment Association, headed by Alexander Graham Bell and by Robert Esnault-Pelterie, a French aircraft builder. Henry Farman's ailerons on the *Farman III* were the first to resemble ailerons on modern aircraft, and have a reasonable claim as the ancestor of the modern aileron. Other claimants include American William Whitney Christmas, who claimed to have invented the aileron in the 1914 patent for what would become the Christmas Bullet (built in 1918) and American Glenn Curtiss, who flew an aileron-controlled aircraft in 1908. Curtiss had previously been a member of Bell's Aerial Experiential Association, which had the developed ailerons for their aircraft. The AEA members were later dismayed when Curtiss dropped out of their organization, patented their innovation and sold the patent to the United States Government.

Aileron spades

These are flat metal plates, usually attached to the aileron lower surface, ahead of the aileron hinge, by a lever arm. They reduce the force needed by the pilot to deflect the aileron and are often seen on aerobatic aircraft. As the aileron is deflected upward, the spade produces a downward aerodynamic force, which tends to rotate the whole assembly so as to further deflect the aileron upward. The size of the spade (and its lever arm) determine how much force the pilot needs to apply to deflect the aileron.

Aileron balance weights

To prevent control surface flutter (aeroelastic flutter), the center of lift of the control surface should be behind the center of gravity of that surface. To achieve this, lead weights may be added to the front of the aileron. In some aircraft the aileron construction may be too heavy to allow this system to work without huge weight increases. In this case, the weight may be added to a lever arm to move the weight well out in front to the aileron body. These balance weights are tear drop shapes (to reduce drag) which make them appear quite different from spades, although both project forward and below the aileron.

Types of ailerons

Frise Ailerons

Engineer Leslie George Frise (1897–1979) developed an aileron shape which is often used due to its ability to counteract adverse yaw. The Frise aileron is pivoted at about its 25 to 30% chord line and near its bottom surface. When the aileron is deflected up (to make its wing go down), the leading edge of the aileron dips into the airflow beneath the wing. The moment of the leading edge in the airflow helps to move up the trailing edge, decreasing the stick force. The down-moving aileron also adds energy to the boundary layer by the airflow from the under-side of the wing that scoops air by the edge of the aileron that follows the upper surface of the aileron and creates a lifting force on the upper surface of the aileron aiding the lift of the wing. That reduces the needed deflection angle of the aileron. If the leading edge of the aileron is sharp or bluntly rounded, that adds significant drag to that wing and help the aircraft to yaw (turn) in the desired direction, but adds some unpleasant or potentially dangerous aerodynamic vibration (flutter).

Differential ailerons

By careful design of the mechanical linkages, the up aileron can be made to deflect more than the down aileron (e.g.). This helps reduce the likelihood of a wing tip stall when aileron deflections are made at high angles of attack. The idea is that the loss of lift associated with the up aileron carries no penalty while the increase in lift associated with the down aileron is minimized. The rolling couple on the aircraft is always the difference in lift between the two wings.

The de Havilland Tiger Moth classic British biplane is one of the best-known aircraft, and one of the earliest, to use differential ailerons.

Combinations with other control surfaces

- A control surface that combines an aileron and flap is called a **flaperon**. A single surface on each wing serves both purposes: used as an aileron, the flaperons left and right are actuated differentially; when used as a flap, both flaperons are actuated downwards. When a flaperon is actuated downwards (i.e. used as a flap) there is enough freedom of movement left to be able to still use the aileron function.
- A further form of roll control, common on modern jet transport aircraft, utilises spoilers in conjunction with ailerons. This is called a **spoileron**.

- In a delta-winged aircraft, the ailerons are combined with the elevators to form an **elevon**.
- Several modern fighter aircraft may have no ailerons on the wings at all, and combine roll control with an all moving tailplane. This is a **stabilator** or a rolling tail.

Research

Several technology research and development efforts exist to incorporate the function of ailerons and flaps into wings to perform the aerodynamic purpose without the weight and mechanical complexity of aileron systems. Desired traits include lower: mass, cost, drag, inertia (for faster, stronger control response), complexity (mechanically simpler, fewer moving parts or surfaces, less maintenance), and radar cross section for stealth. These may be used in many unmanned aerial vehicles (UAVs) and 6th generation fighter aircraft. The two main approaches are flexible wings, and fluidics.

In flexible wings, much or all of a wing surface can change shape in flight to deflect air flow. The X-53 Active Aeroelastic Wing is a NASA effort. The Adaptive Compliant Wing is a commercial effort.

In fluidics, forces in vehicles occur via circulation control, in which larger more complex mechanical parts are replaced by smaller simpler fluidic systems (slots which emit air flows) where larger forces in fluids are diverted by smaller jets or flows of fluid intermittently, to change the direction of vehicles. In this use, fluidics promises lower mass, costs (up to 50% less), and very low inertia and response times, and simplicity.

Chapter- 2

Aircraft Engine Controls

Aircraft engine controls provide a means for the pilot to control and monitor the operation of the aircraft's powerplant. We describes controls used with a basic internal-combustion engine driving a propeller. Jet turbine engines use different operating principles and have their own sets of controls and sensors.

Basic Controls and Indicators

- **Master Switch** - Most often actually two separate switches, the Battery Master and the Alternator Master. The Battery Master activates a relay (sometimes called the battery contactor) which connects the battery to the aircraft's main electrical bus. The alternator master activates the alternator by applying power to the alternator field circuit. These two switches provide electrical power to all the systems in the aircraft.
- **Throttle** - Sets the desired power level. The throttle controls the mass flow-rate of air (in fuel-injected engines) or air/fuel mixture (in carburetted engines) delivered to the cylinders.
- **Pitch Control** - Adjusts the Constant Speed Unit, which in turn adjusts the propeller pitch & regulates the engine load as necessary to maintain the set R.P.M.
- **Mixture Control** - Sets the amount of fuel added to the intake airflow. At higher altitudes the air pressure (and therefore the oxygen level) declines so the fuel volume must also be reduced to give the correct air/fuel mixture. This process is known as "leaning".
- **Ignition Switch** - Activates the magnetos by opening the grounding or 'p-lead' circuit; with the p-lead ungrounded the magneto is free to send its high-voltage output to the spark plugs. In most aircraft the ignition switch also applies power to the starter motor during engine start. In piston aircraft engines, the battery does not generate the spark for combustion. This is accomplished using devices called magnetos. Magnetos are connected to the engine by gearing. When the crankshaft turns, it turns the magnetos which mechanically generate voltage for spark. In the event of an electrical failure, the engine will continue to run. The Ignition Switch has the following positions:
    1. Off - Both magneto p-leads are connected to electrical ground. This disables both magnetos, no spark is produced.

2. Right - The left magneto p-lead is grounded, and the right is open. This disables the left magneto and enables the right magneto only.
3. Left - The right magneto p-lead is grounded, and the left is open. This disables the right magneto and enables the left magneto only.
4. Both - This is the normal operating configuration, both p-leads are open enabling both magnetos.
5. Start - The pinion gear on the starter motor is engaged with the flywheel and the starter motor runs to turn the engine over. In most cases, only the left magneto is active (the right p-lead is grounded) due to timing differences between the magnetos at low PRMs.

- **Tachometer** - A gauge to indicate engine speed in revolutions per minute (RPM) or percentage of maximum.
- **Manifold Pressure (MP) Gauge** - Indicates the pressure in the intake manifold.
- **Oil Temperature Gauge** - Indicates the engine oil temperature.
- **Oil Pressure Gauge** - Indicates the supply pressure of the engine lubricant.
- **Exhaust Gas Temperature (EGT) Gauge** - Indicates the temperature of the exhaust gas just after combustion. Used to set the fuel/air mixture (leaning) correctly.
- **Cylinder Head Temperature (CHT) Gauge** - Indicates the temperature of at least one of the cylinder heads. Used to set the fuel/air mixture.
- **Carburetor Heat Control** - Controls the application of heat to the carburetor venturi area to remove or prevent the formation of ice in the throat of the carburetor as well as bypassing the air filter in case of impact icing.
- **Alternate Air** - Bypasses the air filter on a fuel-injected engine.

Fuel

- **Fuel Primer Pump** - A manual pump to add a small amount of fuel at the cylinder intakes to assist in starting a cold engine. Fuel injected engines do not have this control. For fuel injected engines, a fuel boost pump is used to prime the engine prior to start.
- **Fuel Quantity Gauge** - Indicates the amount of fuel remaining in the identified tank. One per fuel tank.
- **Fuel Select Valve** - Connects the fuel flow from the selected tank to the engine.

If the aircraft is equipped with a fuel pump:

- **Fuel Pressure Gauge** - Indicates the supply pressure of fuel to the carburetor (or in the case of a fuel injected engine, to the fuel controller.)
- **Fuel Boost Pump Switch** - Controls the operation of the auxiliary electric fuel pump to provide fuel to the engine before it starts or in case of failure of the engine powered fuel pump. Some large airplanes have a fuel system that allows the flight crew to jettison or dump the fuel. When operated, the boost pumps in the fuel tanks pump the fuel to the dump chutes or jettison nozzles and overboard to atmosphere.

Propeller

If the aircraft is equipped with adjustable-pitch or constant-speed propeller(s):

- **Propeller Control** - Used to set the desired propeller speed. Once the pilot has set the desired propeller speed, the propeller governor maintains that propeller speed by adjusting the pitch of the propeller blades, using the engine's oil pressure to move a hydraulic piston in the propeller hub.
- **Manifold Pressure Gauge** - Indicates the (absolute) pressure in the engine's intake manifold. When the engine is running normally, there is a good correlation between the intake manifold pressure and the torque the engine is developing.

Cowl

If the aircraft is equipped with adjustable Cowl Flaps:

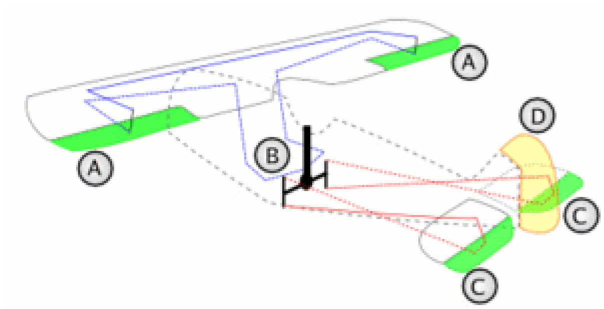
- **Cowl Flap Position Control -** Cowl Flaps are opened during high power/low airspeed operations like takeoff to maximize the volume of cooling airflow over the engine's cooling fins.
- **Cylinder Head Temperature Gauge** - Indicates the temperature of all cylinder heads or on a single CHT system, the hottest head. A Cylinder Head Temperature Gauge has a much shorter response time than the oil temperature gauge, so it can alert the pilot to a developing cooling issue more quickly. Engine overheating may be caused by:
    1. Running too long at a high power setting.
    2. Poor leaning technique.
    3. Restricting the volume of cooling airflow too much.
    4. Insufficient delivery of lubricating oil to the engine's moving parts.

Chapter- 3

Aircraft Flight Control System

A conventional fixed-wing **aircraft flight control system** consists of flight control surfaces, the respective cockpit controls, connecting linkages, and the necessary operating mechanisms to control an aircraft's direction in flight. Aircraft engine controls are also considered as flight controls as they change speed.

The fundamentals of aircraft controls are explained in flight dynamics.



A typical aircraft's primary flight controls in motion

Cockpit controls

Primary controls

Generally the primary cockpit controls are arranged as follows:

- A control column or a control yoke attached to a column—for roll and pitch, which moves the ailerons when turned or deflected left and right, and moves the elevators when moved backwards or forwards
- Rudder pedals to control yaw, which move the rudder; left foot forward will move the rudder left for instance.
- Throttle controls to control engine speed or thrust for powered aircraft.

Even when an aircraft uses different kinds of surfaces, such as a V-tail/ruddervator, flaperons, or elevons, to avoid pilot confusion the aircraft will still normally be designed so that the yoke or stick controls pitch and roll in the conventional way, as will the rudder pedals for yaw.

Secondary controls

In addition to the primary flight controls for roll, pitch, and yaw, there are often secondary controls available to give the pilot finer control over flight or to ease the workload. The most commonly-available control is a wheel or other device to control elevator trim, so that the pilot does not have to maintain constant backward or forward pressure to hold a specific pitch attitude (other types of trim, for rudder and ailerons, are common on larger aircraft but may also appear on smaller ones). Many aircraft have wing flaps, controlled by a switch or a mechanical lever or in some cases are fully automatic by computer control, which alter the shape of the wing for improved control at the slower speeds used for takeoff and landing. Other secondary flight control systems may be available, including slats, spoilers, air brakes and variable-sweep wings.

Basic flight control systems

Mechanical

de Havilland Tiger Moth elevator and rudder cables

Mechanical or manually-operated flight control systems are the most basic method of controlling an aircraft. They were used in early aircraft and are currently used in small aircraft where the aerodynamic forces are not excessive. Very early aircraft used a system of wing warping where no movable control surfaces were used, except for the rudder. A manual flight control system uses a collection of mechanical parts such as rods, tension cables, pulleys, counterweights, and sometimes chains to transmit the forces applied to the cockpit controls directly to the control surfaces. Turnbuckles are often used to adjust control cable tension. The Cessna Skyhawk is a typical example of an aircraft that uses this type of system. Gust locks are often used on parked aircraft with mechanical systems to protect the control surfaces and linkages from damage from wind. Some aircraft have gust locks fitted as part of the control system.

Increases in the control surface area required by large aircraft or higher loads caused by high airspeeds in small aircraft lead to a large increase in the forces needed to move them, consequently complicated mechanical gearing arrangements were developed to extract maximum mechanical advantage in order to reduce the forces required from the pilots. This arrangement can be found on bigger or higher performance propeller aircraft such as the Fokker 50.

Some mechanical flight control systems use servo tabs that provide aerodynamic assistance. Servo tabs are small surfaces hinged to the control surfaces. The flight control mechanisms move these tabs, aerodynamic forces in turn move, or assist the movement of the control surfaces reducing the amount of mechanical forces needed. This arrangement was used in early piston-engined transport aircraft and in early jet transports. The Boeing 737 incorporates a system, whereby in the unlikely event of total hydraulic system failure, it automatically and seamlessly reverts to being controlled via servo-tab.

Hydro-mechanical

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. With hydraulic flight control systems, the aircraft's size and performance are limited by economics rather than a pilot's muscular strength. At first, only-partially boosted systems were used in which the pilot could still feel some of the aerodynamic loads on the control surfaces (feedback).

A hydro-mechanical flight control system has two parts:

- The *mechanical circuit*, which links the cockpit controls with the hydraulic circuits. Like the mechanical flight control system, it consists of rods, cables, pulleys, and sometimes chains.

- The *hydraulic circuit*, which has hydraulic pumps, reservoirs, filters, pipes, valves and actuators. The actuators are powered by the hydraulic pressure generated by the pumps in the hydraulic circuit. The actuators convert hydraulic pressure into control surface movements. The electro-hydraulic servo valves control the movement of the actuators.

The pilot's movement of a control causes the mechanical circuit to open the matching servo valve in the hydraulic circuit. The hydraulic circuit powers the actuators which then move the control surfaces. As the actuator moves, the servo valve is closed by a mechanical feedback linkage - one that stops movement of the control surface at the desired position.

This arrangement was found in the older-designed jet transports and in some high-performance aircraft. Examples include the Antonov An-225 and the Lockheed SR-71.

Artificial feel devices

With purely mechanical flight control systems, the aerodynamic forces on the control surfaces are transmitted through the mechanisms and are felt directly by the pilot. This gives tactile feedback of airspeed and aids flight safety.

With hydromechanical flight control systems however, the load on the surfaces cannot be felt and there is a risk of overstressing the aircraft through excessive control surface movement. To overcome this problem artificial feel systems are used. For example, for the controls of the RAF's Avro Vulcan jet bomber and the RCAF's Avro Canada CF-105 Arrow supersonic interceptor, both 1950's-era designs, the required force feedback was achieved by a spring device. The fulcrum of this device was moved in proportion to the square of the air speed (for the elevators) to give increased resistance at higher speeds. For the controls of the American Vought F-8 Crusader and the LTV A-7 Corsair II warplanes, a "bob-weight" was used in the pitch axis of the control stick, giving force feedback that was proportional to the airplane's normal acceleration.

Stick shaker

A stick shaker is a device (available in some hydraulic aircraft) which is fitted into the control column which shakes the control column when the aircraft is about to stall. Also in some aircraft like the McDonnell Douglas DC-10 there is/was a back-up electrical power supply which the pilot can turn on to re-activate the stick shaker in case the hydraulic connection to the stick shaker is lost.

Fly-by-wire control systems

A fly-by-wire (FBW) system replaces manual flight control of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term), and flight control computers determine how to move the actuators at each control surface to provide the expected response. Commands from the computers are also input without the pilot's knowledge to stabilize the aircraft and perform other tasks.

Fluidic flight controls

Conventional mechanical flight control surfaces may also be replaced completely, by a fluidic flight control system, provided by differential streams of blown air, such as with the Demon (UAV), aircraft which flew for the first time, in the UK, in September 2010.

Chapter- 4

Blown Flap

Blown flaps of the Hunting H.126

Blown flaps are a powered aerodynamic high-lift device invented by the British and used on the wings of certain aircraft to improve low-speed lift during takeoff and landing. The process is sometimes called a **boundary layer control system** (**BLCS**). They were a popular design feature in the 1960s, but fell from use due to their complex maintenance needs. Today a simpler version can be found on military transport aircraft, although the term is not widely used. Additionally, the early concepts have been built upon by modern engineers to create the circulation control wing, a far more effective device with applications in the modern aviation industry.

Mechanism

In a conventional blown flap, a small amount of the compressed air produced by the jet engine is "bled" off at the compressor stage and piped to channels running along the rear of the wing. There, it is forced through slots in the wing flaps of the aircraft when the flaps reach certain angles. Injecting high energy air into the boundary layer produces an increase in the stalling angle of attack and maximum lift coefficient by delaying boundary layer separation from the airfoil. Boundary layer control by mass injecting (blowing) prevents boundary layer separation by supplying additional energy to the particles of fluid which are being retarded in the boundary layer. Therefore injecting a high velocity air mass into the air stream essentially tangent to the wall surface of the airfoil reverses the boundary layer friction deceleration thus the boundary layer separation is delayed.

The effectiveness of wings can be greatly improved by using blow-type flow control, while if the intensity of the blown jet is high enough, even the lift predicted by potential flow theory can be surpassed (i.e. the jet flap effect) due to the initiation of supercirculation. Streamwise blowing however can require large amounts of air and energy thus reducing the overall benefits of the flow control solution itself. At low speeds, the amount of air being delivered by this system can be a significant fraction of the overall airflow, generating as much lift as if the plane were traveling at much higher speeds. This costs little, during landing at least, as the engine power is significantly reduced anyway. During takeoff the trade-off is not so obvious, particularly in conditions of low air density.

Development of the general concept continued at NASA in the 1950s and 60s, leading to simplified systems with similar performance. The *externally-blown flap* arranges the engine to blow across the flaps at the rear of the wing. Some of the jet exhaust is deflected downward directly by the flap, while additional air travels through the slots in the flap and follows the outer edge due to the Coandă effect. The similar *upper-surface blowing* system arranges the engines over the wing and relies completely on the Coandă effect to redirect the airflow. Although not as effective as direct blowing, these "powered lift" systems are nevertheless quite powerful and much simpler to build and maintain.

A more recent and promising blow-type flow control concept is the counter-flow fluid injection which is able to exert high-authority control to global flows using low energy modifications to key flow regions. In this case the air blow slit is located at the pressure side near the leading edge stagnation point location and the control air-flow is directed tangentially to the surface but with a forward direction. During the operation of such a flow control system two different effects are present. One effect, the Boundary Layer Enhancement, is caused by the increased turbulence levels away from the wall region thus transporting higher-energy outer flow into the wall region. In addition to that another effect, the Virtual shaping effect is utilized to aerodynamically thicken the airfoil at high angles of attack. Both these effects help to delay or eliminate flow separation.

In general, blown flaps can improve the lift of a wing by two to three times. Whereas a complex triple-slotted flap system on a Boeing 747 delivers a coefficient of lift of about 2.8, external blowing improves this to about 7, and internal blowing to 9.

History

During the 1950s and 60s, fighter aircraft generally evolved towards smaller and smaller wing planforms in order to have low drag at high speeds. Compared to the fighters of a generation earlier, they had wing loadings about four times as high; for instance the Supermarine Spitfire had a wing loading of 24 lb/ft^2 (117 kg/m^2) and the Messerschmitt Bf 109 had the "very high" loading of 30 lb/ft^2 (146 kg/m^2), whereas the 1950s-era F-104 Starfighter had 111 lb/ft^2 (542 kg/m^2).

One serious downside to these higher wing loadings is at low speed, when there simply isn't enough wing left to provide lift to keep the plane flying. Even huge flaps could not offset this to any large degree, and as a result many aircraft landed at fairly high speeds, and were noted for accidents as a result.

The major reason flaps were not effective is that the airflow over the wing could only be "bent so much" before it stopped following the wing profile, a condition known as **flow separation**. Effectively, there is a limit to how much air the flaps can deflect overall. There are ways to improve this, through better flap design; modern airliners use complex multi-part flaps for instance. However, large flaps tend to add considerable complexity, and take up room on the outside of the wing, which makes them unsuitable for use on a fighter.

The concept was first tested on the experimental Hunting H.126. It reduced the stall speed to only 32 mph (51 km/h), a number most light aircraft cannot match. The first production aircraft with BLCS was the Lockheed F-104 Starfighter, where after prolonged development problems, it proved to be enormously useful in compensating for the Starfighter's tiny wing surface. It was shortly adopted for North American Aviation's A-5 Vigilante, the F-4 Phantom, the Blackburn Buccaneer and the ill-fated BAC TSR-2. On the TSR-2 it reduced the takeoff distance for this large and highly loaded aircraft from 6,000 feet (1,800 m) without the blowers, to about 1,600 feet (490 m) with them turned on.

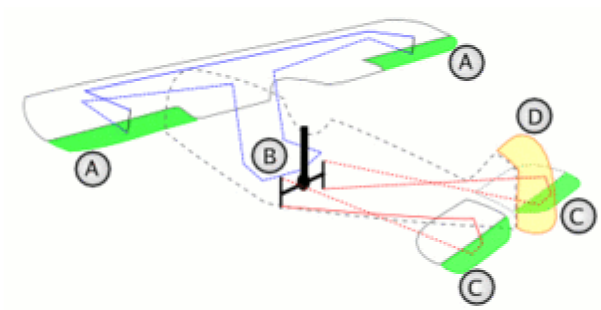
In production aircraft, blown-flap systems were found to be a maintenance nightmare. They were continually breaking down due to clogging with dirt, and were generally unreliable. This made blown flaps practically useless as a landing aid on many aircraft. They were removed from later production runs of some aircraft.

Starting in the 1970s the lessons of air combat over Vietnam changed thinking considerably. Instead of aircraft designed for outright speed, general maneuverability and load capacity became more important in most designs. The result is an evolution back to larger planforms to provide more lift. For instance the F-16 has a wing loading of 78.5 lb/ft^2 (383 kg/m^2), and uses leading edge extensions to provide considerably more lift at higher angles of attack, including approach and landing. Given the problems in service and the better lift from the larger wings, blown flaps have generally disappeared. More recently designed fighter aircraft achieve the same improved low-speed characteristics using the technically more complex swing-wing design.

In the 1970s new methods of constructing blown flaps were designed, with the original system becoming known as **internal blowing**. Two systems of **externally blown flaps** were developed, both using the direct exhaust of wing-mounted engines on otherwise simple flaps. Typical flap designs are split near the engine such that they don't deflect the thrust; however, with sufficiently powered engines, the effect of the flaps being in the path of the exhaust can be tremendous. The Airbus 380, because of its massive size, is one of the few major commercial airliners to use externally blown flaps, which continue behind its engines.

Chapter- 5

Flight Control Surfaces



Basic aircraft control surfaces and motion.

Aircraft **flight control surfaces** allow a pilot to adjust and control the aircraft's flight attitude.

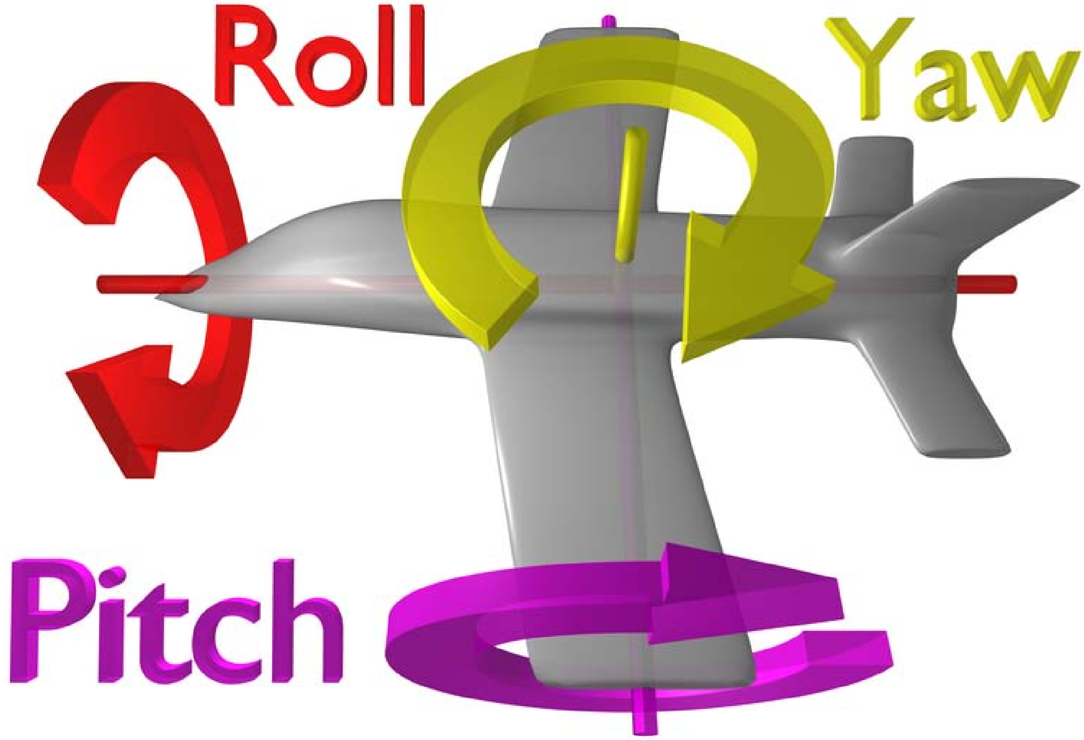
Development of an effective set of flight controls was a critical advance in the development of aircraft. Early efforts at fixed-wing aircraft design succeeded in generating sufficient lift to get the aircraft off the ground, but once aloft, the aircraft proved uncontrollable, often with disastrous results. The development of effective flight controls is what allowed stable flight.

Here we, describes the control surfaces used on a fixed wing aircraft of conventional design. Other fixed wing aircraft configurations may use different control surfaces but the basic principles remain. The controls (stick and rudder) for rotary wing aircraft (helicopter or autogyro) accomplish the same motions about the three axes of rotation, but manipulate the rotating flight controls (main rotor disk and tail rotor disk) in a completely different manner.

Development

The Wright brothers are credited with developing the first practical control surfaces. It is a main part of their patent on flying. Unlike modern control surfaces they used wing warping. In an attempt to circumvent the Wright patent, Glen Curtis made hinged control surfaces. Hinged control surfaces have the advantage of not causing stresses that are a problem of wing warping and are easier to build into structures.

Axes of motion



Rotation around the three axes

An aircraft is free to rotate around three axes which are perpendicular to each other and intersect at its center of gravity (CG). To control position and direction a pilot must be able to control rotation about each of them.

Lateral axis

The lateral axis passes through an aircraft from wingtip to wingtip. Rotation about this axis is called **pitch**. Pitch changes the vertical direction that the aircraft's nose is pointing. The elevators are the primary control surfaces for pitch.

Longitudinal axis

The longitudinal axis passes through the aircraft from nose to tail. Rotation about this axis is called **roll**. Rolling motion changes the orientation of the aircraft's wings with respect to the downward force of gravity. The pilot changes bank angle by increasing the lift on one wing and decreasing it on the other. This differential lift causes bank rotation around the longitudinal axis. The ailerons are the primary control of bank. The rudder also has a secondary effect on bank.

Vertical axis

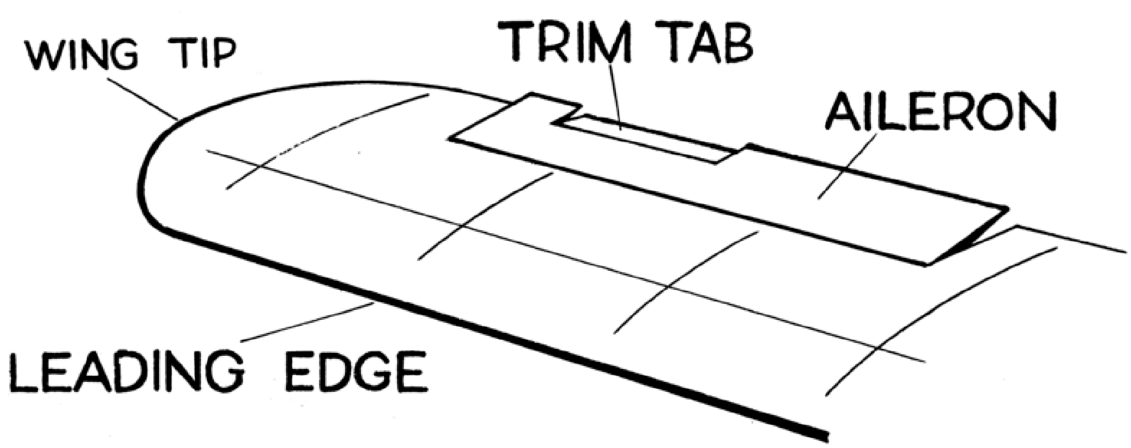
The vertical axis passes through an aircraft from top to bottom. Rotation about this axis is called **yaw**. Yaw changes the direction the aircraft's nose is pointing, left or right. The primary control of yaw is with the rudder. Ailerons also have a secondary effect on yaw.

It is important to note that these axes move with the aircraft, and change relative to the earth as the aircraft moves. For example, for an aircraft whose left wing is pointing straight down, its "vertical" axis is parallel with the ground, while its "lateral" axis is perpendicular to the ground.

Main control surfaces

The main control surfaces of a fixed-wing aircraft are attached to the airframe on hinges or tracks so they may move and thus deflect the air stream passing over them. This redirection of the air stream generates an unbalanced force to rotate the plane about the associated axis.

Ailerons



Aileron surface

Ailerons are mounted on the trailing edge of each wing near the wingtips, and move in opposite directions. When the pilot moves the stick left, or turns the wheel counter-clockwise, the left aileron goes up and the right aileron goes down. A raised aileron reduces lift on that wing and a lowered one increases lift, so moving the stick left causes the left wing to drop and the right wing to rise. This causes the aircraft to roll to the left and begin to turn to the left. Centering the stick returns the ailerons to neutral maintaining the bank angle. The aircraft will continue to turn until opposite aileron motion returns the bank angle to zero to fly straight.

Elevator

An elevator is mounted on the trailing edge of the horizontal stabilizer on each side of the fin in the tail. They move up and down together. When the pilot pulls the stick backward, the elevators go up. Pushing the stick forward causes the elevators to go down. Raised elevators push down on the tail and cause the nose to pitch up. This makes the wings fly at a higher angle of attack which generates more lift and more drag. Centering the stick returns the elevators to neutral and stops the change of pitch. Many aircraft use a stabilator — a moveable horizontal stabilizer — in place of an elevator. Some aircraft, such as an MD-80, use a servo tab within the elevator surface to aerodynamically move the main surface into position. The direction of travel of the control tab will thus be in a direction opposite to the main control surface. It is for this reason that an MD-80 tail looks like it has a 'split' elevator system.

Rudder

The rudder is typically mounted on the trailing edge of the fin, part of the empennage. When the pilot pushes the left pedal, the rudder deflects left. Pushing the right pedal causes the rudder to deflect right. Deflecting the rudder right pushes the tail left and causes the nose to yaw to the right. Centering the rudder pedals returns the rudder to neutral and stops the yaw.

Secondary effects of controls

Ailerons

The ailerons primarily control roll. Whenever lift is increased, induced drag is also increased. When the stick is moved left to roll the aircraft to the left, the right aileron is lowered which increases lift on the right wing and therefore increases induced drag on the right wing. Using ailerons causes adverse yaw, meaning the nose of the aircraft yaws in a direction opposite to the aileron application. When moving the stick to the left to bank the wings, adverse yaw moves the nose of the aircraft to the *right*. Adverse yaw is more pronounced for light aircraft with long wings, such as gliders. It is counteracted by the pilot with the rudder. Differential ailerons are ailerons which have been rigged such that the downgoing aileron deflects less than the upward-moving one, reducing adverse yaw.

Rudder

Using the rudder causes one wing to move forward faster than the other. Increased speed means increased lift, and hence rudder use causes a roll effect. Also, since rudders generally extend above the aircraft's center of gravity, a torque is imparted to the aircraft resulting in an adverse bank. Pushing the rudder to the right not only pulls the tail to the left and the nose to the right, but it also "spins" the aircraft as if a left turn were going to be made. Out of all the control inputs, rudder input creates the greatest amount of adverse effect. For this reason ailerons and rudder are generally used together on light aircraft: when turning to the left, the control column is moved left, and adequate left rudder is applied.

Turning the aircraft

Unlike a boat, turning an aircraft is not normally carried out with the rudder. With aircraft, the turn is caused by the horizontal component of lift. The lifting force, perpendicular to the wings of the aircraft, is tilted in the direction of the intended turn by rolling the aircraft into the turn. As the bank angle is increased the lifting force, which was previously acting only in the vertical, is split into two components: One acting vertically and one acting horizontally.

If the total lift is kept constant, the vertical component of lift will decrease. As the weight of the aircraft is unchanged, this would result in the aircraft descending if not countered. To maintain level flight requires increased positive (up) elevator to increase the angle of attack, increase the total lift generated and keep the vertical component of lift equal with the weight of the aircraft. This cannot continue indefinitely. The wings can only generate a finite amount of lift at a given air speed. As the load factor (commonly called G loading) is increased an accelerated aerodynamic stall will occur, even though the aircraft is above its 1G stall speed.

The total lift (load factor) required to maintain level flight is directly related to the bank angle. This means that for a given airspeed, level flight can only be maintained up to a certain given angle of bank. Beyond this angle of bank, the aircraft will suffer an accelerated stall if the pilot attempts to generate enough lift to maintain level flight.

Alternate main control surfaces

Some aircraft configurations have non-standard primary controls. For example instead of elevators at the back of the stabilizers, the entire tailplane may change angle. Some aircraft have a tail in the shape of a V, and the moving parts at the back of those combine the functions of elevators and rudder. Delta wing aircraft may have "elevons" at the back of the wing, which combine the functions of elevators and ailerons.

Secondary control surfaces

KLM Fokker 70, showing position of flap and liftdumpers **flight controls**. The liftdumpers are the lifted cream-coloured panels on the wing upper surface (in this picture there are five on the right wing). The flaps are the large drooped surfaces on the trailing edge of the wing.

Spoilers

On low drag aircraft like sailplanes, spoilers are used to disrupt airflow over the wing and greatly increase the amount of drag. This allows a glider pilot to lose altitude without gaining excessive airspeed. Spoilers are sometimes called "lift dumpers". Spoilers that can be used asymmetrically are called spoilerons and are able to affect an aircraft's roll.

Flaps

Flaps are mounted on the trailing edge of each wing on the inboard section of each wing (near the wing roots). They are deflected down to increase the effective curvature of the wing. Flaps raise the Maximum Lift Coefficient of the aircraft and therefore reduce its stalling speed. They are used during low speed, high angle of attack flight including take-off and descent for landing. Some aircraft are equipped with "flapperons", which are more commonly called "inboard ailerons". These devices function primarily as ailerons, but on some aircraft, will "droop" when the flaps are deployed, thus acting as both a flap and a roll-control inboard aileron.

Slats

Slats, also known as Leading Edge Devices, are extensions to the front of a wing for lift augmentation, and are intended to reduce the stalling speed by altering the airflow over the wing. Slats may be fixed or retractable - fixed slats (e.g. as on the Fieseler Fi 156 Storch) give excellent slow speed and STOL capabilities, but compromise higher speed performance. Retractable slats, as seen on most airliners, provide reduced stalling speed for take-off and landing, but are retracted for cruising.

Air brakes

Air brakes, also called spoilers, are used to increase drag. On a typical airliner, for example, the spoilers are a series of panels on the upper surface of the wing which deploy upwards to disrupt airflow over the wing, thus adding drag. The number of panels that deploy, as well as the degree to which they deploy, depends on the regime of flight in which they are used. For example, if a pilot must descend quickly without increasing speed, he may select a speed brake setting for the desired effect. In such a case, only certain spoiler panels will deploy to create the most efficient reduction in speed without overstressing the wing. On most airliners, spoiler panels on the wings mix with aileron inputs to enhance roll control. For example, a left bank will engage the ailerons as well as deploy certain spoiler panels on the down-going wing. Ground spoilers are essentially similar to flight spoilers, except that they deploy upon touchdown on the runway, and include all spoiler panels for maximum "lift dump". After touchdown, the ground spoilers deploy, and "dump" the lift generated by the wings, thus placing the aircraft's weight on the wheels, which accomplish the vast majority of braking after touchdown. Most jet airliners also have a thrust reverser, which simply deflects exhaust from the engines forward, helping to slow the aircraft down.

Other control surfaces

Trim controls

Trimming controls allow a pilot to balance the lift and drag being produced by the wings and control surfaces over a wide range of load and airspeed. This reduces the effort required to adjust or maintain a desired flight attitude.

Elevator trim

Elevator trim balances the control force necessary to maintain the aerodynamic down force on the tail. Whilst carrying out certain flight exercises, a lot of trim could be required to maintain the desired angle of attack. This mainly applies to slow flight, where maintaining a nose-up attitude requires a lot of trim. Elevator trim is correlated with the speed of the airflow over the tail, thus airspeed changes to the aircraft require re-trimming. An important design parameter for aircraft is the stability of the aircraft when trimmed for level flight. Any disturbances such as gusts or turbulence will be damped over a short period of time and the aircraft will return to its level flight trimmed airspeed.

Trimming tail plane

Except for very light aircraft, trim tabs on elevators are unable to provide the force and range of motion desired. To provide the appropriate trim force the entire horizontal tail plane is made adjustable in pitch. This allows the pilot to select exactly the right amount of positive or negative lift from the tail plane while reducing drag from the elevators.

Control horn

A control horn is a section of control surface which projects ahead of the pivot point. It generates a force which tends to increase the surface's deflection thus reducing the control pressure experienced by the pilot. Control horns may also incorporate a counterweight which helps to balance the control and prevent it from "fluttering" in the airstream. Some designs feature separate anti-flutter weights.

Spring trim

In the simplest cases trimming is done by a mechanical spring (or bungee) which adds appropriate force to augment the pilot's control input. The spring is usually connected to an elevator trim lever to allow the pilot to set the spring force applied.

Rudder and aileron trim

Trim often does not only apply to the elevator, as there is also trim for the rudder and ailerons in larger aircraft. The use of this is to counter the effects of slip stream, or to counter the effects of the centre of gravity being to one side. This can be caused by a larger weight on one side of the aircraft compared to the other, such as when one fuel tank has a lot more fuel in it than the other.

Chapter- 6

Fly-by-Wire

Green colored flight control wiring of a test aircraft

A **fly-by-wire** (FBW) system replaces manual flight control of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term), and 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.

Development

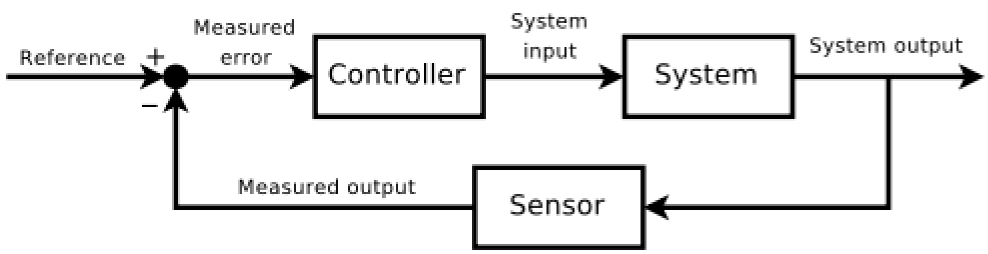
Mechanical and hydro-mechanical flight control systems are relatively heavy and require careful routing of flight control cables through the aircraft by systems of pulleys, cranks, tension cables and hydraulic pipes. Both systems often require redundant backup to deal with failures, which again increases weight. Furthermore, both have limited ability to compensate for changing aerodynamic conditions. Dangerous characteristics such as stalling, spinning and pilot-induced oscillation (PIO), which depend mainly on the stability and structure of the aircraft concerned rather than the control system itself, can still occur with these systems.

The term "fly-by-wire" implies a purely electrically-signaled control system. However, it is used in the general sense of computer-configured controls, where a computer system is interposed between the operator and the final control actuators or surfaces. This modifies the manual inputs of the pilot in accordance with control parameters.

Side-sticks, center sticks, or conventional flight control yokes can be used to fly FBW aircraft. While the side-stick offers the advantages of being lighter, mechanically simpler, and unobtrusive, The Boeing Company's aerospace engineers decided that the lack of visual feedback (none given by side-sticks) is a significant problem, and so they designed conventional control yokes in the Boeing 777 and the brand-new Boeing 787, which is undergoing flight tests as of June 2010. This same approach has been used for the Embraer 170/190 jets. Most Airbus airliners are operated with side-sticks.

Basic operation

Command



Simple feedback loop

Fly-by wire systems are by their nature quite complex however their operation can be explained in relatively simple terms. When a pilot moves the control column (or sidestick) a signal is sent to a computer, this is analogous to moving a game controller, the signal is sent through multiple wires (channels) to ensure that the signal reaches the computer. When there are three channels being used this is known as 'Triplex'. The computer receives the signals, performs a calculation (adds the signal voltages and divides by the number of signals received to find the mean average voltage) and adds another channel. These four 'Quadruplex' signals are then sent to the control surface actuator and the surface begins to move. Potentiometers in the actuator send a signal back to the computer (usually a negative voltage) reporting the position of the actuator. When the actuator reaches the desired position the two signals (incoming and outgoing) cancel each other out and the actuator stops moving (completing a feedback loop).

Automatic Stability Systems

Fly-by-wire control systems allow aircraft computers to perform tasks without pilot input. Automatic stability systems operate in this way. Gyroscopes fitted with sensors are mounted in an aircraft to sense movement changes in the pitch, roll and yaw axes. Any movement (from straight and level flight for example) results in signals to the computer, which automatically moves control actuators to stabilize the aircraft.

Safety and redundancy

Aircraft systems may be quadruplexed (four independent channels) to prevent loss of signals in the case of failure of one or even two channels. High performance aircraft that have FBW controls (also called CCVs or Control-Configured Vehicles) may be deliberately designed to have low or even negative aerodynamic stability in some flight regimes, the rapid-reacting CCV controls compensating for the lack of natural stability.

Pre-flight safety checks of a fly-by-wire system are often performed using Built-In Test Equipment (BITE). On programming the system, either by the pilot or groundcrew, a number of control movement steps are automatically performed. Any failure will be indicated to the crews.

Some aircraft, the Panavia Tornado for example, retain a very basic hydro-mechanical backup system for limited flight control capability on losing electrical power, in the case of the Tornado this allows rudimentary control of the stabilators only for pitch and roll axis movements.

Weight Saving

A FBW aircraft can be lighter than a similar design with conventional controls. Partly due to the lower overall weight of the system components; and partly because the natural aerodynamic stability of the aircraft can be relaxed, slightly for a transport aircraft and more for a maneuverable fighter, which means that the stability surfaces that are part of the aircraft structure can therefore be made smaller. These include the vertical and horizontal stabilizers (fin and tailplane) that are (normally) at the rear of the fuselage. If these structures can be reduced in size, airframe weight is reduced. The advantages of FBW controls were first exploited by the military and then in the commercial airline market. The Airbus series of airliners used full-authority FBW controls beginning with their A320 series, A320 flight control (though some limited FBW functions existed on A310). Boeing followed with their 777 and later designs.

Electronic fly-by-wire systems can respond flexibly to changing aerodynamic conditions, by tailoring flight control surface movements so that aircraft response to control inputs is appropriate to flight conditions. Electronic systems require less maintenance, whereas mechanical and hydraulic systems require lubrication, tension adjustments, leak checks, fluid changes, etc. Furthermore, putting circuitry between pilot and aircraft can enhance safety; for example the control system can try to prevent a stall, or it can stop the pilot from over stressing the airframe.

The main concern with fly-by-wire systems is reliability. While traditional mechanical or hydraulic control systems usually fail gradually, the loss of all flight control computers could immediately render the aircraft uncontrollable. For this reason, most fly-by-wire systems incorporate either redundant computers (triplex, quadruplex etc.), some kind of mechanical or hydraulic backup or a combination of both. A "mixed" control system such as the latter is not desirable and modern FBW aircraft normally avoid it by having more independent FBW channels, thereby reducing the possibility of overall failure to minuscule levels that are acceptable to the independent regulatory and safety authority responsible for aircraft design, testing and certification before operational service.

History

F-8C Crusader digital fly-by-wire testbed

Electronic signalling of the control surfaces was tested in the 1950s. This replaced long runs of mechanical and hydraulic connections with electrical ones.

The first non-experimental aircraft that was designed and flown (in 1958) with a fly-by-wire flight control system was the Avro Canada CF-105 Arrow. a feat not repeated with a production aircraft until Concorde in 1969. This system also included solid-state components and system redundancy, was designed to be integrated with a computerised navigation and automatic search and track radar, was flyable from ground control with data uplink and downlink, and provided artificial feel (feedback) to the pilot.

The first digital fly-by-wire aircraft to take to the air (in 1972) was an F-8 Crusader, which had been modified electronically by the National Aeronautics and Space Administration of the United States as a test aircraft, a feat mirrored in the USSR by the Sukhoi T-4. At about the same time in the United Kingdom a trainer variant of the British Hawker Hunter fighter was modified at the British Royal Aircraft Establishment with fly-by-wire flight controls for the right-seat pilot. This was test-flown, with the left-seat pilot having conventional flight controls for safety reasons, and with the capability for him to override and turn off the fly-by-wire system.

Analog systems

All "fly-by-wire" flight control systems eliminate the complexity, the fragility, and the weight of the mechanical circuit of the hydromechanical or electromechanical flight control systems. Fly-by-wire replace those with electronic circuits. The control mechanisms in the cockpit now operate signal transducers, which in turn generate the appropriate electronic commands. These are next processed by an electronic controller, either an analog one, or more modernly, a digital one. Aircraft and spacecraft autopilots are now part of the electronic controller.

The hydraulic circuits are similar except that mechanical servo valves are replaced with electrically-controlled servo valves, operated by the electronic controller. This is the simplest and earliest configuration of an analog fly-by-wire flight control system. In this configuration, the flight control systems must simulate "feel". The electronic controller controls electrical feel devices that provide the appropriate "feel" forces on the manual controls. This was used in Concorde, the first production fly-by-wire airliner.

In more sophisticated versions, analog computers replaced the electronic controller. The canceled 1950s Canadian supersonic intercepter, the Avro Canada CF-105 Arrow, employed this type of system. Analog computers also allowed some customization of flight control characteristics, including relaxed stability. This was exploited by the early versions of F-16, giving it impressive maneuverability.

Digital systems

The Airbus A320, first airliner with digital fly-by-wire controls

A digital fly-by-wire flight control system is similar to its analog counterpart. However, the signal processing is done by digital computers and the pilot literally can "fly-via-computer". This also increases the flexibility of the flight control system, since the digital computers can receive input from any aircraft sensor (such as the altimeters and the pitot tubes. This also increases the electronic stability, because the system is less dependent on the values of critical electrical components in an analog controller.

The computers sense position and force inputs from pilot controls and aircraft sensors. They solve differential equations to determine the appropriate command signals that move the flight controls to execute the intentions of the pilot.

The programming of the digital computers enable flight envelope protection. In this aircraft designers precisely tailor an aircraft's handling characteristics, to stay within the overall limits of what is possible given the aerodynamics and structure of the aircraft. For example, the computer in flight envelope protection mode can try to prevent the aircraft from being handled dangerously by preventing pilots from exceeding preset limits on the aircraft's flight-control envelope, such as those that prevent stalls and spins, and which limit airspeeds and g forces on the airplane. Software can also be included that stabilize the flight-control inputs to avoid pilot-induced oscillations.

Since the flight-control computers continuously "fly" the aircraft, pilot's workloads can be reduced. Also, in military and naval applications, it is now possible to fly military aircraft that have relaxed stability. The primary benefit for such aircraft is more maneuverability during combat and training flights, and the so-called "carefree handling" because stalling, spinning. and other undesirable performances are prevented automatically by the computers.

Digital flight control systems enable inherently unstable combat aircraft, such as the F-117 Nighthawk and the B-2 Spirit flying wing to fly in usable and safe manners.

Applications

A Dassault Falcon 7X, the first business jet with digital fly-by-wire controls

- The Space Shuttle Orbiter has an all-digital fly-by-wire control system. This system was first exercised (as the only flight control system) during the glider unpowered-flight "Approach and Landing Tests" that began on the Space Shuttle *Enterprise* during 1977.
- During 1984, the Airbus Industries Airbus A320 became the first airliner to fly with an all-digital fly-by-wire control system.
- During 2005, the Dassault Falcon 7X became the first business jet with fly-by-wire controls.

Legislation

The Federal Aviation Administration (FAA) of the United States has adopted the RTCA/DO-178B, titled "Software Considerations in Airborne Systems and Equipment Certification", as the certification standard for aviation software. Any safety-critical component in a digital fly-by-wire system including applications of the laws of aeronautics and computer operating systems will need to be certified to DO-178B Level A, which is applicable for preventing potential catastrophic failures.

Nevertheless, the top concern for computerized, digital, fly-by-wire systems is reliability, even more so than for analog electronic control systems. This is because the digital computers that are running software are often the only control path between the pilot and aircraft's flight control surfaces. If the computer software crashes for any reason, the pilot may be unable to control an aircraft. Hence virtually all fly-by-wire flight control systems are either triply or quadruply redundant in their computers and electronics. These have three or four flight-control computers operating in parallel, and three or four separate data buses connecting them with each control surface.

Redundancy

If one of the flight-control computers crashes, or is damaged in combat, or suffers from "insanity" caused by electromagnetic pulses, the others overrule the faulty one (or even two of them), they continue flying the aircraft safely, and they can either turn off or re-boot the faulty computers. Any flight-control computer whose results disagree with the others is ruled to be faulty, and it is either ignored or re-booted. (In other words, it is voted-out of control by the others.)

In addition, most of the early digital fly-by-wire aircraft also had an analog electrical, a mechanical, or a hydraulic back-up flight control system. The Space Shuttle has, in addition to its redundant set of four digital computers running its primary flight-control software, a fifth back-up computer running a separately developed, reduced-function, software flight-control system - one that can be commanded to take over in the event that a fault ever affects all of the computers in the other four. This back-up system serves to reduce the risk of total flight-control-system failure ever happening because of a general-purpose flight software fault has escaped notice in the other four computers.

For airliners, flight-control redundancy improves their safety, but fly-by-wire control systems also improve economy in flight because they are lighter, and they eliminate the need for many mechanical, and heavy, flight-control mechanisms. Furthermore, most modern airliners have computerized systems that control their jet engine throttles, air inlets, fuel storage and distribution system, in such a way to minimize their consumption of jet fuel. Thus, digital control systems do their best to reduce the cost of flights.

Airbus/Boeing

Airbus and Boeing commercial airplanes differ in their approaches in using fly-by-wire systems. In Airbus airliners, the flight-envelope control system always retains ultimate flight control, and it will not permit the pilots to fly outside these performance limits. However, in the event of multiple failures of redundant computers, the A320 does have mechanical back-up system for its pitch trim and its rudder. The A340-600 has a purely electrical (not electronic) back-up rudder control system, and beginning with the new A380 airliner, all flight-control systems have back-up systems that are purely electrical through the use of a so-called "three-axis Backup Control Module" (BCM)

With the Boeing 777 model airliners, the two pilots can completely override the computerized flight-control system to permit the aircraft to be flown beyond its usual flight-control envelope during emergencies. Airbus's strategy, which begun with the Airbus A320, has been continued on subsequent Airbus airliners.

Engine digital control

The advent of FADEC (Full Authority Digital Engine Control) engines permits operation of the flight control systems and autothrottles for the engines to be fully integrated. On modern military aircraft other systems such as autostabilization, navigation, radar and weapons system are all integrated with the flight control systems. FADEC allows maximum performance to be extracted from the aircraft without fear of engine misoperation, aircraft damage or high pilot workloads.

In the civil field, the integration increases flight safety and economy. The Airbus A320 and its fly-by-wire brethren are protected from dangerous situations such as low-speed stall or overstressing by flight envelope protection. As a result, in such conditions, the flight control systems commands the engines to increase thrust without pilot intervention. In economy cruise modes, the flight control systems adjust the throttles and fuel tank selections more precisely than all but the most skillful pilots. FADEC reduces rudder drag needed to compensate for sideways flight from unbalanced engine thrust. On the A330/A340 family, fuel is transferred between the main (wing and center fuselage) tanks and a fuel tank in the horizontal stabilizer, to optimize the aircraft's center of gravity during cruise flight. The fuel management controls keep the aircraft's center of gravity accurately trimmed with fuel weight, rather than drag-inducing aerodynamic trims in the elevators.

Further developments

Fly-by-optics

Fly-by-optics is sometimes used instead of fly-by-wire because it can transfer data at higher speeds, and it is immune to electromagnetic interference. In most cases, the cables are just changed from electrical to optical fiber cables. Sometimes it is referred to as "fly-by-light" due to its use of fiber optics. The data generated by the software and interpreted by the controller remain the same.

Power-by-wire

Having eliminated the mechanical transmission circuits in fly-by-wire flight control systems, the next step is to eliminate the bulky and heavy hydraulic circuits. The hydraulic circuit is replaced by an electrical power circuit. The power circuits power electrical or self-contained electrohydraulic actuators that are controlled by the digital flight control computers. All benefits of digital fly-by-wire are retained.

The biggest benefits are weight savings, the possibility of redundant power circuits and tighter integration between the aircraft flight control systems and its avionics systems.

The absence of hydraulics greatly reduces maintenance costs. This system is used in the Lockheed Martin F-35 Lightning II and in Airbus A380 backup flight controls. The Boeing 787 will also incorporate some electrically operated flight controls (spoilers and horizontal stabilizer), which will remain operational with either a total hydraulics failure and/or flight control computer failure.

Fly-by-wireless

Wiring adds a considerable amount of weight to an aircraft; therefore, researchers are exploring implementing fly-by-wireless solutions. Fly-by-wireless systems are very similar to fly-by-wire systems, however, instead of using a wired protocol for the physical layer a wireless protocol is employed.

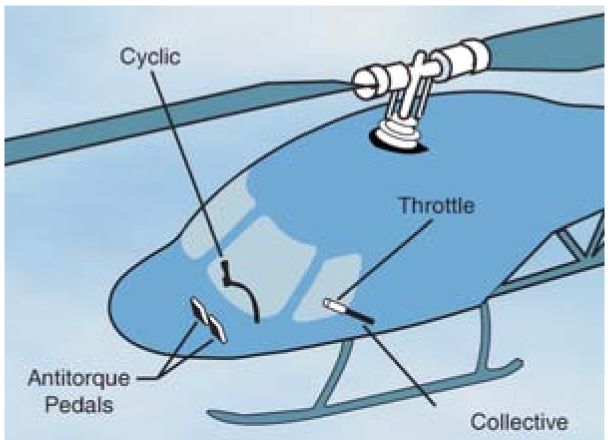
In addition to reducing weight, implementing a wireless solution has the potential to reduce costs throughout an aircraft's life cycle. For example, many key failure points associated with wire and connectors will be eliminated thus hours spent troubleshooting wires and connectors will be reduced. Furthermore, engineering costs could potentially decrease because less time would be spent on designing wiring installations, late changes in an aircraft's design would be easier to manage, etc.

Intelligent Flight Control System

A newer flight control system, called Intelligent Flight Control System (IFCS), is an extension of modern digital fly-by-wire flight control systems. The aim is to intelligently compensate for aircraft damage and failure during flight, such as automatically using engine thrust and other avionics to compensate for severe failures such as loss of hydraulics, loss of rudder, loss of ailerons, loss of an engine, etc. Several demonstrations were made on a flight simulator where a Cessna-trained small-aircraft pilot successfully landed a heavily-damaged full-size concept jet, without prior experience with large-body jet aircraft. This development is being spearheaded by NASA Dryden Flight Research Center. It is reported that enhancements are mostly software upgrades to existing fully computerized digital fly-by-wire flight control systems.

Chapter- 7

Helicopter Flight Controls



Location of flight controls in a helicopter

A helicopter pilot manipulates the **helicopter flight controls** in order to achieve controlled aerodynamic flight. The changes made to the flight controls are transmitted mechanically to the rotor, producing aerodynamic effects on the helicopter's rotor blades which allow the helicopter to be controlled. For tilting forward and back (pitch), or tilting sideways (roll), the angle of attack of the main rotor blades is altered *cyclically* during rotation, creating differing amounts of lift at different points in the cycle. For increasing or decreasing overall lift, the angle of attack for all blades is *collectively* altered by equal amounts at the same time resulting in ascents, descents, acceleration and deceleration.

A typical helicopter has three separate flight control inputs. These are the cyclic stick, the collective lever, and the anti-torque pedals. Depending on the complexity of the helicopter, the cyclic and collective may be linked together by a *mixing unit*, a mechanical or hydraulic device that combines the inputs from both and then sends along the "mixed" input to the control surfaces to achieve the desired result. The manual throttle may also be considered a flight control because it is needed to maintain rotor speed on smaller helicopters without governors.

Controls

Cyclic

The cyclic control is usually located between the pilot's legs and is commonly called the *cyclic stick* or just *cyclic*. On most helicopters, the cyclic is similar in appearance to a joystick in a conventional aircraft. By contrast, the Robinson R22 and Robinson R44 have a unique teetering bar cyclic control system and a few early helicopters have had a cyclic control that descended into the cockpit from overhead, one example being the HC-2 "Heli Baby", HC-102. The control is called the cyclic because it changes the pitch of the rotor blades cyclically. That is, the pitch or *feathering angle* of the rotor blades changes depending upon their position as they rotate around the hub so that all blades will change their angle the same amount at the same point in the cycle. The change in cyclic pitch has the effect of changing the angle of attack and thus the lift generated by a single blade as it moves around the rotor *disk*. This in turn causes the blades to fly up or down in sequence, depending on the changes in lift affecting each individual blade.

The result is to tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction. If the pilot pushes the cyclic forward, the rotor disk tilts forward, and the rotor produces a thrust vector in the forward direction. If the pilot pushes the cyclic to the right, the rotor disk tilts to the right and produces thrust in that direction, causing the helicopter to move sideways in a hover or to roll into a right turn during forward flight, much as in a conventional aircraft.

On any rotor system there is a delay between the point in rotation where a change in pitch is introduced by the flight controls and the point where the desired change is manifest in the rotor blade's flight. While often discussed as gyroscopic precession for ease of teaching, this phase lag varies with the geometry of the rotor system and is the angular difference between the point of application of a cyclic pitch change and the point where the effect of that pitch change reaches maximum amplitude. This lag is an example of a dynamic system in resonance but is never more than ninety degrees.

Collective

The collective pitch control, or *collective lever*, is normally located on the left side of the pilot's seat with an adjustable friction control to prevent inadvertent movement. The collective changes the pitch angle of all the main rotor blades collectively (*i.e.,* all at the same time) and independent of their position. Therefore, if a collective input is made, all the blades change equally, and the result is the helicopter increases or decreases its total lift derived from the rotor. In level flight this would cause a climb or descent, while with the helicopter pitched forward an increase in total lift would produce an acceleration together with a given amount of ascent.

Anti-torque pedals

The anti-torque pedals are located in the same position as the rudder pedals in an airplane, and serve a similar purpose, namely to control the direction in which the nose of the aircraft is pointed. Application of the pedal in a given direction changes the pitch of the tail rotor blades, increasing or reducing the thrust produced by the tail rotor and causing the nose to yaw in the direction of the applied pedal. The pedals mechanically change the pitch of the tail rotor altering the amount of thrust produced.

Throttle

Helicopter rotors are designed to operate at a specific rotational speed. The *throttle* controls the power produced by the engine, which is connected to the rotor by a transmission. The purpose of the throttle is to maintain enough engine power to keep the rotor speed within allowable limits in order to keep the rotor producing enough lift for flight. In single-engine helicopters, the throttle control is a motorcycle-style twist grip mounted on the collective control, while dual-engine helicopters have power levers.

In many piston engine-powered helicopters, the pilot manipulates the throttle to maintain rotor speed. Turbine engine helicopters, and some piston helicopters, use governors or other electro-mechanical control systems to maintain rotor speed and relieve the pilot of routine responsibility for that task. (There is normally also a manual reversion available in the event of a governor failure.)

Helicopter controls and effects

Name	Directly controls	Primary effect	Secondary effect	Used in forward flight	Used in hover flight
Cyclic (lateral)	Varies main rotor blade pitch with left and right movement	Tilts main rotor disk left and right through the swashplate	Induces roll in direction moved	To turn the aircraft	To move sideways
Cyclic (longitudinal)	Varies main rotor blade pitch with fore and aft movement	Tilts main rotor disk forward and back via the swashplate	Induces pitch nose down or up	Control attitude	To move forwards/backwards
Collective	Collective angle of	Increase/decrease pitch angle of all	Increase/decrease torque. Note: in some	To adjust power	To adjust skid

	attack for the rotor main blades via the swashplate	main rotor blades equally, causing the aircraft to ascend/descend	helicopters the throttle control(s) is a part of the collective stick. Rotor speed is kept basically constant throughout the flight.	through rotor blade pitch setting	height/vertical speed
Anti-torque pedals	Collective pitch supplied to tail rotor blades	Yaw rate	Increase/decrease torque and engine speed (less than collective)	Adjust sideslip angle	Control yaw rate/heading

Flight conditions

There are two basic flight conditions for a helicopter; hover and forward flight.

Hover

Hovering is the most challenging part of flying a helicopter. This is because a helicopter generates its own gusty air while in a hover, which acts against the fuselage and flight control surfaces. The end result is constant control inputs and corrections by the pilot to keep the helicopter where it is required to be. Despite the complexity of the task, the control inputs in a hover are simple. The cyclic is used to eliminate drift in the horizontal plane, that is to control forward and back, right and left. The collective is used to maintain altitude. The pedals are used to control nose direction or heading. It is the interaction of these controls that makes hovering difficult, since an adjustment in any one control requires an adjustment of the other two, creating a cycle of constant correction.

Forward flight

In forward flight a helicopter's flight controls behave more like those in a fixed-wing aircraft. Displacing the cyclic forward will cause the nose to pitch down, with a resultant increase in airspeed and loss of altitude. Aft cyclic will cause the nose to pitch up, slowing the helicopter and causing it to climb. Increasing collective (power) while maintaining a constant airspeed will induce a climb while decreasing collective will cause a descent. Coordinating these two inputs, down collective plus aft cyclic or up collective plus forward cyclic, will result in airspeed changes while maintaining a constant altitude. The pedals serve the same function in both a helicopter and an airplane, to maintain balanced flight. This is done by applying a pedal input in whichever direction is necessary to center the ball in the turn and bank indicator.

Differential pitch control

For helicopters with contra-rotating rotors, helicopter control requires interaction between the two rotors. A helicopter with tandem rotors uses differential collective pitch to change the attitude of the nose of the aircraft. To pitch nose down and accelerate forward, the collective pitch on the front rotor is decreased and the collective pitch on the rear rotor is increased proportionally. Conversely, the synchropter and transverse-mounted rotor helicopters use differential collective pitch to affect the roll of the aircraft. All of these configurations use differential cyclic pitch to control movement about the yaw axis, tilting the rotors in opposite directions to cause the aircraft to spin in the direction of the tilted rotors.

Chapter- 8

Rudder

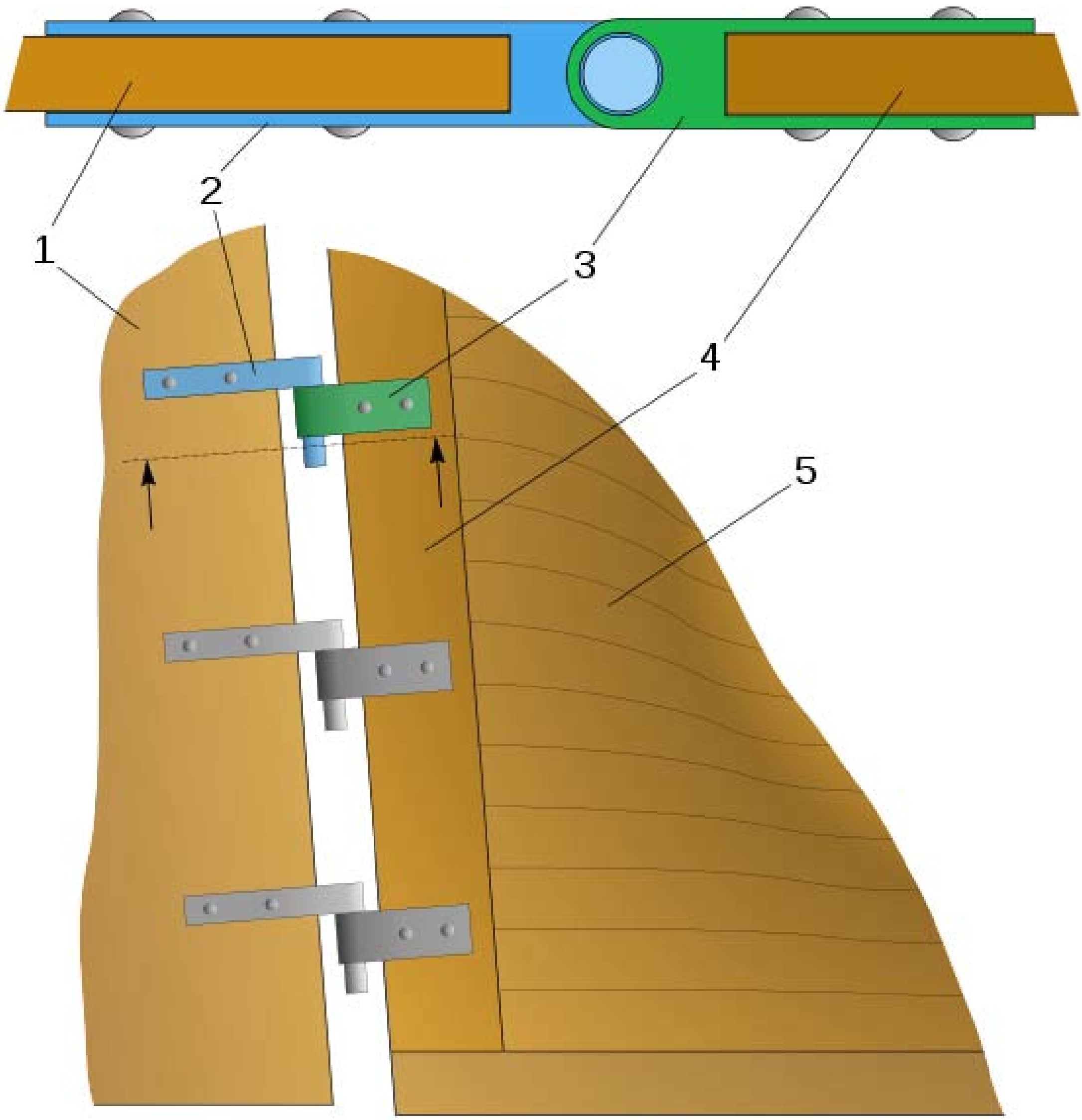
Modern ship rudder

Aircraft rudder

A **rudder** is a device used to steer a ship, boat, submarine, hovercraft, **aircraft**, or other conveyance that moves through a medium (generally air or water). On an aircraft the rudder is used primarily to counter adverse yaw and p-factor and is not the primary control used to turn the airplane. A rudder operates by redirecting the fluid past the hull or fuselage, thus imparting a turning or yawing motion to the craft. In basic form, a rudder is a flat plane or sheet of material attached with hinges to the craft's stern, tail or after end. Often rudders are shaped so as to minimize hydrodynamic or aerodynamic drag. On simple watercraft, a tiller -- essentially, a stick or pole acting as a lever arm—may be attached to the top of the rudder to allow it to be turned by a helmsman. In larger vessels, cables, pushrods, or hydraulics may be used to link rudders to steering wheels. In typical aircraft, the rudder is operated by pedals via mechanical linkages or hydraulics.

History of the rudder

Terminology



Scheme of a sternpost-mounted medieval rudder. The iron hinge system was the first stern rudder permanently attached to the ship hull. It made a vital contribution to the navigation achievements of the age of discovery and thereafter.

Generally, a rudder is "part of the steering apparatus of a boat or ship that is fastened outside the hull", that is denoting all different types of oars, paddles and rudders. More specifically, the steering gear of ancient vessels can be classified into side-rudders and stern-mounted rudders, depending on their location on the ship. A third term, steering oar, can denote both types. In a Mediterranean context, side-rudders are more specifically called quarter-rudders as the later term designates more exactly the place where the rudder was mounted. Stern-mounted rudders are uniformly suspended at the back of the ship in a central position, but the term has historically been found wanting because it does not take into account that the stern rudders were attached to the ship hull in quite a different way: While the European pintle-and-gudgeon rudder was attached to the sternpost by pivoting iron fastenings, the Arabs used instead a system of lashings. Chinese stern rudders also featured tackles, but, unlike their medieval and Arab counterparts, had no sternpost to which to attach them. Roman and particularly ancient Egyptian stern rudders featured again a different method of fastening where the stock, having a single point of contact with the stern, was additionally secured to the ship body by an upright rudderpost or braced ropes.

Although Lawrence Mott in his comprehensive treatment of the history of the rudder, Timothy Runyan, the Propyläen History of Technology, the Encyclopedia Britannica, and The Concise Oxford Dictionary of English Etymology classify a steering oar as a rudder, Joseph Needham, Lefèbre des Noëttes, K.S. Tom, Chung Chee Kit, S.A.M. Adshead, John K. Fairbank, Merle Goldman, Frank Ross, and Leo Block state that the steering oar used in ancient Egypt and Rome (and even ancient China) was not a true rudder; the steering oar has the capacity to interfere with handling of the sails (limiting any potential for long ocean-going voyages) while it was fit more for small vessels on narrow, rapid-water transport; the rudder did not disturb the handling of the sails, took less energy to operate by its helmsman, was better fit for larger vessels on ocean-going travel, and first appeared in ancient China during the 1st century AD. In regards to the ancient Phoenician (1550–300 BC) use of the steering oar without a rudder in the Mediterranean, Leo Block (2003) writes:

A single sail tends to turn a vessel in an upwind or downwind direction, and rudder action is required to steer a straight course. A steering oar was used at this time because the rudder had not yet been invented. With a single sail, a frequent movement of the steering oar was required to steer a straight course; this slowed down the vessel because a steering oar (or rudder) course correction acts like a brake. The second sail, located forward, could be trimmed to offset the turning tendency of the main sail and minimize the need for course corrections by the steering oar, which would have substantially improved sail performance.

Ancient Egypt

Rowing oars set aside for steering appeared on large Egyptian vessels long before the time of Menes (3100 BC). In the Old Kingdom (2686 BC-2134 BC) as much as five steering oars are found on each side of passenger boats. The tiller, at first a small pin run through the stock of the steering oar, can be traced to the fifth dynasty (2504–2347 BC). Both the tiller and the introduction of an upright steering post abaft reduced the usual number of necessary steering oars to one each side. Apart from side-rudders, single rudders put on the stern can be found in a number of tomb models of the time, particularly during the Middle Kingdom when tomb reliefs suggests them commonly employed in Nile navigation. The first literary reference appears in the works of the Greek historian Herodot (484-424 BC), who had spent several months in Egypt: "They make one rudder, and this is thrust through the keel", probably meaning the crotch at the end of the keel.

In Iran, oars mounted on the side of ships for steering are documented from the 3rd millennium BCE in artwork, wooden models, and even remnants of actual boats.

China

In China, miniature models of ships that feature steering oars have been dated to the Zhou Dynasty (c. 1050 BC – 256 BC). Stern mounted rudders started to appear on Chinese ship models starting in the 1st century AD. However, the Chinese continued to use the steering oar long after they invented the rudder, since the steering oar still had limited practical use for inland rapid-river travel. One of oldest known depiction of a stern-mounted rudder in China can be seen on a 2 ft. long tomb pottery model of a junk dating from the 1st century AD, during the Han Dynasty (202 BC-220 AD). It was discovered in Guangzhou in an archaeological excavation carried out by the Guangdong Provincial Museum and Academia Sinica of Taiwan in 1958. Within decades, several other Han Dynasty ship models featuring rudders were found in archaeological excavations. The first solid written reference to the use of a rudder without a steering oar dates to the 5th century.

Chinese rudders were not supported by pintle-and-gudgeon as in the Western tradition; rather, they were attached to the hull by means of wooden jaws or sockets, while typically larger ones were suspended from above by a rope tackle system so that they could be raised or lowered into the water. Also, many junks incorporated "fenestrated rudders" (rudders with holes in them, supposedly allowing for better control). Detailed descriptions of Chinese junks during the Middle Ages are known from various travellers to China, such as Ibn Battuta of Tangier, Morocco and Marco Polo of Venice, Italy. The later Chinese encyclopedist Song Yingxing (1587–1666) and the 17th century European traveler Louis Lecomte would write of the junk design and its use of the rudder with enthusiasm and admiration.

Paul Johnstone and Sean McGrail state that the Chinese invented the "median, vertical and axial" stern-mounted rudder, and that such a kind of rudder preceded the pintle-and-gudgeon rudder found in the West by roughly a millennium. However, Mott points out that the Chinese rudder worked by a very different suspension system, and that it was not permanently attached to a sternpost, leaving little point in comparing two such different types of rudder. The method of mounting steering gear from the stern was well known in Mediterranean navigation by the time the practice appeared in Chinese ships.

Ancient Rome

Roman navigation used sexillie quarter rudders which went in the Mediterranean through a long period of constant refinement and improvement, so that by Roman times ancient vessels reached extraordinary sizes. The strength of quarter rudder lay in its combination of effectiveness, adaptability and simpleness. Roman quarter rudder mounting systems survived mostly intact through the medieval period.

By the first half of the 1st century AD, rudders mounted on the stern were also quite common in Roman river and harbour craft as proved from reliefs and archaeological finds (Zwammderdam, Woerden 7). A tomb plaque of Hadrianic age shows a harbour tug boat in Ostia with a long stern-mounted oar for better leverage. Interestingly, the boat already featured a spritsail, adding to the mobility of the harbour vessel. Further attested Roman uses of stern-mounted rudders includes barges under tow, transport ships for wine casks, and diverse other ship types. Also, the well-known Zwammerdam find, a large river barge at the mouth of the Rhine, featured a large rudder mounted on the stern. According to new research, the advanced Nemi ships, the palace barges of emperor Caligula (37-41 AD), may have featured 14 m long stern-mounted rudders.

Medieval Near East

Arab ships also used a sternpost-mounted rudder, but which differed technically from both its European and Chinese counterparts, indicating an independent invention. On their ships "the rudder is controlled by two lines, each attached to a crosspiece mounted on the rudder head perpendicular to the plane of the rudder blade." The earliest evidence comes from the *Ahsan al-Taqasim fi Marifat al-Aqalim* ('The Best Divisions for the Classification of Regions') written by al-Muqaddasi in 985:

> *The captain from the crow's nest carefully observes the sea. When a rock is espied, he shouts: "Starboard!" or 'Port!" Two youths, posted there, repeat the cry. The helmsman, with two ropes in his hand, when he hears the calls tugs one or the other to the right or left. If great care is not taken, the ship strikes the rocks and is wrecked.*

Arabs used instead a system of lashings. Chinese stern rudders also featured tackles, but, unlike their medieval and Arab counterparts, had no sternpost to which to attach them. According to Lawrence V. Mott, the "idea of attaching the rudder to the sternpost in a relatively permanent fashion, therefore, must have been an Arab invention independent of the Chinese."

Medieval Europe

Oars mounted on the side of ships evolved into quarter rudders, which were used from antiquity until the end of the Middle Ages in Europe. As the size of ships and the height of the freeboards increased, quarter-rudders became unwieldy and were replaced by the more sturdy stern-mounted rudders with pintle and gudgeon attachment. While stern-mounted rudders were found in Europe on a wide range of vessels since Roman times, including light war galleys in Mediterranean, the oldest known depiction of a pintle-and-gudgeon rudder can be found on church carvings of Zedelgem and Winchester dating to around 1180.. The invention of the rudder in Medieval Europe is attributed to Somerled in 1156, when it was the decisive factor in his defeat of Gofraidh mac Amhlaibh during the formation of the Lordship of the Isles.

Historically, the radical concept of the medieval pintle-and-gudgeon rudder did not come as a single invention into being. It presented rather a combination of ideas which each had been long around before: rudders mounted on the stern, iron hinges and the straight sternpost of northern European ships. While earlier rudders were mounted on the stern by the way of rudderposts or tackles, the iron hinges allowed for the first time to attach the rudder to the entire length of the sternpost in a really permanent fashion. However, its full potential could only to be realized after the introduction of the vertical sternpost and the full-rigged ship in the 14th century. From the age of discovery onwards, European ships with pintle-and-gudgeon rudders sailed successfully on all seven seas.

Contrary to an older hypothesis, all evidence indicates that the European hinged stern-mounted rudder, whose technical specifications considerably differ from the Chinese one, was invented independently:

> *The only actual concept which can be claimed to have been transmitted from the Chinese is the idea of a stern-mounted rudder, and not its method of attachment nor the manner in which it was controlled. Since that idea of putting a rudder on the stern can be traced back to the models found in Egyptian tombs, the need to have the concept brought into the Middle East is questionable at best. There is no evidence to support the contention that the sternpost-mounted rudder came from China, and no need to call on exterior sources for its introduction into the Mediterranean.*

Boat rudders details

Boat rudders may be either outboard or inboard. Outboard rudders are hung on the stern or transom. Inboard rudders are hung from a keel or skeg and are thus fully submerged beneath the hull, connected to the steering mechanism by a rudder post which comes up through the hull to deck level, often into a cockpit.

Rudder post and mast placement defines the difference between a ketch and a yawl, as these two-masted vessels are similar. Yawls are defined as having the mizzen mast abaft (i.e. "aft of") the rudder post; ketches are defined as having the mizzen mast forward of the rudder post.

Small boat rudders that can be steered more or less perpendicular to the hull's longitudinal axis make effective brakes when pushed "hard over." However, terms such as "hard over," "hard to starboard," etc. signify a maximum-rate turn for larger vessels.

Aircraft rudders

The tail of a Martin B-57E with rudder deflected to starboard.

On an aircraft, the **rudder** is a control surface along with the rudder-like elevator (attached to horizontal tail structure) and ailerons (attached to the wings) that control pitch and roll. The rudder is usually attached to the fin (or vertical stabilizer) which allows the pilot to control yaw in the vertical axis, i.e. change the horizontal direction in which the nose is pointing. The rudder's direction is manipulated with the movement of foot pedals by the pilot.

In practice, both aileron and rudder control input are used together to turn an aircraft, the ailerons imparting roll, the rudder imparting yaw, and also compensating for a phenomenon called adverse yaw. Adverse yaw is readily seen if the most simple type of ailerons alone are used for a turn. The downward moving aileron acts like a flap, generating more lift for one wing, and therefore more drag (though since the 1930s, many aircraft have used *frise ailerons* or differential ailerons, which compensate for the adverse yaw and require little or no rudder input in regular turns). Initially, this drag yaws the aircraft in the direction opposite to the desired course. A rudder alone will turn a conventional fixed wing aircraft, but much more slowly than if ailerons are also used in conjunction. Use of rudder and ailerons together produces co-ordinated turns, in which the longitudinal axis of the aircraft is in line with the arc of the turn, neither slipping (under-ruddered), nor skidding (over-ruddered). Improperly ruddered turns at low speed can precipitate a spin which can be dangerous at low altitudes.

Sometimes pilots may intentionally operate the rudder and ailerons in opposite directions in a maneuver called a forward slip. This may be done to overcome crosswinds and keep the fuselage in line with the runway, or to more rapidly lose altitude by increasing drag, or both. The pilots of Air Canada Flight 143 used a similar technique to land the plane as it was too high above the glideslope.

Any aircraft rudder is subject to considerable forces that determine its position via a force or torque balance equation. In extreme cases these forces can lead to loss of rudder control or even destruction of the rudder. (The same principles also apply to water vessels, of course, but it is more important for aircraft because they have lower engineering margins.) The largest achievable angle of a rudder in flight is called its **blowdown limit**; it is achieved when the force from the air or blowdown equals the maximum available hydraulic pressure.

Trim tab

Trim tabs are small surfaces connected to the trailing edge of a larger control surface, such as a rudder, on a boat or aircraft, used to control the trim of the controls, i.e. to counteract hydro- or aero-dynamic forces and stabilise the boat or aircraft in a particular desired attitude without the need for the operator to constantly apply a control force. This is done by adjusting the angle of the tab relative to the larger surface.

Changing the setting of a trim tab adjusts the neutral or resting position of a control surface (such as an elevator or rudder). As the desired position of a control surface changes (corresponding mainly to different speeds), an adjustable trim tab will allow the operator to reduce the manual force required to maintain that position—to zero, if used correctly. Thus the trim tab acts as a servo tab. Because the center of pressure of the trim tab is further away from the axis of rotation of the control surface than the center of pressure of the control surface, the movement generated by the tab can match the movement generated by the control surface. The position of the control surface on its axis will change until the movements from the control surface and the trim surface balance each other.

Chapter- 9

Stabilizer (Aircraft)

The tail of a Lufthansa airliner (Airbus A319) in flight, showing the **horizontal** and **vertical stabilizer**

The Beechcraft Starship of canard configuration

The Beechcraft Bonanza, the most common example of V-Tail empennage configuration

In aviation, the stabilizer (empennage or tail) provides stability when the aircraft is flying straight, and the airfoil of the horizontal stabilizer balances the forces acting on the aircraft.

While the vertical stabilizer and rudder are always placed on the rear of the aircraft (either on the aft fuselage, or at the ends of aft-swept wings), the horizontal surfaces can be placed on the front or the rear. When placed at the rear, the horizontal stabilizer is called a tailplane. When placed at the front, it is called a canard. A combined vertical-horizontal stabilizer is used in the V-tail configuration.

Horizontal stabilizer

Tailplane

The **horizontal stabilizer** or tailplane is a fixed or adjustable surface from which an elevator may be hinged. In some aircraft models (mostly jets), the entire horizontal stabilizer rotates and functions as an elevator. This combination is often called a stabilator.

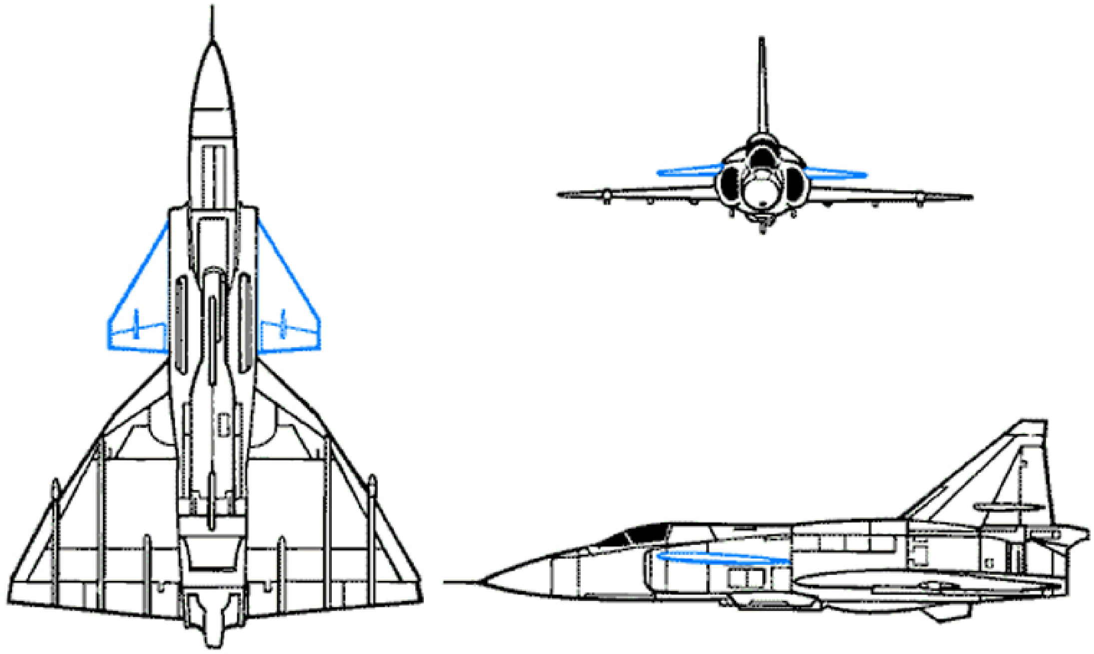
Aircraft with an adjustable stabilizer have the stabilizer hinged so that its setting (angle of incidence) can be altered in flight. The resulting stabilized speed is known as the *trim speed*, and the trim is used to set the desired speed without having to hold the elevator out of its trimmed or faired (trail) position. In aircraft with truly fixed stabilators, a trim tab on the trailing edge of the elevator is used to alter the aircraft's trim speed. The F-86 Sabre first used a fixed stabilizer and elevators with a trim tab, but later versions used a stabilator.

Canard

When placed on the front, the aircraft is called a canard. The Italian-designed Piaggio P.180 Avanti uses a rear-mounted stabilizer/elevator and a forward stabilizer (fixed, with no control surfaces); this combination arrangement is probably unique in present-day aircraft, although some early airplanes tried such arrangements.

In aeronautics, **canard** (French for duck) is an airframe configuration of fixed-wing aircraft in which the forward surface is smaller than the rearward, the former being known as the "canard", while the latter is the main wing. In contrast a conventional aircraft has a small horizontal stabilizer behind the main wing.

Some early aeroplanes such as the Brazilian Santos-Dumont 14-bis and French Canard Voisin had tail-first configuration which were seen by observers to resemble a flying duck — hence the name.



Canards (blue) on the Saab Viggen

General characteristics

Unlike a conventional tailplane, a canard surface is trimmed to increase lift as speed increases. This equates to a negative coefficient for trim drag.

Canard classes

Canard designs fall into two main classes: the lifting-canard and the control-canard.

Other classes include the close-coupled type and active vibration damping.

Canard (yellow) on a Mirage IIIS

Rutan Long-EZ, with lifting-canard ahead of the cockpit.

A deflected control-canard on an RAF Typhoon F2

Lifting-canard

The first airplane to fly, the Wright Flyer, was a lifting-canard. In this configuration, the weight of the aircraft is shared between the main wing and the canard wing. The pros and cons of the canard versus conventional configurations are numerous and complex, and it is impossible to say which is superior without considering a specific design application.

For example, a lifting-canard generates an upload, in contrast to a conventional aft-tail which typically generates a download that must be counteracted by extra lift on the main wing, which may appear to unambiguously favor the canard. However, the downwash interaction between the two surfaces is unfavorable for the canard, and favorable for the downloaded conventional tail, so the difference in overall induced drag is actually not obvious, and depends on the details of the configuration.

Another example is that the upward canard lift appears to increase the overall lift capability of the configuration. However, pitch stability flight safety requirements dictate that the canard must stall before the main wing, so the main wing can never reach its maximum lift capability. Hence, the main wing must then be larger than on the conventional configuration, which increases its weight and profile drag. Again, the relative merit depends on the details of the configuration and cannot be generalized.

In any case, pitch stability requires that the lift generated by the canard wing is significant, so in order to minimise induced drag on the canard, it is usually of higher aspect ratio and greater airfoil camber than a control-canard. To achieve stability, the change in lift coefficient with angle of attack should be less than that for the main plane.

One way in which this can be achieved is to use the same aerofoil for both planes, but to rig the canard at a higher angle of incidence. This tends to increase drag induced by the foreplane, which may be given a high aspect ratio in order to limit drag.

With a lifting-canard, the main wing must be located further aft of the center of gravity range than with a conventional aft tail, and this increases the pitching moment caused by trailing-edge flaps. Aircraft with lifting canards cannot readily be designed with sophisticated trailing-edge flaps.

Control-canard

In the later control-canard, most of the weight of the aircraft is carried by the main wing and the canard wing is used primarily for longitudinal control during maneuvering. A control-canard mostly operates at zero angle of attack. Combat aircraft of canard configuration typically have a control-canard. In combat aircraft, the canard is usually driven by a computerized flight control system.

One benefit obtainable from a control-canard is avoidance of pitch-up. An all-moving canard capable of a significant nose-down deflection will protect against pitch-up. As a result, the aspect ratio and wing-sweep of the main wing can be optimized without having to guard against pitchup.

Control canards have poor stealth characteristics, because they present large, angular surfaces that can reflect RADAR signals. The Eurofighter Typhoon uses software control of its canards in order to reduce its radar cross section.

Close-coupled canard

In the close-coupled canard, the foreplane is located just above and forward of the main wing. At high angles of attack the canard surface directs airflow downwards over the wing, reducing turbulence which results in reduced drag and increased lift.

The canard foreplane may be fixed as on the IAI Kfir, or have landing flaps as on the Saab Viggen, or it may be moveable and also act as a control-canard during normal flight as on the Dassault Rafale.

A **moustache** is a small, high aspect ratio foreplane of close-coupled configuration. The surface is typically retractable at high speed and is deployed only for low-speed flight. First seen on the Dassault Milan, and later on the Tupolev Tu-144.

Active vibration damping

A large aircraft flying fast at low altitude can experience significant aerodynamic buffeting, leading to crew fatigue and reduced airframe life. Aircraft such as the B-1 Lancer incorporate small canard surfaces as part of an active vibration damping system that reduces these adverse effects.

Vertical stabilizer

The vertical stabilizer or fin is fixed to the aircraft and supports the rudder. The fin nearly always employs a small fillet at its forward base, called a dorsal fin, which prevents a phenomenon called *rudder lock*. Rudder lock is where the force on a fully-deflected rudder (in a steady sideslip) suddenly reverses as the rudder reaches its maximum travel. The phenomenon is usually corrected by addition of a dorsal fin.

The **vertical stabilizers**, **vertical stabilisers**, or **fins**, of aircraft, missiles or bombs are typically found on the aft end of the fuselage or body, and are intended to reduce aerodynamic side slip. It is analogical to a **skeg** on boats and ships.

On aircraft, vertical stabilizers generally point upwards. These are also known as the vertical tail, and are part of an aircraft's empennage. The trailing end of the stabilizer is typically movable, and called the rudder; this allows the aircraft pilot to control yaw.

Often navigational radio or airband transceiver antennas are placed on or inside the vertical tail. In most aircraft with three jet engines, the vertical stabilizer houses the central engine or engine inlet duct, as in the Lockheed L-1011, McDonnell Douglas DC-10, McDonnell Douglas MD-11, Boeing 727, BAe Trident, Tupolev Tu-154, and the Yakovlev Yak-40.

Types of vertical stabilizers

Single

Conventional tail

The conventional tail of an Airbus A380, with the vertical stabiliser exactly vertical

The vertical stabilizer is mounted exactly vertically, and the horizontal stabilizer is directly mounted to the empennage (the rear fuselage). This is the most common vertical stabilizer configuration.

T-tail

A T-tail has the horizontal stabilizer mounted at the top of the vertical stabilizer. It is commonly seen on rear-engine aircraft, such as the Bombardier CRJ200, the Boeing 727 and Douglas DC-9, as well as the Silver Arrow small airplane, and most high performance gliders.

T-tails are often incorporated on configurations with fuselage mounted engines to keep the horizontal stabilizer away from the engine exhaust plume.

T-tail aircraft are more susceptible to pitch-up at high angles of attack. This pitch-up results from a reduction in the horizontal stabilizer's lifting capability as it passes through the wake of the wing at moderate angles of attack. This can also result in a deep stall condition.

T-tails present structural challenges since loads on the horizontal stabilizer must be transmitted through the vertical tail.

Cruciform tail

The cruciform tail is arranged like a cross, the most common configuration has the horizontal stabilizer intersecting the vertical tail somewhere near the middle. The PBY Catalina uses this configuration. The "push-pull" twin engined Dornier Do 335 World War II German fighter used a cruciform tail consisting of four separate surfaces, arranged in dorsal, ventral, and both horizontal locations, to form its cruciform tail, just forward of the rear propeller.

Multiple stabilizers

Twin tail

The twin tail of a Chrislea Super Ace, built in 1948

Rather than a single vertical stabilizer, a twin tail has two. These are vertically arranged, and intersect or are mounted to the ends of the horizontal stabilizer. The Beechcraft Model 18 and many modern military aircraft such as the American F-14, F-15, and F/A-18 use this configuration. The F/A-18, F-22 Raptor, and F-35 Lightning II have tailfins that are canted outward, to the point that they have some authority as horizontal control surfaces; both aircraft are designed to deflect their rudders inward during takeoff to increase pitching moment. A twin tail may be either **H-tail**, twin fin/rudder construction attached to a single fuselage such as North American B-25 Mitchell or Avro Lancaster, or **twin boom tail**, the rear airframe consisting of two separate fuselages each sporting one single fin/rudder, such as Lockheed P-38 Lightning or C-119 Boxcar.

Triple tail

A Lockheed Constellation with a triple tail

A variation on the twin tail, it has three vertical stabilizers. The best example of this configuration is the Lockheed Constellation. On the Constellation it was done to give the airplane maximum vertical stabilizer area, but keep the overall height low enough so that it could fit into maintenance hangars.

V-tail

A V-tail has no distinct vertical or horizontal stabilizers. Rather, they are merged into control surfaces known as ruddervators which control both pitch and yaw. The arrangement looks like the letter V, and is also known as a *butterfly tail*. The Beechcraft Bonanza Model 35 uses this configuration, as does the F-117 Nighthawk, and many of Richard Schreder's HP series of homebuilt gliders.

Rutan VariEze with vertical stabilizers on the ends of the wings also serving as winglets

Winglet

Winglets served double duty on Burt Rutan's rear wing forward canard pusher configuration VariEze and Long-EZ, acting as both a wingtip device and a vertical stabilizer. Several other derivatives of these and other similar aircraft use this design element.

V-tail

For aircraft with a V-tail, each stabilizer/fin will support a "ruddervator", combining the functions of both the rudder and the elevator.

In aircraft, a **V-tail** (sometimes called a **Butterfly tail**) is an unconventional arrangement of the tail control surfaces that replaces the traditional fin and horizontal surfaces with two surfaces set in a V-shaped configuration when viewed from the front or rear of the aircraft. The rear of each surface is hinged, and these movable sections, sometimes called **ruddervators**, combine the tasks of the elevators and rudder.

1950 V-tailed B35 still operated by the National Test Pilot School at the Mojave Airport

Design use

The V-tail has not been a popular choice for aircraft manufacturers. The most popular V-tailed aircraft in mass production was the Beechcraft Bonanza Model 35, often known as the *V-tail Bonanza* or simply *V-Tail*. Other examples include the F-117 Nighthawk stealth fighter, the Fouga Magister trainer, and the MQ-1 Predator UAV. The X-shaped tail surfaces of the experimental Lockheed XFV were essentially a V tail that extended both above and below the fuselage. Over 2000 Ultraflight Lazair ultralights were produced, all featuring an inverted V-tail.

The V-tail of a Belgian Air Force Fouga Magister.

Advantages

Ideally, with fewer surfaces than a conventional three-aerofoil tail or a T-tail, the V-tail is lighter, has less wetted surface area, and thus produces less drag. However, NACA studies indicated that the V-tail surfaces must be larger than simple projection into the vertical & horizontal planes would suggest, such that total wetted area is roughly constant; reduction of intersection surfaces from three to two, does, however, produce a net reduction in drag through elimination of some interference drag.

In modern day light jet general aviation aircraft such as the Cirrus Jet, Eclipse 400 or the unmanned aerial drone Global Hawk, the power plant is often placed outside the aircraft to protect the passengers and make certification easier. In such cases V-tails are used to avoid placing the vertical stabilizer in the exhaust of the engine, which would disrupt the flow of the exhaust reducing thrust, and wear on the stabilizer, possibly leading to damage over time.

An Ultraflight Lazair showing its inverted V-tail covered with translucent Tedlar

Disadvantages

Combining the pitch and yaw controls is difficult and requires a more complex control system. The V-tail arrangement also places greater stress on the rear fuselage when pitching and yawing.

In the mid-1980s, the Federal Aviation Administration grounded the Beechcraft Bonanza due to safety concerns. While the Bonanza met the initial certification requirements, it had a history of fatal mid-air breakups during extreme stress, at a rate exceeding the accepted norm. The type was deemed airworthy and restrictions removed after Beechcraft issued a structural modification as an Airworthiness Directive.

Ruddervators

Ruddervators are the control surfaces on an airplane with a V-tail configuration. They are located at the trailing edge of each of the two airfoils making up the tail of the plane. The first use of ruddervators may have been on the Coandă-1910's X-tail, although there is no proof that the aircraft ever flew. The later Coandă-1911 flew with ruddervators on its X-tail. Later Polish engineer Jerzy Rudlicki designed the first practical ruddervators in 1930, tested on a modified Hanriot H-28 trainer in 1931.

The name derives from a combination of the word rudder and elevator. In a conventional aircraft tail configuration, the rudder provides yaw (horizontal) control and the elevator provides pitch (vertical) control.

Ruddervators provide the same control effect as conventional control surfaces, but through a more complex control system that actuates the control surfaces in unison. Yaw moving the nose to the left is produced on an upright V tail by moving the pedals left which deflects the left-hand ruddervator down and left and the right-hand ruddervator up and left. The opposite produces yaw to the right. Pitch nose up is produced by moving the control column or stick back which deflects the left-hand ruddervator up and right and the right-hand ruddervator up and left. Pitch nose down is produced by moving the control column or stick forward which induces the opposite ruddervator movements.

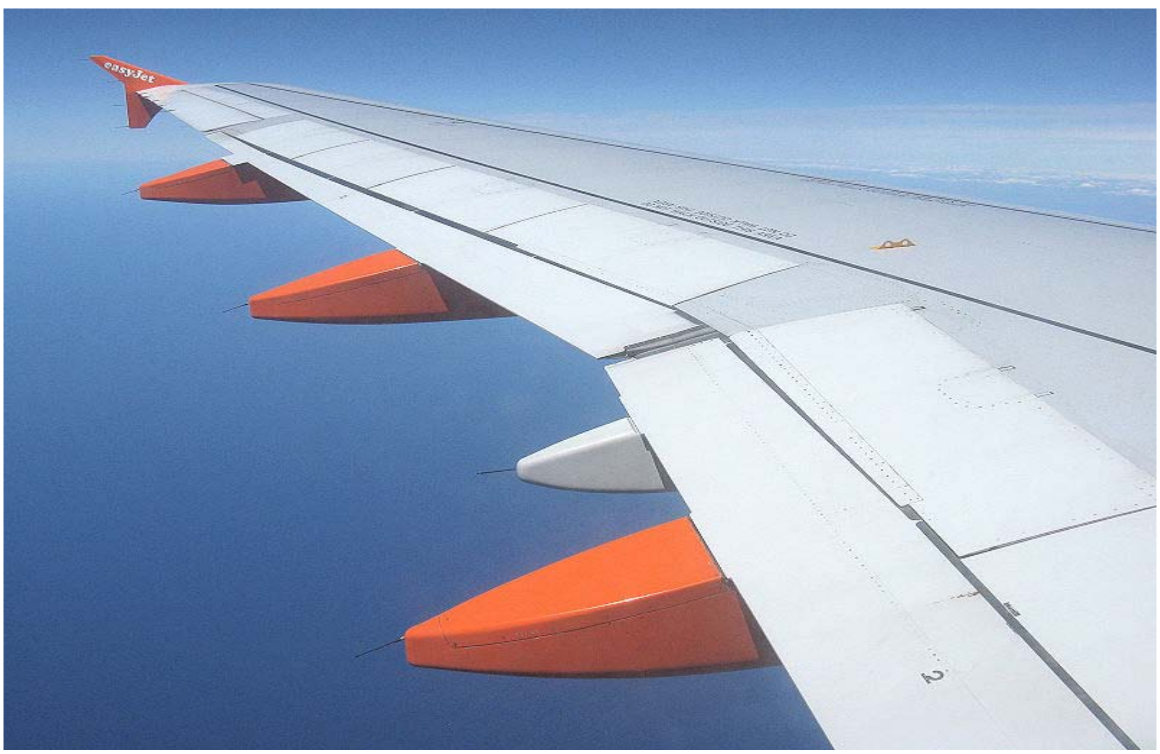
Ruddervators have also been used on some airships, such as the US Navy's N class blimps. Accurate pitch trimming of airships can be difficult and this configuration improves clearance beneath the tail.

Chapter- 10

Flap (Aircraft)

Flaps are hinged surfaces on the trailing edge of the wings of a fixed-wing aircraft. As flaps are extended, the stalling speed of the aircraft is reduced, which means that the aircraft can fly safely at lower speeds (especially during take off and landing). Flaps are also used on the leading edge of the wings of some high-speed jet aircraft, where they may be called Krueger flaps

Extending flaps increases the camber of the wing airfoil, thus raising the maximum lift coefficient. This increase in maximum lift coefficient allows the aircraft to generate a given amount of lift with a lower speed. Therefore, extending the flaps reduces the stalling speed of the aircraft.

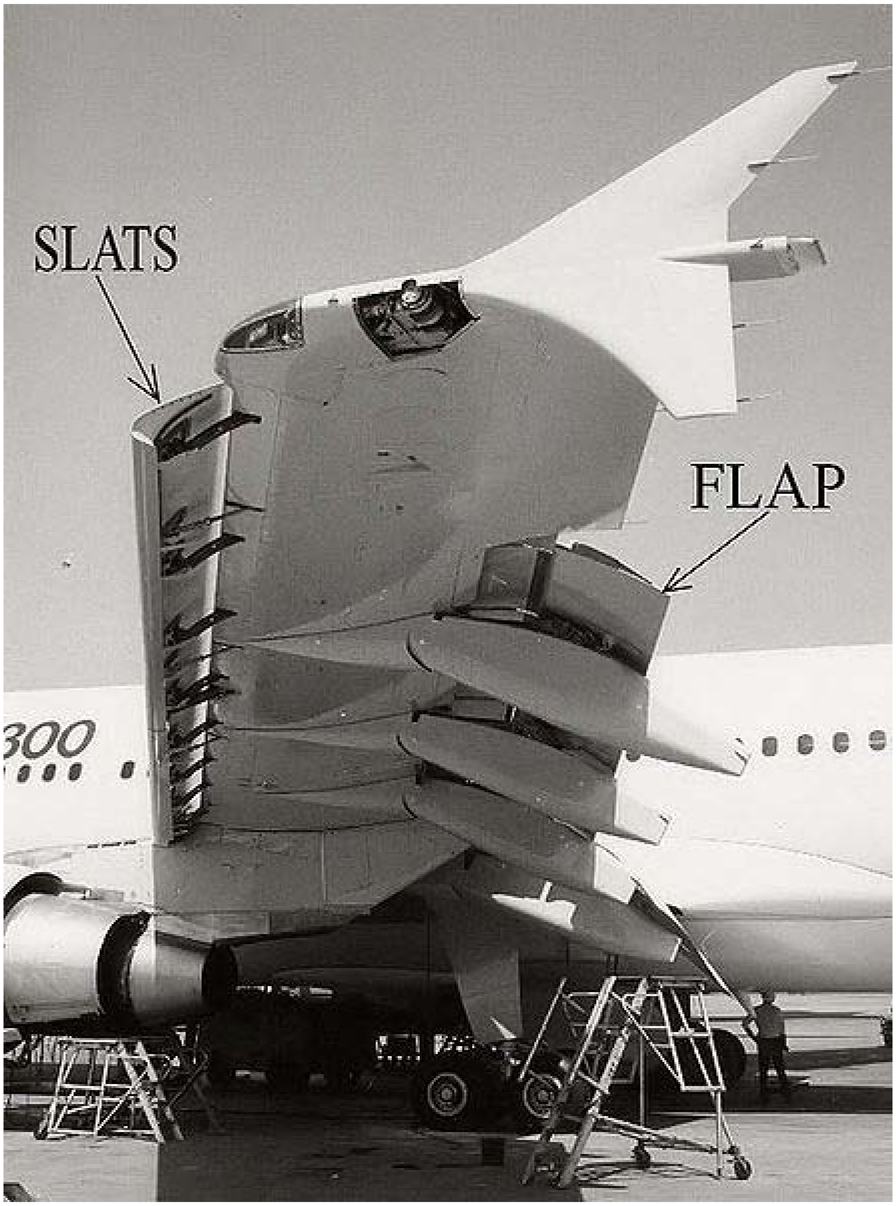


The wing of an Easyjet Airbus A319-100. The three (orange) canoe-shapes are flap track fairings to hide and streamline the flap driving mechanisms. The flaps (two on each side, on the A319) lie directly above the flap track fairings.

Extending flaps also increases drag. This can be beneficial in the approach and landing phase because it helps to slow the aircraft. Another useful side effect of flap deployment is a decrease in aircraft pitch angle. This provides the pilot with a greater view over the nose of the aircraft and allows a better view of the runway during approach and landing.

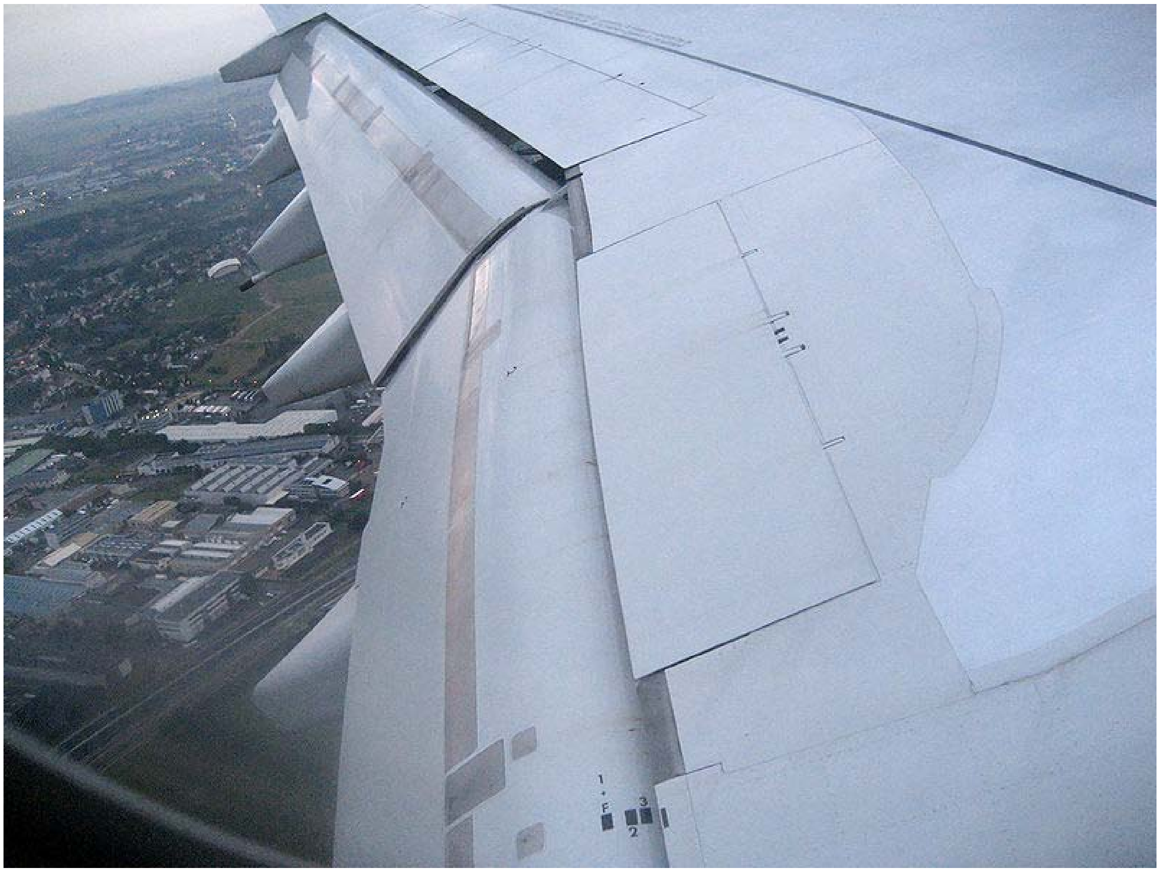
A fully extended flap before landing

Some trailing edge flap systems increase the planform area of the wing in addition to changing the camber. In turn, the larger lifting surface allows the aircraft to generate a given amount of lift with a lower speed, thus further reducing stalling speed. Although this effect is very similar to increasing the lift coefficient, raising the planform area of the wing does not itself raise the lift coefficient. The Fowler flap is an example of a flap system that increases the planform area of the wing in addition to increasing the camber.



The position of the trailing edge flaps on an airliner (Airbus A310-300). In this picture, the flaps are extended, note also the drooped leading edge slats.

Triple-slotted trailing-edge **flaps** and leading edge Krueger (unslotted and slotted) flaps fully extended on a Boeing 747 for landing.



An Air France jet with flaps fully extended as it reduces speed before landing

A British Airways Boeing 757-200 lands with flaps extended

Physics explanation

The general airplane lift equation demonstrates these relationships:

$$L = \frac{1}{2}\rho V^2 S C_L$$

where:

- L is the lift,
- ρ is the air density,
- V is the true airspeed of the airplane
- **S** is the planform area of the wing and
- C_L is the aircraft lift coefficient

Here, it can be seen that increasing the area (S) and lift coefficient (C_L) allow a similar amount of lift to be generated at a lower airspeed (V).

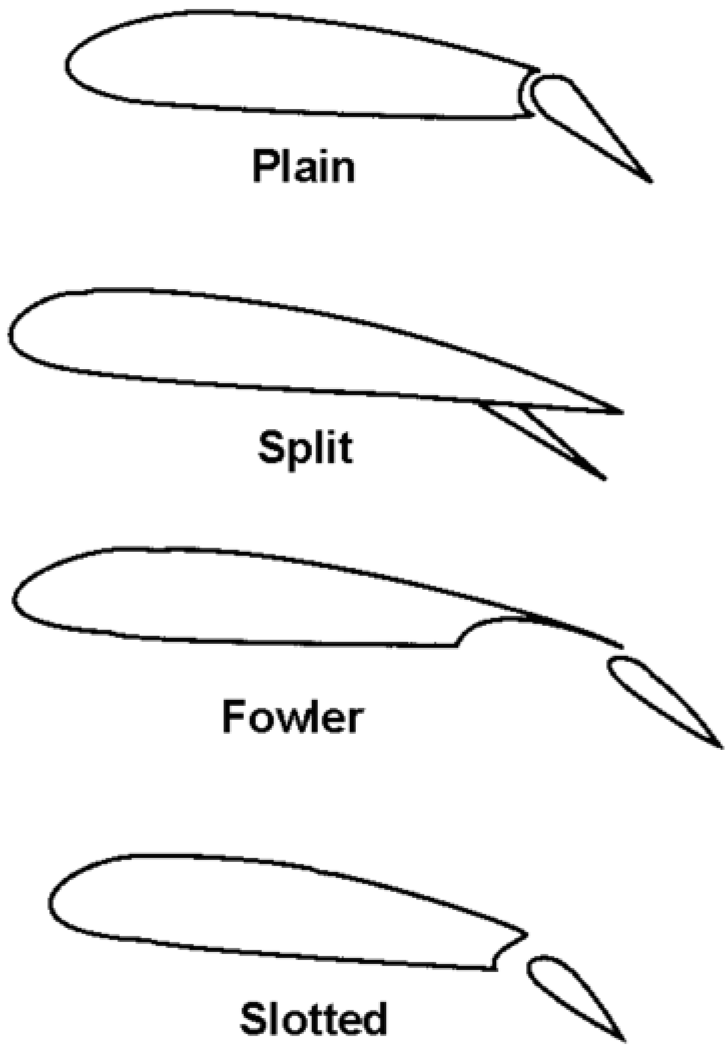
Extending the flaps also increases the drag coefficient of the aircraft. Therefore, for any given weight and airspeed, flaps increase the drag force. Flaps increase the drag coefficient of an aircraft because of higher induced drag caused by the distorted spanwise lift distribution on the wing with flaps extended. Some flaps increase the planform area of the wing and, for any given speed, this also increases the parasitic drag component of total drag.

Depending on the aircraft type, flaps may be partially extended for takeoff. Especially with general aviation aircraft, the use of flaps for takeoff may be optional. This depends on the manufacturer's procedures in the Airplane Flight Manual for a specific takeoff method (e.g., short field, soft field, normal, etc.). Flaps may be partially extended on takeoff to increase the amount of lift generated at a given airspeed, as well as to reduce the stalling speed of the airplane. Together, these two effects help an airplane lift off in a shorter distance at a lower drag penalty than that incurred by a full flap deflection.

Flaps are usually fully extended for landing to give the aircraft a lower stalling speed so the approach to landing can be flown more slowly, allowing the aircraft to land in a shorter distance. The higher lift and drag associated with fully extended flaps allows a steeper and slower approach to the landing site. This demonstrates the combined benefit of the higher lift and drag coefficients of fully extended flaps.

Some gliders not only use flaps when landing but also in flight to optimize the camber of the wing for the chosen speed. When thermalling, flaps may be partially extended to reduce the stalling speed so that the glider can be flown more slowly and thereby turn in a smaller circle to make best use of the core of the thermal. At higher speeds a negative flap setting is used to reduce the nose-down pitching moment. This reduces the balancing load required on the horizontal stabilizer, which in turn reduces the trim drag associated with keeping the glider in longitudinal trim. Negative flap may also be used during the initial stage of an aerotow launch and at the end of the landing run in order to maintain better control by the ailerons.

Types



Four types of flaps

Types of flap systems include:

- Krueger flap: hinged flap on the leading edge. Often called a "droop".
- Plain flap: rotates on a simple hinge.
- Split flap: upper and lower surfaces are separate, the lower surface operates like a plain flap, but the upper surface stays immobile or moves only slightly.
- Gouge flap: a cylindrical or conical aerofoil section which rotates backwards and downwards about an imaginary axis below the wing, increasing wing area and

chord without affecting trim. Invented by Arthur Gouge for Short Brothers in 1936.

- Fowler flap: slides backwards before hinging downwards, thereby increasing both camber and chord, creating a larger wing surface better tuned for lower speeds. It also provides some slot effect. The Fowler flap was invented by Harlan D. Fowler.
- Fairey-Youngman flap: moves body down before moving aft and rotating.
- Slotted flap: a slot (or gap) between the flap and the wing enables high pressure air from below the wing to re-energize the boundary layer over the flap. This helps the airflow to stay attached to the flap, delaying the stall.
- Blown flaps: systems that blow engine air over the upper surface of the flap at certain angles to improve lift characteristics.

Leading edge slats, usually found at the leading edge (frontmost part) of the wing where it meets the air first, have a similar function as the trailing-edge flaps. Note that a Krueger flap and a leading-edge slat differ in how they are extended. A slat allows a separation from the rest of the wing for energized air to pass from the bottom of the surface to the top, delaying boundary layer separation, whereas a Krueger flap does not because it only increases the wing area and wing curvature.

Research

Several technology research and development efforts exist to incorporate the function of flaps and ailerons into wings to perform the aerodynamic purpose without the weight and mechanical complexity of flap systems. Desired traits include lower: mass, cost, drag, inertia (for faster, stronger control response), complexity (mechanically simpler, fewer moving parts or surfaces, less maintenance), and radar cross section for stealth. These may be used in many unmanned aerial vehicles (UAVs) and 6th generation fighter aircraft. The two main approaches are flexible wings, and fluidics.

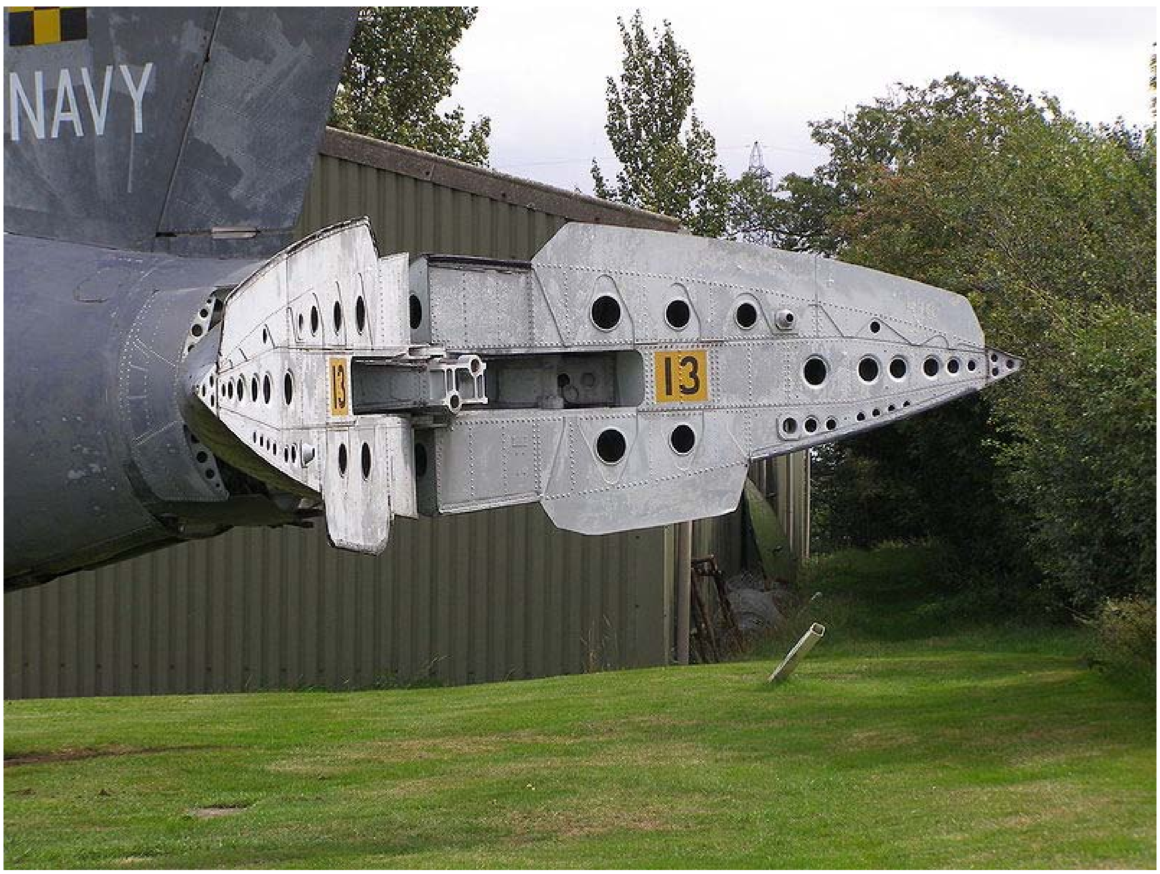
In flexible wings, much or all of a wing surface can change shape in flight to deflect air flow. The X-53 Active Aeroelastic Wing is a NASA effort. The Adaptive Compliant Wing is a commercial effort.

In fluidics, forces in vehicles occur via circulation control, in which larger more complex mechanical parts are replaced by smaller simpler fluidic systems (slots which emit air flows) where larger forces in fluids are diverted by smaller jets or flows of fluid intermittently, to change the direction of vehicles. In this use, fluidics promises lower mass, costs (up to 50% less), and very low inertia and response times, and high simplicity.

Chapter- 11

Other Aircraft Controls

Air brake (aircraft)



Air brake on a Blackburn Buccaneer naval strike aircraft

Air brakes on the rear fuselage of a Eurowings BAe 146-300

In aeronautics, **air brakes** are a type of flight control surface used on an aircraft to increase drag or increase the angle of approach during landing.

The earliest known air brake was developed in 1933 and deployed on the wing support struts as illustrated in this photo.

Air brakes differ from spoilers in that air brakes are designed to increase drag while making little change to lift, whereas spoilers greatly reduce the lift-to-drag ratio and require a higher angle of attack to maintain lift, resulting in a higher stall speed.

Most gliders are equipped with air brakes on the wings for approach control during landing.

Often, characteristics of both spoilers and air brakes are desirable and are combined - most modern airliner jets feature combined spoiler and air brake controls. On landing, the deployment of these spoilers causes a dramatic loss of lift and hence the weight of the aircraft is transferred from the wings to the undercarriage, allowing the wheels to be mechanically braked with much less chance of skidding. In addition, the form drag created by the spoilers directly assists the braking effect. Reverse thrust is also used to help slow the aircraft after landing.

The British Blackburn Buccaneer naval strike aircraft designed in the 1950s had a tail cone that was split and could be hydraulically opened to the sides to act as a variable air brake. It also helped to reduce the length of the aircraft in the confined space on an aircraft carrier.

The F-15 Eagle, Sukhoi Su-27 and other fighters have an air brake just behind the cockpit.

Volkswagen's Bugatti Veyron supercar deploys an airbrake when braking at speeds greater than 200 km/h (120 mph).

Split control surfaces

The deceleron is an aileron that functions normally in flight but can split in half such that the top half goes up as the bottom half goes down to brake. This technique was first used on the F-89 Scorpion and has since been used by Northrop on several aircraft, including the B-2 Spirit.

Space Shuttle Discovery just after touchdown at the end of mission STS-116

The space shuttle uses a similar system. The split rudder opens on landing to act as a speed brake, as shown in the accompanying photo.

Air data module

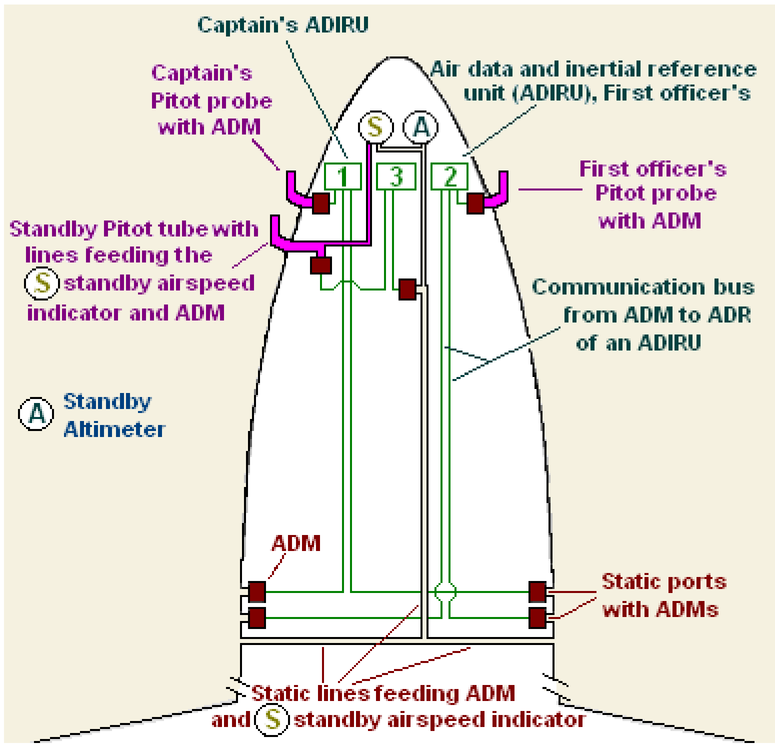


Illustration of the airspeed indication and detection system on fly-by-wire aircraft

Air Data Module is a component of the navigation system on fly-by-wire aircraft, such as Airbus A320 or later Airbus. Each unit converts pneumatic (air pressure) information from a Pitot tube or a static port in to numerical information which is sent on a data bus. This pressure information is received and processed by the Air Data Reference (ADR) component of the Air Data Inertial Reference Unit (ADIRU). This processed information is then sent to a display management computer(s) that present information on the cockpit's primary flight display. Airspeed information is also sent to the flight computers and other electronics. Airspeed information is also sent to the autoflight subsystem (.e.g. flight management and guidance system).

Construction

The Air Data Module is a gas pressure sensor which converts mechanical forces created by gas pressure into digital signals that can be carried to the Air Data Reference unit. ADM generally have a maintenance bus and communication bus, and a connector on the housing for a pressurized gas line that is connected to the Pitot tube or static ports. The maintenance bus can be EIA-485 and the communication bus can be ARINC 429

Centre stick

MHDDs and Pedestal Panel with centre stick in the Typhoon cockpit

A **centre stick** (or **center stick** in the United States), or simply **control stick** is an aircraft cockpit arrangement where the control column (or joystick) is located conventionally in the centre of the cockpit between the pilot's legs. Since the throttle controls are typically located to the left of the pilot, the right hand is used for the stick, although left-hand or both-hands operation is possible if required.

The centre stick is used in many military fighter jets such as Eurofighter Typhoon and the Mirage III, but also in light aircraft such as the Diamond Aircraft line of products such as the DA20, DA40 and DA42.

This arrangement contrasts with the more recently developed "side-stick" which is used in such military fighter jets as the F-16, the F-35 Lightning II and also on civil aircraft such as the Airbus A320.

Central forward area of the Mirage III cockpit, showing centre stick

Control loading system

A **Control Loading System** (**CLS**, also known as **Electric Control Loading**), is used to provide pilots with realistic flight control forces in a flight simulator or training device. These are used in both commercial and military training applications.

History

The history of control loading systems starts with the history of flight simulation. The first flight simulator was the Link Trainer, also known as the Blue Box. This was developed in the 1920’s and used pumps, valves and bellows to provide the flight control forces. The next development in control loading systems was the use of hydraulic actuators to provide the forces required on the flight controls. These were utilized for around 20 years in the simulator industry until the development of electric actuators.

Control Loading Systems

Design and Technology

The main concept is to provide forces to the pilot using an actuator (hydraulic or electric). The approach used in high fidelity applications is to connect this actuator via a linkage to the pilot controls. The actuator is then controlled with a servo controller to control the torque or current of the motor. An outer-loop control then controls the torque provided to the pilot using a control loop around a force sensor.

The control loading system must take in inputs from the simulator and pilot and provide outputs for the pilot and simulator. Inputs are application of force and aircraft states and outputs are flight control position and forces. An aircraft with reversible controls needs to have all of the complex components modeled within the control loading system. These include cables, rods, aero forces from the control surface, centering springs and trim actuators. As the control system gets more complicated they have to simulate effects such as bob-weights and feel units. Fly-by-wire systems are disconnected from the control surfaces and so do not need the complex features but add other functionality which is simulated. The high fidelity architecture has centralized control, individual analog signals to the control module, a brushless DC motor with low gear ratio and linkages to the pilot controls. The modular designs have localized control and digital reporting over a field bus to the central control module. The control loading systems are designed to allow situating the actuators closer to the pilot. This is necessary for mission training systems that can be easily deployed and moved around the world.

Control Loading Systems are similar in design to active sidesticks. These provide cues to pilots during the flight via actuation systems. Some examples of active sidesticks used in aircraft are for the F-35 Lightning II and the T-50 Golden Eagle jet trainer developed by KAI in partnership with LMCO.

Standards and Regulations

The regulations governing control loading systems for civil simulators are the Federal Aviation Administration regulations in North America and EASA (formerly JAA) in Europe. The FAA documents are AC 120-40B for airplane simulator qualification, Advisory circular 120-45A for Airplane Flight Training Device Qualification and AC 120-63 for helicopter Simulator Qualification. The EASA regulations are similar to the FAR’s. Between 2006 and 2008 the International Working Group of the RAeS’s Flight Simulation Group met on several occasions to redefine the standards applicable to flight simulation. This resulted in the release of a draft standards document to ICAO. This will be released by ICAO in 2009 and at this time the FAA and EASA should incorporate this into the regulations. The changes behind the standards will define different levels of simulator training devices which define what training requirements can be trained on with particular levels of simulators.

Electro-hydrostatic actuator

Electro-hydrostatic actuators (EHAs), are an emerging aerospace technology that aims at replacing hydraulic systems with self-contained actuators operated solely by electrical power. EHAs would eliminate the need for separate hydraulic pumps and tubing, simplifying aircraft layout and improving safety and reliability.

Conventional designs

Aircraft were originally controlled by small aerodynamic surfaces operated by cables, attached to levers that magnified the pilot's mechanical advantage. As aircraft grew in size and performance, the aerodynamic forces on these surfaces grew to the point where it was no longer possible for the pilot to manually control them across a wide range of speeds - controls with enough advantage to control the aircraft at high speed left the aircraft with significant overcontrol at lower speeds when the aerodynamic forces were reduced. Numerous aircraft in the early stages of World War II suffered from these problems, notably the Mitsubishi Zero and P-38 Lightning.

Starting in the 1940s, hydraulics were introduced to address these problems. In their early incarnations, hydraulic pumps attached to the engines would feed high-pressure oil through tubes to the various control surfaces. Here, small valves were attached to the original control cables, controlling the flow of oil into an associated actuator connected to the control surface. One of the earliest fittings of a hydraulic boost system was to ailerons late-war models of the P-38L, curing the need for great human strength in order to achieve a higher rate of roll.

Over time, the systems evolved to replace the mechanical linkages to the valves with electrical controls, producing the "fly-by-wire" design, and more recently, optical networking systems in what is known as "fly-by-light". All of these systems require three separate components, the hydraulic supply system, the valves and associated control network, and the actuators. Since any one of these systems could fail and render the aircraft inoperable, redundancies are needed that greatly increase the complexity of the system. Additionally, keeping the hydraulic oil pressurized is a constant power drain.

EHAs

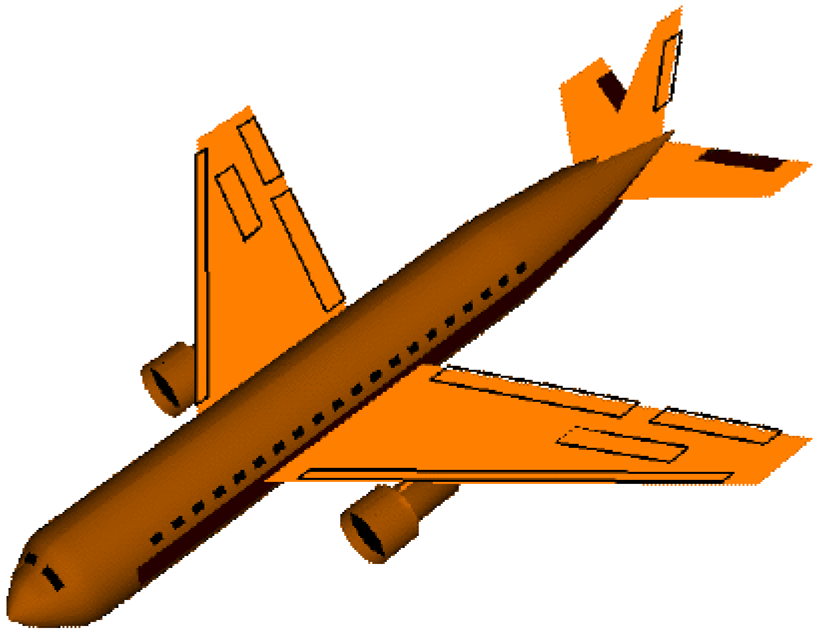
The primary development that leads to the possibility of EHAs are accurate feedback controlled conventional motors, or high-power stepper motors. Stepper motors are designed to move a fixed angle with every application of energy, and do so repeatedly in an extremely accurate fashion. Both types of motor drives have been in use for years, powering the controls on motion control rigs and numeric control machine tools for instance.

With an EHA, high-power versions of these motors are used to drive a reversible pump, which is tied to a hydraulic cylinder. The pump pressurizes a working fluid, typically hydraulic oil, directly raising the pressure in the cylinder, and causing it to move. The entire system, consisting of the pump, the cylinder and a reservoir of hydraulic fluid, is packaged into a single self-contained unit.

Instead of the energy needed to move the controls being supplied by an external hydraulic supply, it is supplied over normal electrical wiring, albeit larger wiring than what would be found in a fly-by-wire system. The speed of the motion is controlled through the use of pulse-code modulation. The result is a "power-by-wire" system, where both the control and energy are sent through a single set of wires.>

Redundancy can thus be provided by using two such units per surface, and two sets of electrical wires. This is far simpler than the corresponding systems using an external hydraulic supply. Additionally, the EHA has the advantage that it only draws power when it is being moved, the pressure is maintained internally when the motor stops. This can reduce power use on the aircraft by eliminating the constant draw of the hydraulic pumps. EHAs also reduce weight, allow better streamlining due to reduced internal routing of piping, and lower overall weight of the control system.

Elevator (aircraft)



Movement caused by the use of elevators.

Elevators are flight control surfaces, usually at the rear of an aircraft, which control the aircraft's orientation by changing the pitch of the aircraft, and so also the angle of attack of the wing. In simplified terms, they make the aircraft nose-up or nose-down. (Ascending and descending are more a function of the wing—aircraft typically land nose up.) An increased wing angle of attack will cause a greater lift to be produced by the profile of the wing, and a slowing of the aircraft speed. A decrease in angle of attack will produce an increase in speed. The elevators may be the only pitch control surface present (and are then called a stabilator), or may be hinged to a fixed or adjustable surface called a tailplane or horizontal stabilizer.

The surface immediately behind the final A of the registration G-ASBA of this Currie Wot is the horizontal stabilizer. The drooped surface hinged to it, nearly touching the grass, is the **elevator**.

The tail of a Lufthansa Airbus A319 in flight, showing the **elevator** (Stab. means Stabiliser)

Pre-installed elevators for a small Airbus. The elevator is the silver surface on the right hand side of the picture, immediately below the red pipes on the factory wall

The rear wing to which elevators are attached have the opposite effect to a wing. They usually create a *downward* pressure which counters the unbalanced moment due to the airplane's center of gravity not being located exactly on the resulting centre of pressure, which in addition to the lift generated by the main wing includes the effects of drag and engine thrust. An elevator decreases or increases the downward force created by the rear wing. An increased downward force, produced by *up* elevator, forces the tail down and the nose up so the aircraft speed is reduced (i.e. the wing will operate at a higher angle of attack, which produces a greater lift coefficient, so that the required lift is produced by a lower speed). A decreased downward force at the tail, produced by *down* elevator, allows the tail to rise and the nose to lower. The resulting lower wing angle of attack provides a lower lift coefficient, so the craft must move faster (either by adding power or going into a descent) to produce the required lift. The setting of the elevator thus determines the airplane's *trim speed* - a given elevator position has only one speed at which the aircraft will maintain a constant (unaccelerated) condition.

In some aircraft pitch-control surfaces are in the front, ahead of the wing; this type of configuration is called a canard, the French word for duck. The Wright Brothers' early aircraft were of this type. The canard type is more efficient, since the forward surface usually is required to produce upward lift (instead of downward force as with the usual empennage) to balance the net pitching moment. The main wing is also less likely to stall, as the forward control surface is configured to stall before the wing, causing a pitch down and reducing the angle of attack of the wing.

Supersonic aircraft have stabilators, because early supersonic flight research revealed that shock waves generated on the trailing edge of tailplanes rendered hinged elevators ineffective. Delta winged aircraft combine ailerons and elevators, and their respective control inputs, into one control surface, called an elevon.

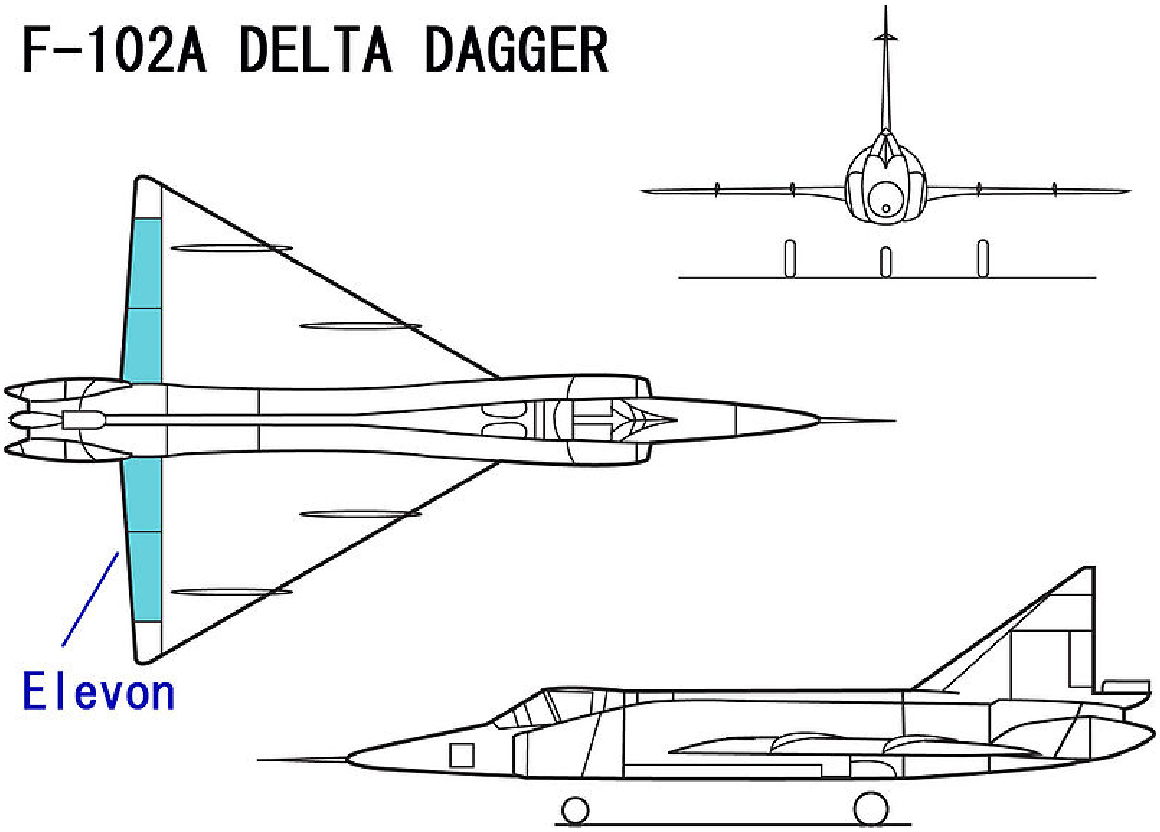
Elevon

Elevons at the wing trailing edge are used for pitch and roll control of the F-117A Nighthawk.

Elevons are aircraft control surfaces that combine the functions of the elevator (used for pitch control) and the aileron (used for roll control), hence the name. They are frequently used on tailless aircraft such as flying wings. An elevon that is not part of the main wing, but instead is a separate tail surface, is a stabilator.

Elevons are installed on each side of the aircraft at the trailing edge of the wing. When moved in the same direction (up or down) they will cause a pitching force (nose up or nose down) to be applied to the airframe. When moved differentially, (one up, one down) they will cause a rolling force to be applied. These forces may be applied simultaneously by appropriate positioning of the elevons e.g. one wing's elevons completely down and the other wing's elevons partly down.

An aircraft with elevons is controlled as though the pilot still has separate aileron and elevator surfaces at his disposal, controlled by the yoke or stick. The inputs of the two controls are mixed either mechanically or electronically to provide the appropriate position for each elevon.



Elevon

They were also used on the Concorde.

Research

Several technology research and development efforts exist to incorporate the function of aircraft flight control systems such as ailerons, elevators, elevons and flaps into wings to perform the aerodynamic purpose without the weight and mechanical complexity of elevon systems. Desired traits include lower: mass, cost, drag, inertia (for faster, stronger control response), complexity (mechanically simpler, fewer moving parts or surfaces, less maintenance), and radar cross section for stealth. These may be used in many unmanned aerial vehicles (UAVs) and 6th generation fighter aircraft. The two main approaches are flexible wings, and fluidics.

In flexible wings, much or all of a wing surface can change shape in flight to deflect air flow. The X-53 Active Aeroelastic Wing is a NASA effort. The Adaptive Compliant Wing is a commercial effort.

In fluidics, forces in vehicles occur via circulation control, in which larger more complex mechanical parts are replaced by smaller simpler fluidic systems (slots which emit air flows) where larger forces in fluids are diverted by smaller jets or flows of fluid intermittently, to change the direction of vehicles. In this use, fluidics promises lower mass, costs (up to 50% less), and very low inertia and response times, and simplicity.

Flaperon

Flaperons on a Kitfox Model 3, built in 1991

A **flaperon** is a type of control surface that combines aspects of both flaps and ailerons. In addition to controlling the roll or bank of an aircraft like conventional ailerons, both flaperons can be lowered together to function much the same as a dedicated set of flaps would. Both ailerons could also be raised, which would give spoilerons.

The pilot has separate controls for ailerons and flaps. A mixer is used to combine the separate pilot input into this single set of control surfaces called flaperons. The use of flaperons instead of separate ailerons and flaps can reduce the weight of an aircraft. The complexity is transferred from having a double set of control surfaces (flaps and ailerons) to the mixer.

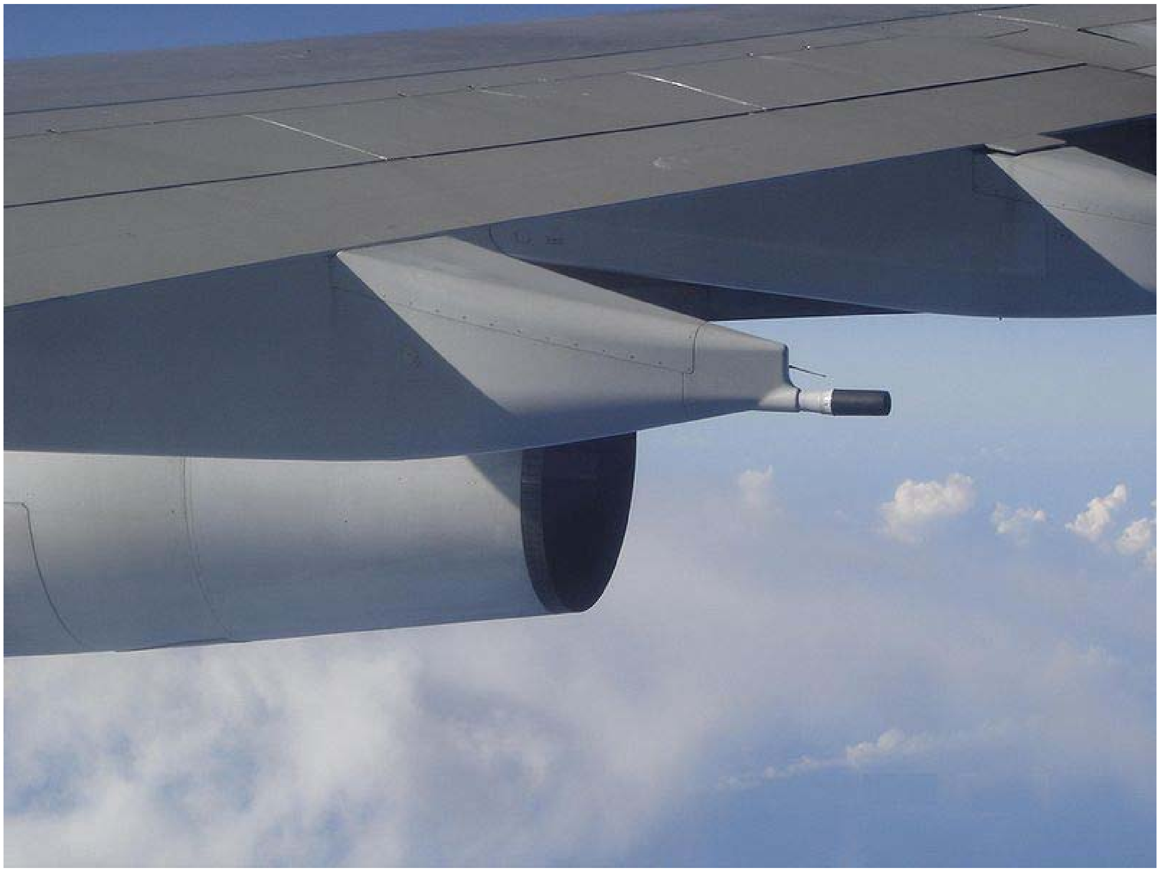
Many designs that incorporate flaperons mount the control surfaces away from the wing so as to provide undisturbed airflow at high angles of attack or low airspeeds.

When the flaperon surface is hinged below the trailing edge of a wing, they are sometimes referred to as "Junker Flaperons", from the *doppelflügel* type of trailing edge surfaces used on a number of Junkers aircraft of the 1930s, such as the Junkers Ju 52 airliner, and Junkers Ju 87 *Stuka* iconic World War II dive bomber.

Notable experimental aircraft using flaperons include the V-22 Osprey, the Zenith STOL CH 701, the Kitfox and the RJ.03 IBIS.

Fuel dumping

Fuel dumping of an Airbus A340-600 above the Atlantic Ocean near Nova Scotia



Fuel dump nozzle of an Airbus A340-311

Fuel dumping (or a **fuel jettison**) is a procedure used by aircraft in certain emergency situations before a return to the airport shortly after takeoff, or before landing short of its intended destination to lighten aircraft's weight.

Aircraft fuel dump

Aircraft have two major types of weight limits: the maximum takeoff weight and the maximum structural landing weight, with the maximum structural landing weight always being the lower of the two. This allows an aircraft on a normal, routine flight to take off at the higher weight, consume fuel en route, and arrive at a lower weight. (There are other variables involving takeoff and landing weights, but they are omitted from this discussion for the sake of simplicity.)

It is the abnormal, non-routine flight where landing weight can be an issue. If a flight takes off at the maximum structural takeoff weight and then faces a situation where it must return to the departure airport (due to certain mechanical problems, or a passenger medical issue), there will not be time to consume the fuel meant for getting to the original destination, and the aircraft may be over the maximum structural landing weight to land back at the departure point.

As jets began flying with U.S. airlines in the late 1950s and early 1960s, the FAA rule in effect at the time mandated that if the ratio between an aircraft's maximum structural takeoff weight and its maximum structural landing weight was greater than 105%, the aircraft had to have a fuel dump system installed. Accordingly, aircraft such as the Boeing 707 and 727 and the Douglas DC-8 had fuel dump systems. Any of those aircraft needing to return to a takeoff airport above the maximum structural landing weight would simply jettison an amount of fuel sufficient to reduce the aircraft's total weight to below that maximum structural landing weight limit, and then land.

During the 1960s, Boeing introduced the 737, and Douglas the DC-9, the original models of each being for shorter routes; the 105% figure was not an issue, thus they had no fuel dump systems installed. During the 1960s and 1970s, both Boeing and Douglas "grew" their respective aircraft as far as operational capabilities were concerned via Pratt & Whitney's development of increasingly powerful variants of the JT8D engines that powered both aircraft series. Both aircraft were now capable of longer duration flights, with increased weight limits, and complying with the existing 105% rule became problematic due to the costs associated with adding a fuel dump system to aircraft in production. Considering the more powerful engines that had been developed, the FAA changed the rules to delete the 105% requirement, and FAR 25.1001 was enacted stating a jettison system was not required if the climb requirements of FAR 25.119 (Landing Climb) and FAR 25.121 (Approach Climb) could be met, assuming a 15-minute flight. In other words, for a go-around with full landing flaps and all engines operating, and at approach flap setting and one engine inoperative, respectively.

Since most twinjet airliners can meet these requirements, most aircraft of this type such as the Boeing 737 (all models), the DC-9/MD80 and Boeing 717, the A320 family and various regional jet ("RJ") aircraft do not have fuel dump systems installed. In the event of an emergency requiring a return to the departure airport, the aircraft circles nearby in order to consume fuel to get down to within the maximum structural landing weight limit, or if the situation demands it, simply lands overweight without delay. Modern aircraft are designed with possible overweight landings in mind, but this is not done except in cases of emergency, and various maintenance inspections are required afterwards.

Many movies and TV news stories mistakenly assume that all aircraft can dump fuel, when in fact most cannot. In certain atmospheric conditions where the moisture content of the air is high, 737s (and other aircraft) flying at low altitudes sometimes leave a moisture trail that can come off the top of the wing, wingtips, or trailing edge flaps. Moisture trails coming off the trailing edge flaps can appear especially odd, since the moisture is being "spun" by aerodynamic forces. It is possible that some people observe these moisture trails and wrongly think fuel is being dumped.

Longer-range twin jets such as the Boeing 767 and the Airbus A300, A310, and A330 may or may not have fuel dump systems, depending upon how the aircraft was ordered, since on some aircraft they are a customer option. Three- and four-engine jets like the Lockheed L-1011, McDonnell Douglas DC-10 / MD-11, Boeing 747 and Airbus A340 usually have difficulty meeting the requirements of FAR 25.119 near maximum structural takeoff weight, so most of those have jettison systems. A Boeing 757 has no fuel dump capability as its maximum landing weight is similar to the maximum take-off weight.

Fuel dumping operations are coordinated with air traffic control, and precautions are taken to keep other aircraft clear of such areas. Fuel dumping is usually accomplished at a high enough altitude where the fuel will dissipate before reaching the ground. Fuel leaves the aircraft through a specific point on each wing, usually closer to the wingtips and further away from engines, and initially appears as more liquid than vapor.

The largest scale fuel dumping occurred on September 11, 2001, when many international flights were refused American airspace entry due to numerous hijacking incidents. Many of these international flights were fueled for travel well into the American interior. Many such flights were diverted into Canadian airspace, Newfoundland specifically, or instructed to return to their point of origin. For those mid-flight aircraft unable to land safely due to excessive fuel weight, dumping became necessary.

Dump-and-burn

RAAF F-111 performing a dump-and-burn.

A dump-and-burn is a fuel dump in which the fuel is ignited, intentionally, using the plane's afterburner. A spectacular flame combined with high speed makes this a popular display for air shows or as a finale to fireworks. Dump-and-burns are also referred to as "torching" or "zippos".

General Dynamics F-111 aircraft have been used for this purpose in Australia during the closing ceremony of the 2000 Summer Olympics and (until 2010) regularly at Brisbane's Riverfestival.

Gouge flap

The **Gouge flap**, invented by Arthur Gouge of Short Brothers in 1936, allowed the pilot to increase both the wing area and the chord of an aircraft's wing. This provided the benefit of a shorter take-off distance for a given load, a shorter distance to achieve a given height and a lower take-off speed. This type of flap, in spite of its use on highly successful aircraft such as the Short Sunderland and the Short Stirling, was superseded by other designs, notably the Fowler flap.

Development

The Gouge flap was patented in 1936, British Patent no. 443,516 being awarded jointly to Short Bros. Ltd. and Arthur Gouge for "Improvements in or connected with Wings for Aircraft, (controller flaps)".

The Gouge flap "consists of a sharp nosed aerofoil, which in the closed position, forms part of the wing profile . The flap tapers with the wing, i.e. the width of the flap at any point is a constant proportion of the wing chord at that point; when open the extended portion also varies with the chord. All sections through the flapped portion of the wing are similar in shape and proportion. The flap moves on tracks, rotating conically about an imaginary axis below the wing, nearly parallel to the trailing edge. When open the flap increases the wing chord and the wing area."

Excellent photographs of the fully-extended flap, taken from obliquely above and below the wing, are given in the British Aeronautical Research Committee's research paper R&M No. 1753 Among the conclusions of that report were that "flap half and fully open decreases the distance from rest to take-off by 14 per cent. and 23 per cent., and also decreases the distance from take-off to clear a 50 ft. obstacle by 21 per cent. and 23 per cent. respectively. The speed at take-off is reduced by 3 and 8 m.p.h, respectively."

History

Short Brothers first installed the Gouge flap on a Scion fitted with the (scaled-down) wings being prepared for the Short Empire flying-boat. The flaps on this aircraft, which was designated 'M.3', were submitted to extensive testing by the Royal Aircraft Establishment Farnborough, their report appearing as R&M No. 1753. Shorts used the Gouge flaps on several successful aircraft types, e.g. the Empire boats, the Short S.26 G-class 'Golden Boats', the Short Sunderland and the Stirling.

When *Flight* Magazine described the Fowler flap in 1942, the article's subtitle read "An American High-lift Device With Properties Similar to Those of the Better-known British

Types", and the Gouge, Handley Page, and Fairey/Youngman flaps were all given equal mention. The Gouge flap, although widely used on Shorts aircraft, was not adopted by other manufacturers, several of which developed their own variants. The Aeronautical Research Council's R&M no. 2622 entitled "The Aerodynamic Characteristics of Flaps" dated 1947 compared many variants but merely mentions the Gouge flap in a footnote on p.10, where it is described as being "rather like the Blackburn flap ... but with no slot between the flap and wing."

The advantage of the additional lift generated by a slot acted in the Fowler flap's success relative to the Gouge flap, as did its natural tendency to retract itself in flight.

Shorts themselves did not use the Gouge flap on their next project, the Shetland, preferring the use of slotted flaps on this large seaplane.

Gust lock

Gust lock on a rudder.

A **gust lock** on an aircraft is a mechanism that locks control surfaces in place preventing random movement and possible damage of the surface from wind while parked. Gust locks may be internal or external.

Safety

A gust lock can pose a serious safety hazard if its removal is omitted before an aircraft's takeoff because it renders the flight control inoperative.

The prototype of the B-17's crash on October 30, 1935

The very first example built of the Boeing B-17 Flying Fortress, the initial Model 299 aircraft, was lost in just this way on October 30, 1935, when its self-contained gust locks were left engaged, with the resulting crash killing Boeing chief test pilot Leslie Tower, and United States Army Air Corps test pilot Ployer Peter Hill. Less than a year later, Nazi German Luftwaffe *Generalleutnant* Walter Wever lost his life in a similar accident from gust lock neglect, when his Heinkel He 70 *Blitz* monoplane crashed on June 3, 1936 from the *Blitz's* aileron gust locks not being disengaged before takeoff. Crown Prince Gustav Adolph of Sweden and 21 others were killed in 1947 during the crash of a special KLM flight at Copenhagen Airport due to the flight crew forgetting to disengage the gust lock on the tail fin of the aircraft.

For this reason, gust lock disengagement is a very important step on the takeoff checklist for those aircraft equipped with gust locks.

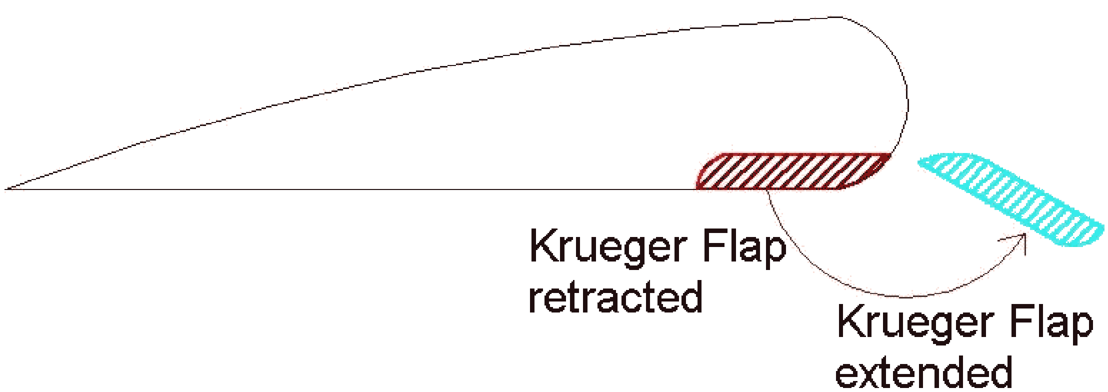
Krueger flaps

Krueger flaps deployed from the leading edge of a Boeing 747

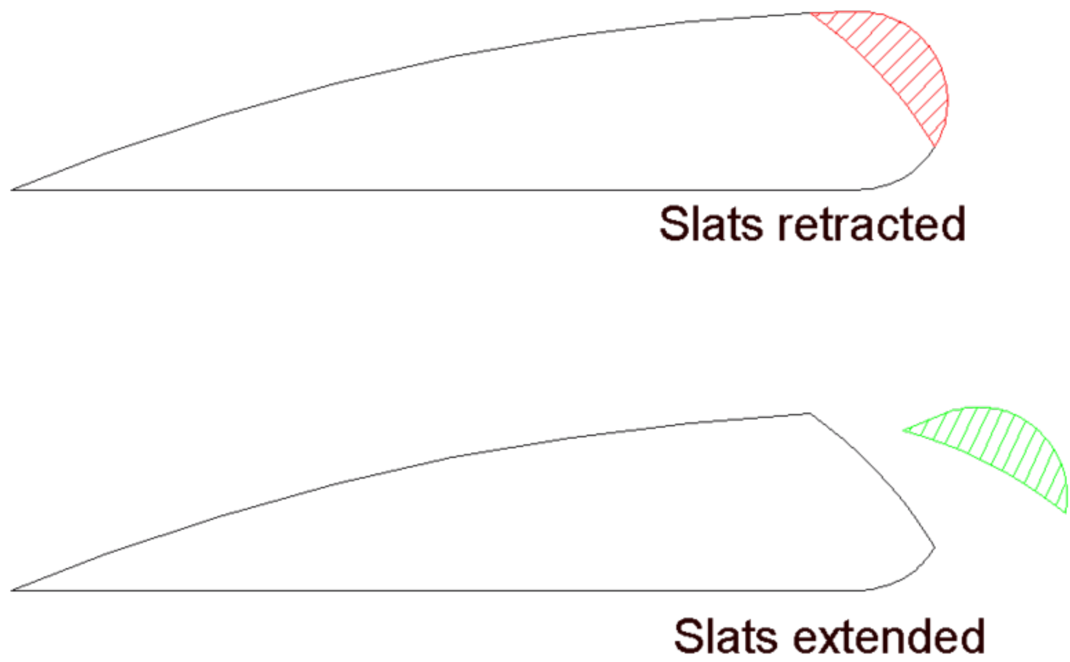
Krueger flaps are lift enhancement devices that may be fitted to the leading edge of an aircraft wing.

Operation

While the aerodynamic effect of Krueger flaps is similar to that of slats or slots, they are deployed differently. Krueger flaps, hinged at their leading edges, hinge forwards from the under surface of the wing, increasing the wing camber and maximum coefficient of lift. Conversely, slats extend forwards from the upper surface of the leading edge.



Krueger flap operation



Slat operation

The Krueger flaps developed for the Boeing 747 were constructed from fiberglass honeycomb material and were designed to be intentionally distorted into an aerofoil section on deployment.

LNAV

Lateral navigation (**LNAV**) refers to navigating over a ground track with guidance from an electronic device which gives the pilot (or autopilot) error indications in the lateral direction only and not in the vertical direction. In aviation lateral navigation is of two guidance types: linear guidance and angular guidance. Linear means that the left and right deviations of the aircraft are available as a distance of the aircraft from the desired ground track to its actual position on either side of the desired track. In angular guidance, the error indication is given in degrees of angle from the desired line relative to a ground-based navigation device. To provide an illustration, as the aircraft approaches the ground device with a constant angular error, its distance to the desired ground line decreases. In the context of aviation instrument approaches, an LNAV approach (one that uses lateral navigation) is implied to be a GPS-based approach and to have linear lateral guidance. A VOR based approach will have angular lateral guidance.

Using LNAV on Instrument Approaches: The Non-precision approach

The approach minimums for LNAV approaches are higher than that of ILS approaches and RNAV approaches that incorporate vertical guidance. Aircraft executing an LNAV instrument approach must descend incrementally rather than follow a fixed glide slope. This is called a 'non-precision' approach to distinguish it from a precision approach in which there is electronic vertical (slope) guidance down to a decision altitude (DA). In the case of the non-precision approach, the aircraft can descend only to what is referred to as a minimum descent altitude or MDA. An MDA segment is flown until the airport is in sight and the pilot can land. If the airport is not in sight by the time the pilot reaches a missed approach point (MAP) on the MDA, the aircraft must execute a missed approach.

The GPS implementation of the non-precision LNAV approach can only be flown if satellite configuration at the time of the approach will accurately support a full scale course deviation indication of 0.3 nautical miles (about 1800 feet to the left and right or 3600 feet total) starting at the final approach fix and extending all the way to the missed approach point. If this sensitivity does not occur, the pilot will be notified by the on-board receiver (via RAIM checking) and must not make the descent onto the final leg.

Side-stick

Airbus 380 flight deck showing side sticks

A **side-stick** or **sidestick controller** is an aircraft cockpit arrangement where the control column (or joystick) is located on the side console of the pilot, usually on the righthand side, or outboard on a two-seat flight deck. Typically this is found in aircraft that are equipped with fly-by-wire control systems.

The throttle controls are typically located to the left of the pilot (or centrally on a two-seat flightdeck). Only the right hand may thus be used for the stick and both-hands operation is neither possible, nor required.

The side-stick is used in many modern military fighter aircraft such as the F-16 Fighting Falcon, Dassault Rafale and F-22 Raptor, and also on civil aircraft such as the Airbus A320 and later Airbus aircraft, including the largest passenger jet in service, the Airbus A380.

This arrangement contrasts with the more conventional design where the stick is located in the centre of the cockpit between the pilot's legs, called a "centre stick".

Stabilator

F-16 Falcon fighter jet parked at an airshow, with stabilators deflected downwards.

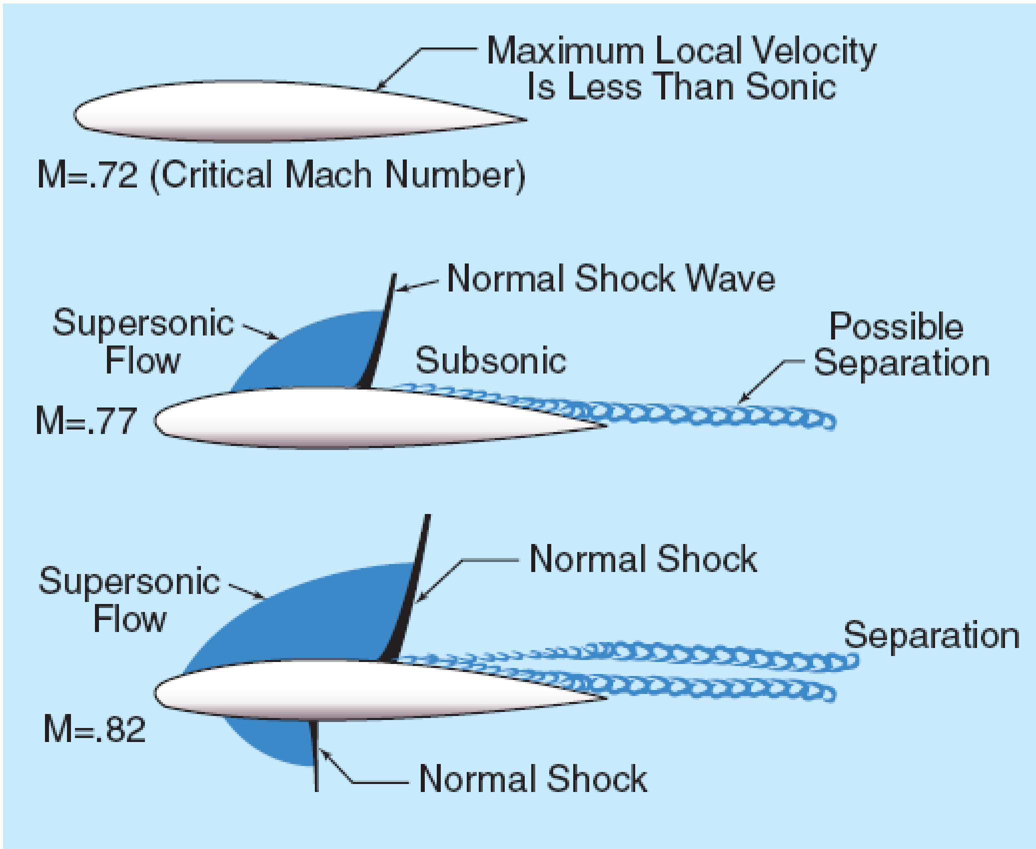
A **stabilator** (**stabil**izer-elev**ator**, also **all moving tailplane** or **all flying tail**) is an aircraft control surface that combines the functions of an elevator and a horizontal stabilizer. Most fixed-wing aircraft control pitch using a hinged horizontal flap — the elevator — attached to the back of the fixed horizontal stabilizer, but some aircraft make the entire stabilizer movable.

General aviation

Piper Cherokee with stabilator (and anti-servo tab) deflected upwards.

Because it involves a large moving surface, a stabilator can allow the pilot to generate greater pitching moment with little effort. Due to the high forces involved in tail balancing loads, stabilators are designed to pivot about their aerodynamic center (at the tail's quarter-chord). This is the point at which the pitching moment is constant regardless of the angle of attack, and thus any movement of the stabilator can be made without added pilot effort. An airplane certified by the appropriate regulatory agency (e.g. the US Federal Aviation Administration) must show an increasing resistance to an increasing pilot input (movement), so to provide this resistance, stabilators on small aircraft contain an anti-servo tab (sometimes combined with the trim tab) that deflects in the same direction as the stabilator, thus providing an aerodynamic force resisting the pilot's input. General aviation aircraft with stabilators include the Piper Cherokee and the Cessna 177.

Military



In transonic flight shockwaves form on the upper surface of the wing at a different point from the lower surface. As speed increases, the shockwave moves backwards over the wing. On conventional tails this high pressure causes the elevator to be deflected downwards.

All flying tailplanes were used from early times and in 1929 the de Havilland DH.77 offering for a Royal Air Force fighter used an all flying tail.

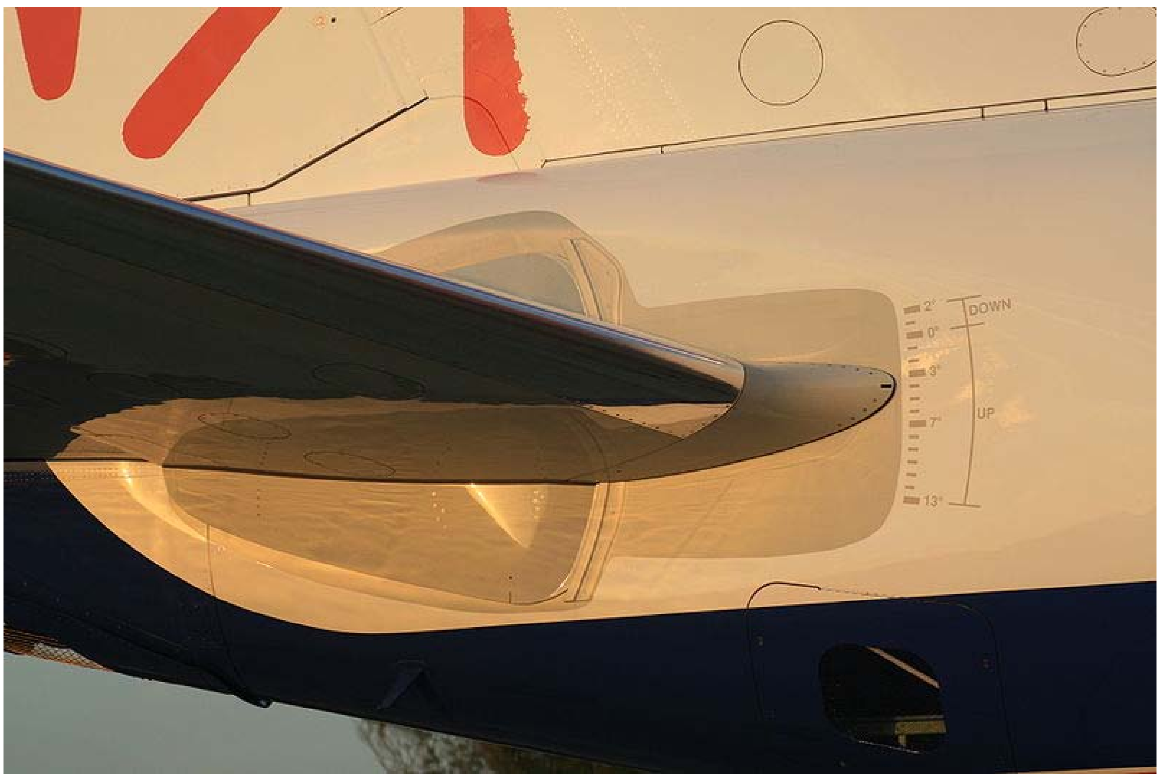
Stabilators were developed in response to the need to achieve adequate pitch control in supersonic flight, and are almost universal on modern military combat aircraft. All non-delta-winged supersonic aircraft use stabilators because with conventional control surfaces, shockwaves can form past the elevator hinge, causing severe mach tuck.

The British wartime Miles M.52 supersonic project had stabilators though the design flew only as a scale rocket. The contemporary US supersonic project, the Bell X-1, adapted its variable incidence tailplane into an all-moving tailplane (based on Miles M.52 data) and was operated successfully. The North American Aviation F-86 Sabre, the first USAF aircraft which could go supersonic (although in a shallow dive) was introduced with a conventional horizontal stabilizer with elevators, which was eventually replaced with a stabilator.

Stabilators are also known in military terminology as **all-moving** or **all-flying tailplanes**. When stabilators can move differentially to perform the roll control function of ailerons, as they do on many modern fighter aircraft they become **tailerons** or **rolling tails**. A stabilator can also be mounted in front of the main wing in a **canard** configuration.

Stabilators on military aircraft have the same problem of overcontrol as general aviation aircraft. In older jet fighter aircraft, a resisting force was generated within the control system, either by springs or a resisting hydraulic force, rather than by an external anti-servo tab. For example in the F-100 Super Sabre, springs were attached to the control stick to provide increasing resistance to pilot input. In modern fighters, control inputs are moderated by computers ("fly by wire"), and there is no direct connection between the pilot's stick and the stabilator.

Airliners



Adjustable stabilizer on an Embraer ERJ-170, with markings showing the degree of nose-up and nose-down trim available

Most modern airliners adjust the angle of the tailplane to trim during flight as fuel is burned and the center of gravity moves. These adjustments are handled by adjustable (in angle of attack) horizontal stabilizers. However, such adjustable stabilizers are not the same as stabilators; a stabilator is controlled by the pilot's control yoke (or stick), and an adjustable stabilizer is controlled by the trim system. One example of an airliner with a genuine stabilator used for flight control is the Lockheed L-1011.