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Introduction to Aircraft Systems

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Aircraft control systems

- Introduction
- Principles of flight control
- Flight control surfaces
  - Primary flight control
  - Secondary flight control
- Flight control linkage systems
- Artificial feel system
- Flight control actuation
- Summary

The famous Wright Flyer in 1903
with multiple control surfaces

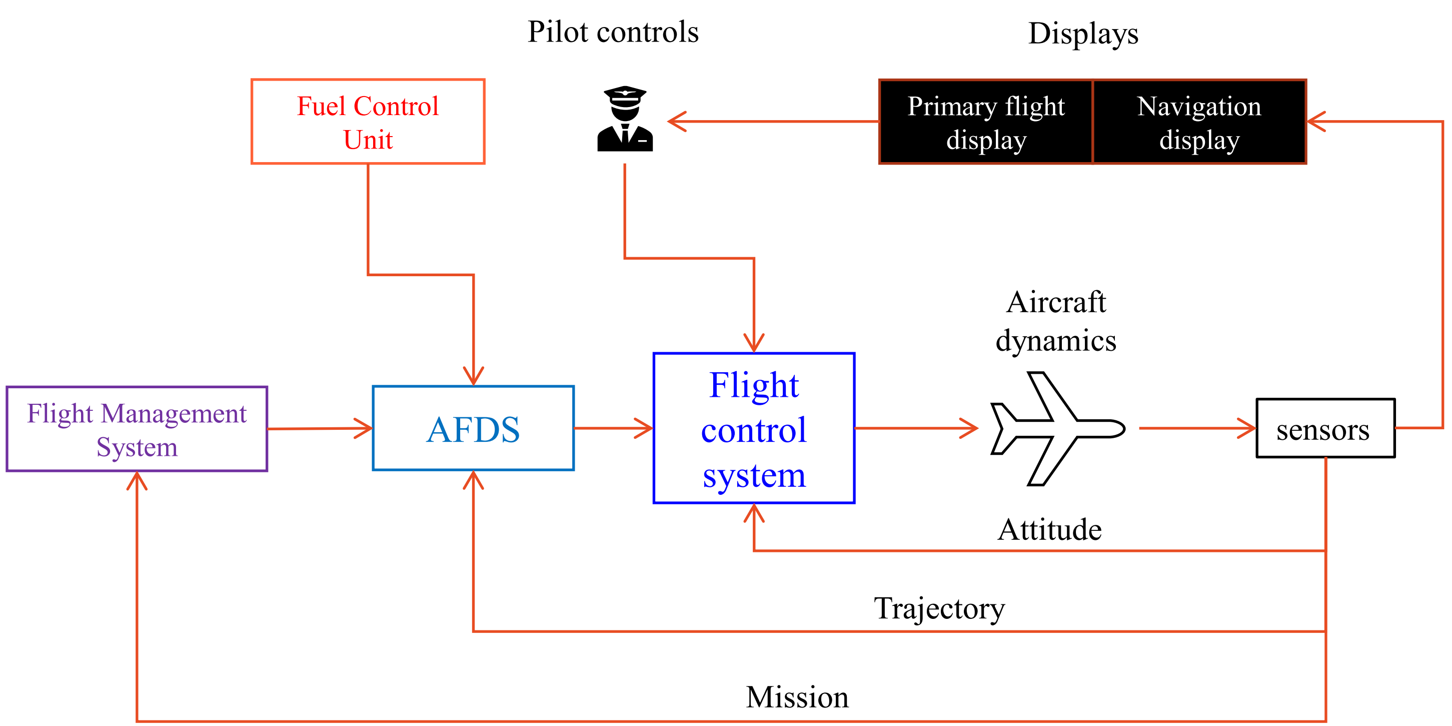
Introduction

Motions of an aircraft

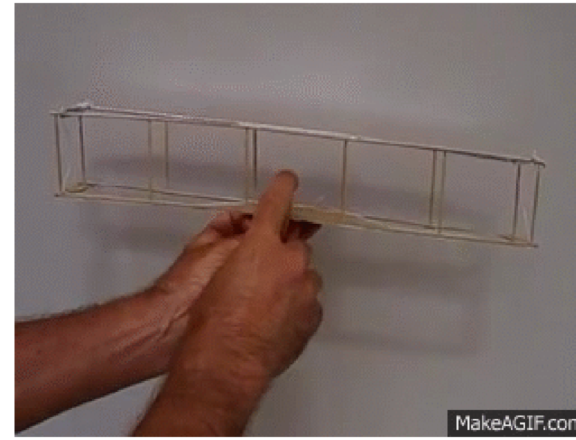
AFDS: Autopilot Flight Director System
FCU: Fuel Control Unit

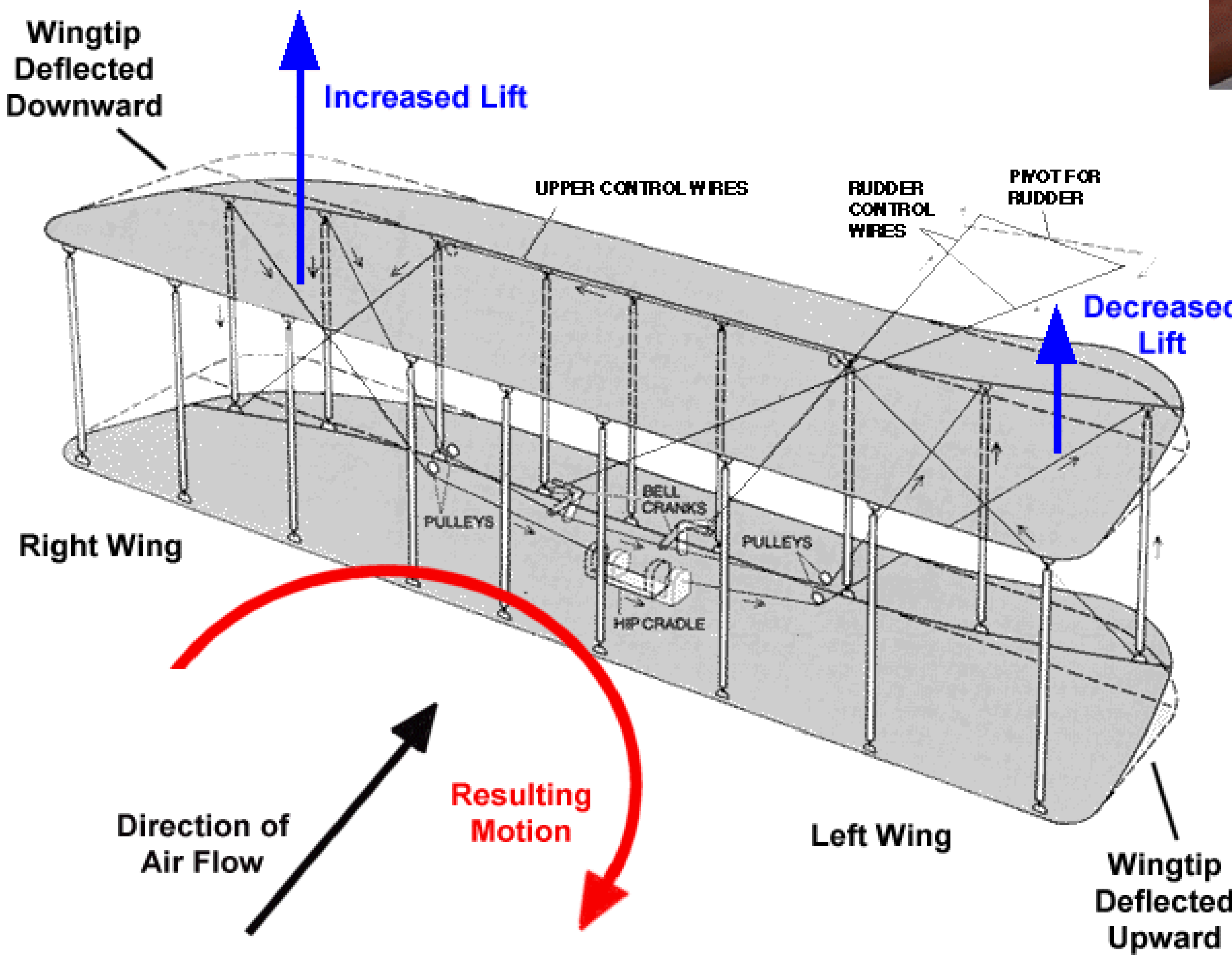
Aircraft control: key role in realize a flight

- An aircraft should be controlled to:
  - Maintain stability and safety of the aircraft
  - Realize the given flight trajectory
  - Realize the given flight mission



Wing warping control in Wright's Flyer





- Wires connected to control surfaces
- Pilot's control

Increasing complexity in flight control

- Challenges in the flight control of modern aircraft:
  - Higher speed of the aircraft with jet propulsion
    - Aerodynamics-related oscillations
  - Higher load of the aircraft:
    - The forces cannot be provided by physical power of pilots
  - More complicated manoeuvred flight
- Advanced flight control systems are needed:
  - Auto-stabilization
  - Control and Stability Augmentation System (CSAS)
  - Digital “fly-by-wire” (FBW) systems

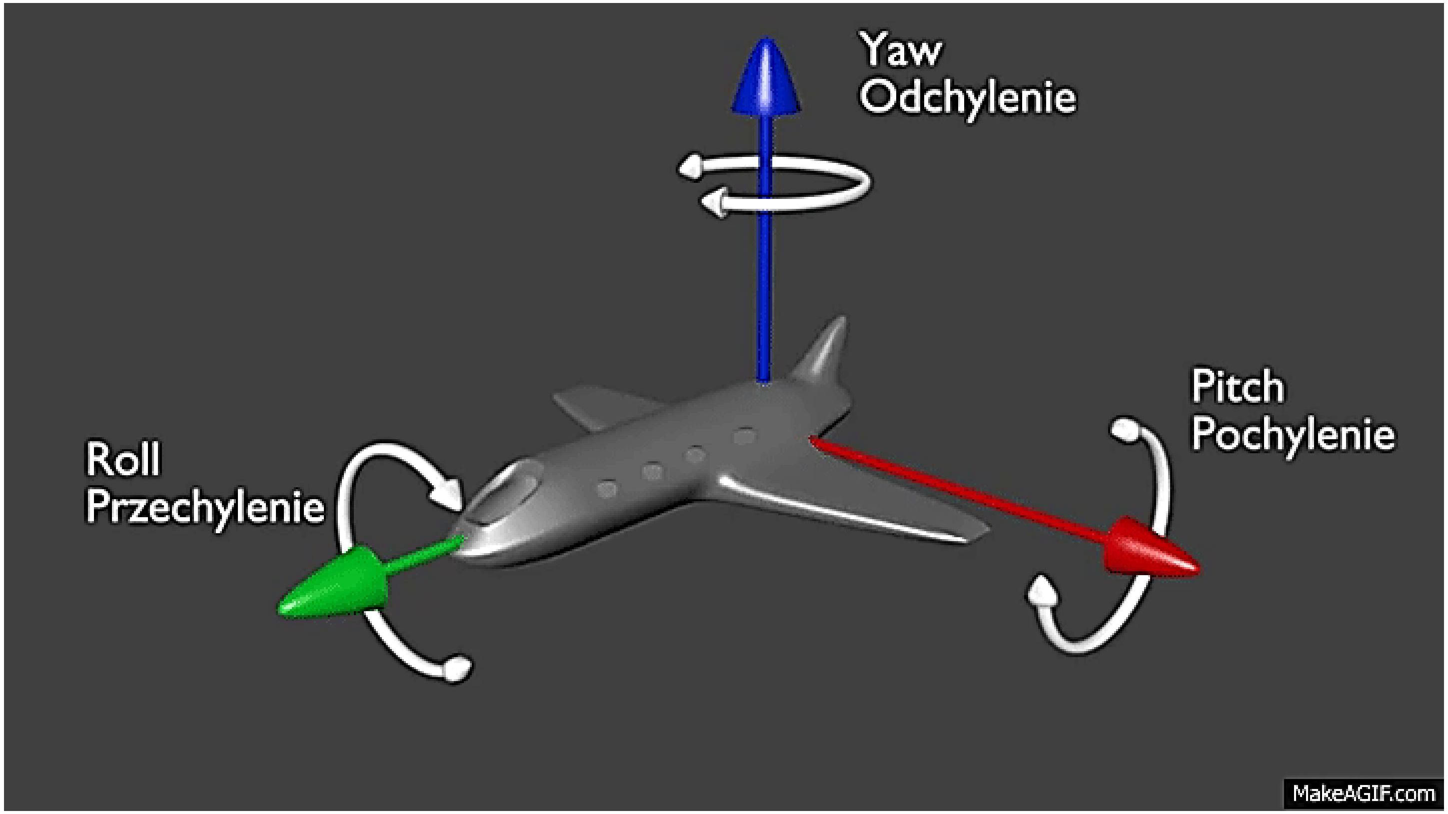
Flight control systems

- An aircraft control system is a collection of components and subsystems to realize controlling the flight of an aircraft. The control system can include mechanical, hydraulic and electrical systems.
- Top companies in Aircraft Flight Control Systems are:
  - Honeywell International Inc. (US)
  - Moog Inc. (US)
  - Safran SA (France)
  - BAE Systems (UK)
  - Rockwell Collins (US)
  - etc.

Principles of flight control

All aircraft, including the simplest and most supplicated ones, are governed by the same basic principles of flight control

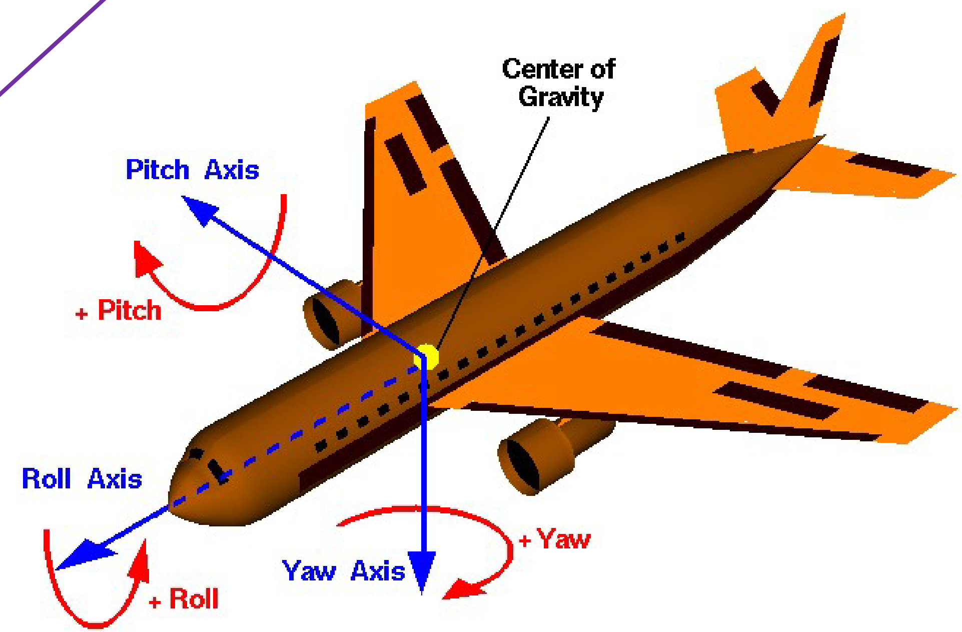
Motions of an aircraft



Motions of an aircraft

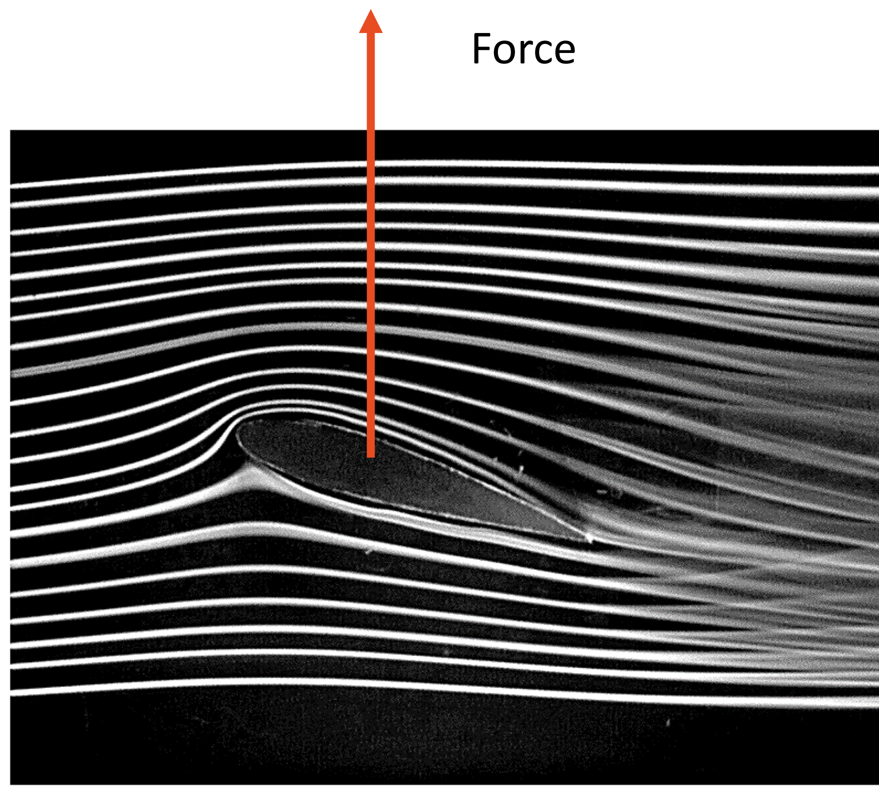
- If the pilot wishes to climb:
  – Rotate around the pitch axis
- If the pilot wishes to alter heading:
  – Rotate around the yaw axis
- If the pilot needs to rotate
  – Rotate around the roll axis
- If the pilot wishes to speed up/deaccelerate
  – Control the engine power

Usually, more than 1 actions are realized simultaneously to achieve the target flight



Flight control surfaces

- The flight control system enables the pilot to complete the motions
- Control surfaces are essential components to allow the aircraft to manoeuvre pitch, roll and yaw, and stabilize the flight
  - Primary flight control
  - Secondary flight control

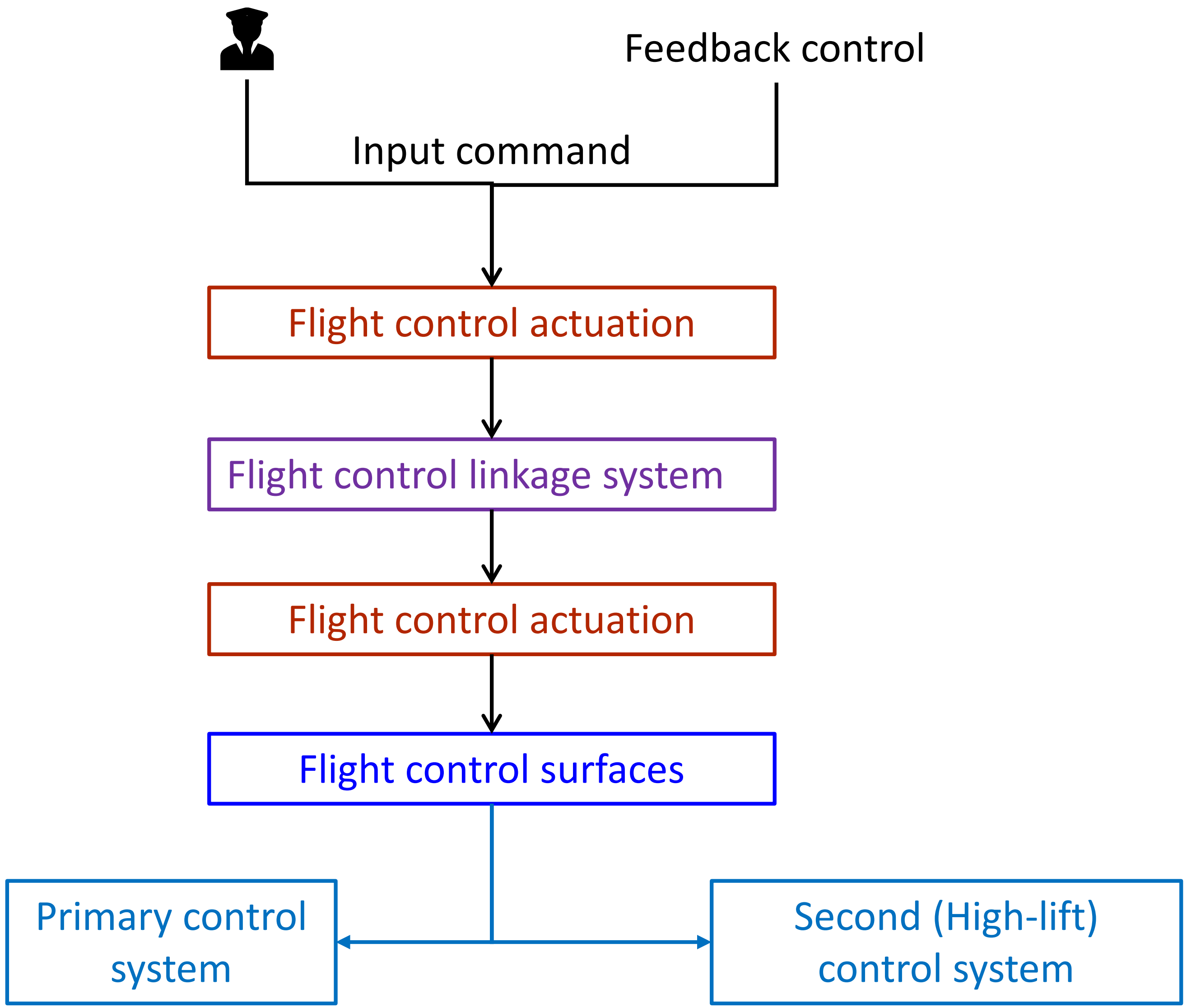


Aircraft control systems

- Aircraft control systems consist of flight control surfaces, the respective cockpit controls, connecting linkages, and the necessary operating mechanisms to control the aircraft direction in flight.
- Aircraft engine control can be considered as flight control as they change speed.
- Aircraft control classification
  - Primary flight control
  - Secondary/ Auxiliary flight control

Flight control components

Actuation: related to the ability of flight control system to attain the performance



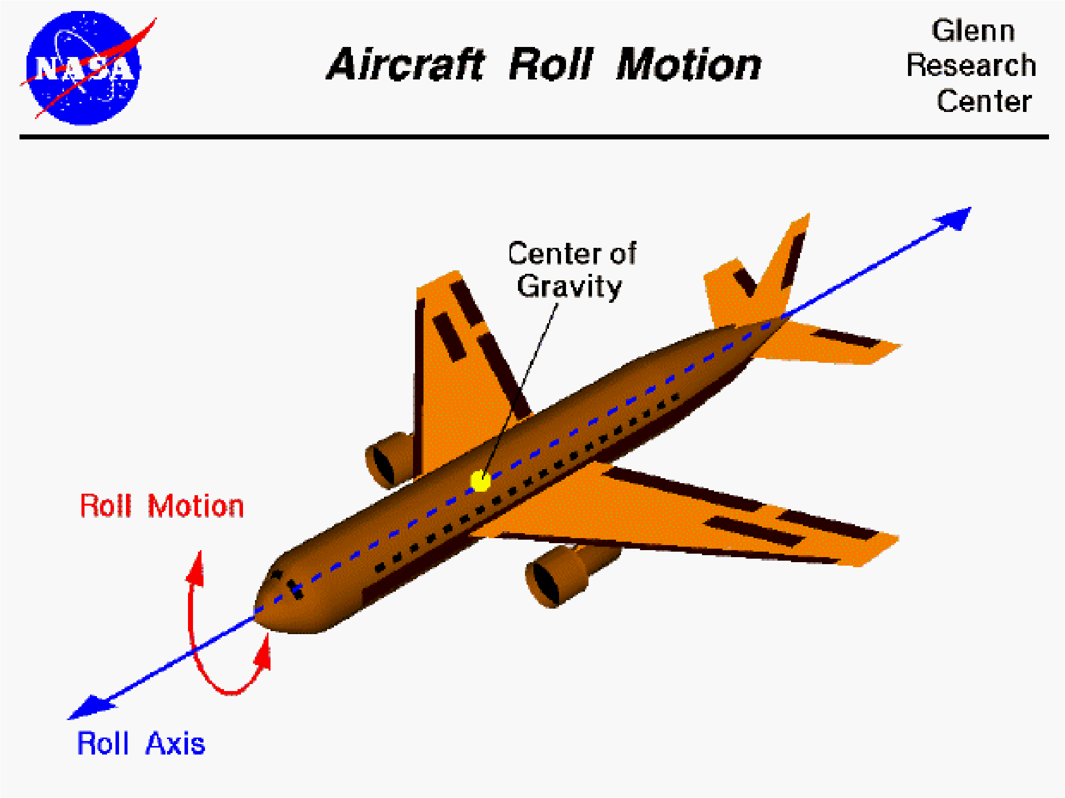
Control surfaces: Primary flight control

Primary flight control

- Primary flight control in pitch, roll and yaw is realized by control surfaces.
  - Aileron control system (roll): on the wing of the aircraft
  - Elevator control system (pitch): on the horizontal tail plane (HTP)
  - Rudder control system (yaw): on the vertical tail plane (VTP)

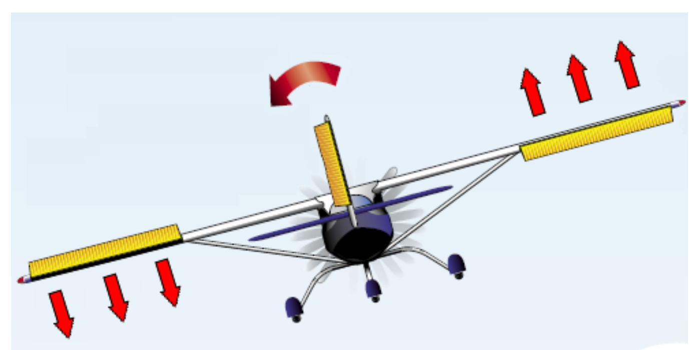
Aileron/副翼

- A hinged flight control surface to control the roll motion
- Ailerons are located at the outboard trailing edge of each wing to give the greatest rolling moment



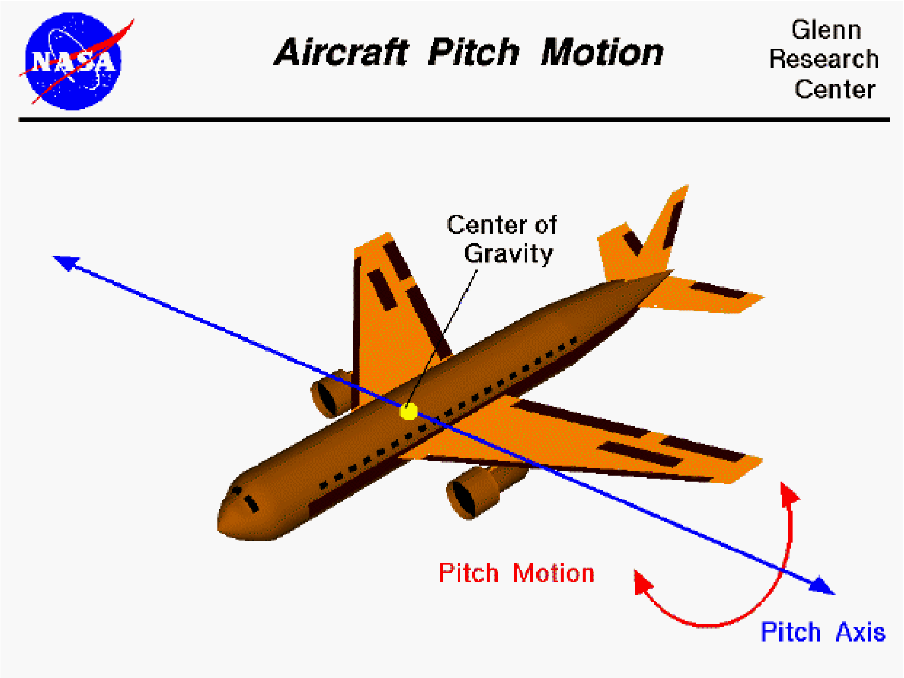
Aileron/副翼

- On small airplanes, ailerons are connected by cables, bell-cranks, pulleys and push-pull rod to a control column or control stick.
- If the control column or yoke is turned to the right, it will deflect the right aileron up and the left aileron down to create positive roll motion.
- If the control column or yoke is turned to the left, the opposite will result. The pair of ailerons always move in opposite directions.



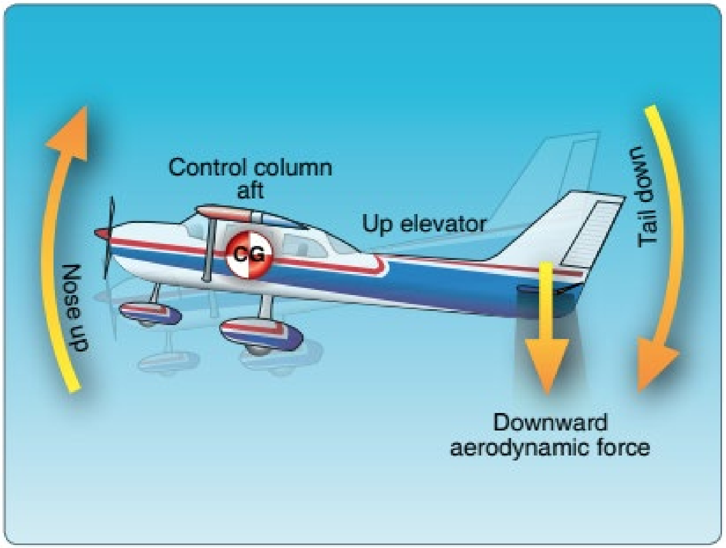
Elevator/升降舵

- Elevator controls aircraft rotation about the lateral axis, i.e., pitch
- It is located at the trailing edge of the HTP
- The strength of the pitching moment depends on the aerodynamic effectiveness of the HTP



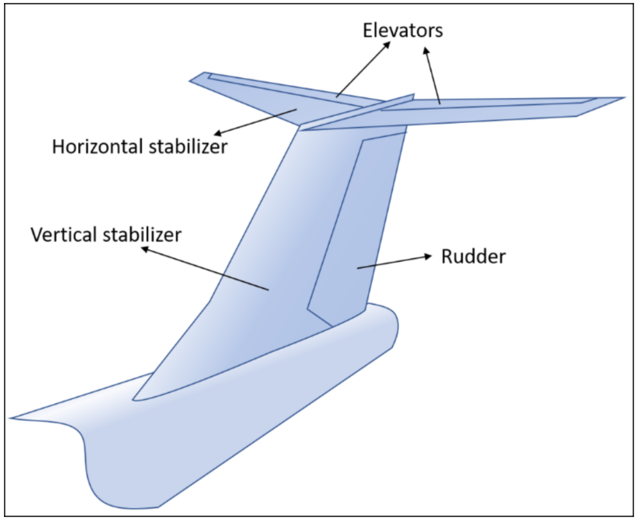
Elevator/升降舵

- On small airplanes, the elevator is connected mechanically and controlled through the control column.
- If the control column is pulled back (control column aft), it will deflect the elevator up (up-elevator) to increase the downward lift on the HTP. The result pitches the nose of the aircraft up.
- If the control column is pushed forward, the opposite will result.



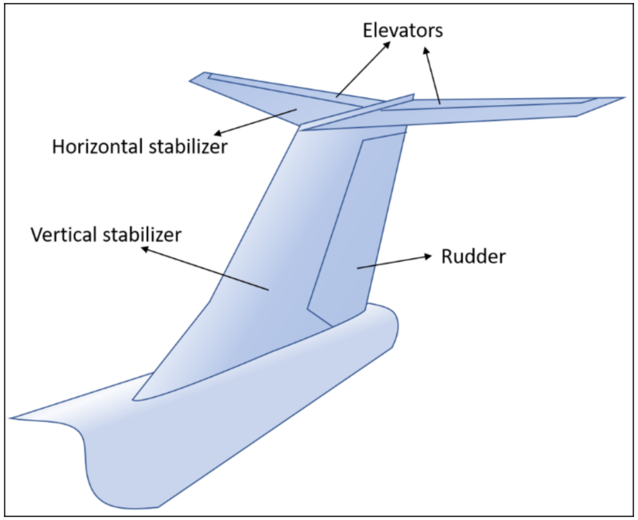
T-tail configuration /T-型尾翼

- T-tail configuration, the elevator is above most of the effects of downwash from the airfoil from propeller, fuselage, etc.
- T-tail configuration is popular for light and large aircraft, e.g., seaplanes



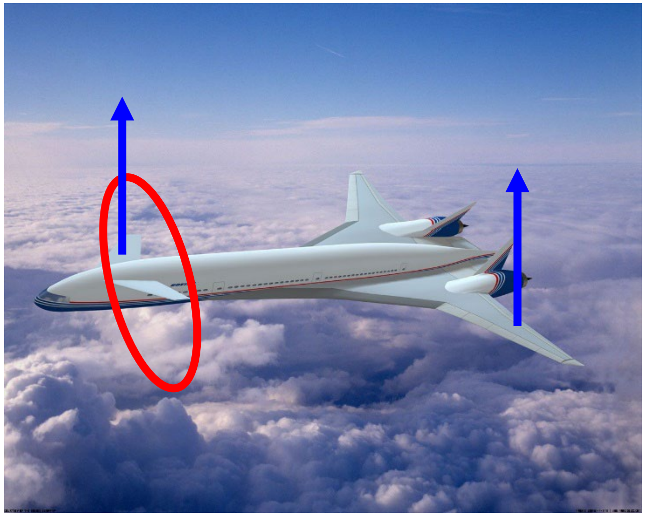
T-tail configuration /T-型尾翼

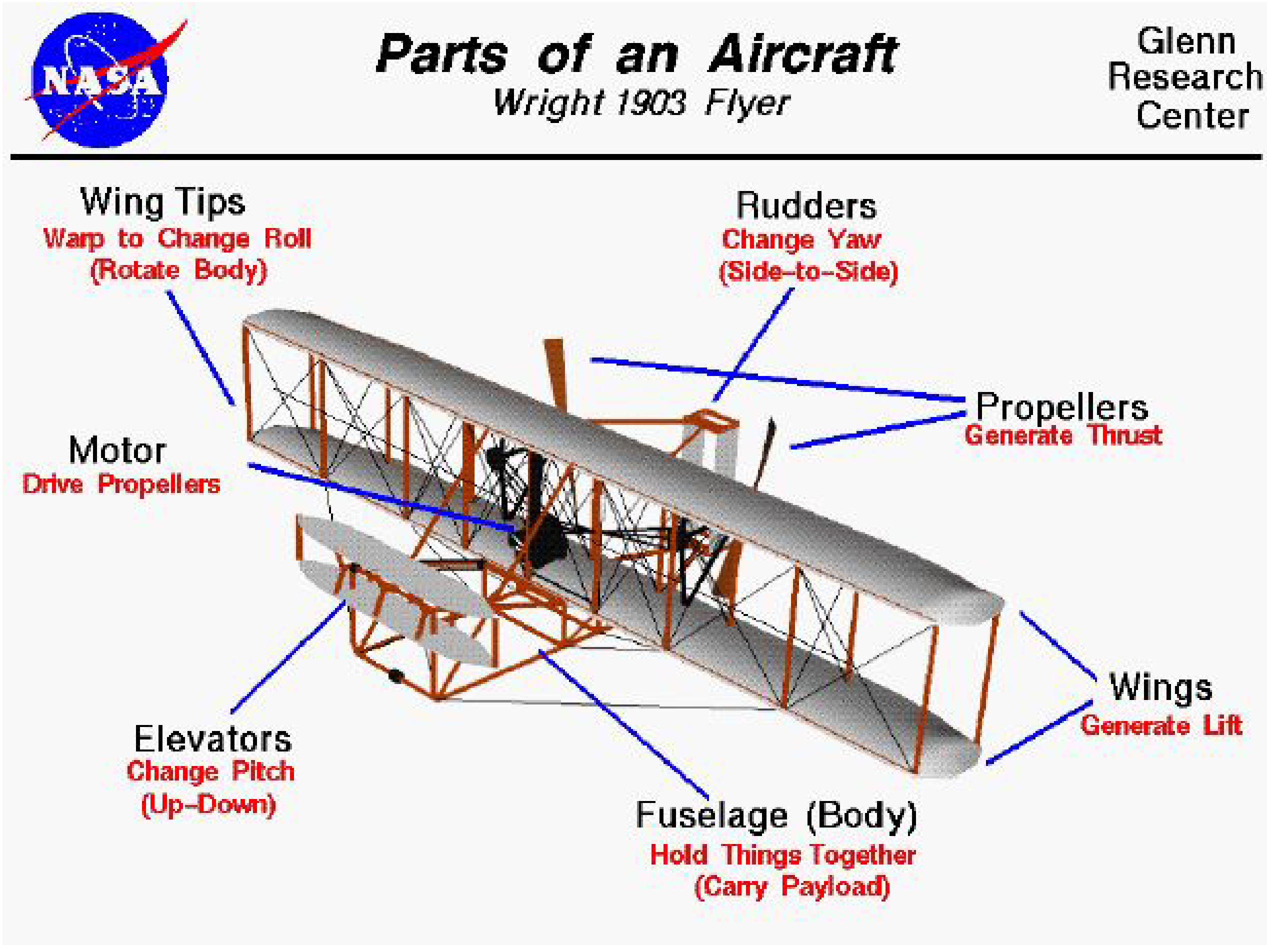
- There are issues such as flutter/顫振, susceptible to deep stall, etc.
- The elevator can cause a relatively large moment acting to the VTH. Therefore, there is additional requirement in the materials used.



Canard/前置翼（鴨翼）

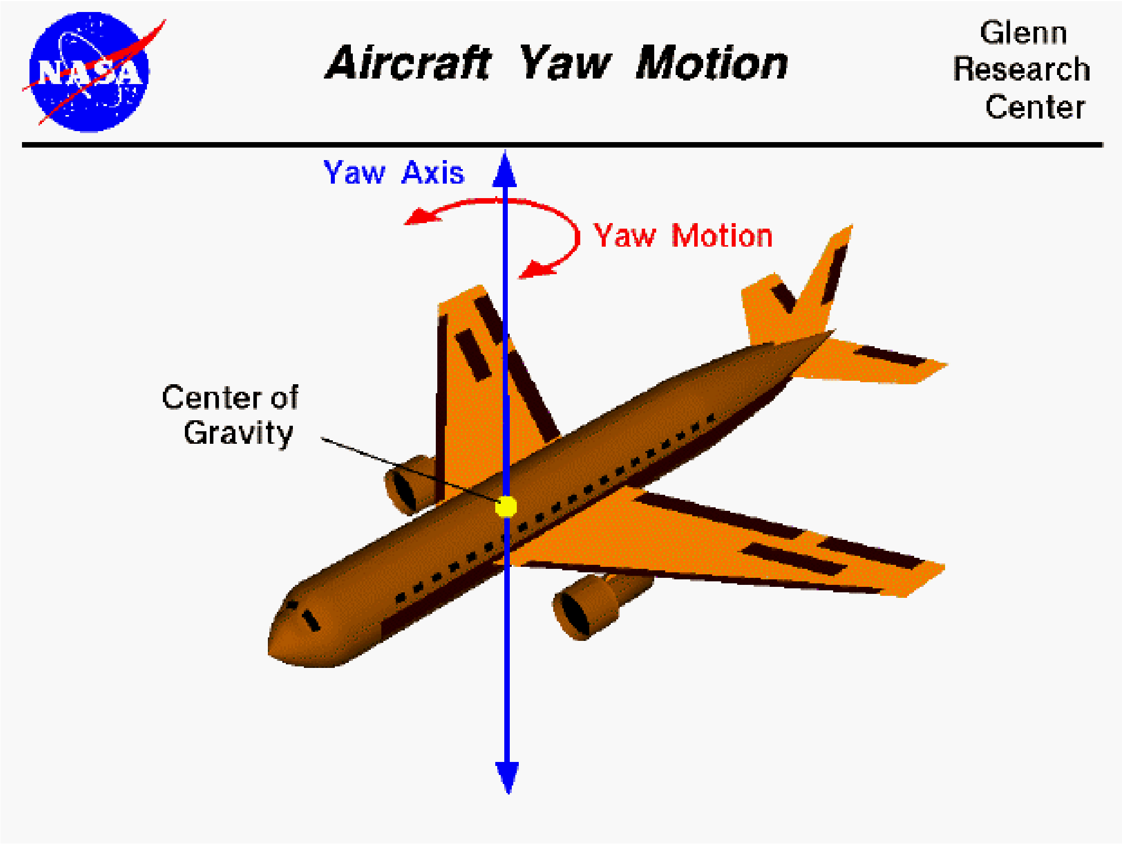
- The canard design uses two lifting surface. In this case, the canard is placed in front the main wings to stabilize the aircraft.
  - Canard: mainly provide force to realize nose-up
  - Aft-tail (elevator): mainly provide lift force to prevent nose-up
- The Wright Flyer utilized the Canard design.




Parts of an Aircraft
Wright 1903 Flyer
Glenn Research Center
Wing Tips
Warp to Change Roll
(Rotate Body)
Rudders
Change Yaw
(Side-to-Side)
Propellers
Generate Thrust
Motor
Drive Propellers
Wings
Generate Lift
Elevators
Change Pitch
(Up-Down)
Fuselage (Body)
Hold Things Together
(Carry Payload)

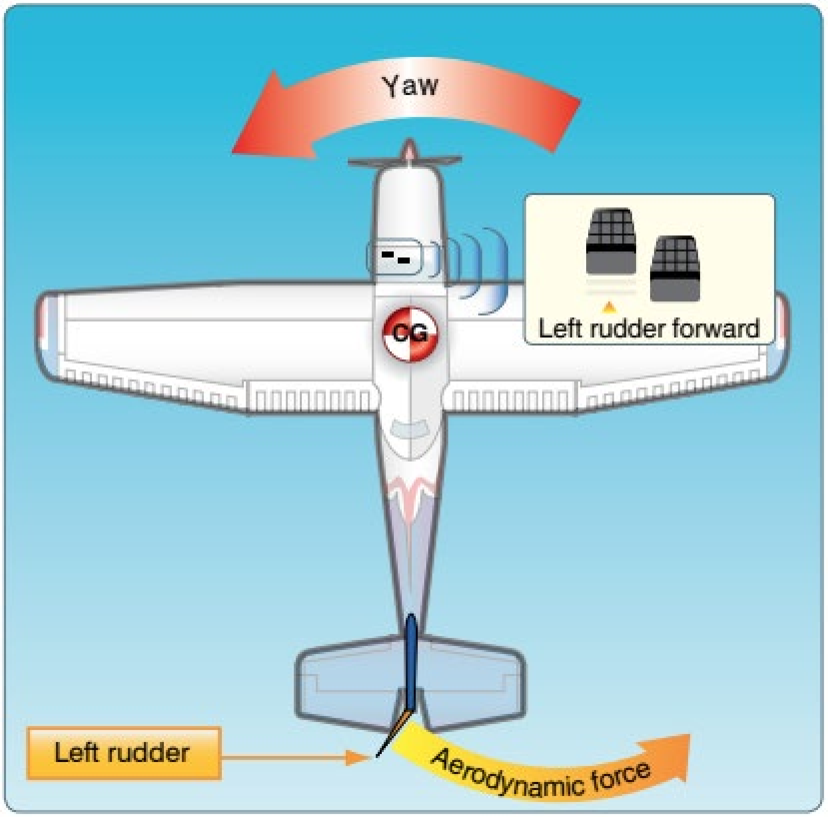
Rudder/方向舵

- Rudder controls the yaw motion of the aircraft



Rudder/方向舵

- On conventional aircraft, the rudder is hinged to the vertical tail plane (VTP)
  - In some aircraft, the rudder is located at the whole VTP
  - In some aircraft, the rudder is located at the trailing edge of VTP



Rudder/方向舵

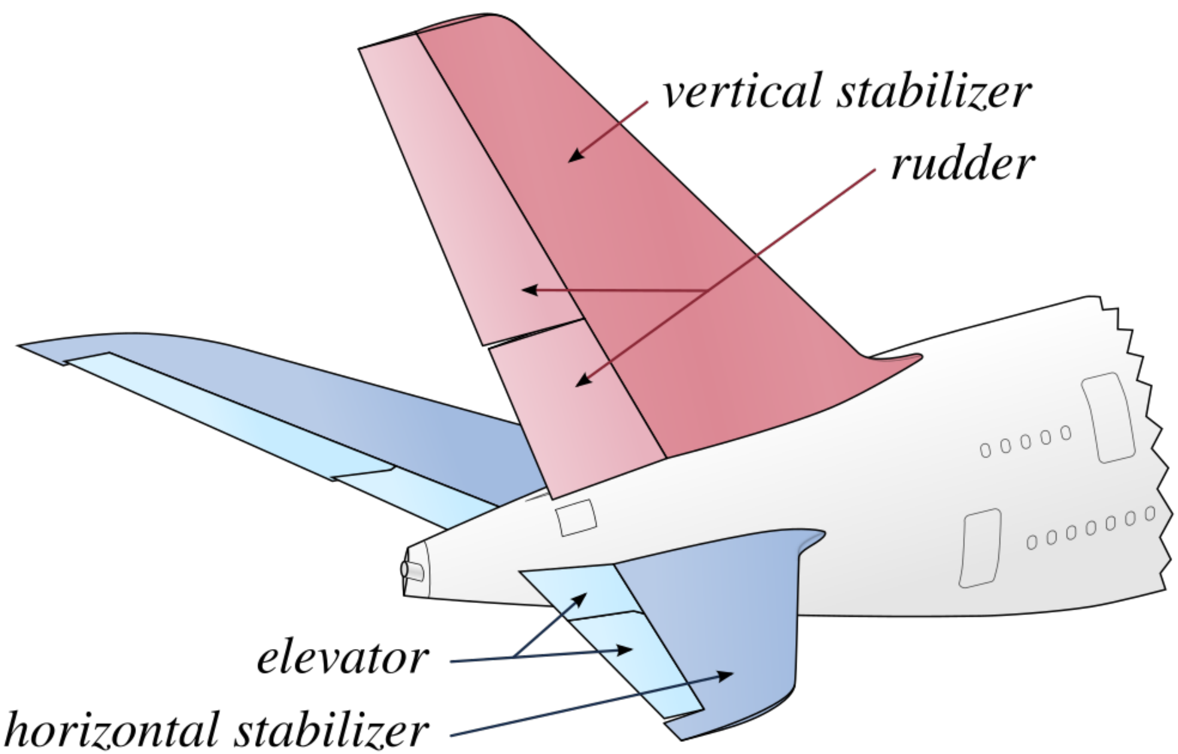
- Deflecting the rudder left or right in the presence of airflow generates an aerodynamic force in the corresponding opposite direction.
- The moment generated by the sideward lift on the tail will yaw the aircraft left or right.

V-Tail/V-型尾翼

- The V-tail design uses two slanted tails to performance the same functions of elevator and rudder.
  - The fixed parts have the same function as the stabilizators
  - The movable parts are often called the ruddervators

Empennage/尾翼 and Stabilizer/穩定器

- In conventional aircraft, the elevator and rudder are often located in the empennage/tail of an aircraft.
- The <u>fixed parts</u> in the vertical and horizontal tails are often called the <u>stabilizer</u>



Control surfaces: Secondary flight control

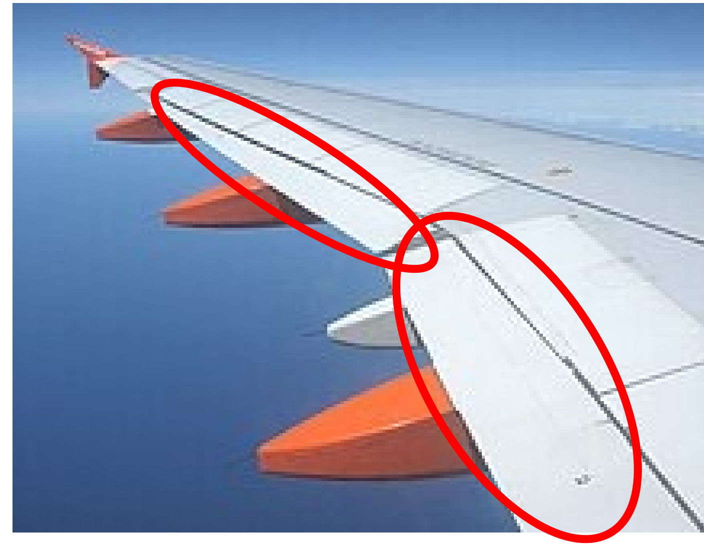
Secondary/Auxiliary flight control

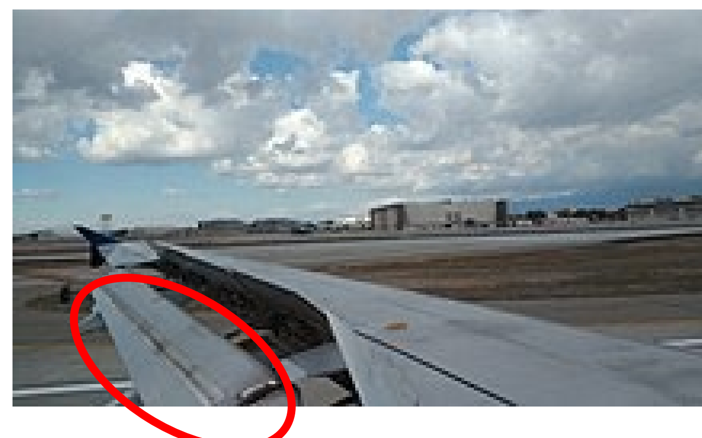
- The secondary flight control systems are used to auxiliary with the primary flight controls to better control the aircraft.
- We may not see all secondary flight controls in every aircraft, depending on the design.
- Secondary flight control contains:
  - High-lift devices: Flaps & Slats
  - Air brakes & Spoilers
  - Trim systems

(Tailing edge) Flap/襟翼

- A flap is a high-lift device used to reduce the stall velocity during the landing and take-off
  - To <u>increase</u> the wing camber and improve the aerodynamic characteristics, i.e., the <u>lift</u> is increased
  - To <u>increase</u> the <u>drag</u> as well: Reduce the take-off and landing distances
- It is often placed at the trailing edge of a wing
  - Spanwise from near the <u>wing root</u> to the <u>ailerons</u>

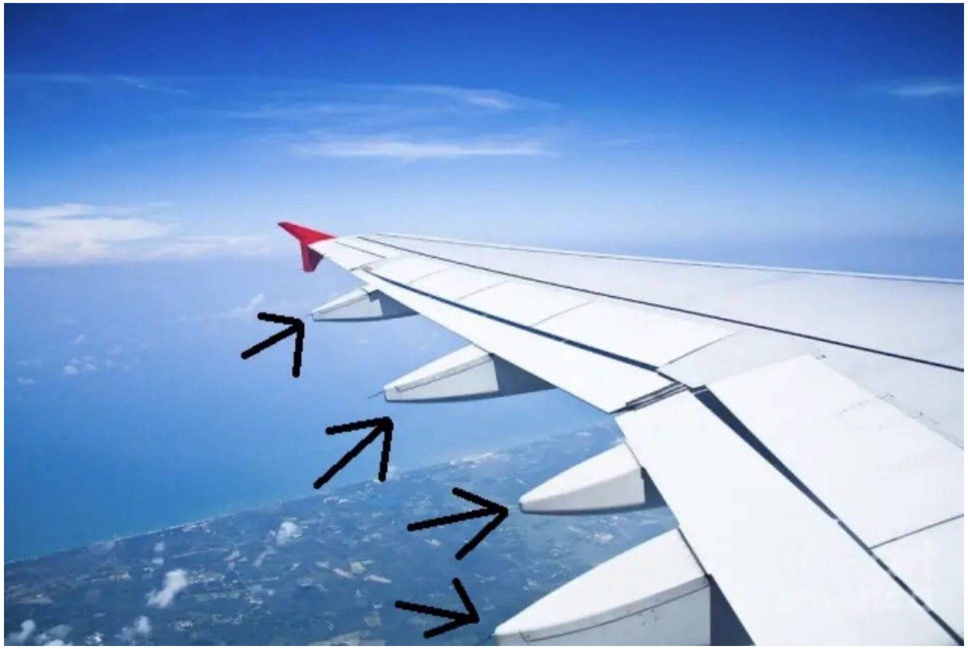
During take-off: extend for increasing lift





During landing: combined with spoilers to increase the drag

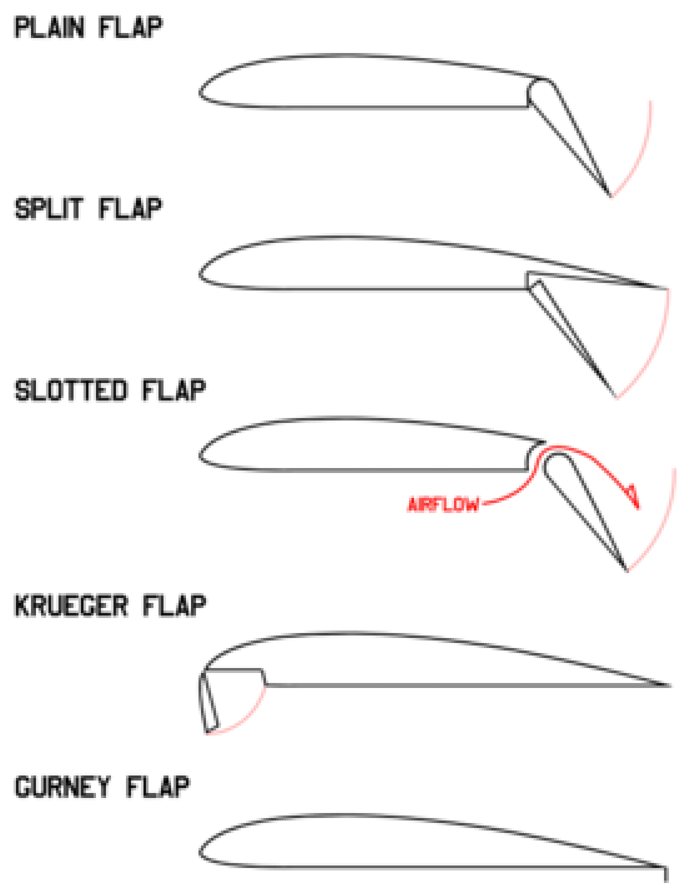
Flat track fairing/襟翼滑轨整流罩



The jackscrew, carriages, gearboxes, and associated mounting bracketry are very un-aerodynamic within these structures. Therefore, the Flap Track Fairings is used to cover them.

Types of flaps

- Flap design is an important part in aircraft aerodynamic design.
- Historically and in practical applications, there are many featured configurations such as:
  - Plain flap
  - Split flap
  - Slotted flap
  - Krueger flap
  - Gurney flap, etc.

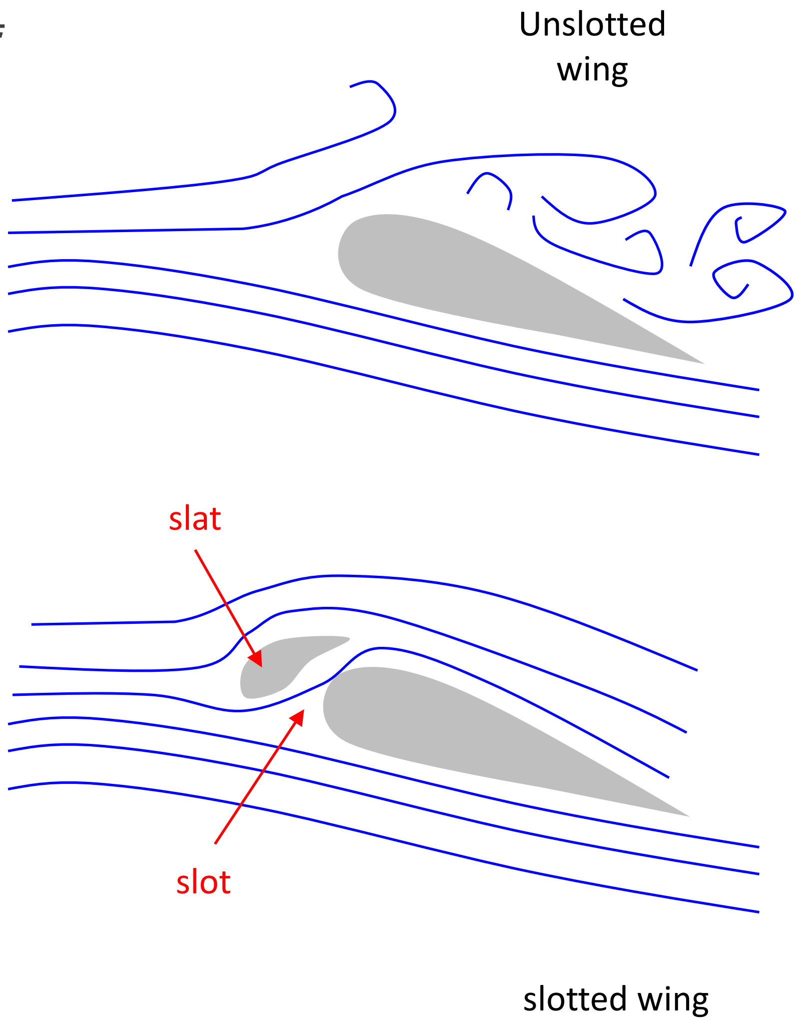


(Leading edge) slat/前緣縫翼

- A slat is an aerodynamic surface on the leading edge of a wing.
- It is operated during the take-off and landing phases.
- The purpose of slat is to:
  - Delay the aerodynamic stall:
  - Increase the lift coefficient

(Leading edge) slat/前緣縫翼

- A slat is a device in the wing that air can goes into the wing such that the flow transition into the turbulence is prevented.
- A slot is a hole that does the same thing.



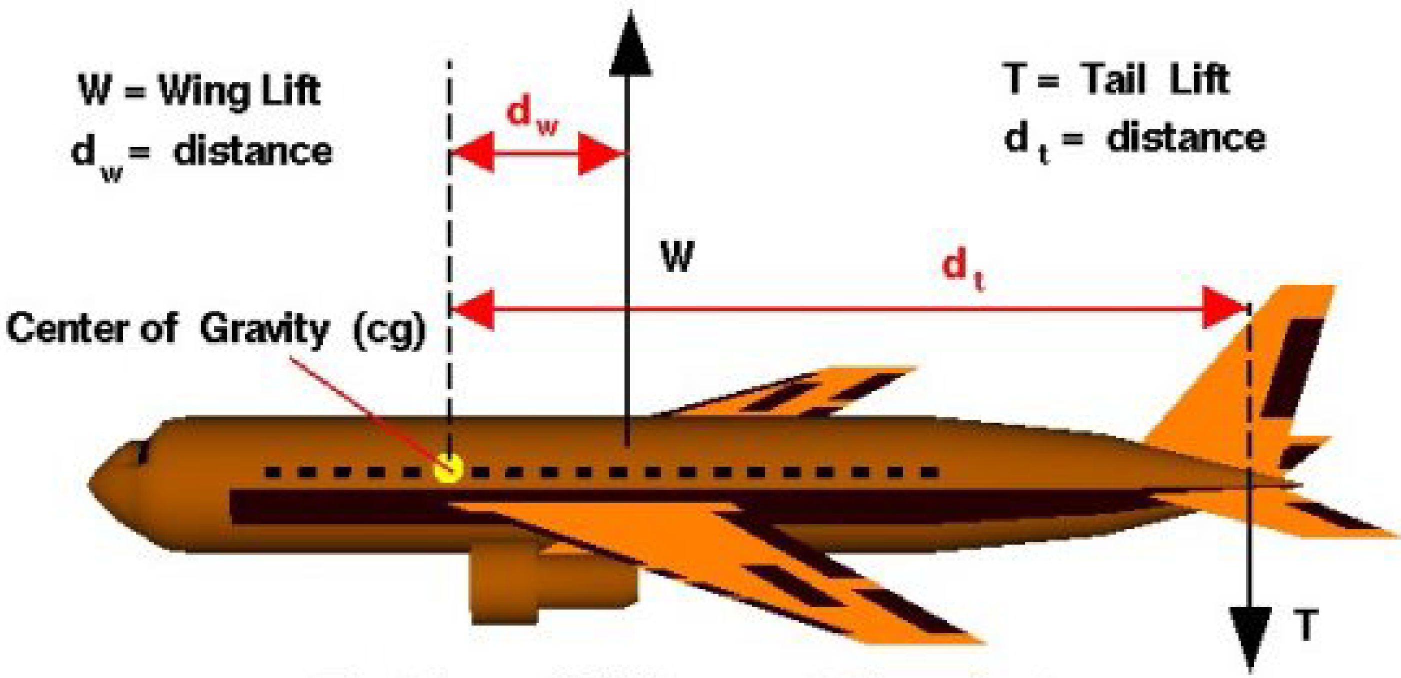
Airbrake and Spoilers/擾流器

- Airbrake are high drag devices for high-performance military aircraft and some commercial aircraft
- Airbrake could be a single surface or symmetrical surfaces

Air brake on a Eurowings Bae 146-300

- Spoilers are found in some fixed-wing aircraft.
- Spoilers are mounted on upper surface of a wing.
  - Reducing lift and increasing drag
- They are used to:
  - Control the descent rate and accurate landing
  - Roll control

Trim/配平



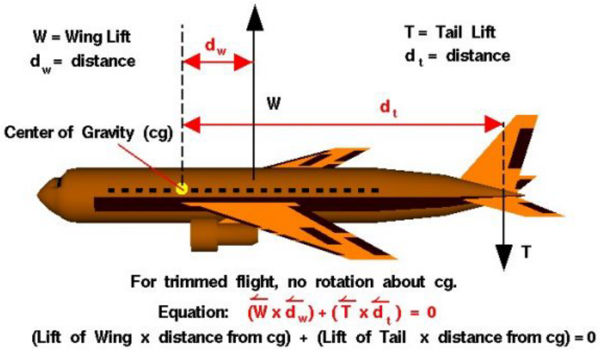
For trimmed flight, no rotation about cg.

Equation: $(\overleftarrow{W} \times \overleftarrow{d_w}) + (\overleftarrow{T} \times \overleftarrow{d_t}) = 0$

(Lift of Wing x distance from cg) + (Lift of Tail x distance from cg) = 0

Trim/配平

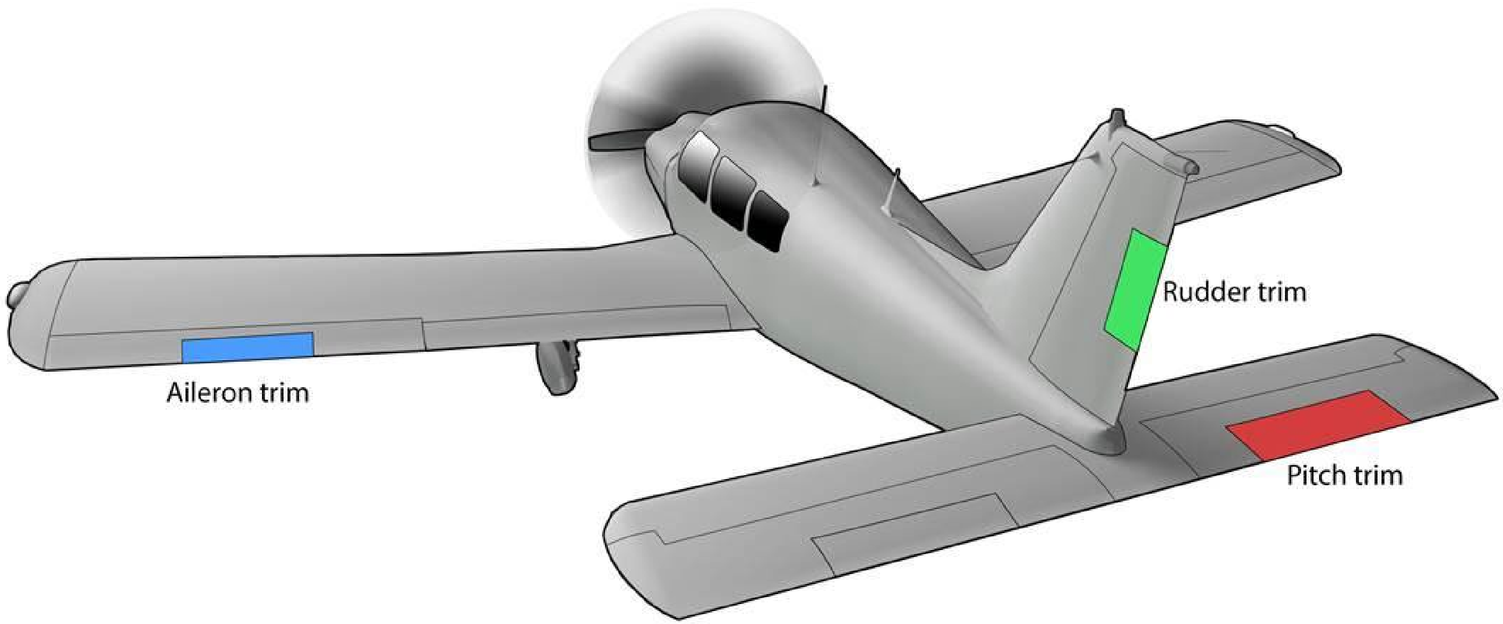
- On most aircraft, the center of gravity (CG) is located near the center of pressure (CP) of the wing.
- If CP is aft CG, the lift can cause anti-clockwise rotation of the airplane about the CG.
- The CP generated by the elevator is aft the CG.
  - A post lift can yield in anti-clockwise rotation of the aircraft. In this case, a negative force is needed to balance the torque.
- In practice, the CG may change due to the fuel consumption and passenger movement, change of speed, etc.
  - The trim system should be operated accordingly.



Trim systems/配平系統

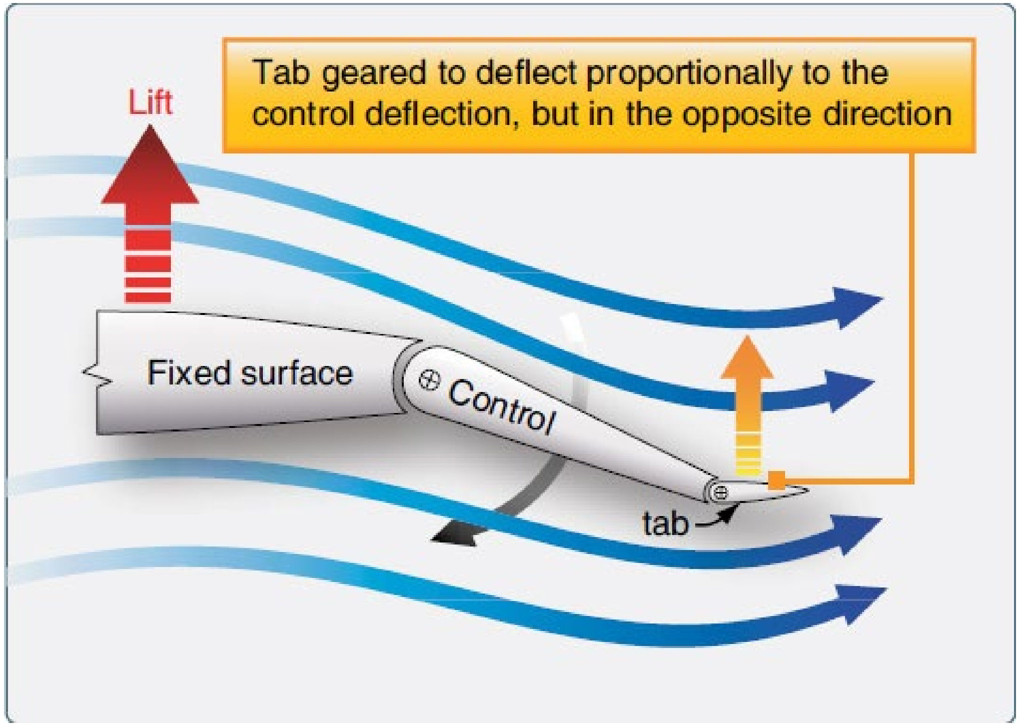
- Trim systems are used to relieve the pilot of the need to maintain constant CP on flight controls
- They are designed to minimize pilot's working load to assist the movement of the flight control surfaces.
- The trim system includes:
  - pitch trim
  - roll trim
  - yaw trim

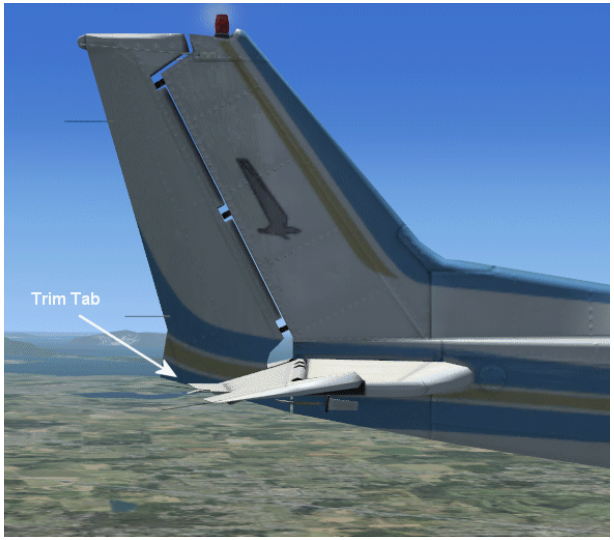
Trim tabs



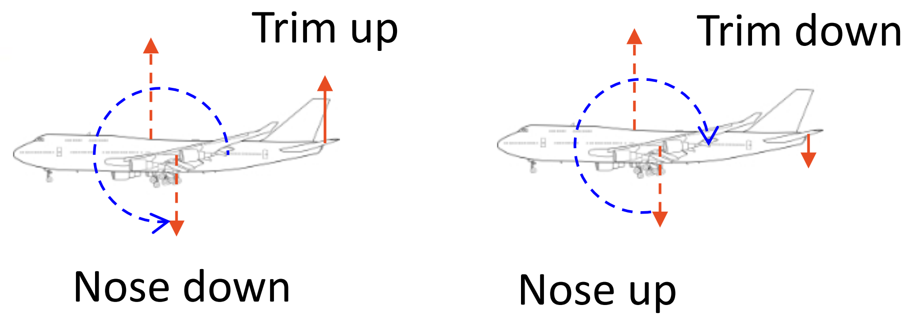
Trim tabs (for pitch trim)

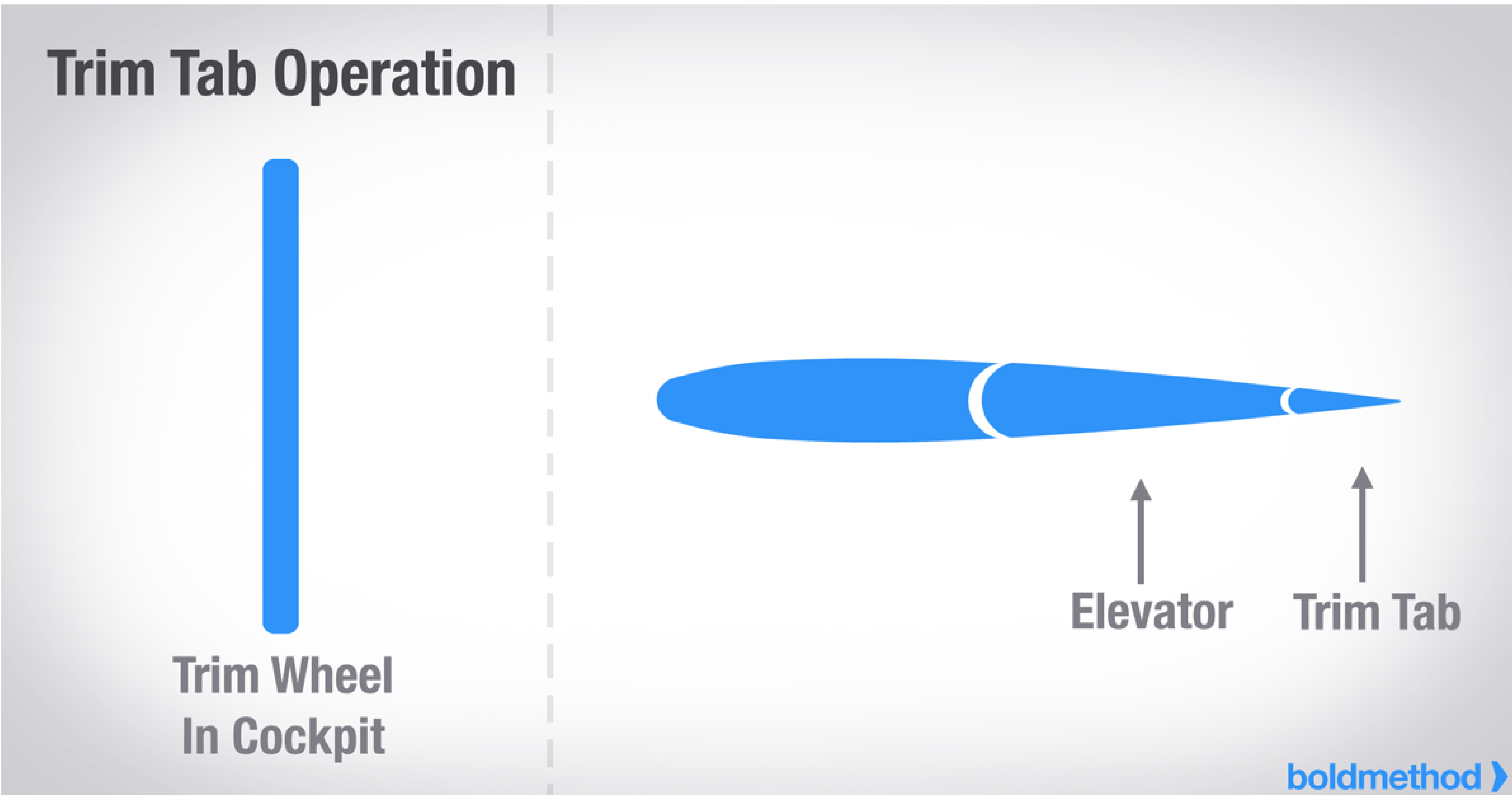
- The trim tabs are often mounted at the tailing edge of the elevator.
  - e.g., with the trim tabs move up in the airstream, the airfoil over the HTP tends to force the trailing edge of the elevator move down, generating a lifting force on the tail and thus the nose-down motion of the aircraft.





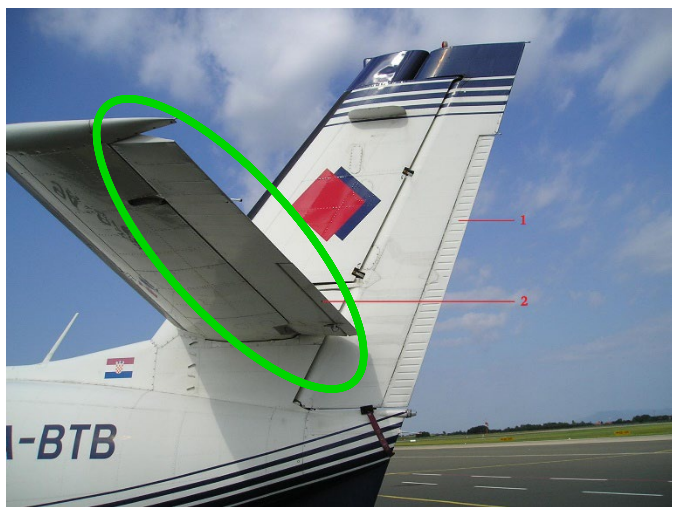
Trim tabs (for pitch trim)



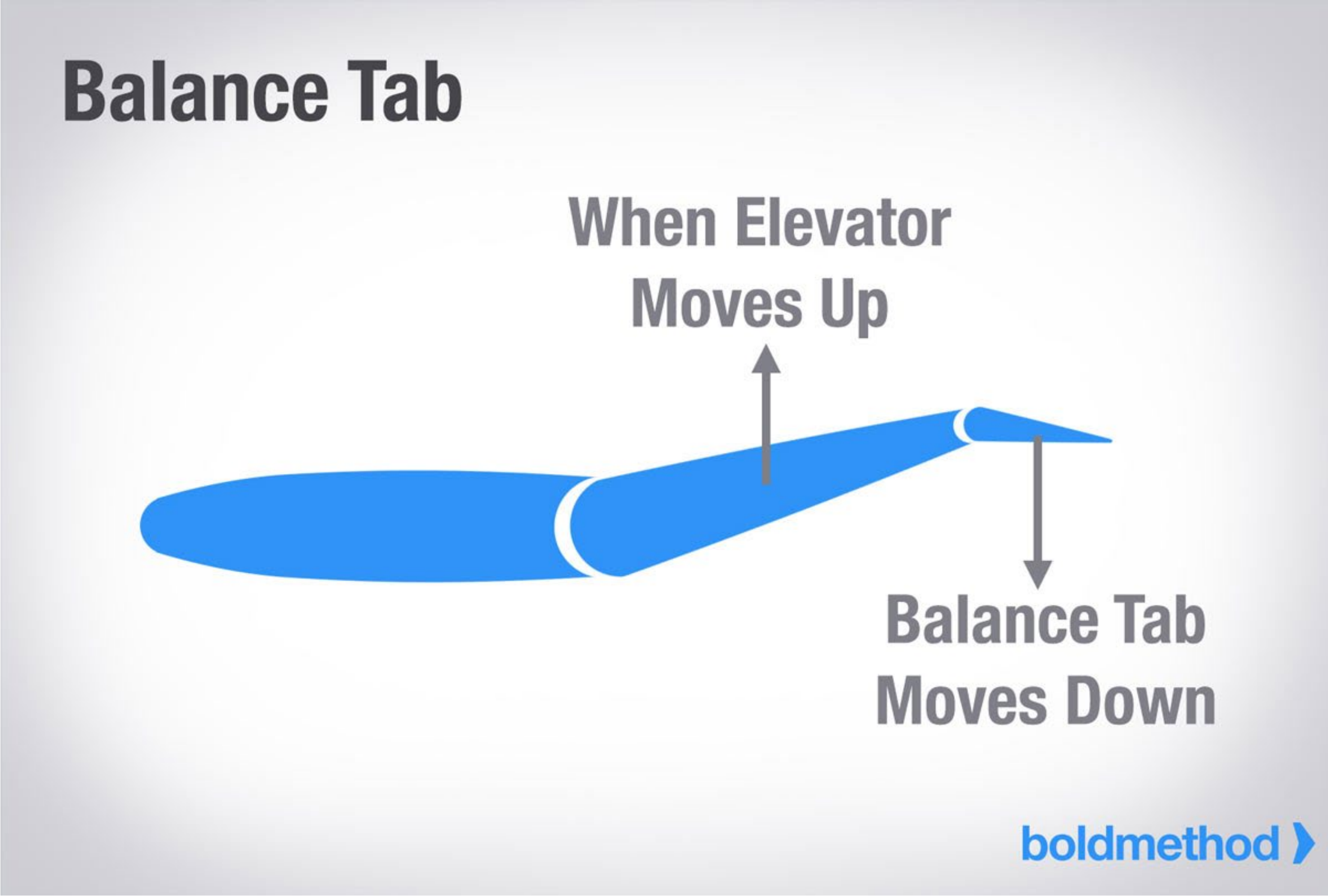


Balance tab/Servo tab (for pitch trim)

- The control forces may be very high in some aircraft.
  - To decrease them, the balance tabs may be used.
- Balance tabs look like trim tabs and are hinged in approximately the same places.
  - Balancing tab is coupled to the control surface rod
  - When the control surface move in one direction, the balance tab moves in the opposite direction



Balance tabs (for pitch trim)



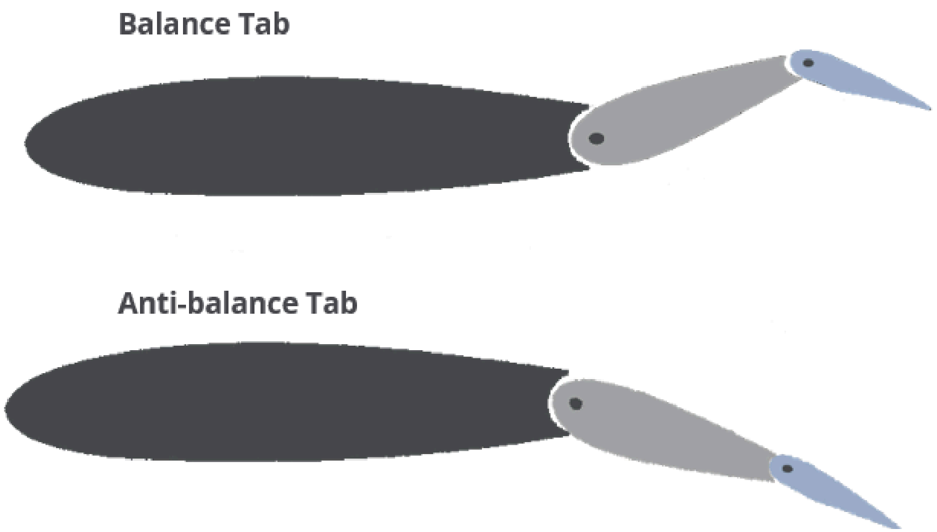
Trim tab v.s. balance tab

- A trim tab and a balance tap are very similar:
  - Purposes
  - Locations
  - Mechanisms
- Difference:
  - The balance tab motion is automatically achieved due to the linkage systems. While the trim tap can be directly controlled by the pilot.
  - The aerodynamic loading of the balance tap is higher

Trim tab control

Anti-balance tab

- An anti-balance tab (or anti-servo tab) works in an opposite way as the balance tab.
- It deploys in the same direction as the control surface, e.g., elevator, making the movement of control surface more difficult.
- The device is used to make the controls feel heavier to avoid the over control of the servo tabs. It is used to increase the stability of the aircraft.



Secondary/auxiliary flight control surfaces

Name	Location	Function
Flap	Inboard trailing edge of wings	Extends the camber of the wing for greater lift and slower flight during takeoffs and landings
Slat	Mid to outboard leading edge of the wing	Extends the camber of the wing for greater lift and slower flight during takeoffs and landings
Spoilers	Upper and/or trailing edge of wing	Decreases (spoils) lift. Can augment aileron function
Trim tab	Trailing edge of primary flight control surfaces	Reduces the force needed to move a primary control surface
Balance tab	Trailing edge of primary flight control surfaces	Reduces the force needed to move a primary control surface
Anti-balance tab	Trailing edge of primary flight control surfaces	Increases feel and effectiveness of primary control surface.

Flight control linkage systems

Conventions of pilot's control on flight motion

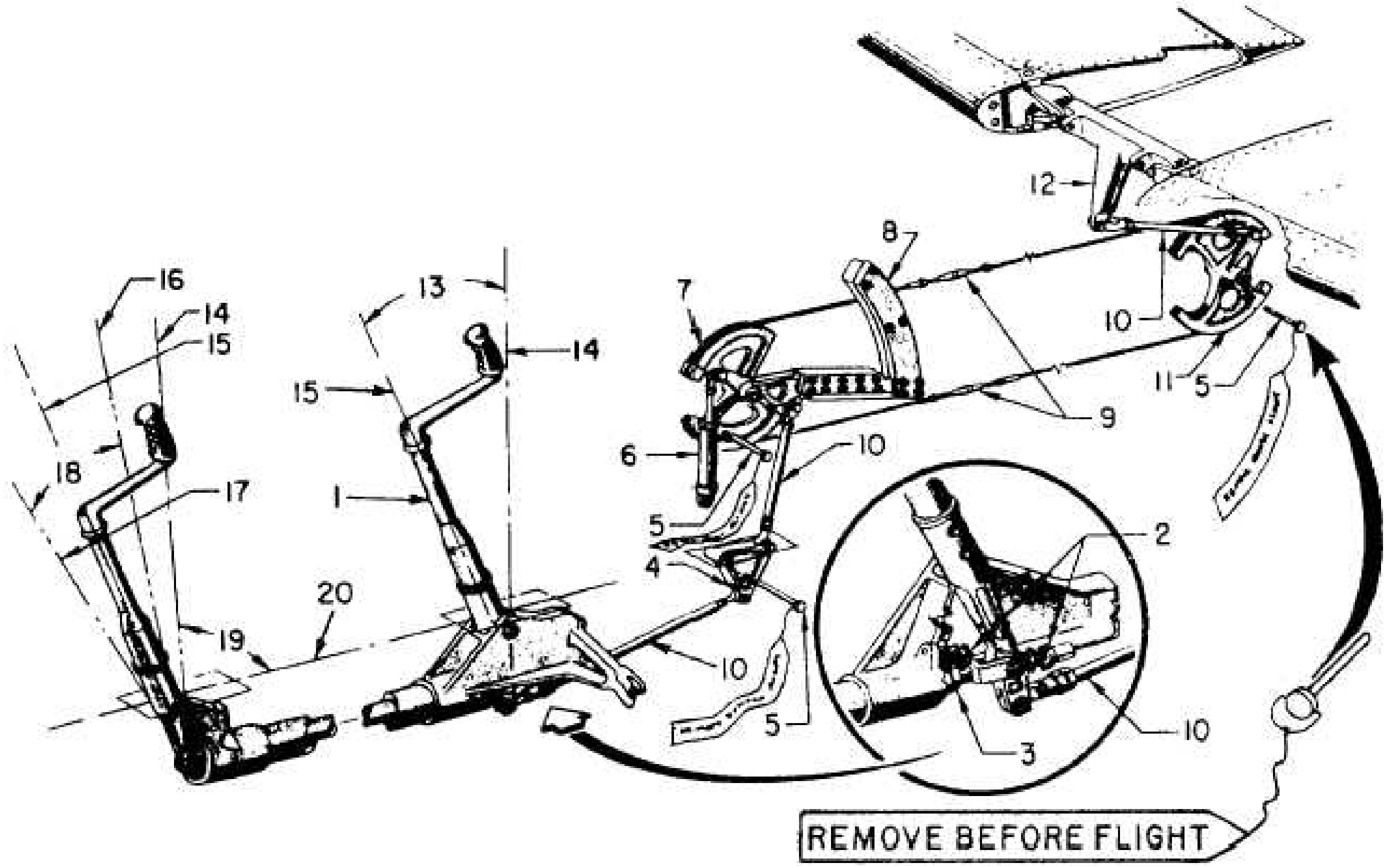
- Conventions in the cockpit control column and rudder pedals:
  - Pitch control: moving the control column fore and aft;
    - Push: pitch down
    - Pull: pitch up
  - Roll control: moving the control column from side to side
  - Yaw control: through rudder pedals;
    - Pushing the left pedal means turning left

Cockpit control column and rudder pedals

Flight control linkage systems/飛行操縱聯動系統

- Flight control linkage systems: to transmit pilot's manual inputs to the control surfaces.
  - A simple control linkage system might be all mechanical.
  - Sophisticated flight control may include electrical and hydraulic power.
- Two main methods of connecting pilot's control to the rest of the control system:
  - Push-pull control rod systems
  - Cable and pully systems

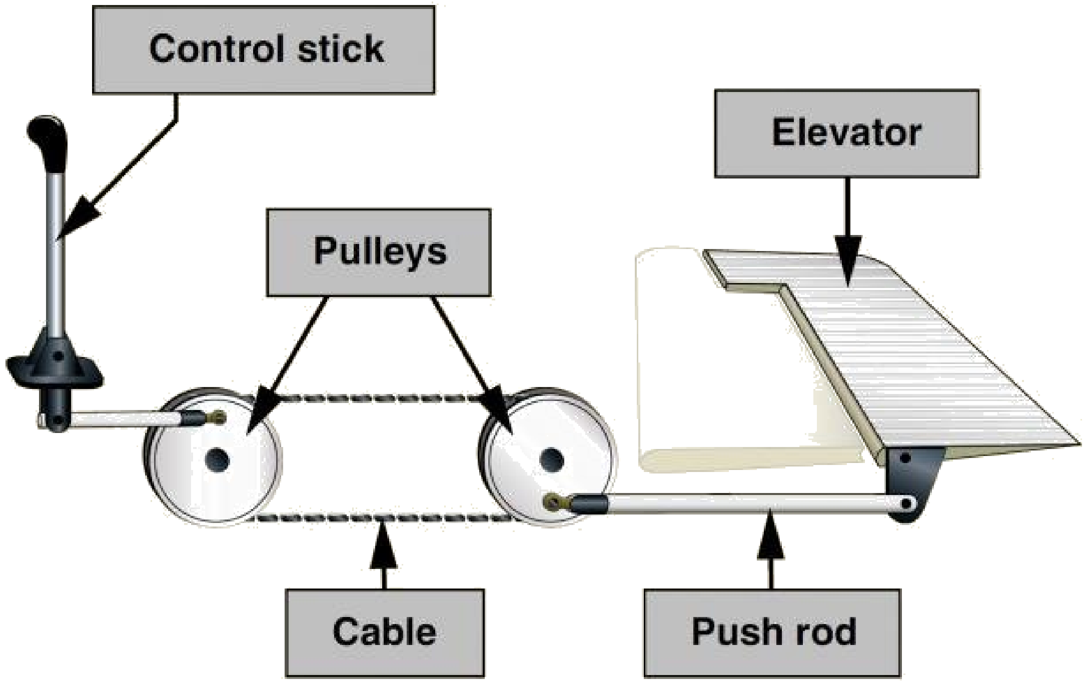
Conventional mechanical control system

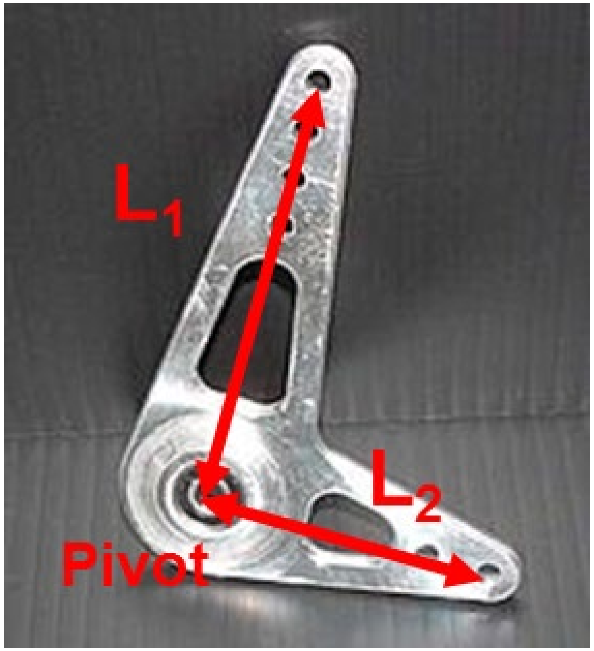


1. Aft control stick
2. Stop bolts
3. Push-pull tube adjustment
4. Bell crank
5. Rig pins (3 places)
6. Bungee
7. Forward sector
8. Bobweight
9. Turnbuckles
10. Push-pull tubes
11. Aft sector
12. Elevator fitting assembly
13. Rigging dimension
14. Vertical references line
15. Center line-stick neutral
16. Stick throw limit-UP elevator
17. Stick throw limit-DOWN elevator
18. Stick throw range-elevator control
19. Locating angle-vertical reference line
20. Longitudinal reference line (cockpit floor)

- In the appendix of this lecture note, we list several common mechanical control system components.
- In the following several pages, we only give some examples showing the key features of the two types of linkage systems

Cable and pully systems

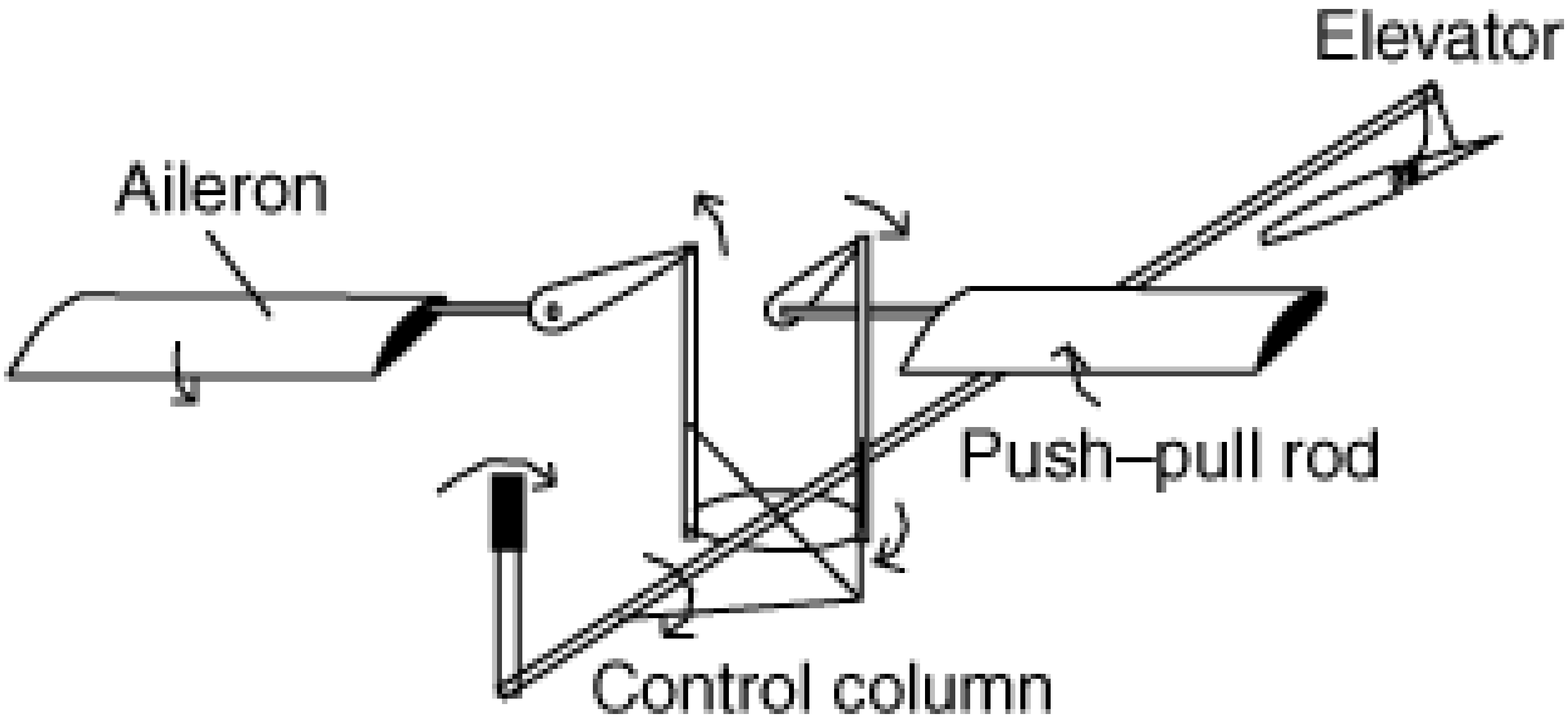




Bell crank/搖臂

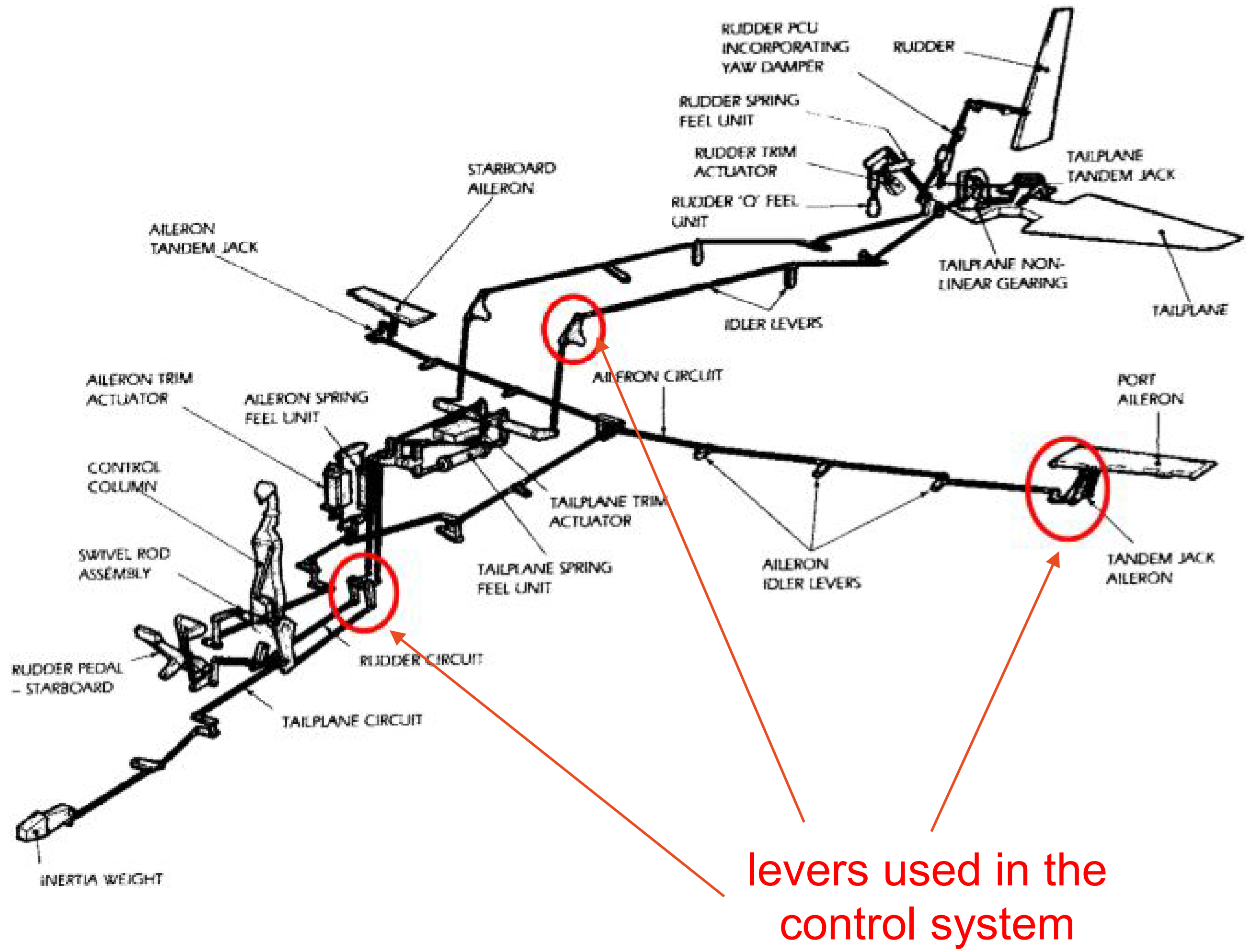
- Cables are connected from the control in cockpit to a bell crank, which is connected to the control surface.
- Forces are transferred from the system to move the control surface.

Push-pull control rod systems



- Metal push-pull rods are used as substitute for cables.

Example of the Hawk 200 flight control system



Artificial feel system

Feel of the airplane

- Feeling the airplane: the ability to sense the flight condition without relying on instrumentation, e.g.,
  - Sound of the airflow across the airframe
  - Vibration through the controls
  - Engine sound, etc.
- Humans sense “feel” through kinesthesis and proprioception:
  - Kinesthesis/運動感覺: the ability to sense the movement by body
  - Proprioception/本體感覺: unconscious perception of movement or orientation
- When properly developed, kinesthesis can provide the pilot with critical information about changes in the airplane’s direction and speed
- However, there are limits in kinesthetic sense. Sole reliance on the kinesthetic sense ultimately leads to disorientation and loss of control.

Feel of the airplane

- Sources of the actual "feel" of the airplane is important for pilot.
- The actual feel is the result of acceleration
  - The pilot can feel the forces in different directions from the forces push on the seat
  - The forces should not be strong! They are only used for the perception of pilot.

Artificial feel system

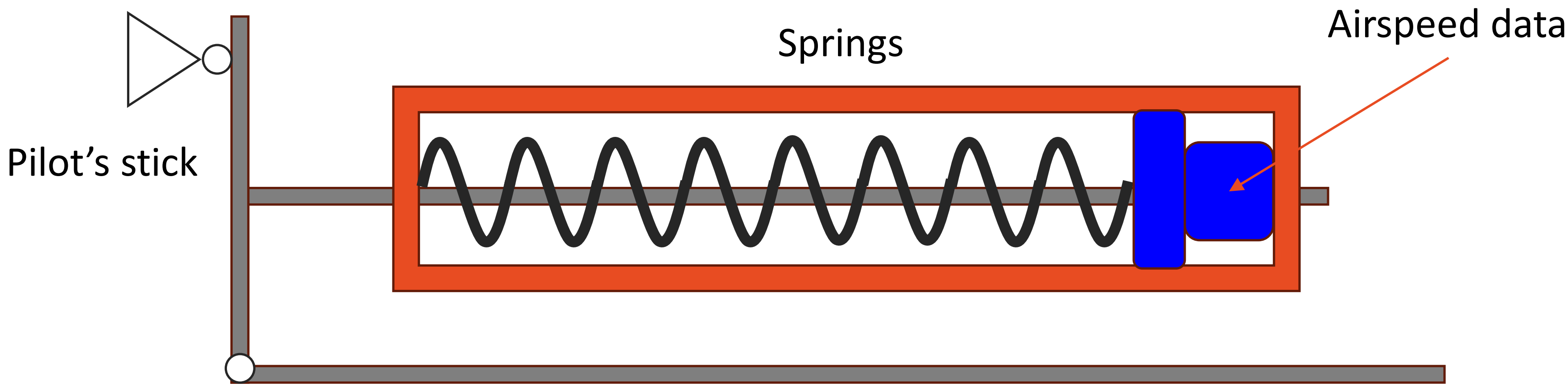
- With the increased performance of aircraft, it is physically impossible for the pilot to apply high forces for the flight control. To this end, measures are employed:
  - Improved mechanical designs
  - Hydraulic systems
  - Electrical flight control systems
- However, pilot may not be aware the stressing being imposed on the aircraft!
- Designers has to use artificial feel to ensure the pilot senses the magnitude of the effect that has been applied to the control actions.
  - Artificial feel system produces an opposition to the pilot's movement

Artificial feel system

- In modern aircraft, there are two main types of artificial feel system
  - Spring feel system
  - “Q”-feel system

Spring feel system

- Most elementary force producer is the spring.
- As pilot inputs a signal to control the surface, a resistance of the spring is felt.
  - It is effective at low speeds and with large deflections

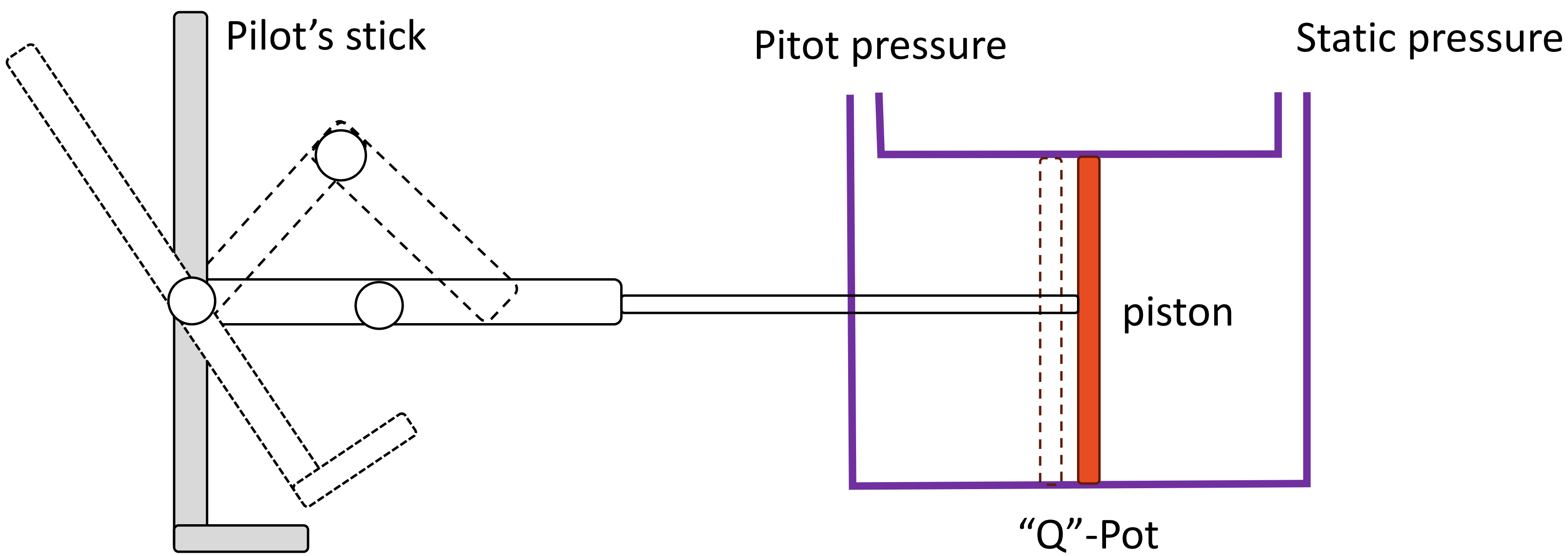


"Q"-feel system

- Q is referred to the dynamic pressure measured from the pitot tube

$$q = \frac{1}{2}\rho u^2$$

- The velocity measurements is based on Bernoulli's equation
- Linear motion of a piston leads to feel resistance to pilot.



"Q"-feel system

- With the increasing development of the devices, "Q"-feel unit can be realized by the hydraulic system.

"Q" feel unit for GR5/AV8B

Artificial feel system

- Usually, the spring feel system and 'Q'-feel system are designed to complement each other
  - Spring feel system: dominate at low speed and for high deflection control demands
  - 'Q'-feel system: dominate at high speed and for low deflection controls

Flight control actuation

Flight control actuation system/飛行控制作動系統

- Actuator: a component of machine to produce force, torque and displacement when input command is supplied to a system
- Actuation: it is important to the ability of the flight control
- Following an ascending order of complexity, the flight control actual actuation system can be classified to:
  - Mechanical actuation/hydraulically powered
  - Mechanical actuation with simple electromechanical features
  - Multiple redundancy actuation

Mechanical actuation

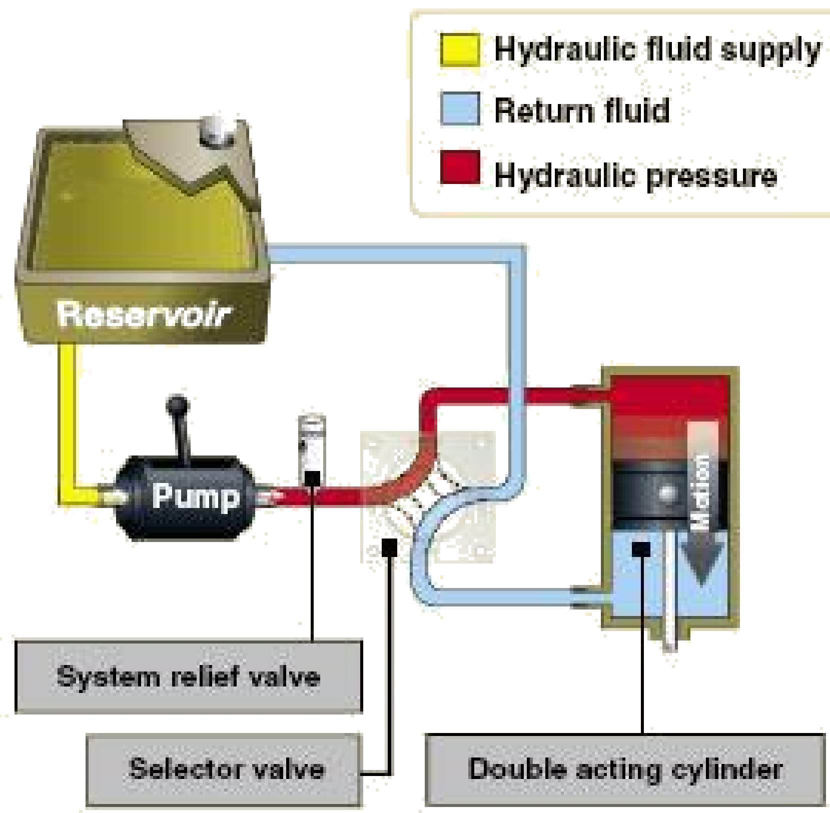
- In the flight control linkage system, we introduced that the fundamental mechanical parts, e.g., cables, pulleys, pushrods, etc., are used to transfer the input from the pilot to the control surfaces
- In Wright Flyer I, the cables are used by the pilot to control the deflection of the wings
- The complexity and weight of the mechanical flight control systems increases with the aircraft performance and size, making it impossible to be handled manually.
  - Therefore, the hydraulic and electric systems are needed.

Hydraulically powered mechanical actuation

- We will specifically introduce the hydraulic system, which can efficiently provide forces using the hydraulic pressure
- Two main parts in the hydraulic mechanical system
  - Mechanical circuit: links the cockpit with hydraulic circuit. It contains rods, cables, pulleys, chains, etc.
  - Hydraulic circuit: contains the pumps, reservoirs, valves, etc.
    - The hydraulic pressure is generated by the pumps

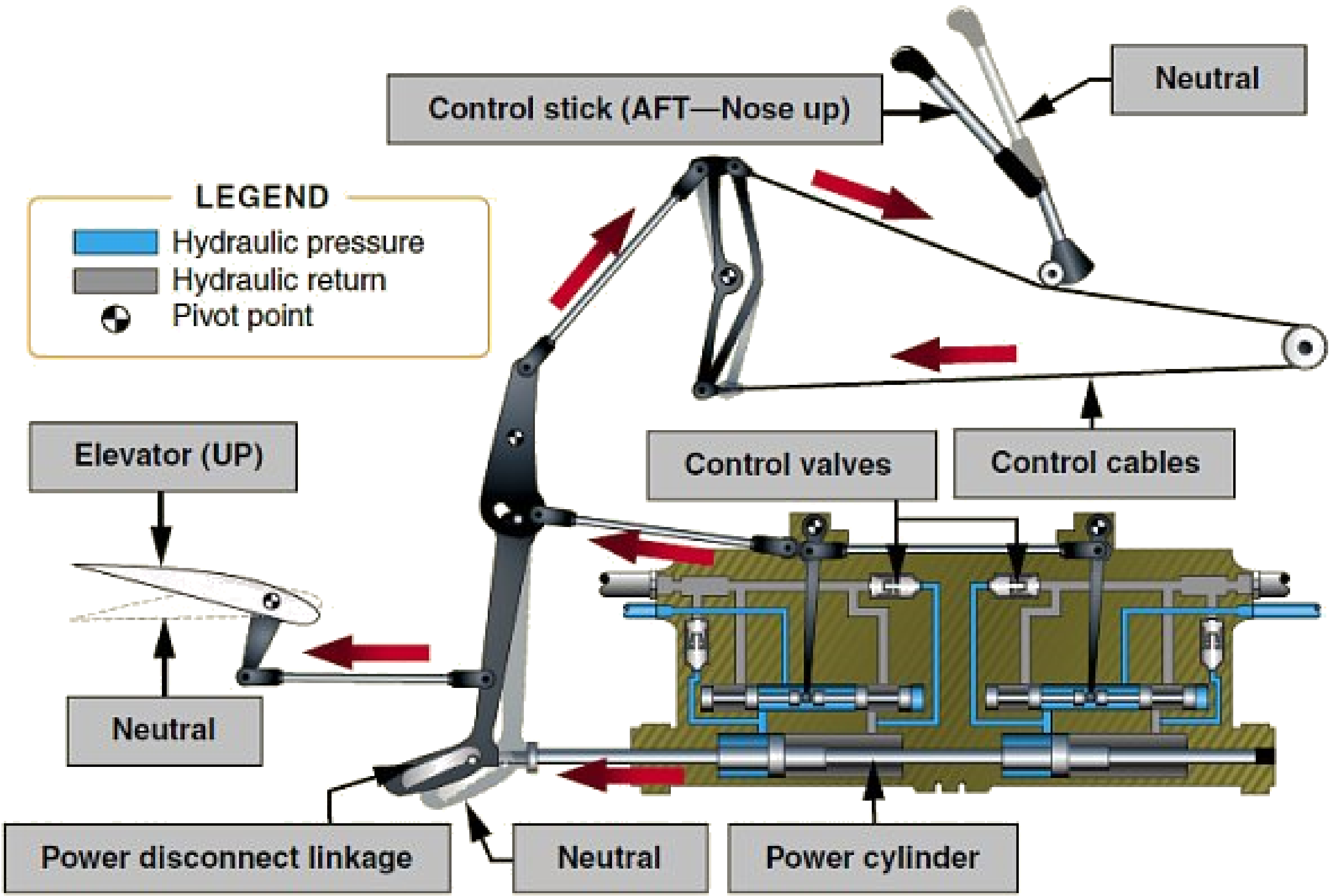
Hydraulically powered mechanical actuation

- Basic operation of the hydraulic mechanical system:
  - Pilot inputs at the control stick
  - Input causes mechanical circuit to open the servo vale (SV) in the hydraulic circuit
  - The hydraulic circuit powers the actuator which then moves the control surface.
  - As the actuator moves, the servo valve is closed by a mechanical feedback linkage, which stops movement of the control surface at the desired position.

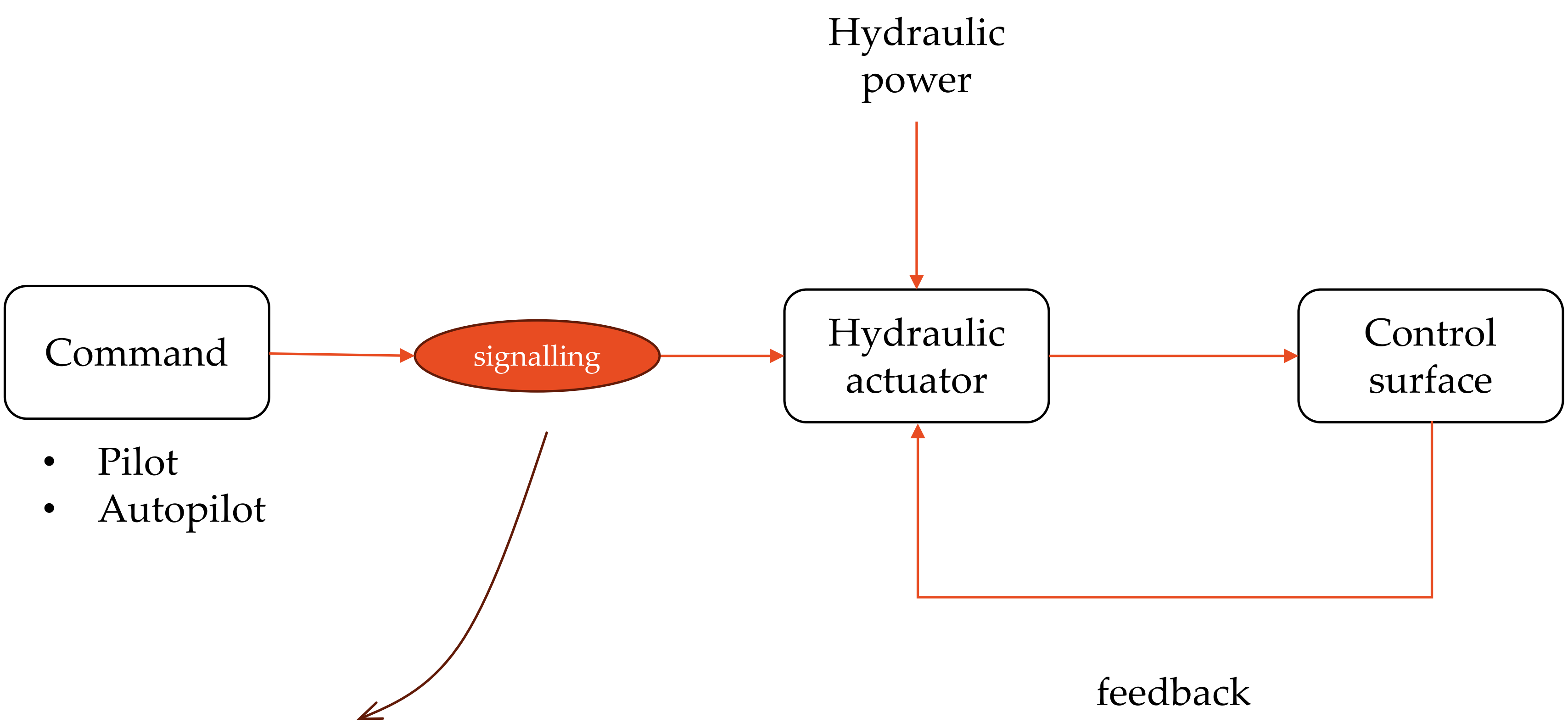


The basis of a hydraulic circuit

Hydraulically powered mechanical actuation



Mechanical actuation with electrical Signaling

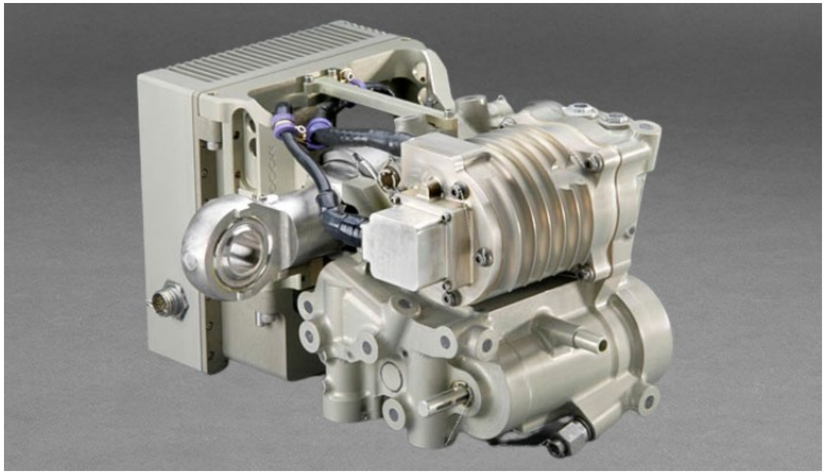


In mechanical actuation with electrical signaling, the mechanical signaling is replaced by electric means

Electro-hydraulic actuators (EHA)

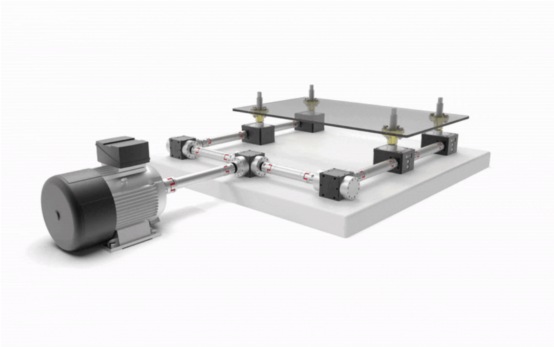
- The majority of the modern aircraft use electrical signalling and hydraulically powered (i.e., EHA, electro-hydraulic actuators)
- EHA is often referred to as "power by wire".
  - It is a fully self-contained actuation system that combines design elements from electric and electrohydraulic actuation.
  - It receives power from electric source and transform input command into motion.
  - It also includes hydraulic pump, accumulator, etc.

- The hydraulic actuator is operated by electric power.
- Development with the high-precision stepper motor

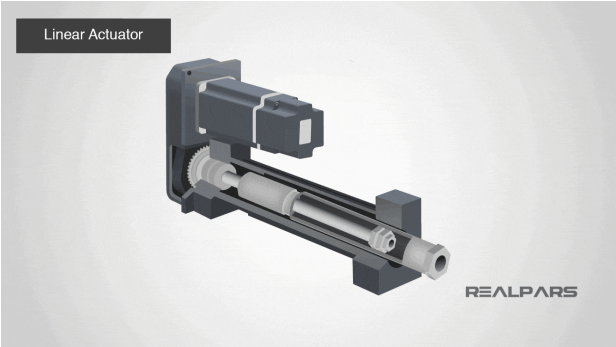


Flight control actuation

- Other flight control actuators, including:
  - Conventional screw-jack actuator:
  - Electro-mechanical actuator (EMA): replaces the electrical signalling and power actuation of EHA with an electric motor and gearbox assembly
  - Integrated Actuator Package (IAP):
- Various actuators are used in an aircraft



screw-jack actuator



EHA actuator

Flight control actuation

- The flight control surfaces are generally hydraulically powered and are either electronically controlled or mechanically controlled.
- For example, for an A320 FBW system:

Electronic control:

- Elevators
- Ailerons
- Roll spoilers
- Tail plane trim
- Slats
- Flaps
- Airbrakes
- Lift dumpers

Mechanical control:

- Rudder
- Tail plane trim

Fly-by-wire (FBW) actuator

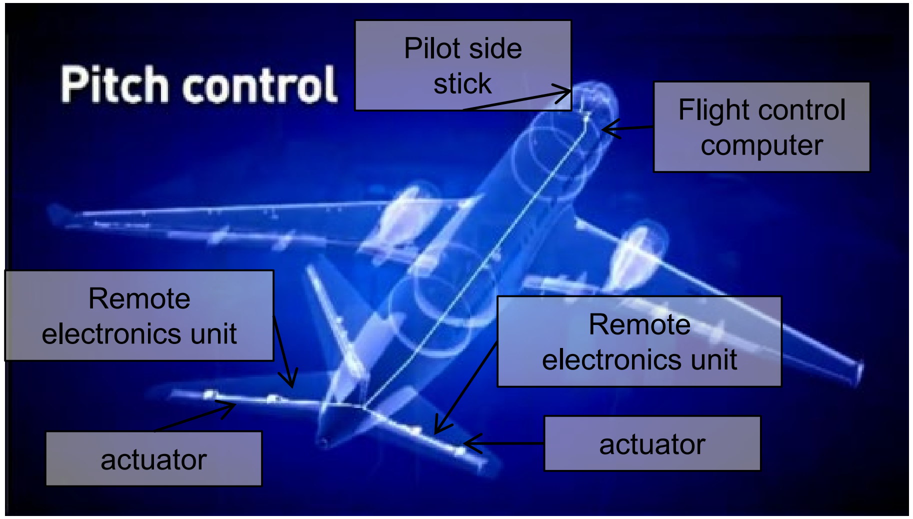
- A fly-by-wire (FBW) system replaces mechanical linkage system of the hydro-mechanical flight control systems of an aircraft with an electronic interface with flight control computers.
  - The inputs of the pilot using side stick are converted to electronic signals transmitted by wires (hence the fly-by-wire term);
  - Flight control computers determine how to move the actuators at each control surface to provide the expected response;
  - In order to stabilize the aircraft and alleviate gust loads on the airframe structure, the flight computers are constantly evaluating the motion of the aircraft and input control commands without the pilot's knowledge, which significantly eases pilots' workload.

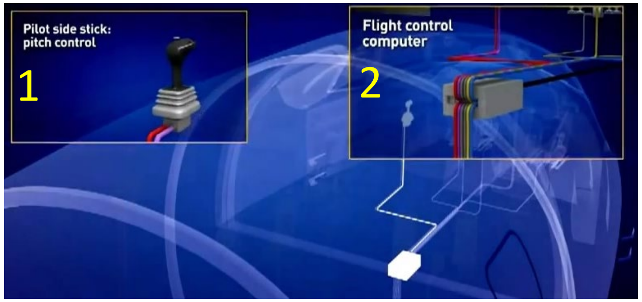
Fly-by-wire (FBW) actuator

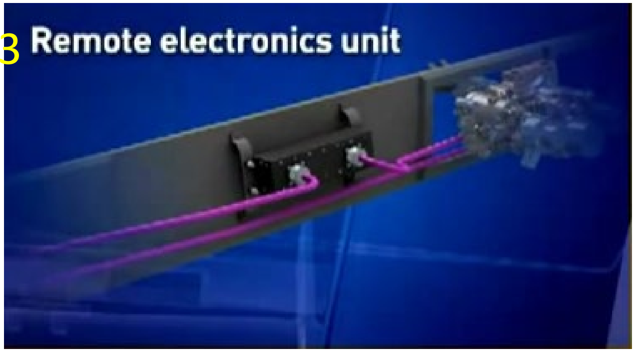
- The Concorde was the first aircraft to introduce and utilize Fly-By-Wire technology.
- Soon after, Airbus also introduced the Fly-By-Wire system on its popular A320-200 commercial transport aircraft.

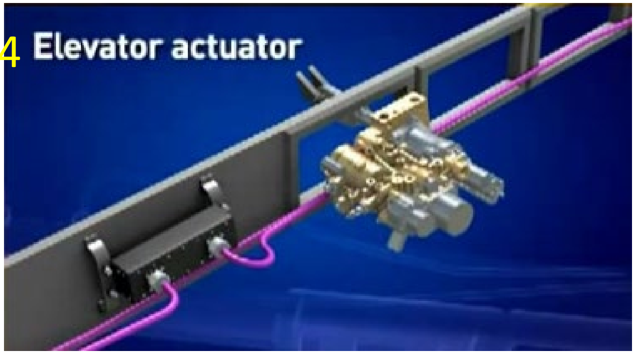
FBW – Elevator Pitch Control

1. Elevator input is made and controlled through the side stick.
2. The input is sent to the flight control computer.
3. The flight control computer sends instructions to the remote electronics unit.
4. The remote electronics unit controls the actuator to deflect the elevator.



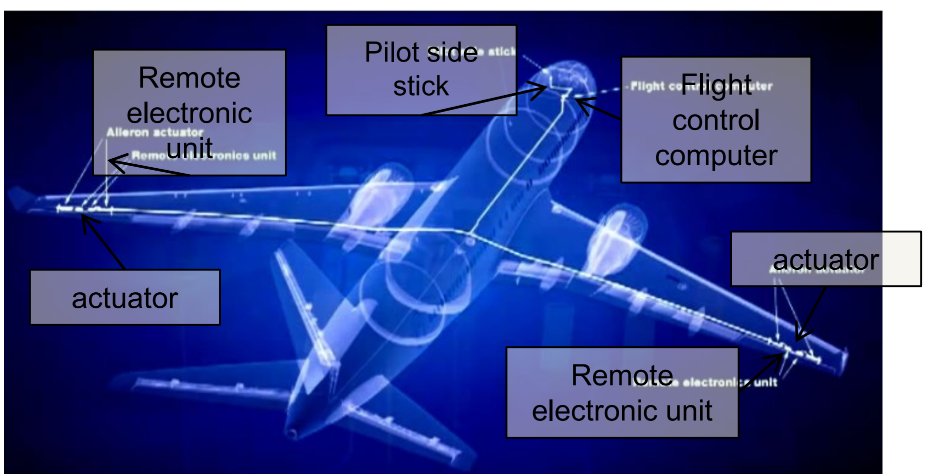


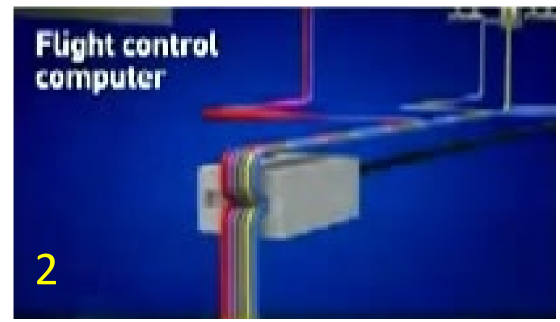




FBW – Aileron Roll Control

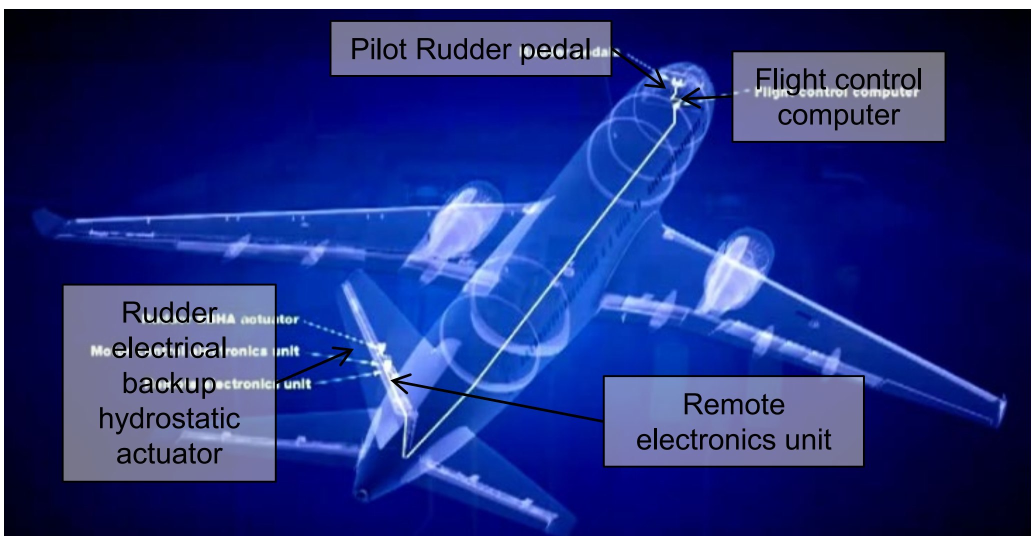
1. Aileron input is made and controlled through the side stick.
2. The input is sent to the flight control computer.
3. The flight control computer sends instructions to the remote electronics unit.
4. The remote electronics unit controls the actuator to deflect the aileron.

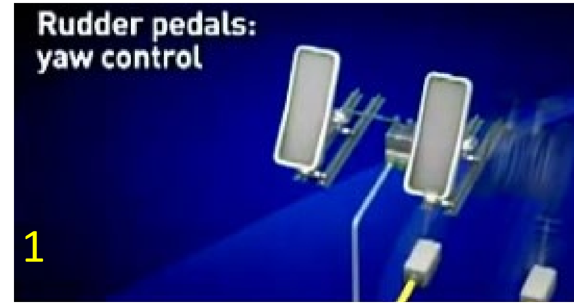


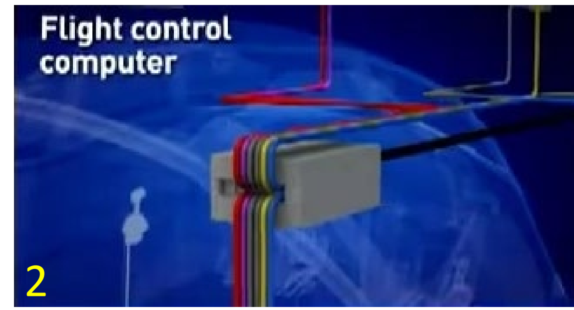


FBW – Rudder Yaw Control

1. Rudder input is made and controlled through the rudder pedals.
2. The input is sent to the flight control computer.
3. The flight control computer sends instructions to the remote electronics unit.
4. The remote electronics unit controls the actuator to deflect the rudder.







Flight control actuation: redundancy

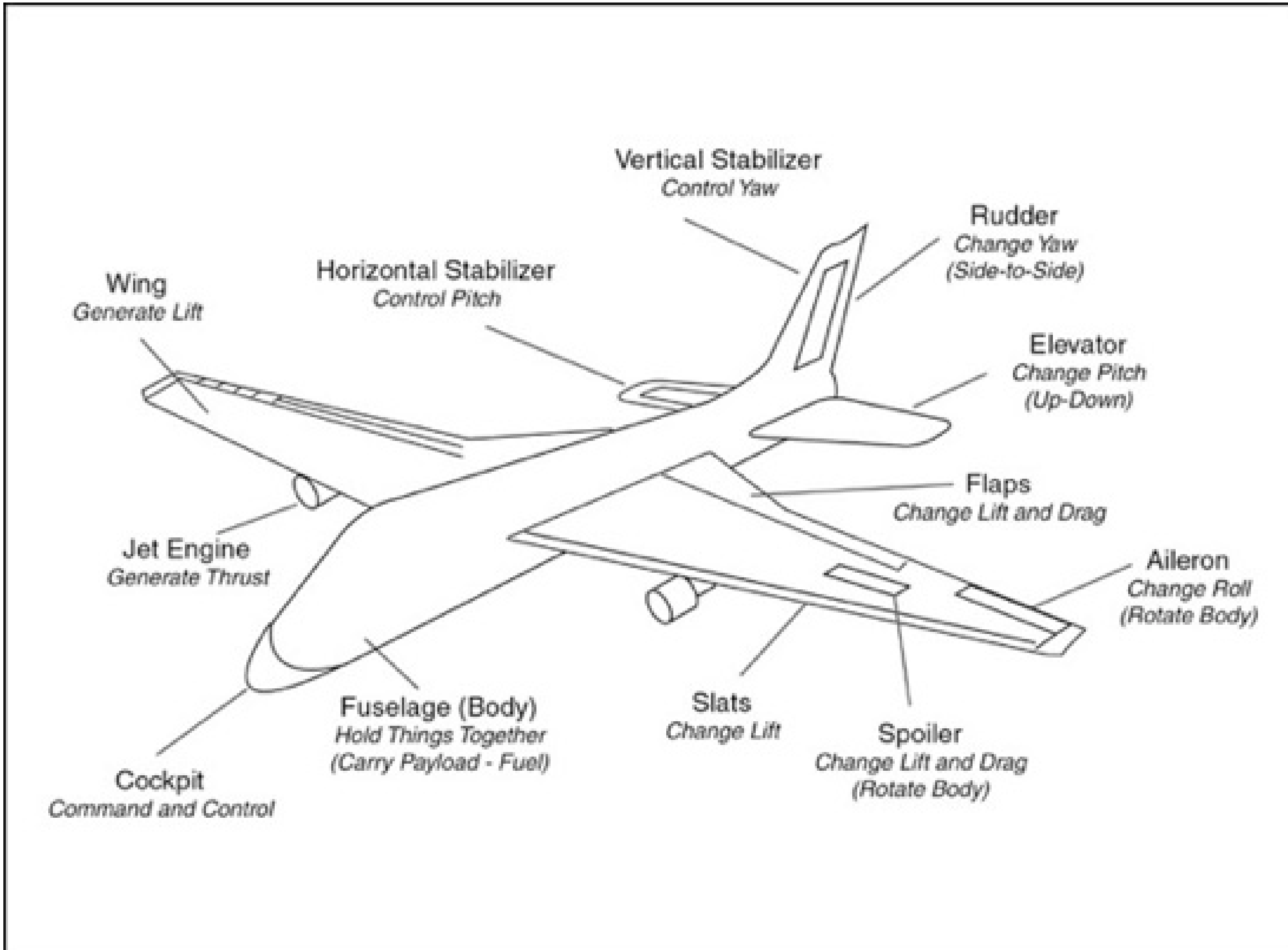
- For the aircraft, a certain redundancy is necessary to ensure the safety and reliability. The failure of a system can only lead to a partial lose in control ability.
- e.g., for the A320 FBW system, there are a total of 7 flight control computers (FCC) for flight control computation simultaneously.
  - Two Elevator / Aileron Computers (ELACs), that control the elevator and aileron actuators.
  - Three spoiler / elevator computers (SECs) that control the spoilers and secondary control to the elevator actuators in the case of ELACs failure.
  - Two flight augmentation computers (FACs) that provide yaw damper function.

Summary

Summary

- Principles of flight control:
  - Realize the target flight motion and ensure stability and safety
- Direct interaction of the aircraft with air is achieved through control surfaces:
  - Primary control surfaces: elevator, rudder, ailerons
  - Secondary flight control: HLD, spoilers, airbrakes, trim tabs
- Connection between command and control surface: linkage system
- Actuation system: to realize the control actions

Summary

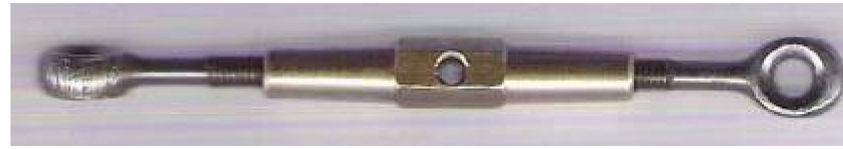


Vertical Stabilizer
Control Yaw
Rudder
Change Yaw
(Side-to-Side)
Horizontal Stabilizer
Control Pitch
Wing
Generate Lift
Elevator
Change Pitch
(Up-Down)
Flaps
Change Lift and Drag
Jet Engine
Generate Thrust
Aileron
Change Roll
(Rotate Body)
Fuselage (Body)
Hold Things Together
(Carry Payload - Fuel)
Slats
Change Lift
Spoiler
Change Lift and Drag
(Rotate Body)
Cockpit
Command and Control

Appendix: Mechanical control components

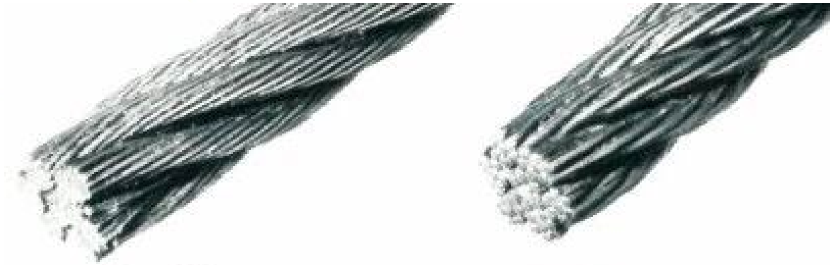
Turnbuckles

- Turnbuckles are designed to adjust cable length or adjust the amount of tension in cables.
- Turnbuckles have long been used in aircraft construction, e.g., in biplanes to adjust the tension on structural wires.
- Turnbuckles are also used on flexible cables in flight control systems. To prevent turning and losing tension due to vibration, aviation turnbuckles are secured with lockwire or specifically designed wire clips.



Cable

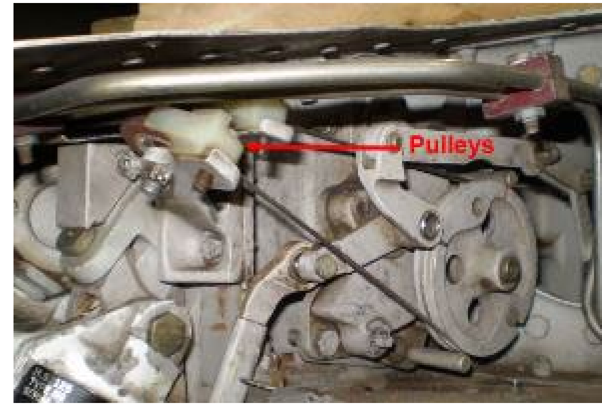
- Cable is the most widely used component in conventional flight control systems. Cable-type linkage is also used in engine controls, emergency extension systems for the landing gear, and various other systems. They are usually made from galvanized stainless carbon steels.
- Advantages: Strong and light weight, and its flexibility makes it easy to route through the aircraft.
- Disadvantages: Tension must be adjusted periodically due to stretching and temperature changes.
- **Aviation Cable types**
  Cables are made by twisting or winding a number of single wires to form a strands, followed by winding strands to form a cable. For most aircraft applications, strands are made up of 7 or 19 wires.

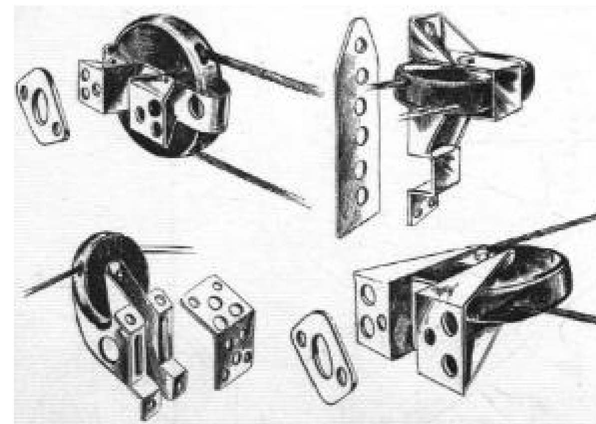


7 x19   7 x 7

- The strength and durability of aircraft cables are dependent on the following factors:
  - Material;
  - Thickness of individual wires, number of wires in a strand and the number of strands in the cable;
  - The length of one full winding relative to the cable diameter;
  - Finer wires are more susceptible to abrasion failure caused by friction between wires.

Pulleys

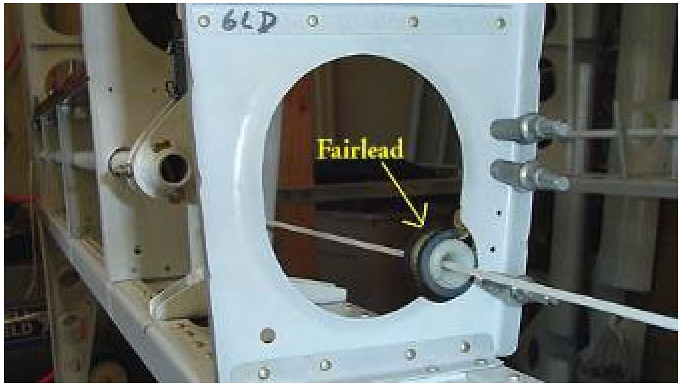




- Pulleys are grooved wheels used to change cable direction and to allow the cable to move with minimum of friction.
- Most pulleys used on aircrafts are made from aluminum or phenolic compounds.
- Aircraft pulleys are extremely strong and durable, and cause minimum wear on the cable passing over them.
- Pulley brackets are often required to safeguard the cable from slipping out of the groove of the pulley wheel.
- Bell cranks are used to guide and change the direction of movement. The input and output direction of movement can be designed to any angle required.

Fairlead & pushrod

- A fairlead is a component designed to guide cable and to stop the cable from moving laterally.
- Typically, a fairlead will be a ring or hook.
- For application in aviation, no fairlead may cause a change in cable direction of more than three degrees.
- For larger angles, a pulley is used in place of a fairlead to reduce friction.



- A pushrod is a rigid structural link used in flight control mechanisms.
- A pushrod typically connects to a bellcrank and/or forms the coupler link of a four-bar linkage assembly.
- Pushrods are commonly made from steel but also can be manufactured out of aluminum or composite material.