

UNIT - II

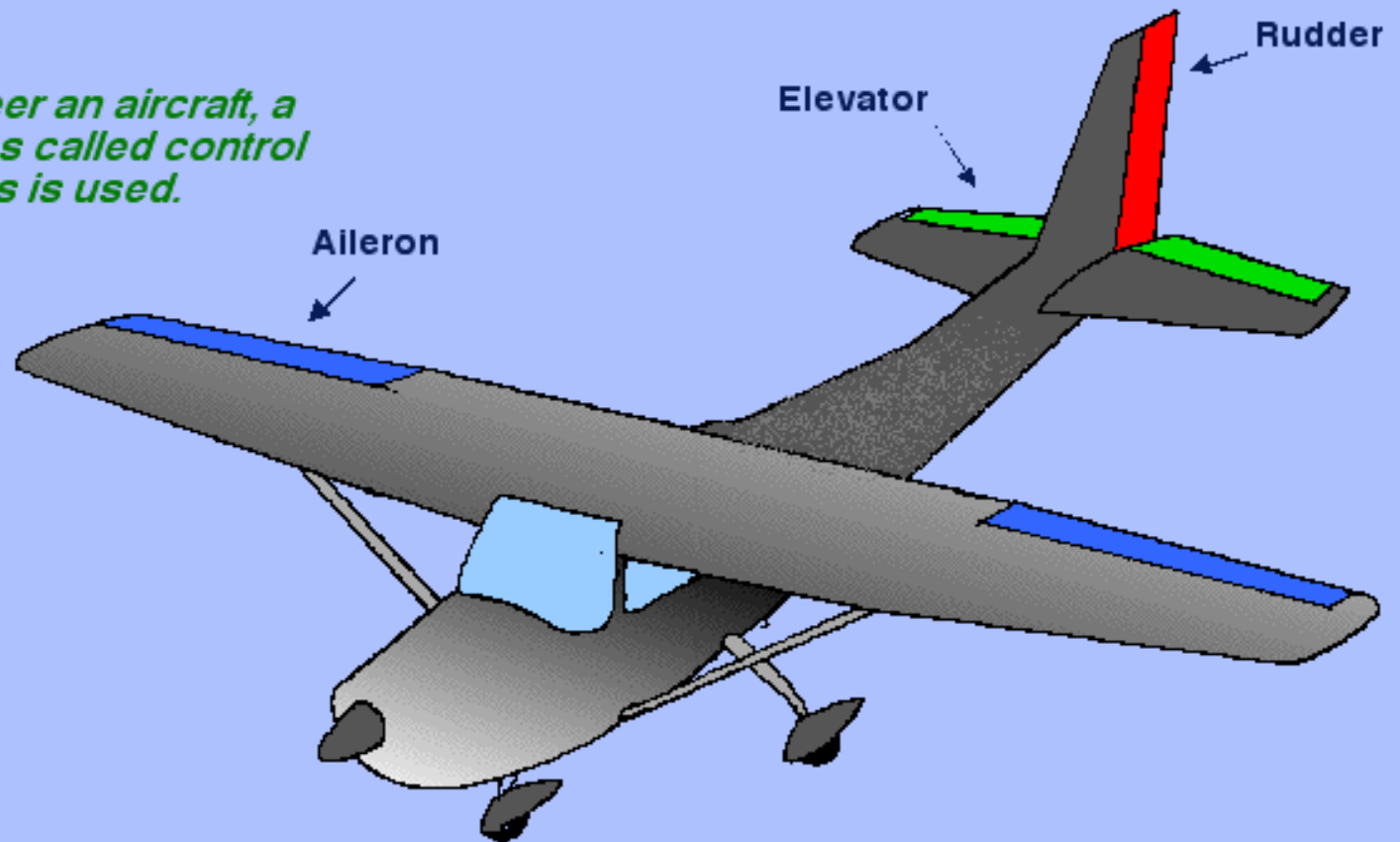
AIRCRAFT CONTROL SYSTEMS

What is an Aircraft Control System?

- A **control system** is a collection of mechanical and electronic equipment that allows an aircraft to be flown with exceptional precision and reliability.
- A control system consists of **cockpit controls**, **sensors**, **actuators** (hydraulic, mechanical or electrical) and **computers**.

Aircraft Maneuvers are produced by moving Control Surfaces

In order to steer an aircraft, a system of flaps called control surfaces is used.

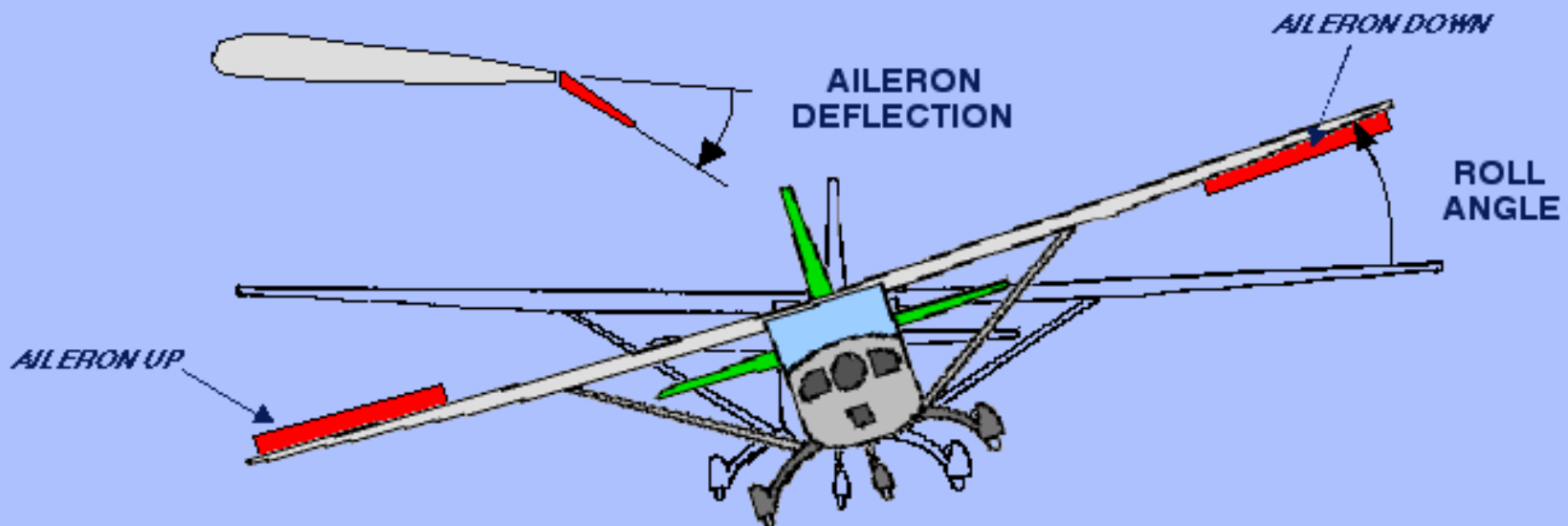


Control surfaces deflect the air flow around an aircraft and turn or twist the aircraft so that it rotates about the center of gravity.

The main control surfaces that perform movement are the ailerons, elevators, and rudder. This movement is made by a control stick and pedals.

The Ailerons Control the Roll Angle

Ailerons are used to roll or rotate the aircraft .

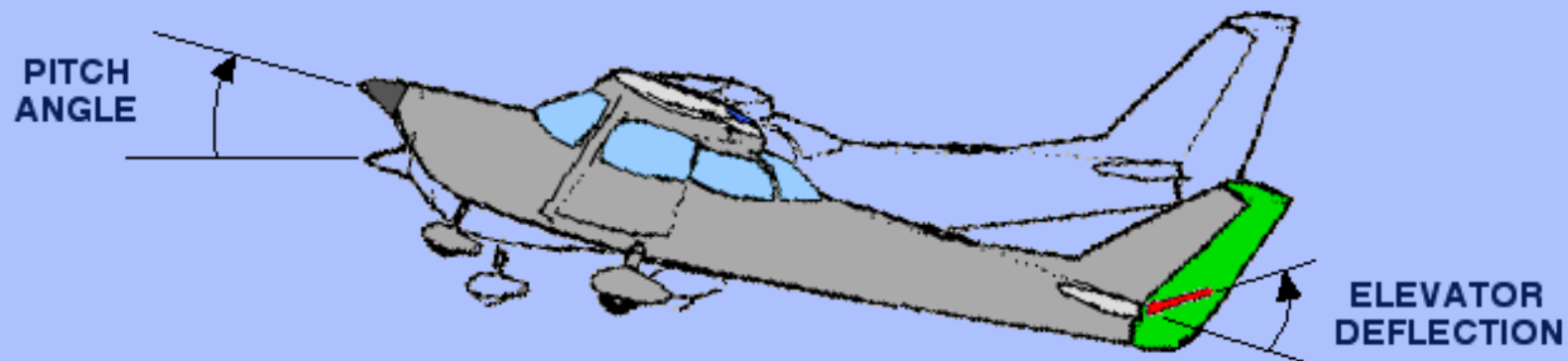


Aileron deflections are necessary for smooth coordinated turns. The combination of roll and yaw causes the aircraft to “lean” into turns.

When the pilot moves the control stick to the right the right aileron moves up and the left moves down. This causes more lift on the left wing and less lift on the right wing. The difference in forces causes the aircraft to roll to the right.

The Elevator Controls the Pitch Angle

Elevators are used to pitch the aircraft up or down causing it to climb or dive.



To climb, the pilot pulls the control stick back causing the elevators to be deflected up. This in turn causes the airflow to force the tail down and the nose up thereby increasing the pitch angle as shown.

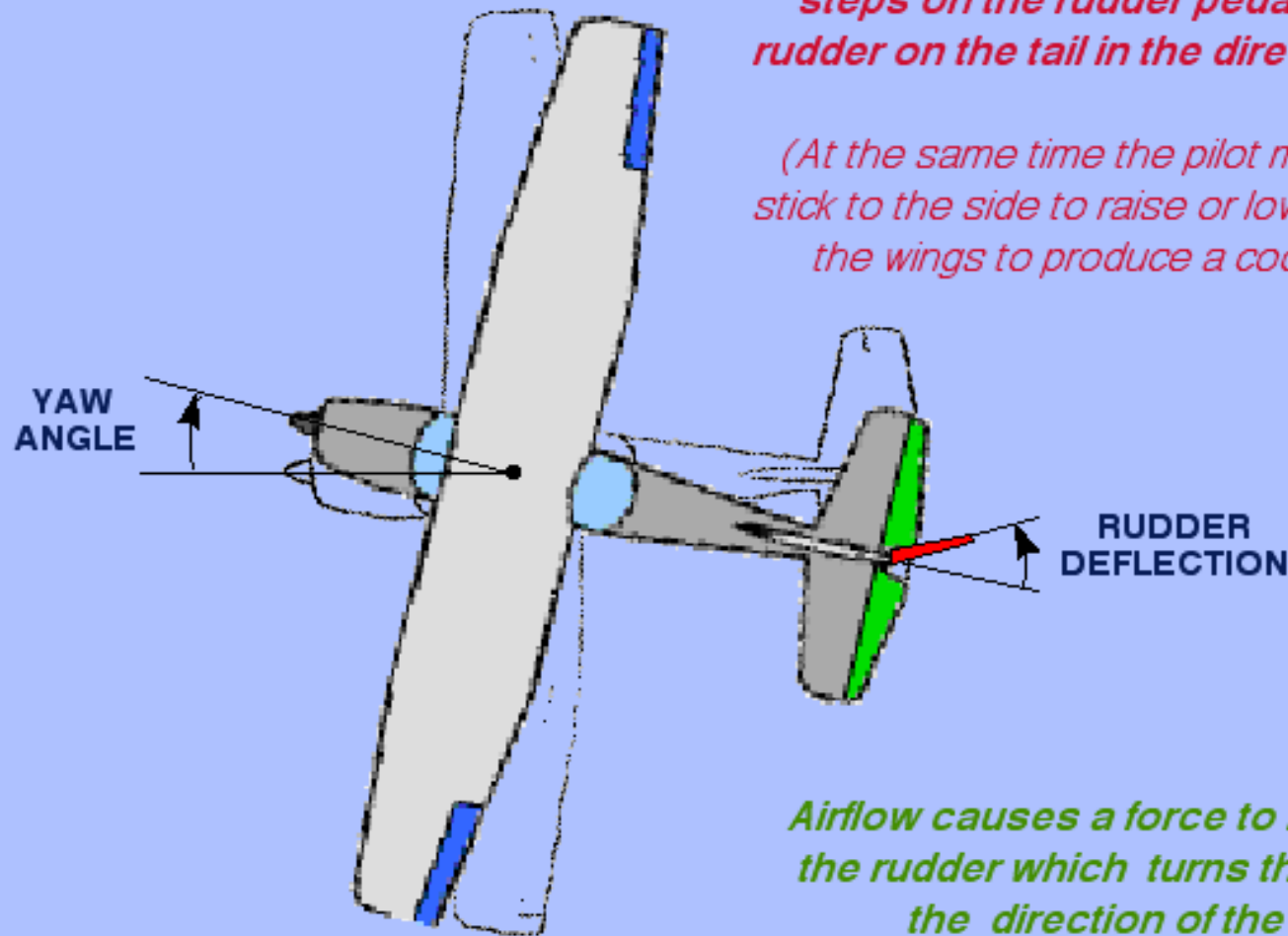
To dive, the pilot pushes the control stick forward causing the elevator to deflect down. This in turn causes the airflow to lift the tail up and the nose down thereby decreasing the pitch angle.

The Rudder Controls the Yaw Angle

The rudder turns the aircraft right or left, this is called yawing

To yaw right or left, the pilot steps on the rudder pedals to swivel the rudder on the tail in the direction of the turn.

(At the same time the pilot moves the control stick to the side to raise or lower the ailerons on the wings to produce a coordinated turn.)

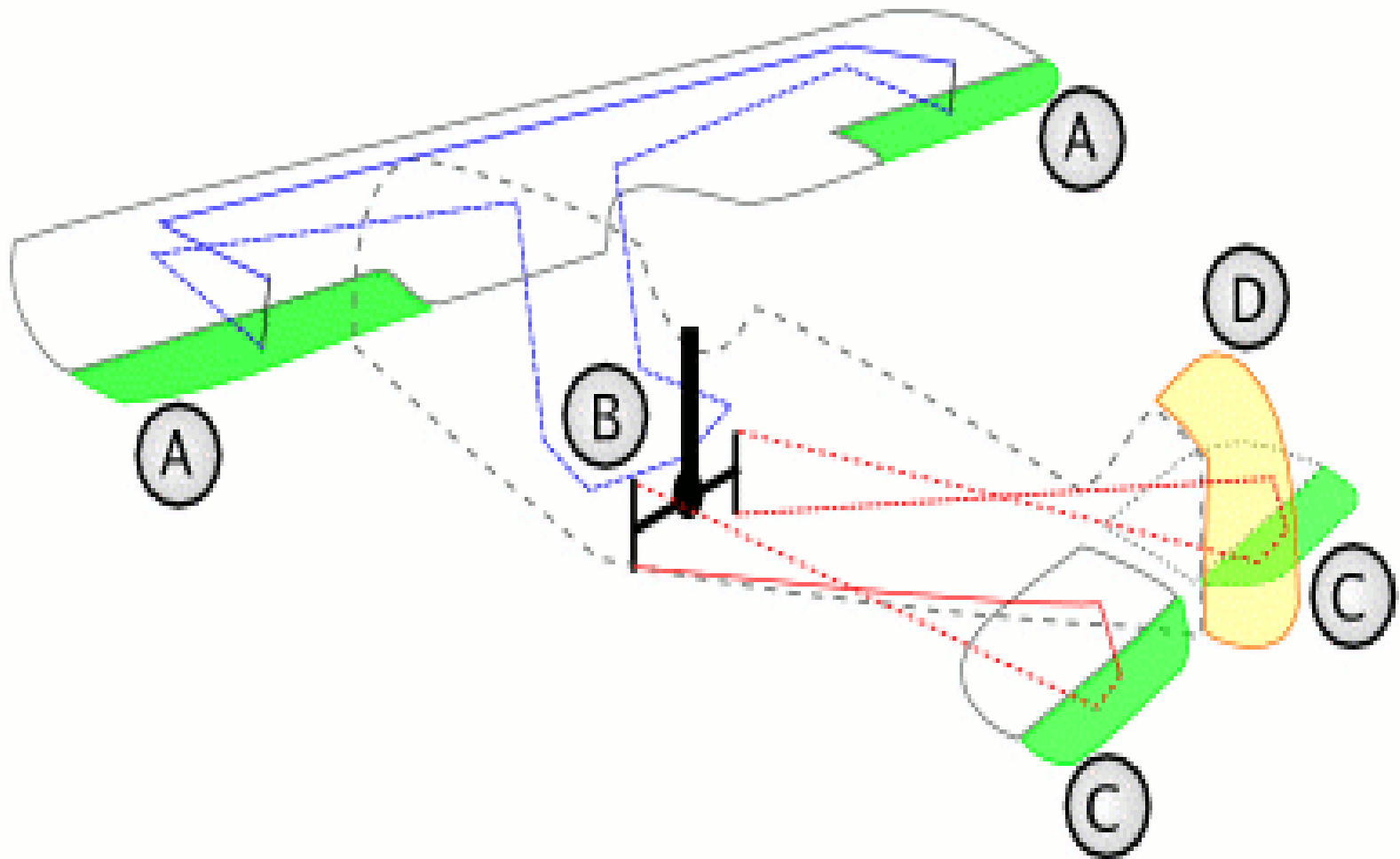


Airflow causes a force to be applied to the rudder which turns the aircraft in the direction of the force.

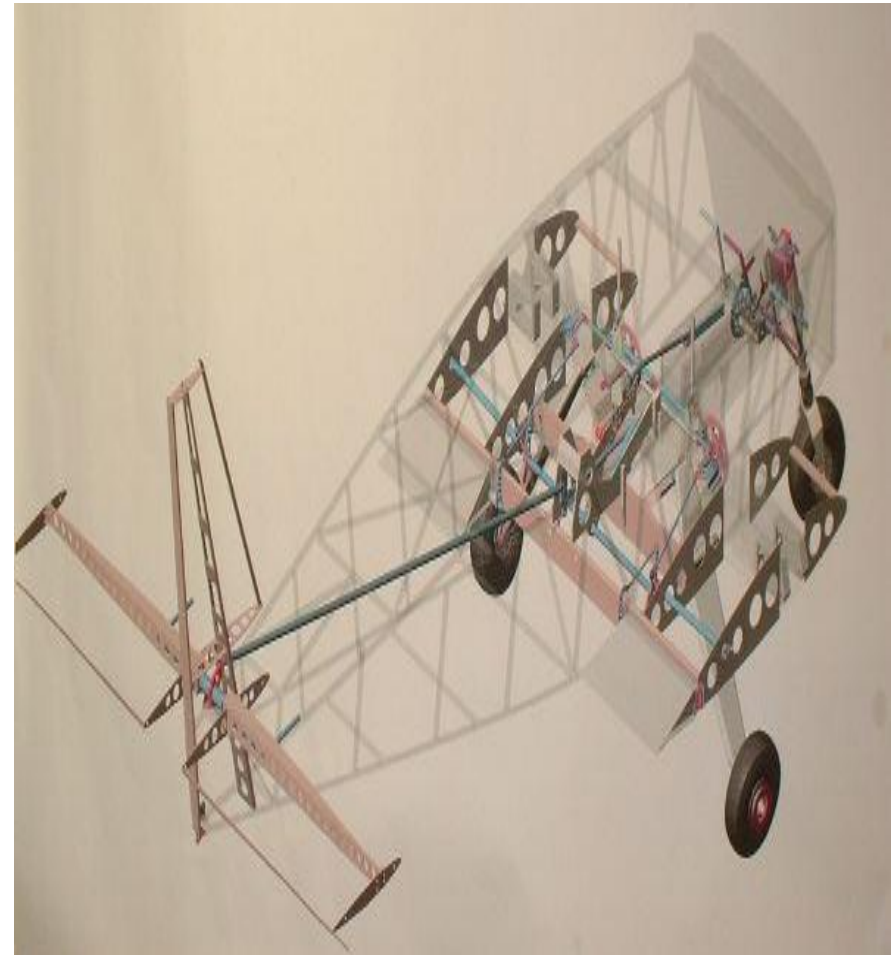
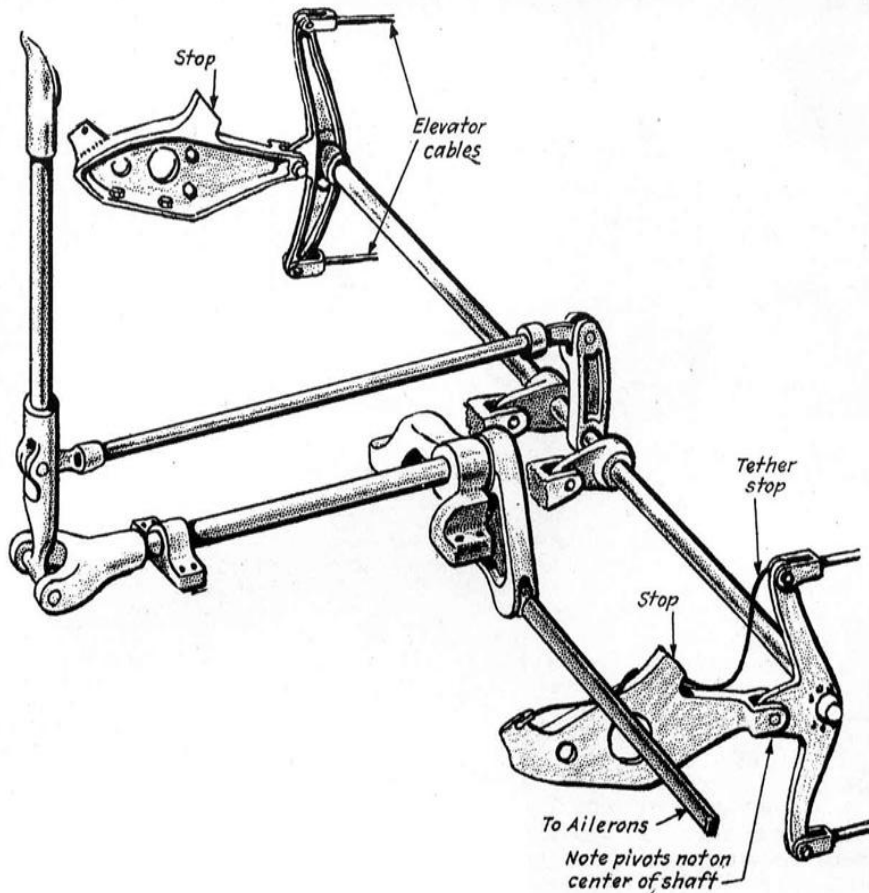
Control Column (or) Control Yoke



Aircraft Primary Flight Controls In Motion



Conventional Flight Control System Components Push Pull Rods



Turnbuckles



A **turnbuckle**, **stretching screw** or **bottlescrew** is a device for **adjusting the tension or length** of **ropes, cables, tie rods** and other tensioning systems.

Torque Tube



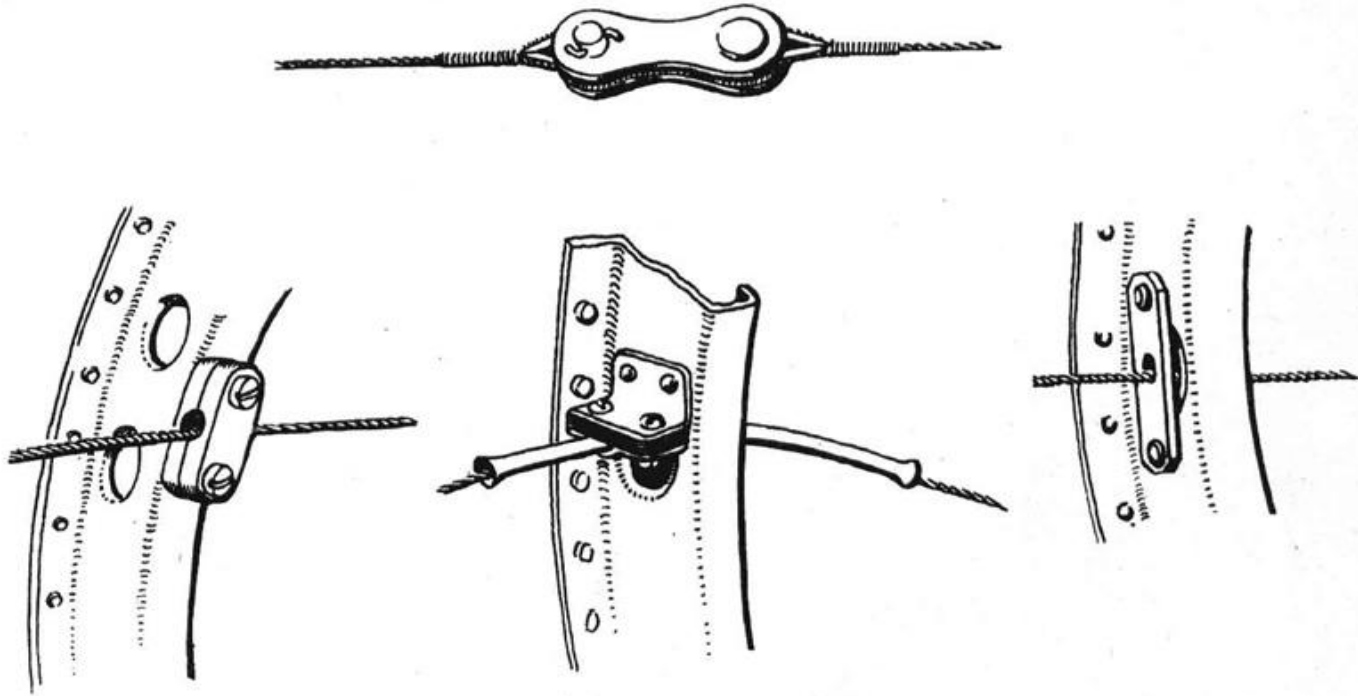
A tube in an aircraft control system that **transmits a torsional force** from the operating control to the control surface. Torque tubes are often used to **actuate ailerons and flaps.**

Bell Crank



A double lever in an aircraft control system used to change the direction of motion. Bell cranks are normally used in aileron controls and in the steering system of nosewheels.

Fairleads

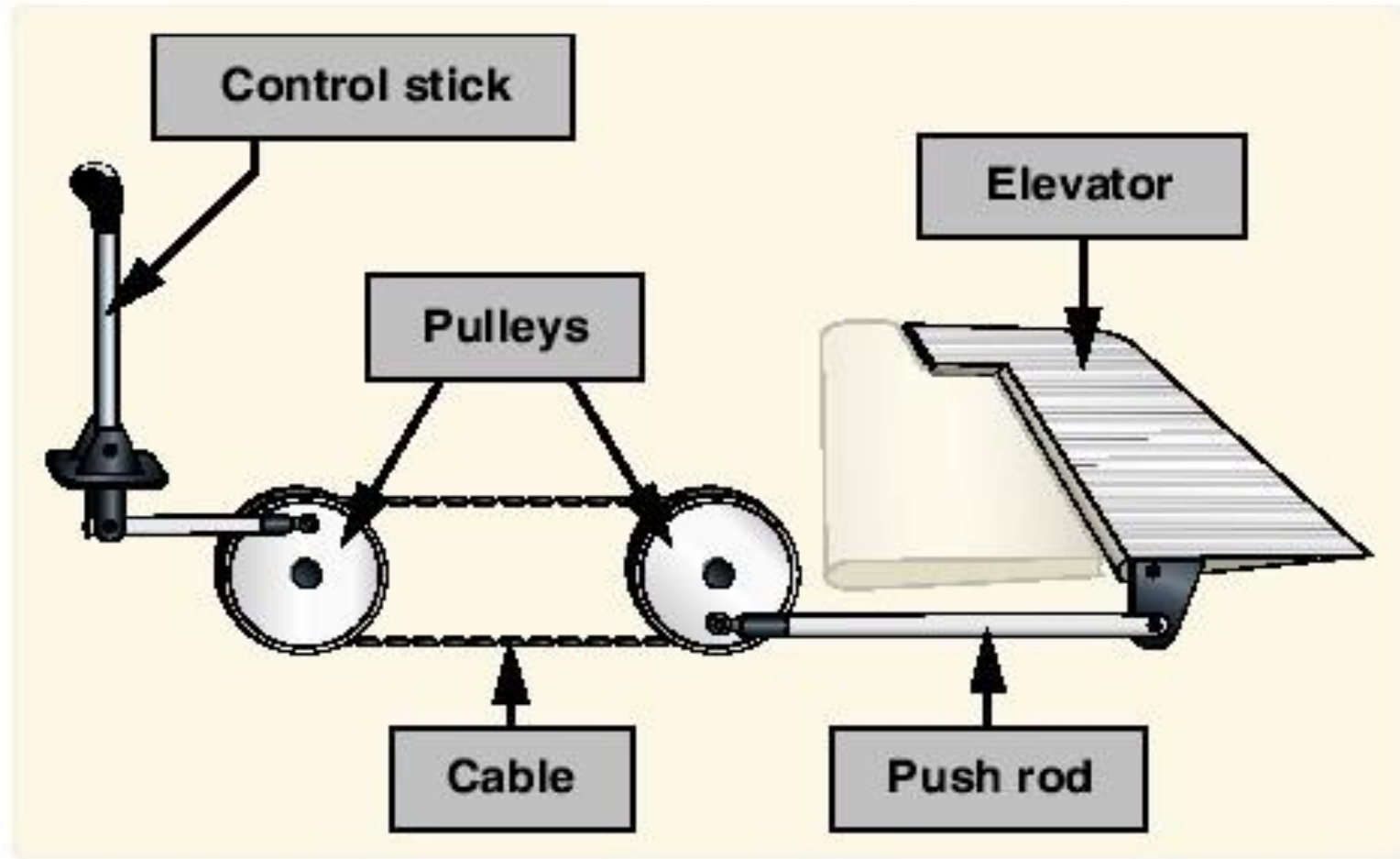


A **fairlead** is a device to **guide a line, rope or cable** around an object, out of the way or to **stop it from moving laterally**. Typically a fairlead will be a **ring or hook**. The fairlead may be a separate piece of hardware, or it could be a hole in the structure.

Mechanical Flight Control System

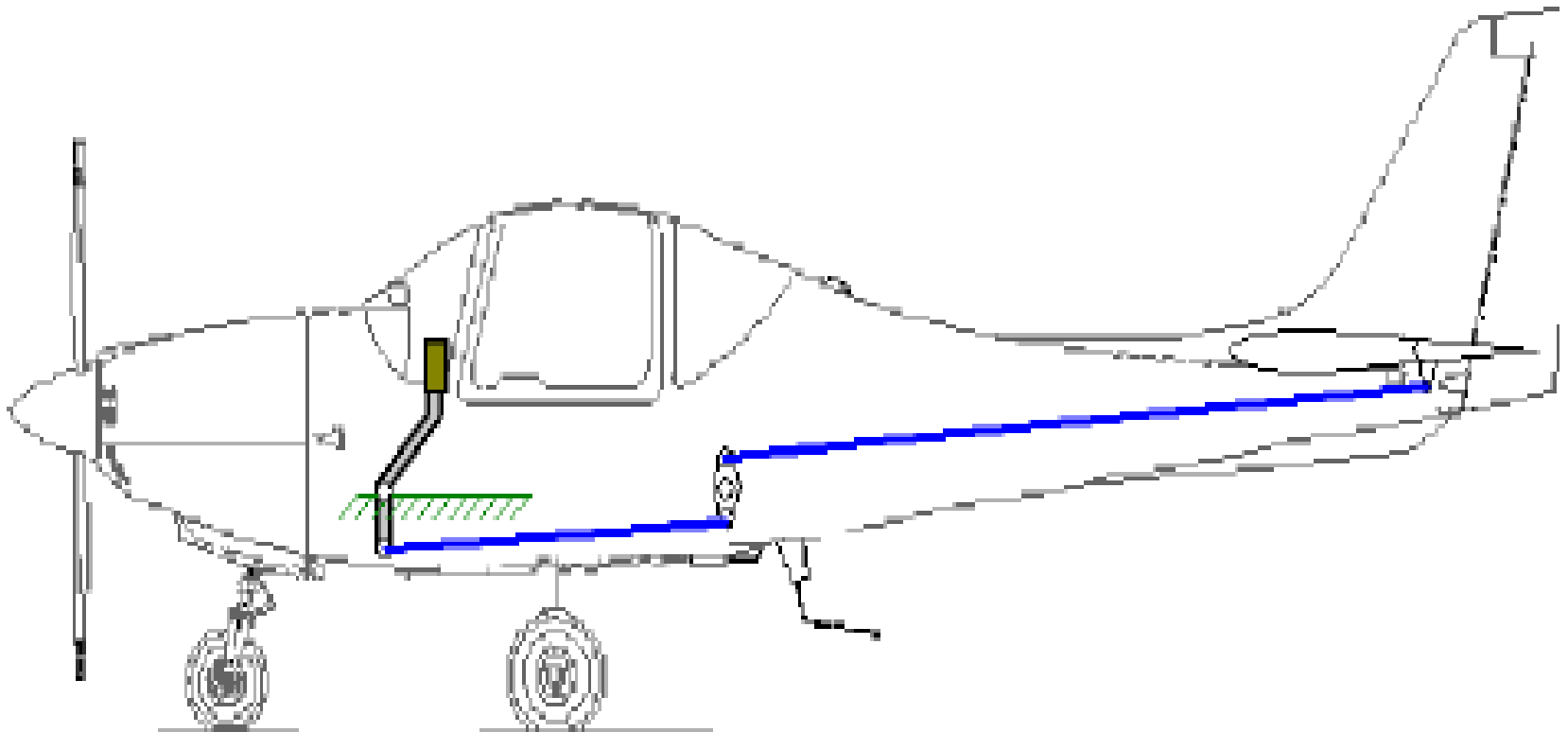
- Basic method of controlling an aircraft
- Used in early aircraft and currently in small aircraft where the aerodynamic forces are not excessive.
- It uses a collection of mechanical parts such as rods, tension cables, pulleys, counterweights, and sometimes chains to transmit the forces applied from the cockpit controls directly to the control surfaces

Mechanical Flight Control System



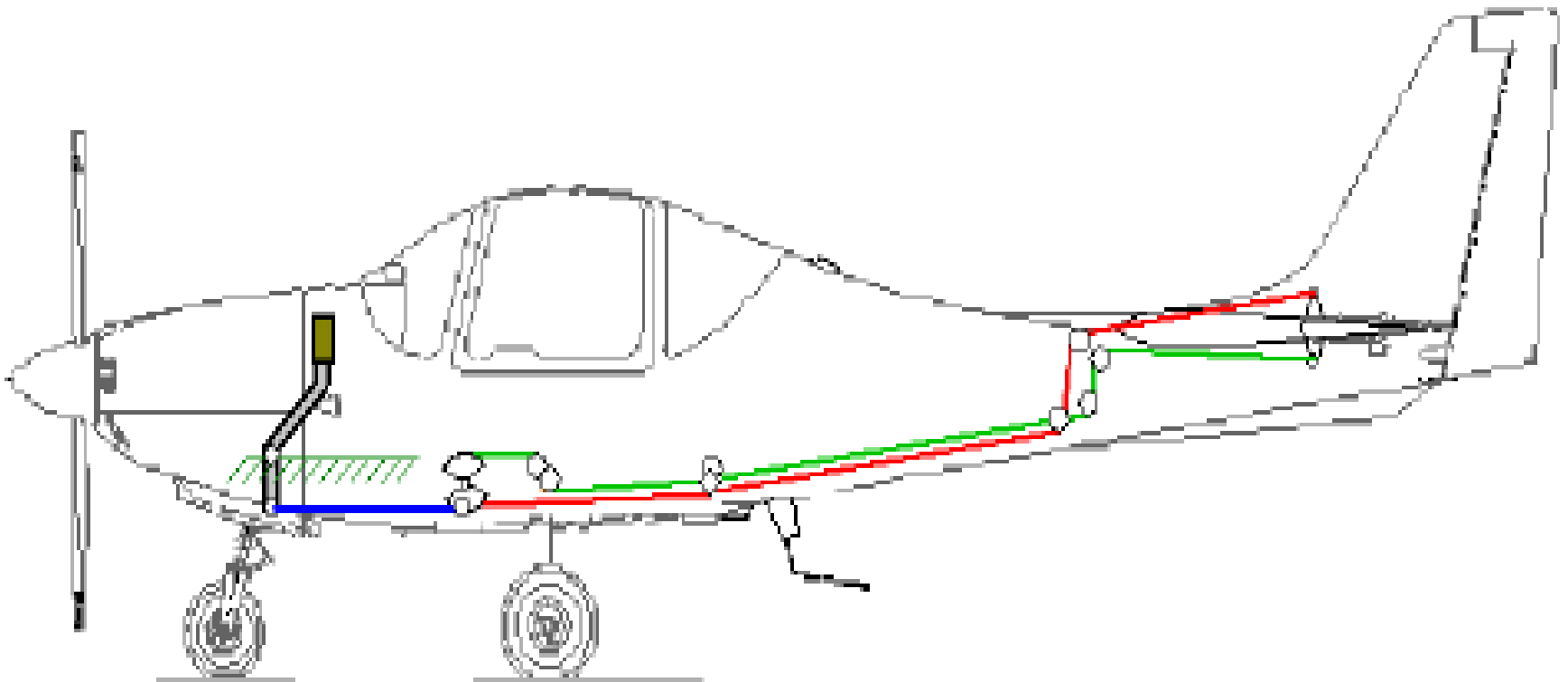
Mechanical Flight Control System

Push Pull Rod System for Elevator Control



Mechanical Flight Control System

Cables & Pulleys System for Elevator Control



Mechanical Flight Control System

- **Gust locks** are often used on parked aircraft with mechanical systems to **protect the control surfaces and linkages** from **damage from wind**



Mechanical Flight 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**.

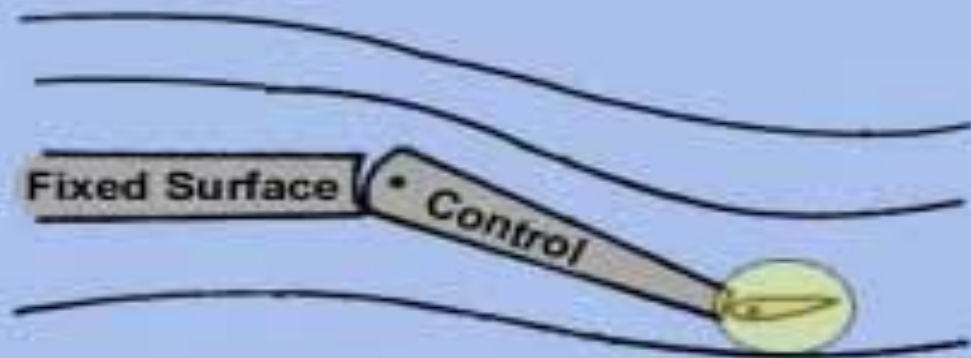
Mechanical Flight Control System

- 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**.

Servo Tabs

- In **large aircrafts** the control surfaces are operated by **power operated hydraulic actuators** controlled by **valves moved by control yoke and rudder pedals**. An **artificial feel system** gives the pilot **resistance** that is **proportional to the flight loads on the surfaces**.
- In the event of **hydraulic system failure**, the control surfaces are **controlled by servo tabs** in a process known as **manual reversion**.
- In the **manual mode** the **flight control column** moves **the tab** on the c/surface and the **aerodynamic forces** **caused by the deflected tab** moves the **main control surface**

Elevator Trim Tab



The trim tab holds a control surface in a fixed position, without effort from the pilot.

Nose-Down Trim



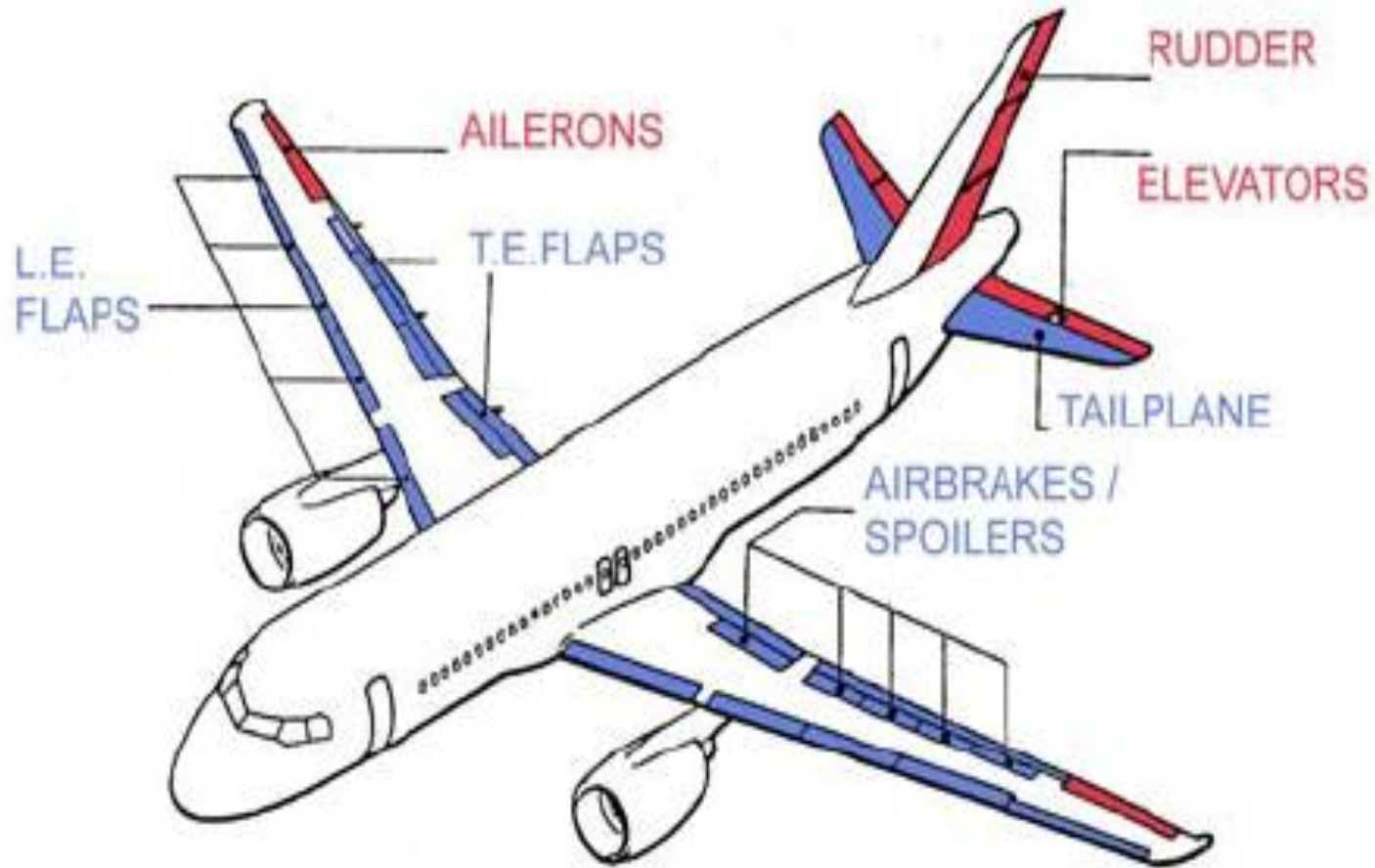
Tab Up; Elevator Down

Nose-Up Trim



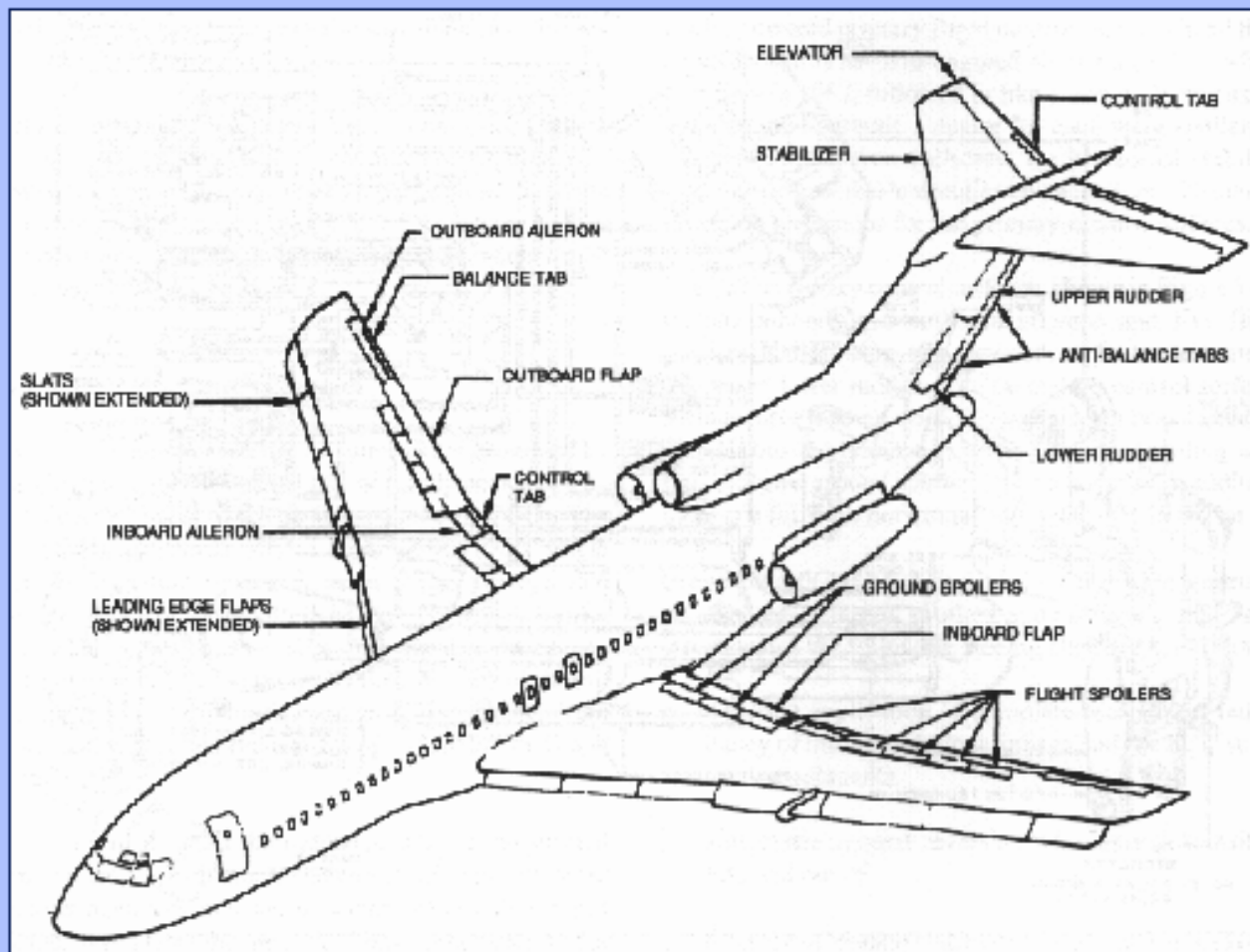
Tab Down; Elevator Up

Flight Control Surfaces On An Modern Advanced Aircraft



Modern Advanced Aircraft Have Many Control Surfaces

- Each set of control surfaces has a different purpose
- The pilot cannot control each surface directly **there are just too many!**
- **A flight control system is used to tell which control surfaces to move, and by how much, based on simple inputs from the pilot.**



Need for Powered Control System

- The **Complexity** and **Weight** of the system (Mechanical) increased with **Size** and **Performance** of the aircraft.
- When the pilot's action is not **directly sufficient** for the control, the main option is a **powered system** that **assists the pilot**.
- The **hydraulic system** has demonstrated to be a more suitable solution for actuation in terms of **reliability, safety, weight per unit power** and **flexibility**, with respect to the electrical system

Powered Assisted Control System

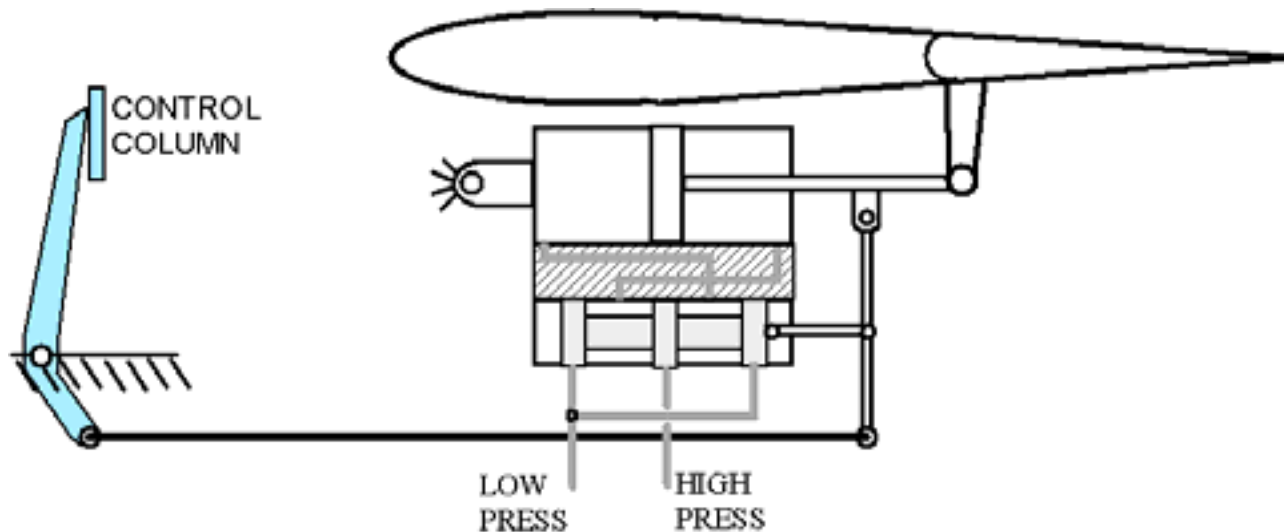
- The **pilot, via the cabin components**, sends a signal, or demand, to a valve that opens ports through which **high pressure hydraulic fluid flows and operates** one or more actuators.
- The valve, that is located near the actuators, can be signalled in two different ways: **mechanically** or **electrically**
- **Mechanical signalling** is obtained by **push-pull rods**, or more commonly by **cables and pulleys**
- **Electrical signalling** is a solution of more modern and sophisticated vehicles

Powered Assisted Control System

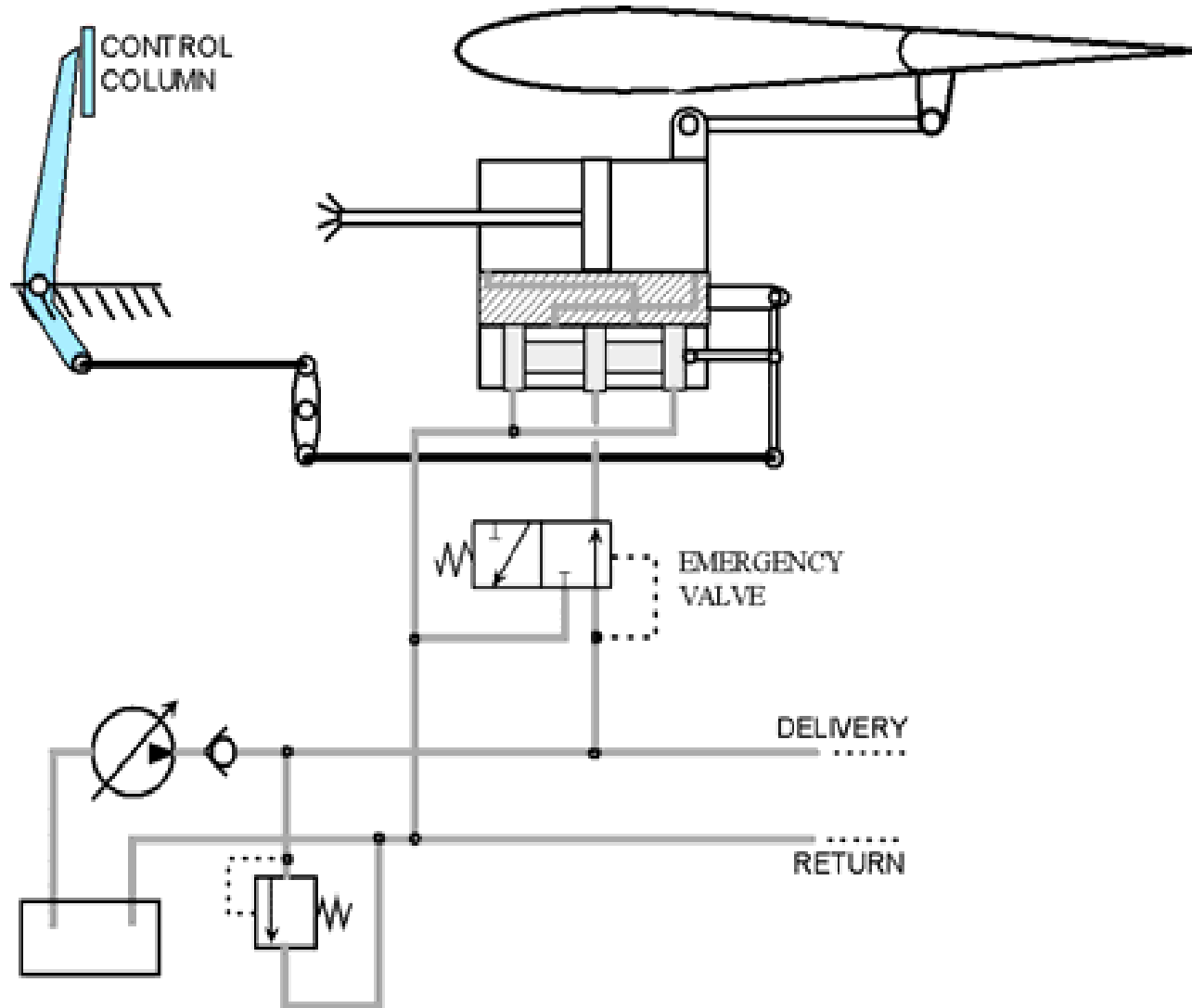
- The basic principle of the hydraulic control is simple, but **two aspects** must be noticed when a **powered control** is introduced:
- The system must **control the surface** in a **proportional way**, i.e. the surface response (deflection) must be function to the pilot's demand (stick deflection, for instance)
- The pilot that with **little effort acts on a control valve** must have a **feedback on the maneuver intensity**

Powered Assisted Control System

- The first problem is solved by using (hydraulic) servo-mechanisms, where the components are linked in such a way to introduce an actuator stroke proportional to the pilot's demand



Powered Assisted Control System



Powered Assisted Control System

- The pilot, in normal hydraulic operating conditions, is requested for a **very low effort**, necessary to contrast the mechanical frictions of the linkage and the movement of the control valve
- The pilot is then **no more aware** of the **load condition** being **imposed to the aircraft**.
- An **artificial feel** is introduced in powered systems, acting directly on the **cabin control stick or pedals**.

Powered Assisted Control System

- The simplest solution is a **spring system**, then responding to the **pilot's demand with a force proportional to the stick deflection**; this solution has of course the limit to be **not sensitive to the actual flight conditions**.
- A more sophisticated artificial feel is the so-called **Q feel**. This system **receives data** from the **pitot-static probes**, reading the **dynamic pressure**, or the difference between total (pt) and static (ps) pressure, that is proportional to the aircraft speed v through the air density ρ :

$$p_t - p_s = \frac{1}{2} \rho v^2 .$$

Powered Assisted Control System

- This signal is used to modulate a hydraulic cylinder that increases the stiffness in the artificial feel system, in such a way that the pilot is given a contrast force in the pedals or stick that is also proportional to the aircraft speed.

Disadvantages of Mechanical and Hydro-Mechanical Systems

- **Heavy** and require **careful routing of flight control cables** through the aircraft using pulleys, cranks, tension cables and hydraulic pipes.
- They require **redundant backup** to deal with failures, which again **increases weight**.
- **Limited ability to compensate** for changing aerodynamic conditions

Disadvantages of Mechanical and Hydro-Mechanical Systems

- 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
- By using **electrical control circuits** combined with **computers**, designers can **save weight**, **improve reliability**, and use the **computers** to mitigate the **undesirable characteristics** mentioned above. Modern advanced fly-by-wire systems are also used to control **unstable fighter aircraft**

Fly –By –Wire System (FBW)

- The term "fly-by-wire" implies a purely electrically-signalled control system
- It is a computer-configured controls, where a computer system is interposed between the operator and the final control actuators or surfaces
- It modifies the manual inputs of the pilot in accordance with control parameters
- These are carefully developed and validated in order to produce maximum operational effect without compromising safety

FBW – Introduction

- The FBW architecture was developed in 1970's
- Initially starting as an analogue technique and later on transformed into digital.
- It was first developed for military aviation, where it is now a common solution
- The supersonic Concorde can be considered a first and isolated civil aircraft equipped with a (analogue) fly-by-wire system

FBW – Introduction

- In the 80's the digital technique was imported from military into civil aviation by Airbus, first with the A320, then followed by A319, A321, A330, A340, Boeing 777 and A380 (scheduled for 2005).
- This architecture is based on computer signal processing

Operation

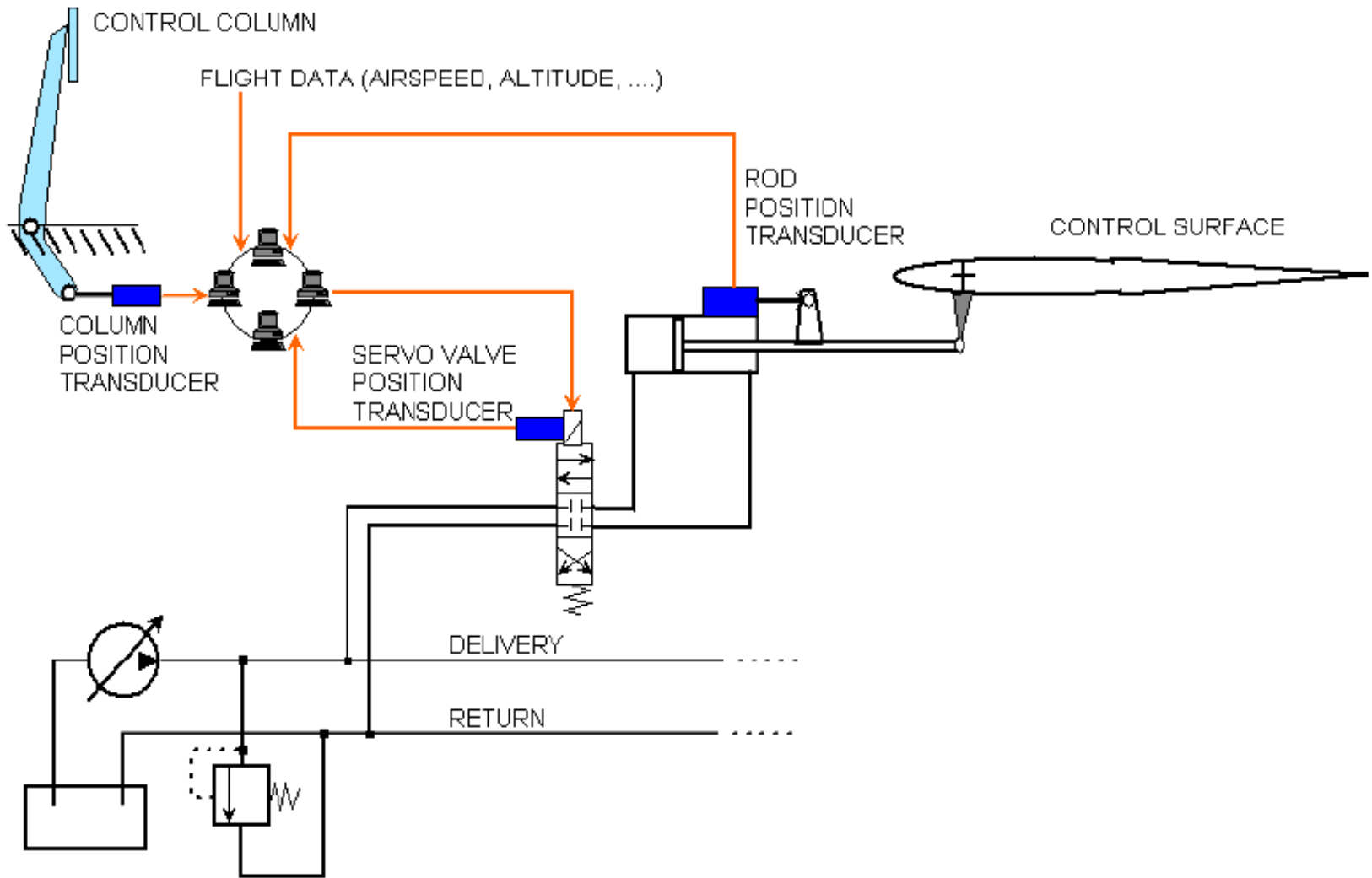
- The pilot's demand is first of all transduced into **electrical signal** in the cabin and sent to a group of **independent computers** (Airbus architecture substitute the cabin control column with a side stick)
- The **computers sample also data** concerning the **flight conditions** and **servo-valves** and **actuators positions**
- The pilot's demand is then processed and sent to the actuator, properly tailored to the actual flight status.

Operation

- The flight data used by the system mainly depend on the aircraft category; in general the following data are sampled and processed:
 - pitch, roll, yaw rate and linear accelerations
 - Angle of attack and sideslip
 - Airspeed/Mach number, Pressure, Altitude and radio altimeter indications
 - Stick and pedal demands
 - Other cabin commands such as landing gear condition, thrust lever position, etc.

Operation

- The full system has high redundancy to restore the level of reliability of a mechanical or hydraulic system, in the form of multiple (triplex or quadruplex) parallel and independent lanes to generate and transmit the signals, and independent computers that process them



Fly-By-Wire System

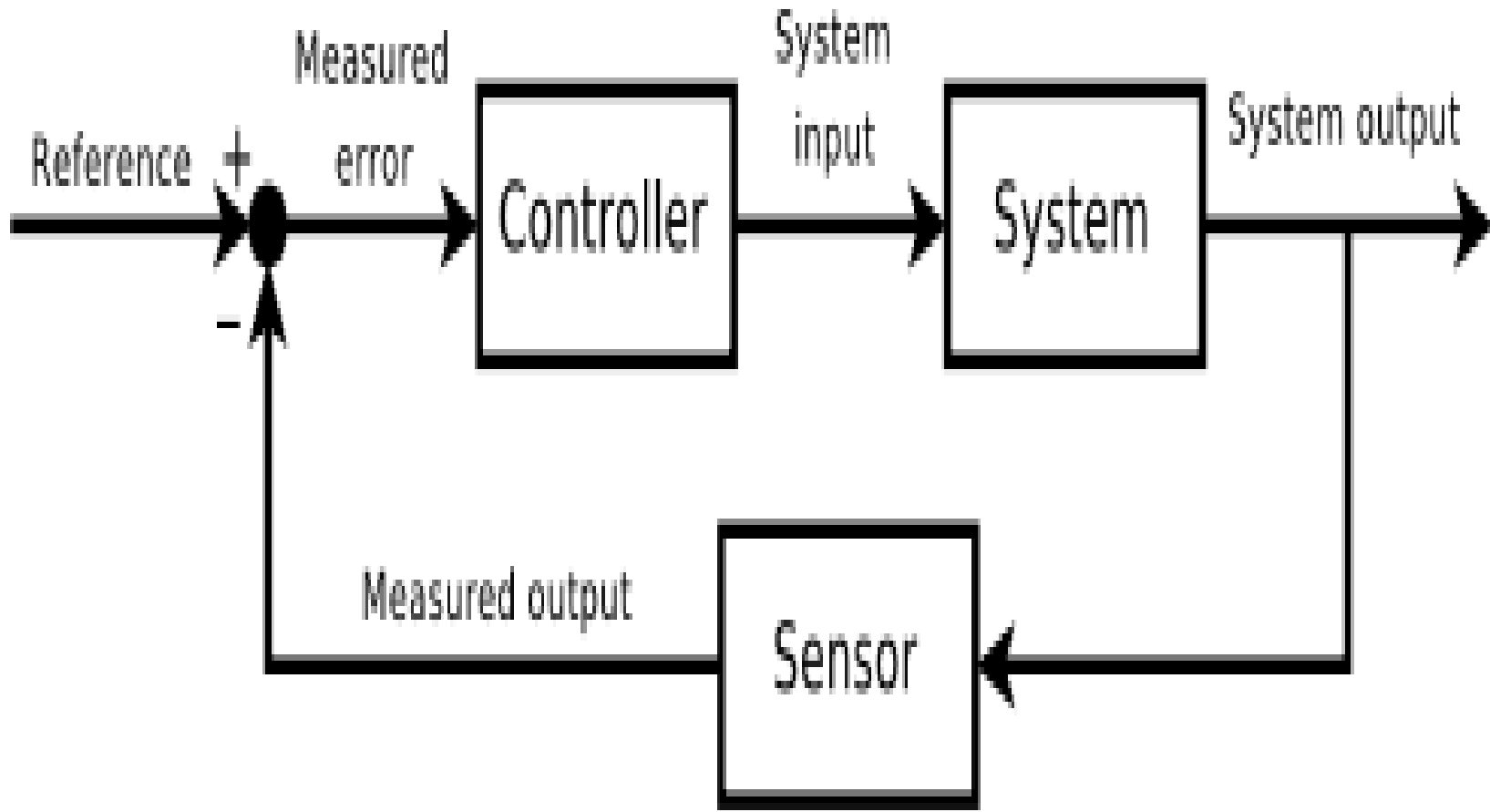
FBW – Basic Operation

- When a pilot moves the control, 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.

FBW – Basic Operation

- 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).

FBW – Basic Operation

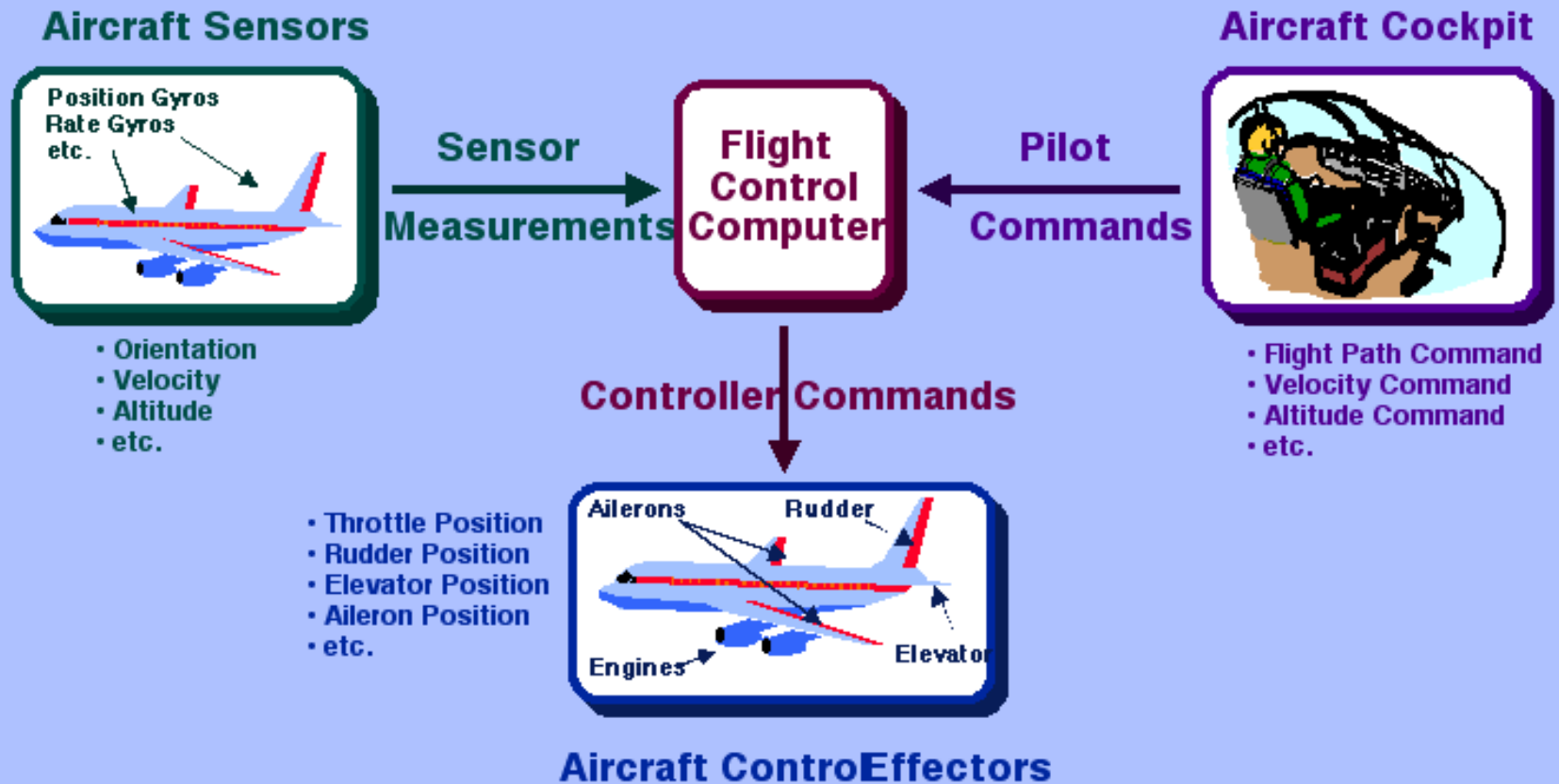


FBW – Stability

- Three gyroscopes fitted with sensors are fitted in the aircraft to sense movement changes in the pitch, roll and yaw axes.
- Any movement (from straight and level flight for example) results in signals being sent to the computer which again moves the relevant control actuators, however, the input is done without the pilot's knowledge; the cockpit controls do not move

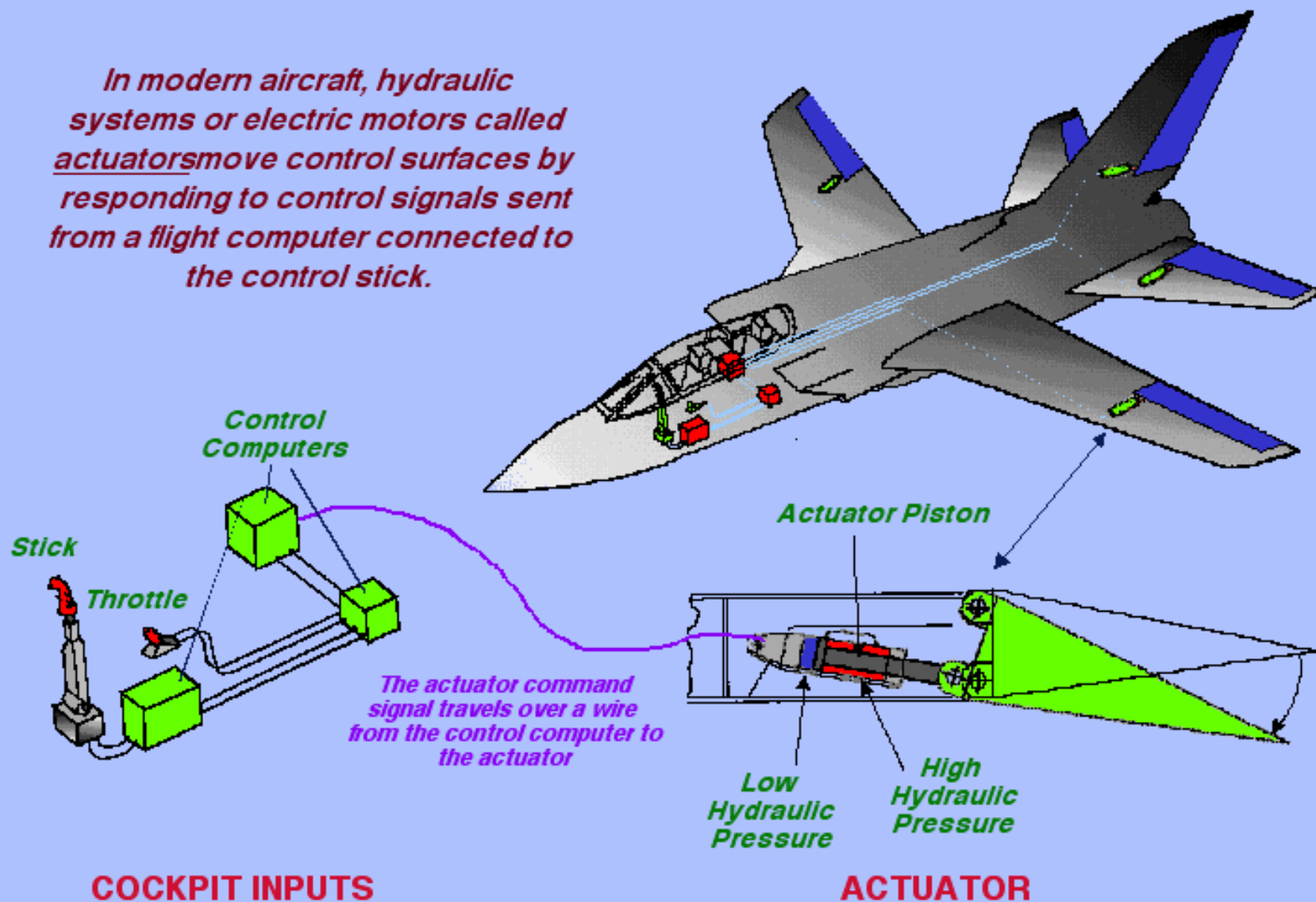
“Putting it All Together”

Flight Control System



Control Surfaces are Moved with Actuators

In modern aircraft, hydraulic systems or electric motors called actuators move control surfaces by responding to control signals sent from a flight computer connected to the control stick.



FBW – Safety and Redundancy

- Aircraft systems may be **quadruplexed** (four independent channels) in order 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

FBW – Safety and Redundancy

- 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 ground crew, a number of control movement steps are automatically performed.
- Any **failure** will be indicated to the **crews**

FBW – Advantages

- **Flight envelope protection** (the computers will reject and tune pilot's demands that might exceed the airframe load factors)
- **Increase of stability and handling qualities** across the **full flight envelope**, including the possibility of **flying unstable vehicles**
- **Turbulence suppression** and **consequent decrease of fatigue loads** and increase of passenger comfort

FBW – Advantages

- Use of **thrust vectoring** to augment or replace **lift aerodynamic control**, then extending the aircraft flight envelope
- **Drag reduction** by an optimised **trim setting**
- **Higher stability** during release of **tanks and weapons**

FBW – Advantages

- **Easier interfacing** to **auto-pilot** and other automatic flight control systems
- **Weight reduction** (mechanical linkages are substituted by wirings)
- **Maintenance reduction**
- Reduction of airlines' **pilot training costs** (flight handling becomes very similar in an whole aircraft family)



F-8C Crusader
Digital fly-by-wire test bed
(1972)



The Airbus A320,
First airliner with Digital fly-by-wire controls
(1984)



A Dassault Falcon 7X,
The first business jet with Digital fly-by-wire controls
(2005)

Digital Fly-By-Wire (DFBW)

- A digital fly-by-wire flight control system is **similar** to **analog** system. However, the **signal processing** is done by **digital computers** and the pilot literally can "**fly-via-computer**".
- Increases in **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).
- Increase in **electronic stability** - system is less dependent on the values of critical electrical components in an analog controller

Digital Fly-By-Wire (DFBW)

- The computers "read" position and force inputs from the pilot's controls and aircraft sensors.
- They solve differential equations to determine the appropriate command signals that move the flight controls in order to carry out the intentions of the pilot
- The programming of the digital computers enable flight envelope protection.

Digital Fly-By-Wire (DFBW)

- 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.
- Flight-control computers continuously "fly" the aircraft, pilot's workloads can be reduced
- In **military** and **naval applications**, it is now possible to fly military aircraft that have **relaxed stability**.

Digital Fly-By-Wire (DFBW)

- Better maneuverability during combat and training flights and "carefree handling" because stalling, spinning, and other undesirable performances are prevented automatically by the computers
- 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

DFBW - 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**.

DFBW - Redundancy

- 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.

DFBW - Redundancy

- 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**
- 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**

DFBW - Redundancy

- 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**

Engine Control Systems

- To allow the engine to **perform at maximum efficiency** for a **given condition**
- Aids the pilot to **control and monitor** the operation of the **aircraft's power plant**
- Originally, engine control systems consisted of **simple mechanical linkages** controlled by the pilot then evolved and became the responsibility of the **third pilot-certified crew member**, the **flight engineer**

Engine Control Systems

- By **moving throttle levers** directly connected to the engine, the pilot or the flight engineer could **control fuel flow, power output, and many other engine parameters.**
- Following mechanical means of engine control came the introduction of **analog electronic engine control.**
- Analog electronic control **varies an electrical signal** to **communicate the desired engine settings**

Engine Control Systems

- It had its **drawbacks** including **common electronic noise interference** and **reliability issues**
- **Full authority analogue control** was used in the **1960s**.
- It was introduced as a **component of the Rolls Royce Olympus 593 engine** of the supersonic transport aircraft **Concorde**. However the more **critical inlet control** was **digital** on the **production aircraft**.

Engine Control Systems

- In the **1970s** **NASA** and **Pratt and Whitney** experimented with the **first experimental FADEC**, first flown on an **F-111** fitted with a **highly modified Pratt & Whitney TF30** left engine



Rolls Royce Olympus 593 engine



F-111C - Fighter - Bomber

Engine Control Systems

- Pratt & Whitney F100 – First Military Engine
- Pratt & Whitney PW2000 - First Civil Engine fitted with FADEC
- Pratt & Whitney PW4000 - First commercial "dual FADEC" engine.
- The Harrier II Pegasus engine by Dowty & Smiths Industries Controls - The first FADEC in service



Harrier II



Pegasus Engine

Functions

- FADEC works by **receiving multiple input variables** of the current flight condition including **air density, throttle lever position, engine temperatures, engine pressures**, and many other parameters
- The inputs are received by the **EEC** and analyzed up to **70 times per second**
- Engine operating parameters such as **fuel flow, stator vane position, bleed valve position**, and others are **computed from this data** and applied as appropriate

Functions

- It controls engine starting and restarting.
- Its basic purpose is to provide optimum engine efficiency for a given flight condition.
- It also allows the manufacturer to program engine limitations and receive engine health and maintenance reports. For example, to avoid exceeding a certain engine temperature, the FADEC can be programmed to automatically take the necessary measures without pilot intervention.

Functions

- The **flight crew** first enters **flight data** such as wind conditions, runway length, or cruise altitude, into the **flight management system (FMS)**. The FMS uses this data to **calculate power settings** for different phases of the flight.
- At takeoff, the flight crew **advances the throttle to a predetermined setting**, or opts for an **auto-throttle takeoff** if available.
- The FADECs now apply the **calculated takeoff thrust setting** by sending an **electronic signal to the engines**

Functions

- There is **no direct linkage to open fuel flow**. This procedure can be repeated for any other phase of flight
- In flight, **small changes in operation** are **constantly made** to **maintain efficiency**.
- **Maximum thrust** is available for **emergency situations** if the throttle is advanced to full, but limitations can't be exceeded
- **The flight crew** has **no means** of **manually overriding the FADEC**

Functions

- True full authority digital engine controls have no form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer
- If a total FADEC failure occurs, the engine fails
- If the engine is controlled digitally and electronically but allows for manual override, it is considered solely an EEC or ECU.
- An EEC, though a component of a FADEC, is not by itself FADEC. When standing alone, the EEC makes all of the decisions until the pilot wishes to intervene.

Safety

- With the operation of the engines so heavily relying on automation, **safety is a great concern.**
- **Redundancy** is provided in the form of **two or more, separate identical digital channels.**
- **Each channel** may provide **all engine functions** without restriction.
- FADEC also **monitors a variety of analog, digital and discrete data** coming from the engine subsystems and related aircraft systems, providing for **fault tolerant engine control**

Applications

- FADECs are employed by **almost all current generation jet engines**, and increasingly in **piston engines** for **fixed-wing aircraft** and **helicopters**.
- The system **replaces both magnetos in piston-engined aircraft**, which makes **costly magneto maintenance obsolete** and **eliminates carburetor heat, mixture controls and engine priming**.
- Since, it **controls each engine cylinder independently for optimum fuel injection and spark timing**, the pilot no longer needs to monitor fuel mixture.

Applications

- More precise mixtures create less engine wear, which reduces operating costs and increases engine life for the average aircraft.
- Tests have also shown significant fuel savings

Advantages

- Better **fuel efficiency**
- **Automatic engine protection** against out-of-tolerance operations
- Safer as the multiple channel FADEC computer provides **redundancy** in case of failure
- **Care-free engine handling**, with guaranteed thrust settings
- **Ability to use single engine type** for wide thrust requirements by just reprogramming the FADECs

Advantages

- Provides semi-automatic engine starting
- Better systems integration with engine and aircraft systems
- Can provide engine long-term health monitoring and diagnostics
- Reduces the number of parameters to be monitored by flight crews

Advantages

- Due to the high number of parameters monitored, the FADEC makes possible "Fault Tolerant Systems" (where a system can operate within required reliability and safety limitation with certain fault configurations)
- Can support automatic aircraft and engine emergency responses (e.g. in case of aircraft stall, engines increase thrust automatically).

Disadvantages

- No form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer.
- If a total FADEC failure occurs, the engine fails.
- In the event of a total FADEC failure, pilots have no way of manually controlling the engines for a restart, or to otherwise control the engine.
- With any single point of failure, the risk can be mitigated with redundant FADECs

Disadvantages

- **High system complexity** compared to hydromechanical, analogue or manual control systems
- **High system development and validation effort** due to the complexity

Autopilot System

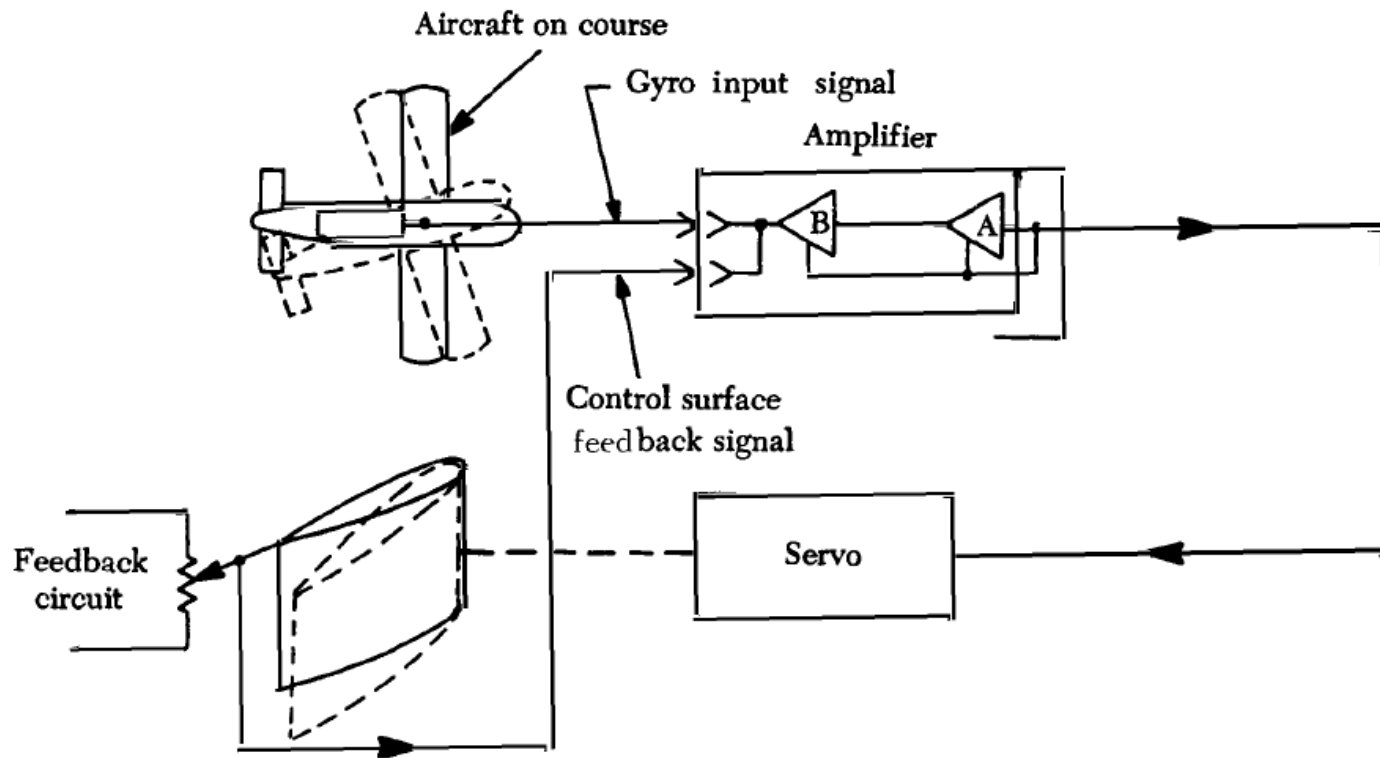


FIGURE 12-73. Basic autopilot system.

Autopilot Controller

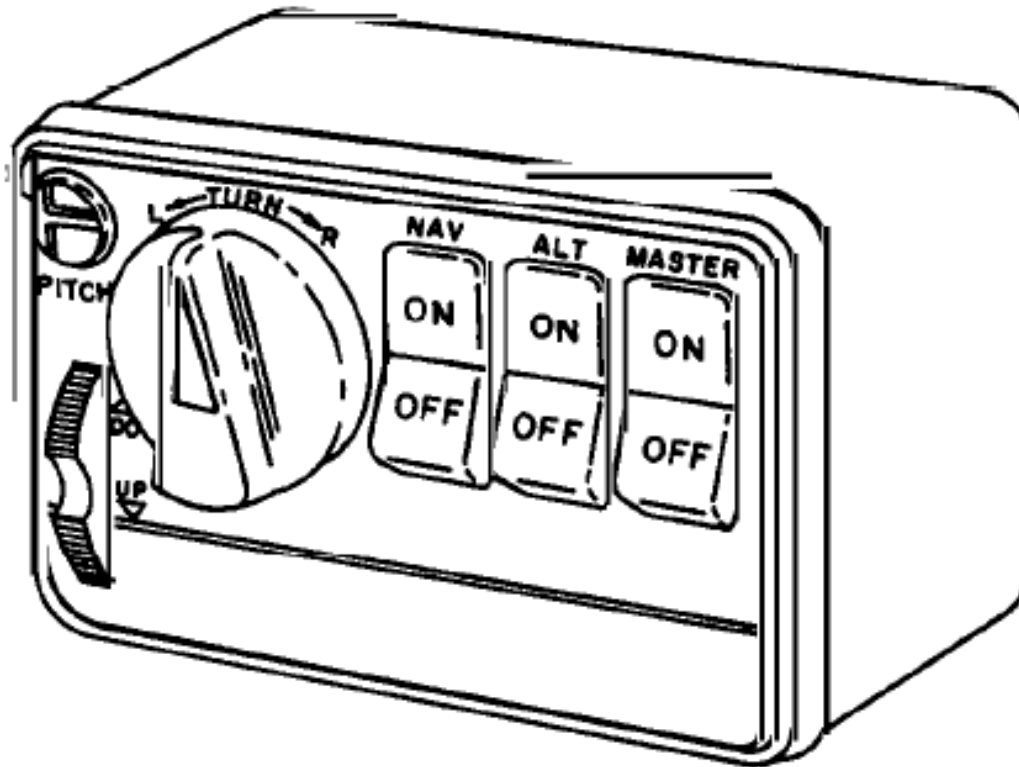


FIGURE 12-76. Typical autopilot controller.

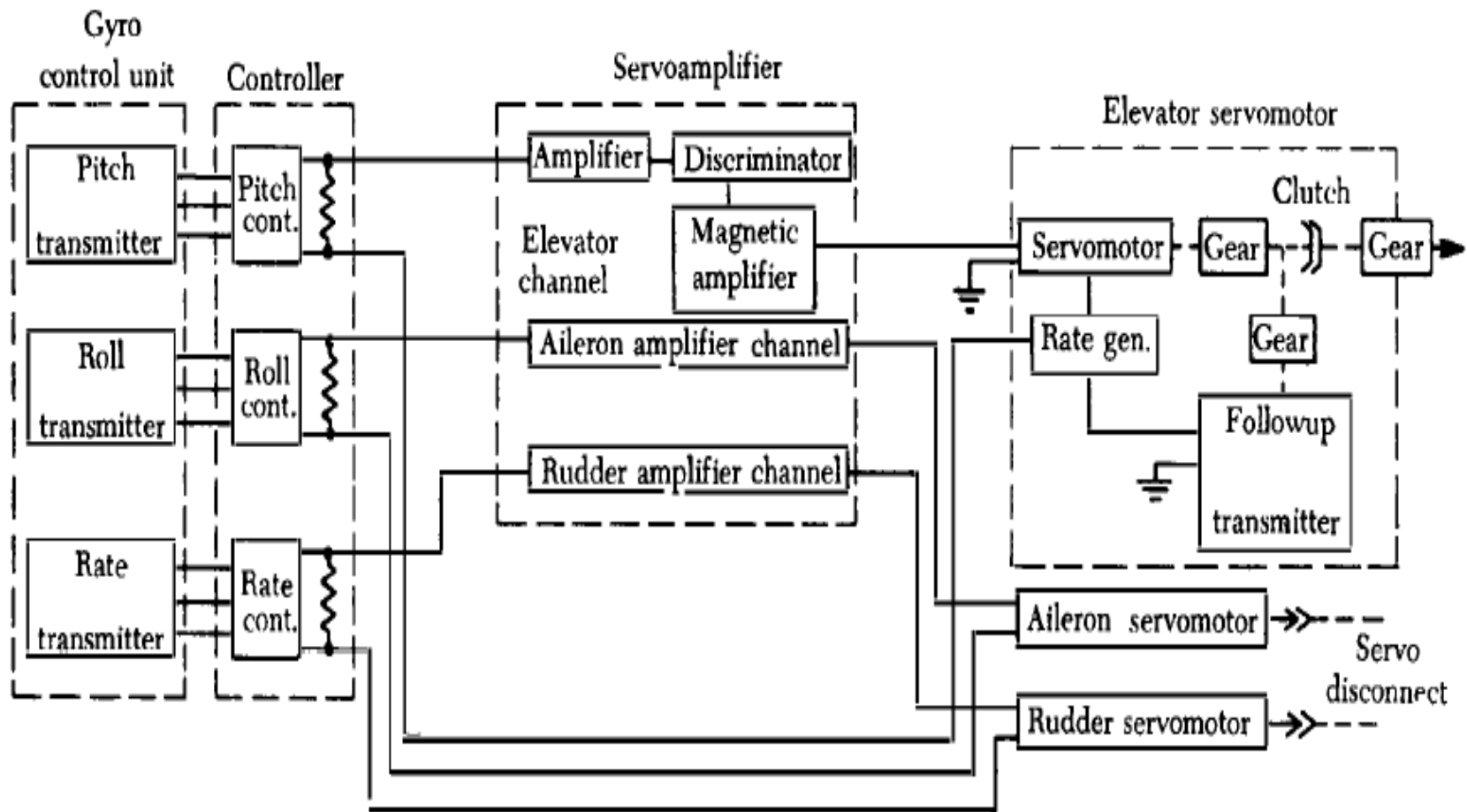


FIGURE 12-74. Autopilot block diagram.

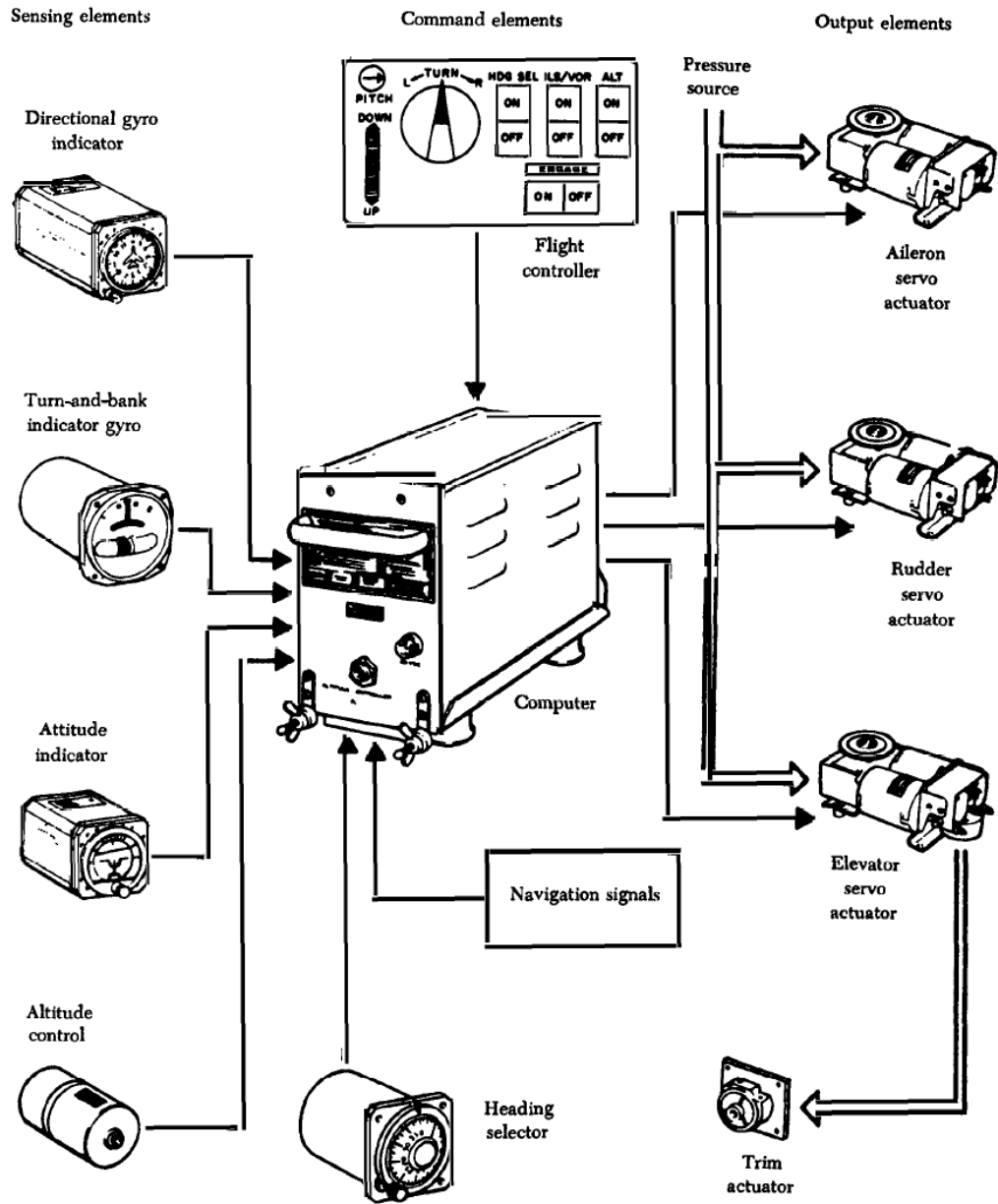


FIGURE 12-75. Typical autopilot system components.

COMMUNICATION AND NAVIGATION SYSTEMS

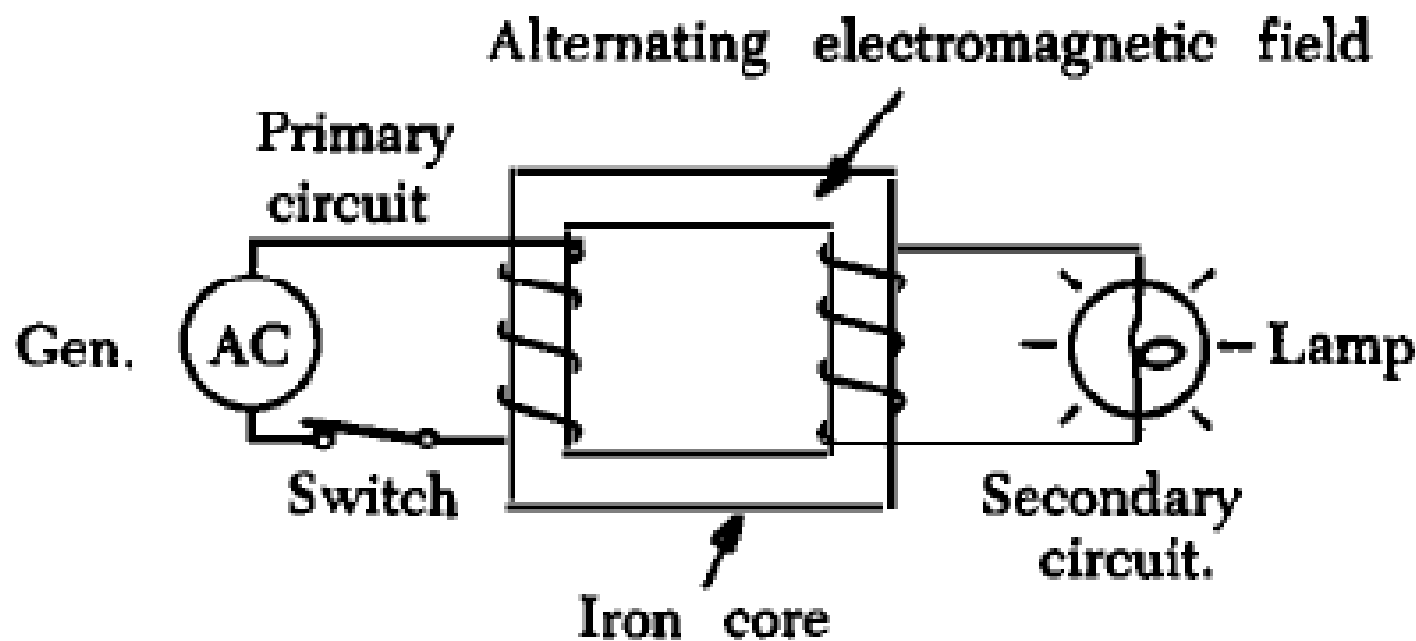


FIGURE 13-1. A simple transformer circuit.

Frequency Bands

<i>Frequency Range</i>	<i>Band</i>
Low frequency (L/F) -----	30 to 300 kHz
Medium frequency (M/F) --	300 to 3,000 kHz
High frequency (H/F) -----	3,000 kHz to 30 MHz
Very high frequency (VHF) _	30 to 300 MHz
Ultra high frequency (UHF) _	300 to 3,000 MHz
Superhigh frequency (SHF) _	3,000 to 30,000 MHz

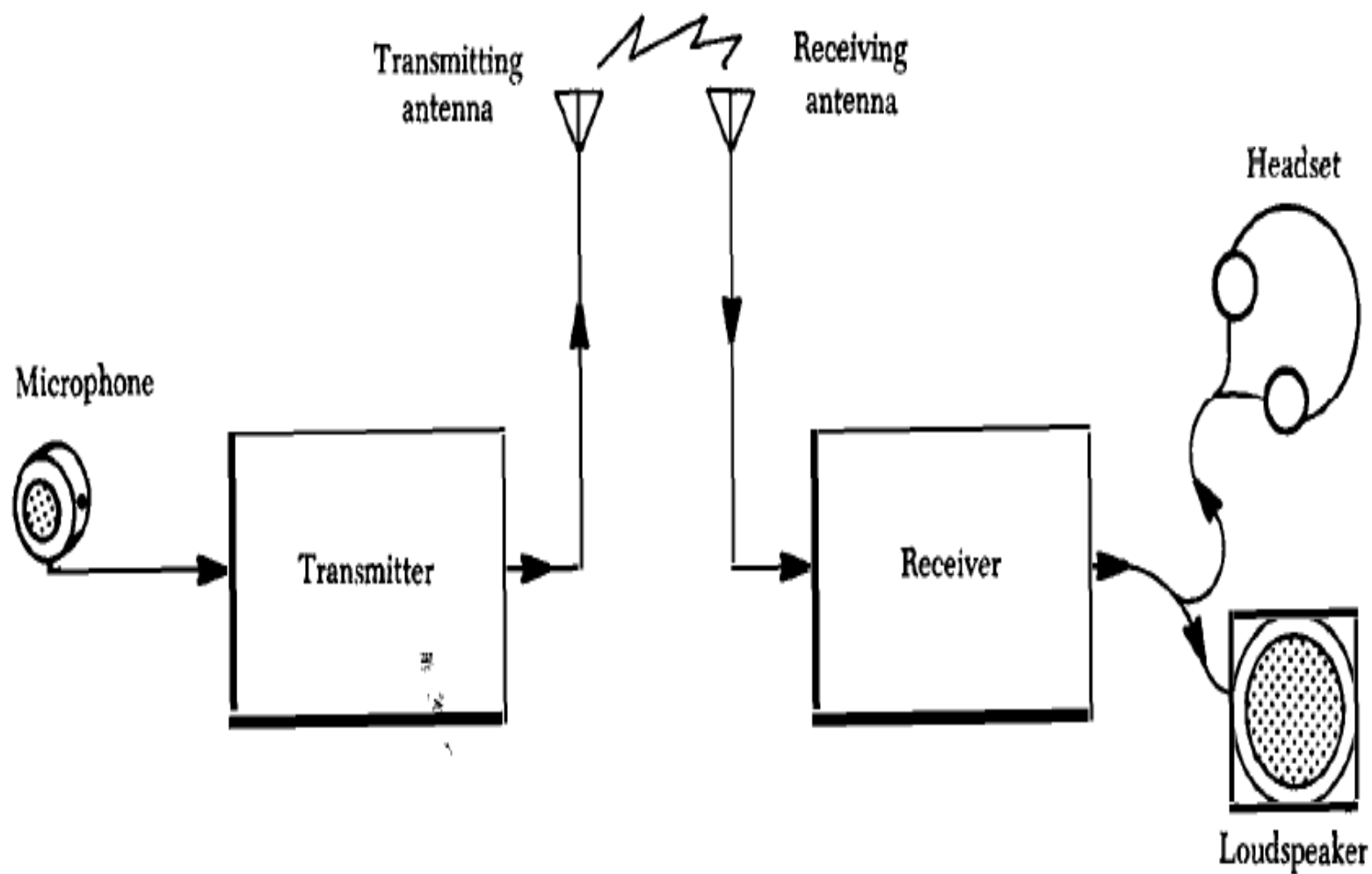
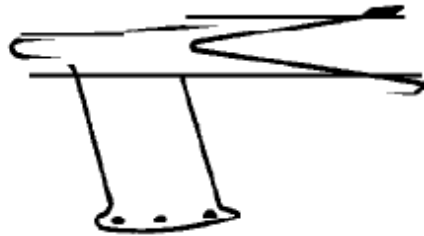
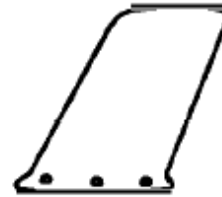


FIGURE 13-2. Basic communication equipment.

Antennas



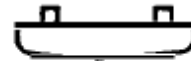
Communication,
navigation



VHF communication



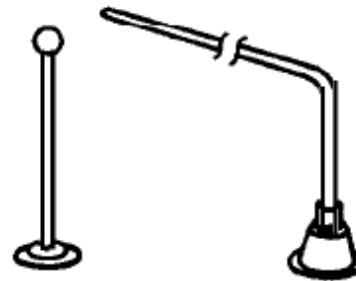
Distance measuring
equipment



Marker beacon



Glidescope



VHF communication

FIGURE 13-3. Antennas.

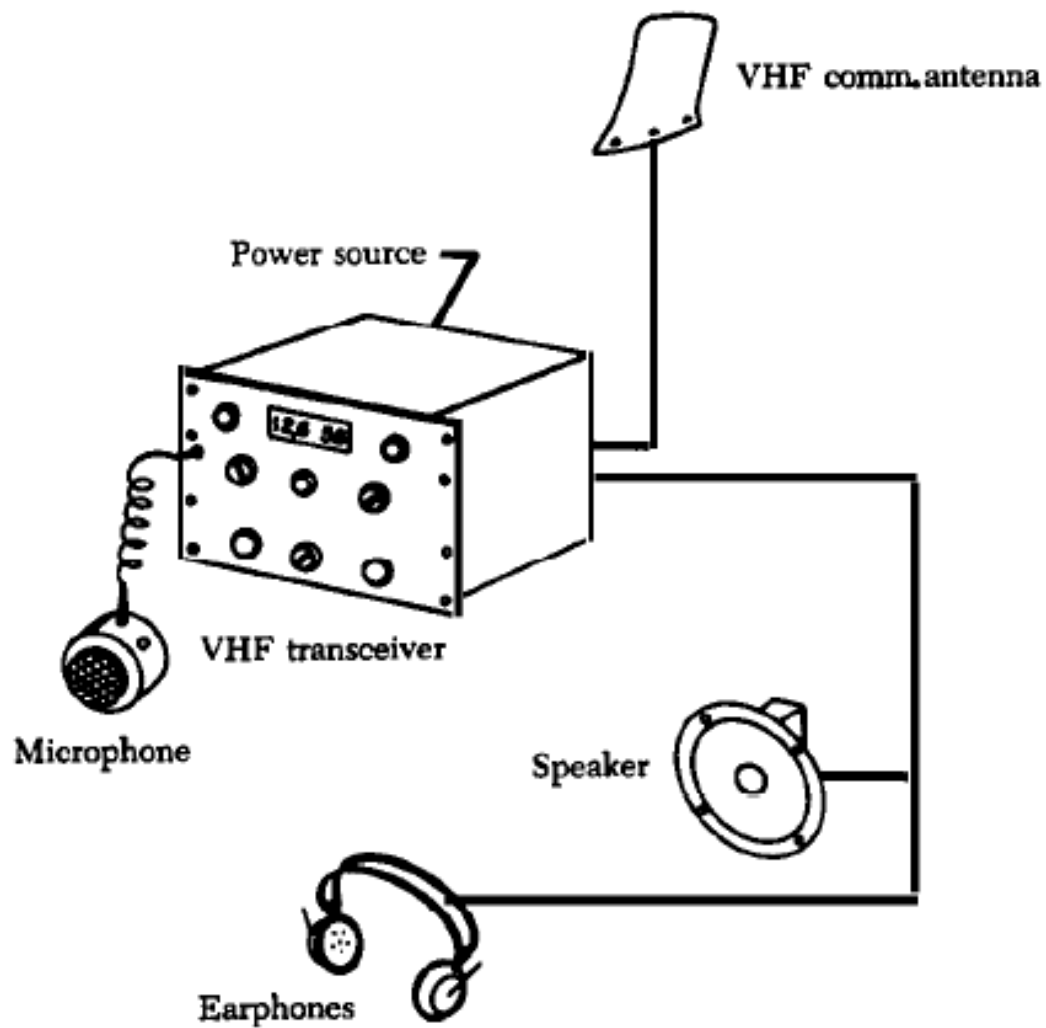


FIGURE 13-4. VHF system diagram.

INSTRUMENT LANDING SYSTEM (ILS)

What Is ILS?

- ILS is stand for **Instrument Landing System**.
- It has been existence for over 60 years.
- But today, it is still the most accurate **approach** and **landing** aid that is used by the airliners.
- Why need ILS?

History of ILS



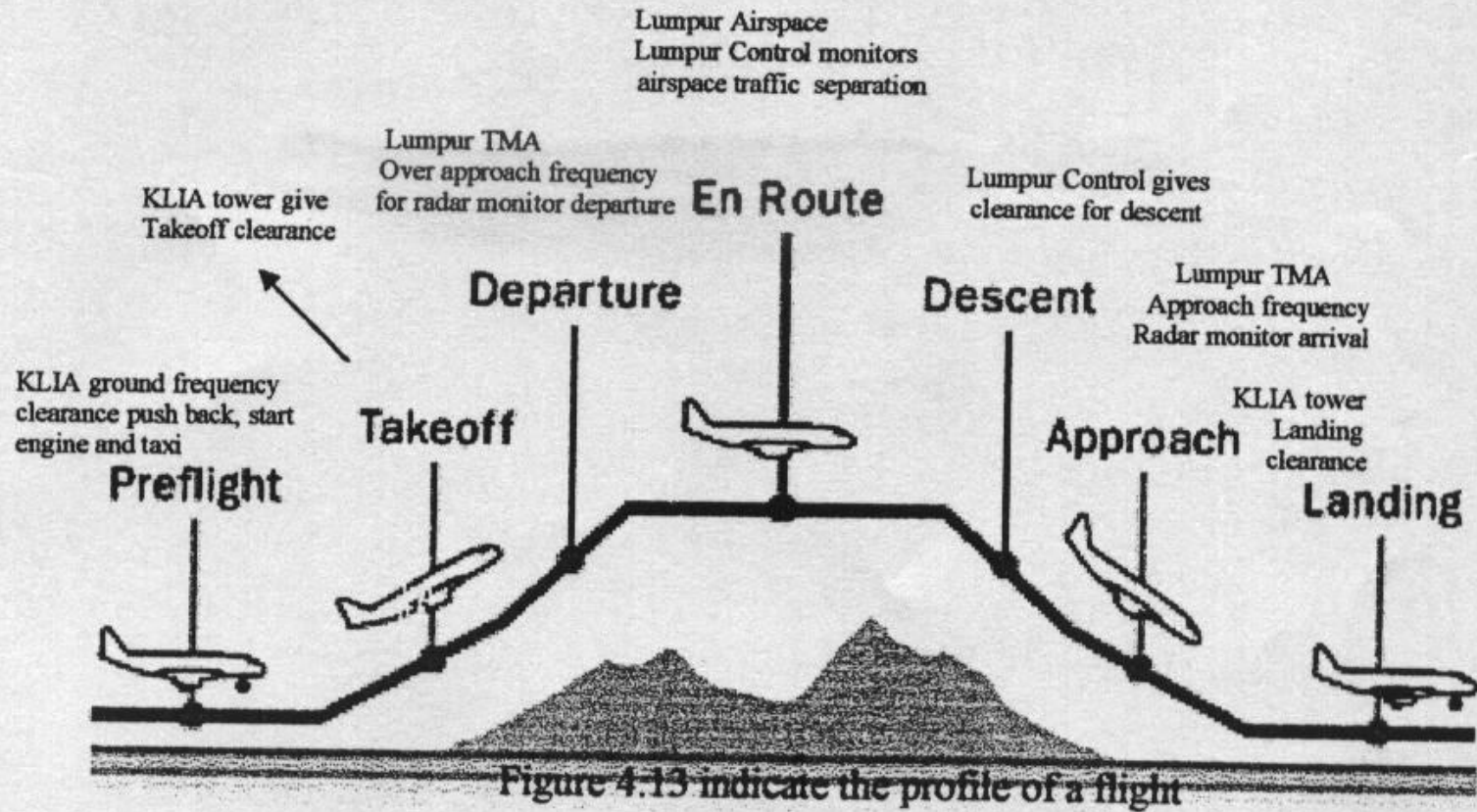
The first scheduled passenger airliner to land using ILS was in 1938.

The Uses of ILS



- To guide the pilot during the approach and landing.
 - It is very helpful when visibility is limited and the pilot cannot see the airport and runway.
- To provide an aircraft with a **precision final approach**.
- To help the aircraft to a runway **touchdown point**.
- To provide an aircraft guidance to the runway both in the **horizontal and vertical** planes.
- To increase safety and situational awareness.

Flight Profile



Poor Visibility Landings



- Scheduled service would be impossible without a way to land in poor weather.



Poor Visibility Landings



Runway Approach

Non-Instrument Runway (NI)



Precision Runway (P)



Aiming point

Touchdown zone

Threshold

Non-Precision Runway (NP)

Types of Runway Approach



1. Non-Instrument Runway (NI)

- A runway intended for the operation of aircraft using visual approach procedure

2. Instrument Runway

- A runway intended for the operation of aircraft using **instrument approach procedures**
- a) **Non-Precision Runway (NP)**
 - An instrument runway served by visual aids and a non-visual aid providing at least lateral guidance adequate for a straight-in approach
- b) **Precision Runway (P)**
 - **Allow operations with a decision height and visibility corresponding to Category 1, or II, or III**

Precision Runway (P) Categories



- **Runway Threshold:** Beginning of runway for landing.
- **Touchdown zone:** The first point for the aircraft should touch the runway during landing.
- **Aiming point:** serves as a visual aiming point for a landing aircraft.

ILS Components

- ILS consists of **Ground Installations** and **Airborne Equipments**
- There are **3 equipments for Ground Installations**, which are:
 1. **Ground Localizer (LLZ) Antenna** – To provide horizontal navigation
 2. **Ground Glide path (GP) Antenna** – To provide vertical navigation
 3. **Marker Beacons** – To enable the pilot cross check the aircraft's height.
- There are **2 equipments for Airborne Equipments**, which are:
 1. **LLZ and GP antennas located on the aircraft nose.**
 2. **ILS indicator inside the cockpit**

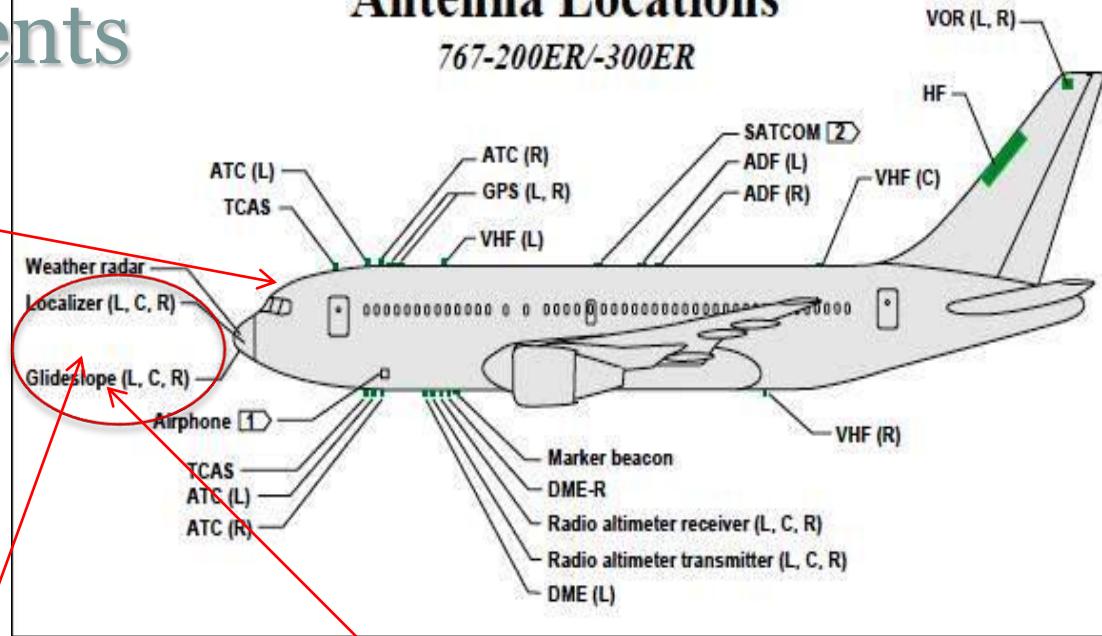
ILS Components



ILS Indicator inside the cockpit

Antenna Locations

767-200ER/-300ER



Ground Localizer Antenna



Ground Glide Path Antenna

ILS Indicator



Signal Integrity Flag
Indicates if instrument is
unreliable

Glidepath
Deviation from optimal
glide path

Localizer
Deviation from runway
centre line

“Dots”
Each “dot” on the
instrument represents 2° of
deviation

How ILS works?



- **Ground localizer antenna transmit VHF signal** in direction opposite of runway **to horizontally** guide aircraft to the runway centre line.
- **Ground Glide Path antenna transmit UHF signal** in vertical direction **to vertically** guide aircraft to the touchdown point.
- **Localizer and Glide Path antenna located at aircraft nose receives both signals and sends it to ILS indicator in the cockpit.**
- **These signals activate the vertical and horizontal needles inside the ILS indicator to tell the pilot either go left/right or go up/down.**
- **By keeping both needles centered, the pilot can guide his aircraft down to end of landing runway aligned with the runway center line and aiming the touch down.**

ILS Components

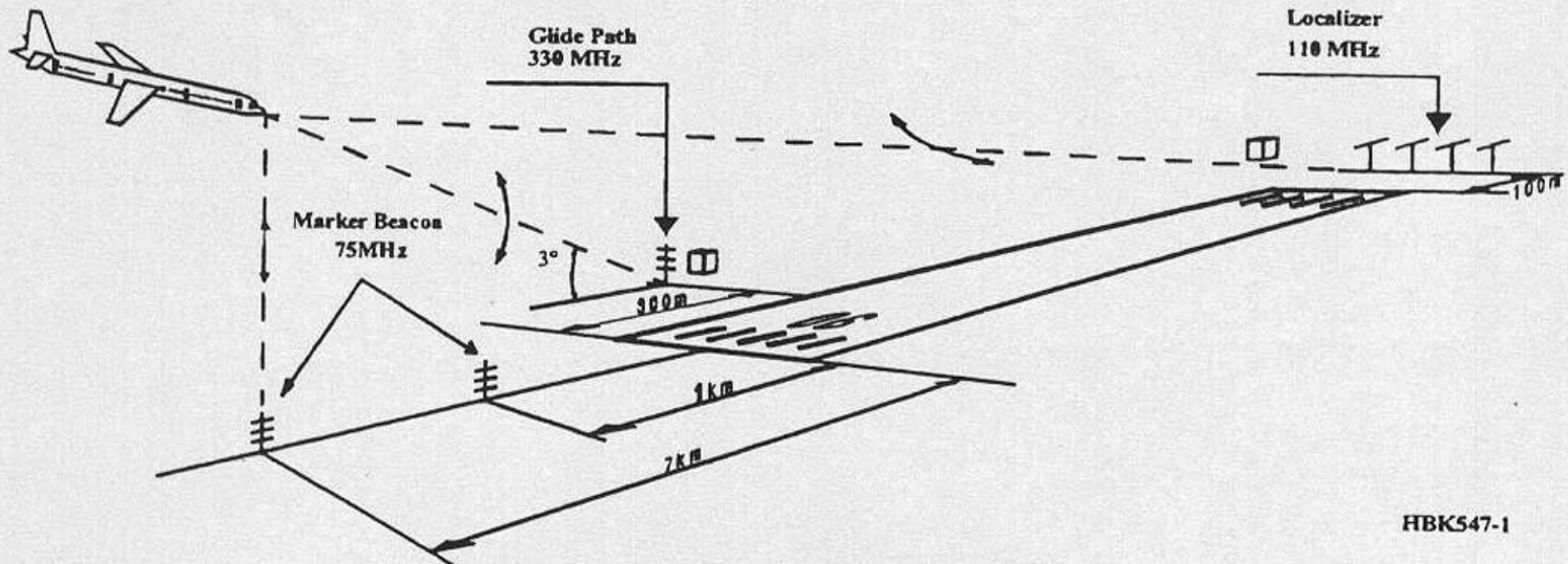
Marker Beacons: the height aircraft



Glide Path:
vertical guidance

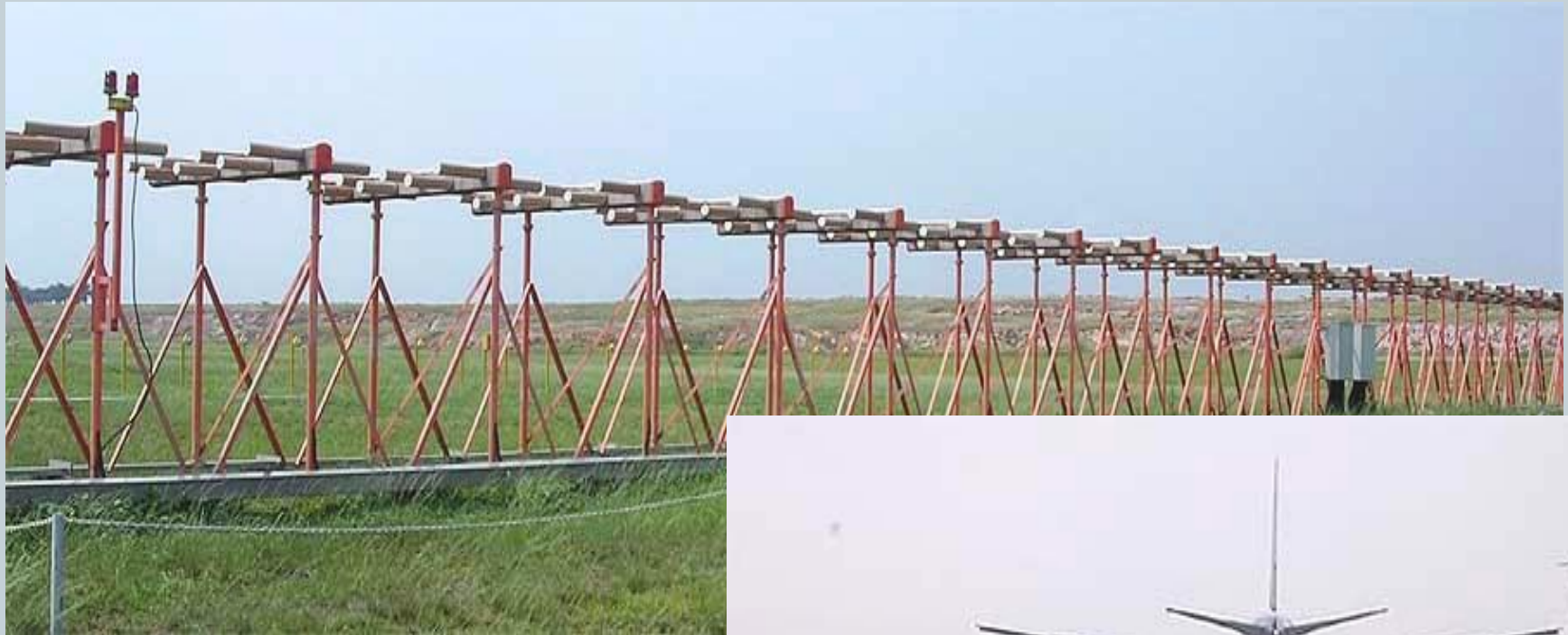


Localizer:
horizontal guidance



Localizer

- Localizer is the horizontal antenna array located at the opposite end of the runway.
- **Localizer** operates in **VHF band between 108 to 111.975 MHz**

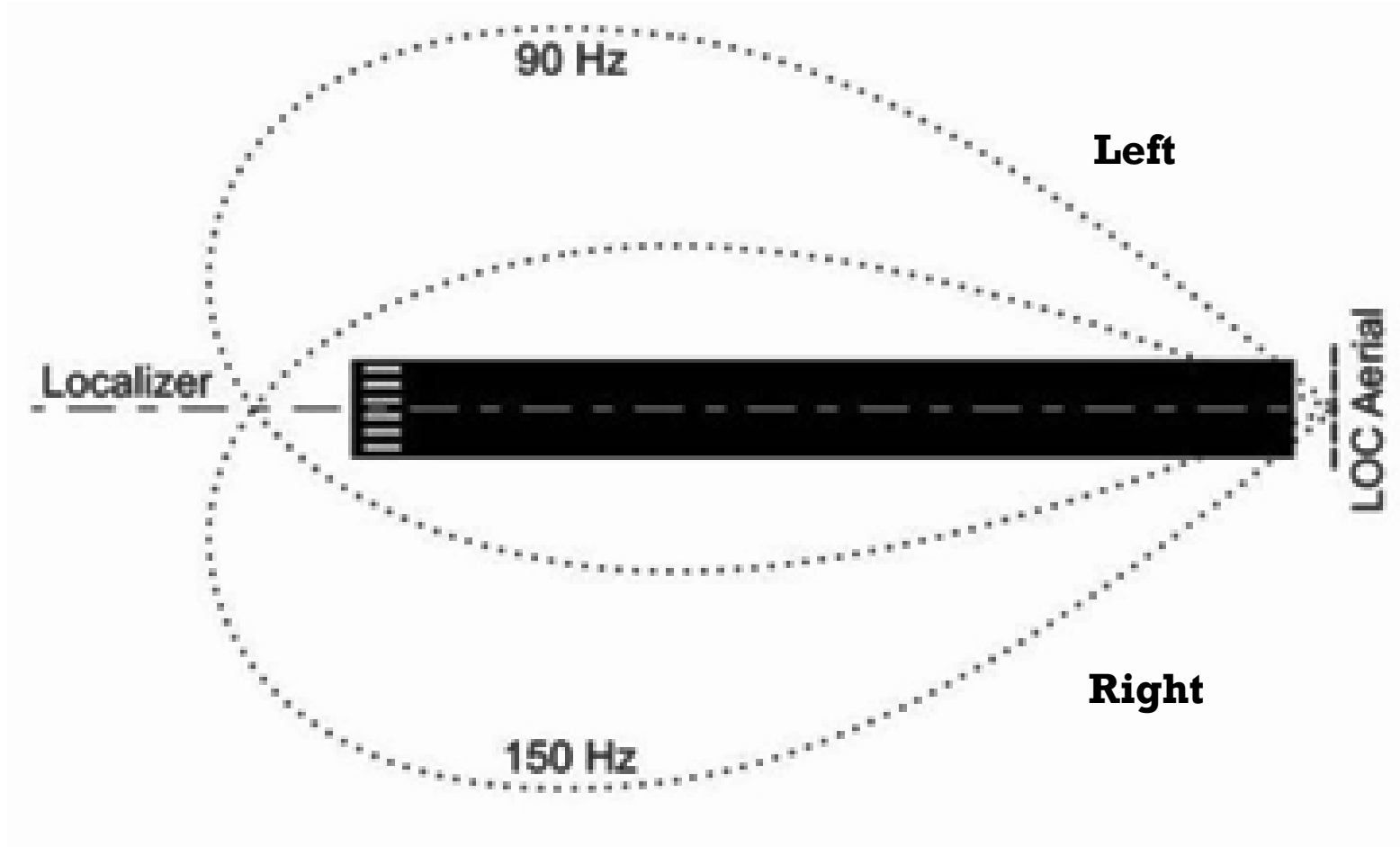


How Localizer Works



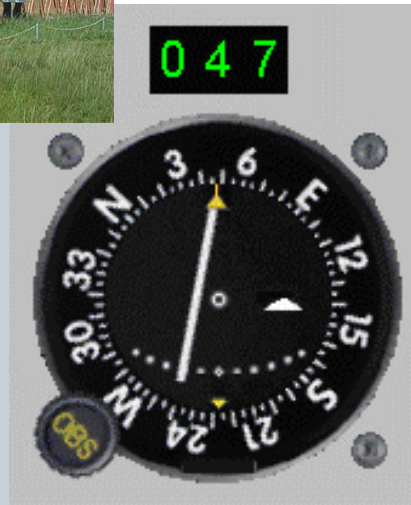
- Localizer transmit two signals which overlap at the centre.
- The left side has a 90 Hz modulation and the right has a 150 Hz modulation.
- The overlap area provides the on-track signal.
- For example, if an aircraft approaching the runway centre line **from the right, it will receive more of the 150 Hz modulation** than 90Hz modulation.
- Difference in **Depth of Modulation** will **energizes the vertical needle of ILS indicator**.
- Thus, aircraft will be given the direction to **GO LEFT**.

How Localizer Works





Localizer



Needle indicates
direction of runway.

Centered Needle =
Correct Alignment

Glide Path Antenna Array



- Glide Path is the vertical antenna located on one side of the runway about 300 m to the end of runway.
- **Glide Path** operates in **UHF band between 329.15 and 335 MHz**

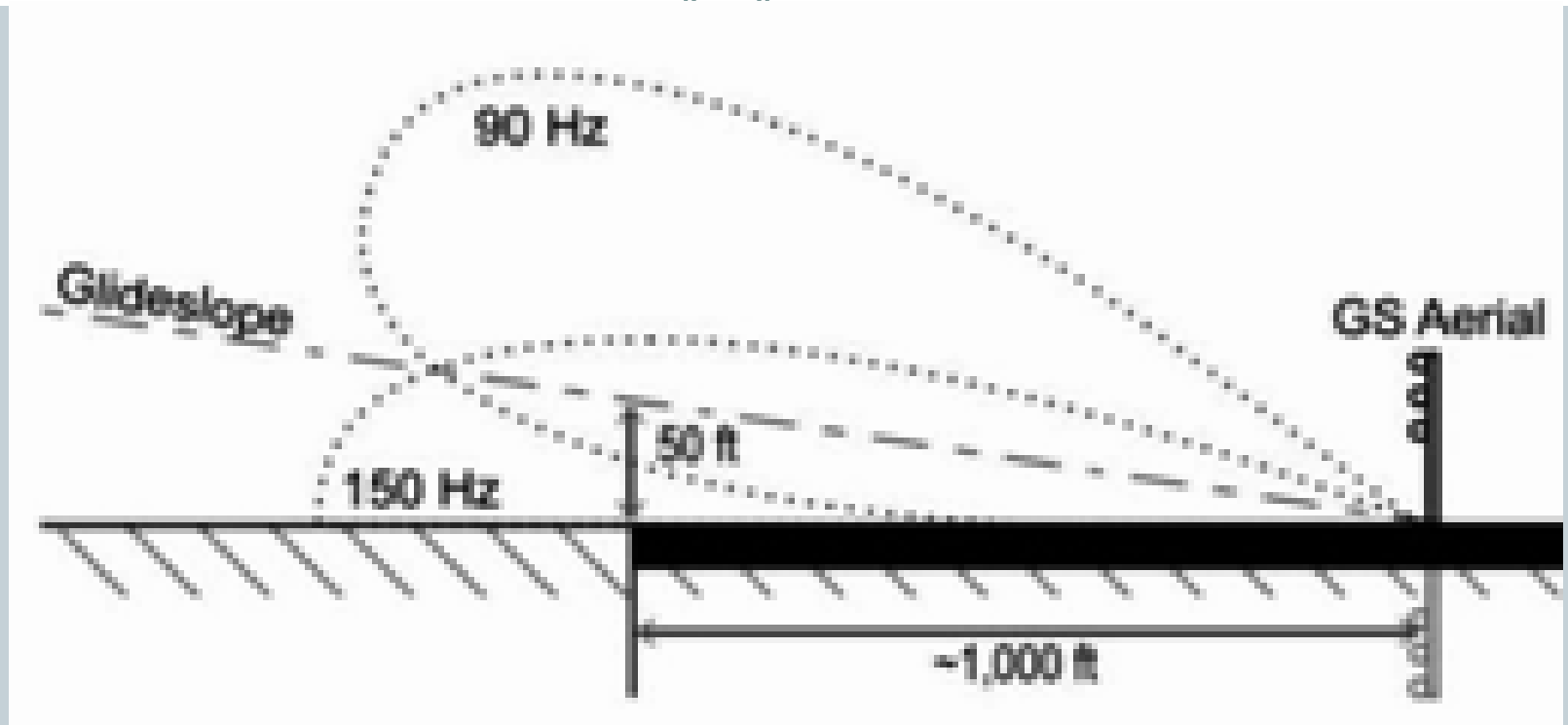


How Glide Path Works

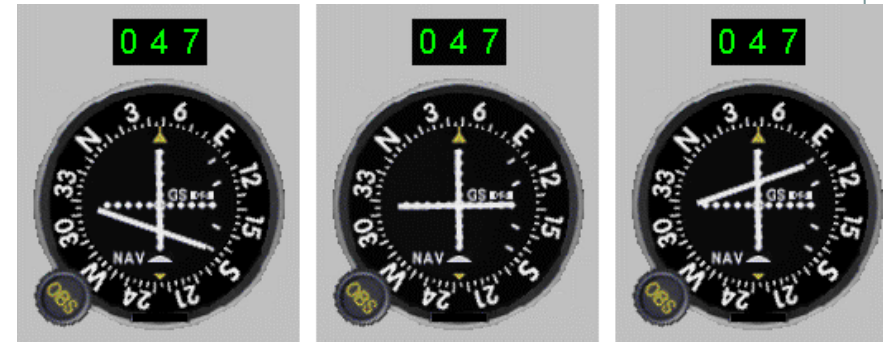


- Glide path produces two signals in the vertical plane.
- The upper has a 90 Hz modulation and the bottom has a 150 Hz modulation.
- For example, if an aircraft approaching the runway too high, **it will receive more of the 90 Hz modulation than 150Hz modulation.**
- Difference in **Depth of Modulation** will **energizes the horizontal needle of ILS indicator.**
- Thus, aircraft will be given the direction to **GO DOWN.**

How Glide Path Works



Glide Path



Needle indicates
above/below glide path.

Centered Needle =
Correct Glide path



Marker Beacons



- Marker beacons operating at a carrier frequency of 75 MHz are provided.
- When the transmission from a marker beacon is received it activates an indicator on the pilot's instrument panel.
- The correct height the aircraft should be at when the signal is received in an aircraft.

Marker Beacons



Outer marker

- The outer marker should be located about 7.2 km from the threshold.
- The modulation is repeated Morse-style dashes of a 400 Hz tone.
- The cockpit indicator is a [blue](#) lamp that flashes accordingly with the received audio code.
- The purpose of this beacon is to provide height, distance and equipment functioning checks to aircraft on intermediate and final approach.

Marker Beacons



Middle marker

- The middle marker should be located so as to indicate, in low visibility conditions.
- Ideally at a distance of 1050m from the threshold.
- The cockpit indicator is an amber lamp that flashes in accordingly with the received audio code.

Marker Beacons



Inner marker

- The inner marker, shall be located so as to indicate in low visibility conditions.
- This is typically the position of an aircraft on the ILS as it reaches Category II minima.
- The cockpit indicator is a [white](#) lamp that flashes in accordingly with the received audio code.

ILS Categories



- There are three categories of ILS the operation.
- **Category I** - A precision instrument approach and landing with a decision height not lower than 60 m (200 ft) above touchdown zone elevation and with either a visibility not less than 800 m or a runway visual range not less than 550 m.
- An aircraft equipped with an Enhanced Flight Vision System may, under certain circumstances, continue an approach to CAT II minimums.
- **Category II** - Category II operation: A precision instrument approach and landing with a decision height lower than 60 m (200 ft) above touchdown zone elevation but not lower than 30 m (100 ft), and a runway visual range not less than 350 m.

ILS Categories



- **Category III** is further subdivided
 - **Category III A** - A precision instrument approach and landing with:
 - ✦ a) a decision height lower than 30 m (100 ft) above touchdown zone elevation, or no decision height; and
 - ✦ b) a runway visual range not less than 200 m.
 - **Category III B** - A precision instrument approach and landing with:
 - ✦ a) a decision height lower than 15 m (50 ft) above touchdown zone elevation, or no decision height; and
 - ✦ b) a runway visual range less than 200 m but not less than 50 m.
 - **Category III C** - A precision instrument approach and landing with no decision height and no runway visual range limitations. A Category III C system is capable of using an aircraft's autopilot to land the aircraft and can also provide guidance along the runway.

Advantages of ILS



- The most accurate **approach** and **landing** aid that is used by the airliners.

Disadvantages of ILS



- Interference due to large reflecting objects, other vehicles or moving objects.
- This interference can reduce the strength of the directional signals.



VOR : VHF Omnidirectional Range

Introduction



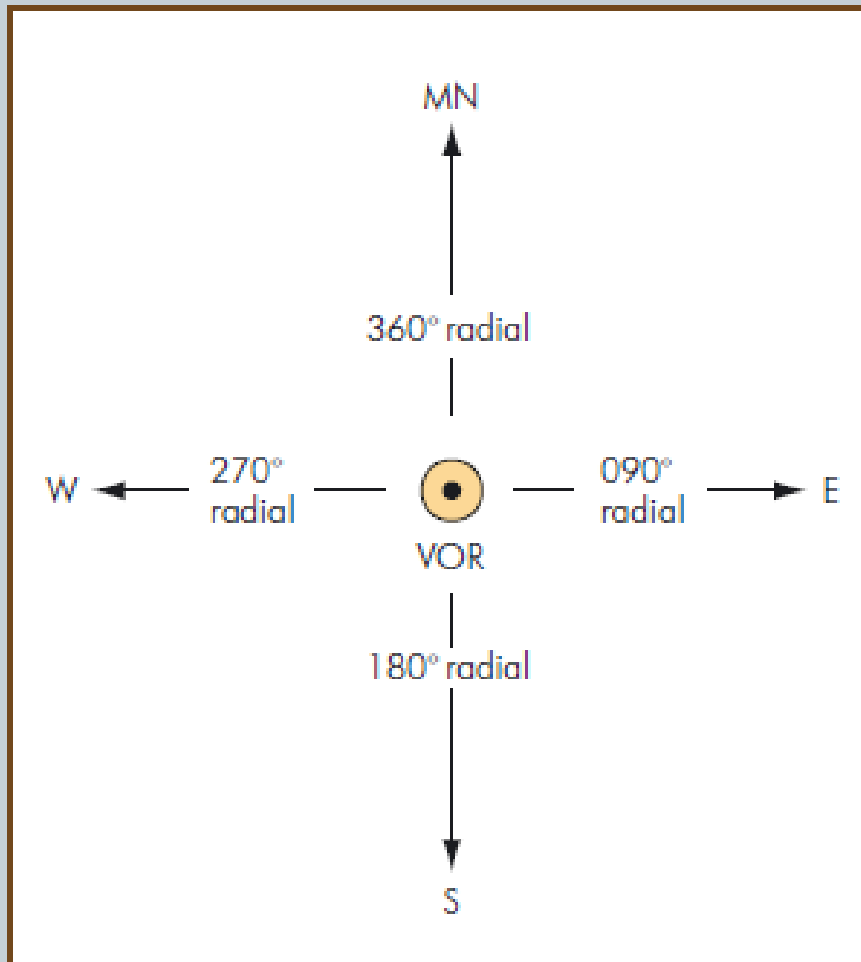
- VOR, short for **VHF Omni-directional Range**, is a type of radio navigation system for aircraft.
- VOR navigation system is one of the most **significant aviation invention**.
- With it, a pilot can **simply, accurately**, and without ambiguity **navigate** from Point A to Point B.

Introduction



- As opposed to the NDB, which transmits a non-directional signal, the **signal transmitted** by the VOR **contains directional information.**
- VOR provide **MAGNETIC BEARING** information to and from the station.
- “Omni-” means all and an Omni-directional range means VOR station **transmits signal in all directions.**

Signal Transmission



“Omni-” means all and an Omnidirectional range means VOR station transmits signal in all directions.

VOR Equipments



- VOR equipments can be divided into three equipments:
 - Aerial / Antenna
 - Receiver
 - Indicator
- As for aircraft, VOR consist of VOR antenna, at vertical tail and VOR receiver and indicator inside cockpit.
- As for ground station (also known as VOR beacon) consist of antenna (transmitter and receiver).

VOR Equipments

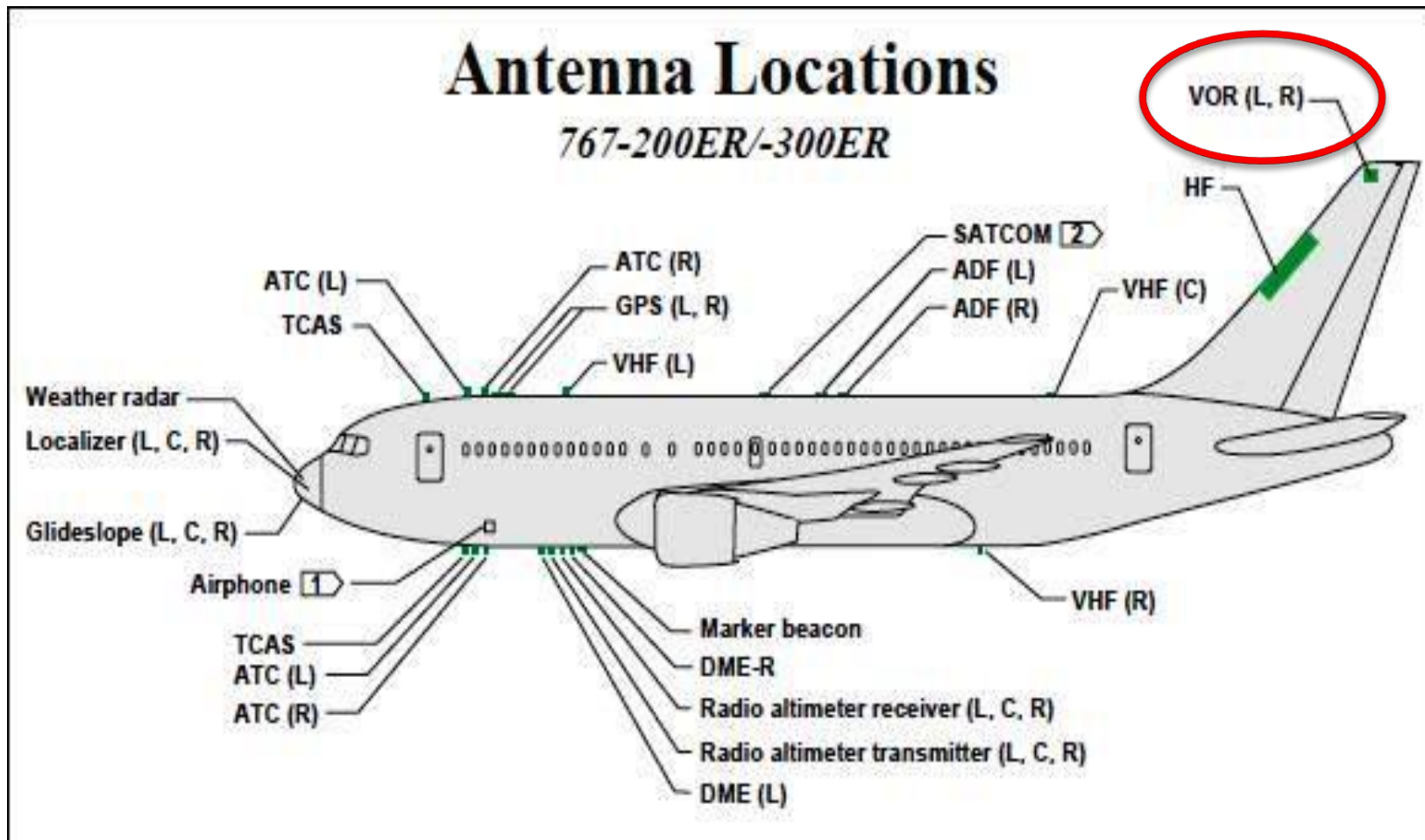


VOR Indicator



VOR Receiver

VOR Equipments



VOR Equipments



VOR Ground Antenna

**Stationary
Antennas**

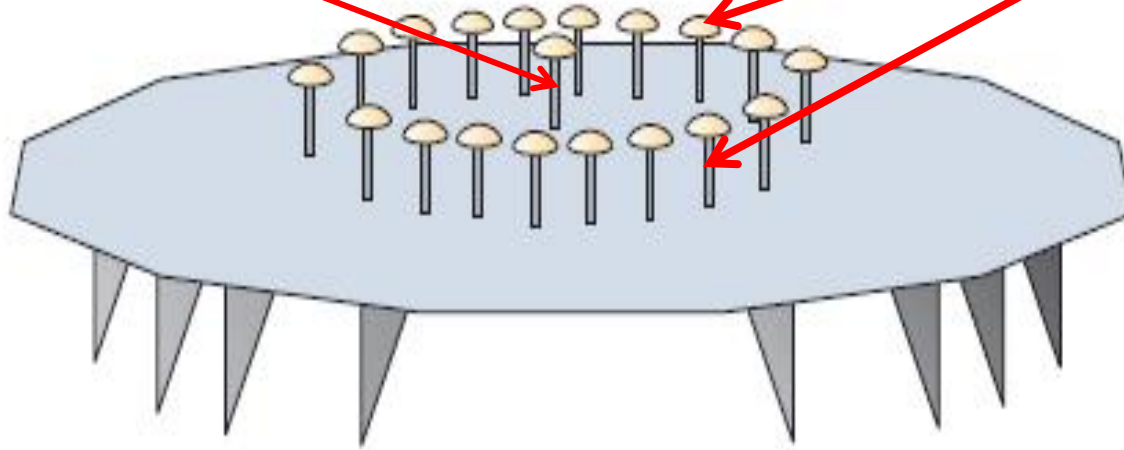


**Rotating
Antennas**

VOR station for broadcast the signal

**Stationary
Antennas**

**Rotating
Antennas**

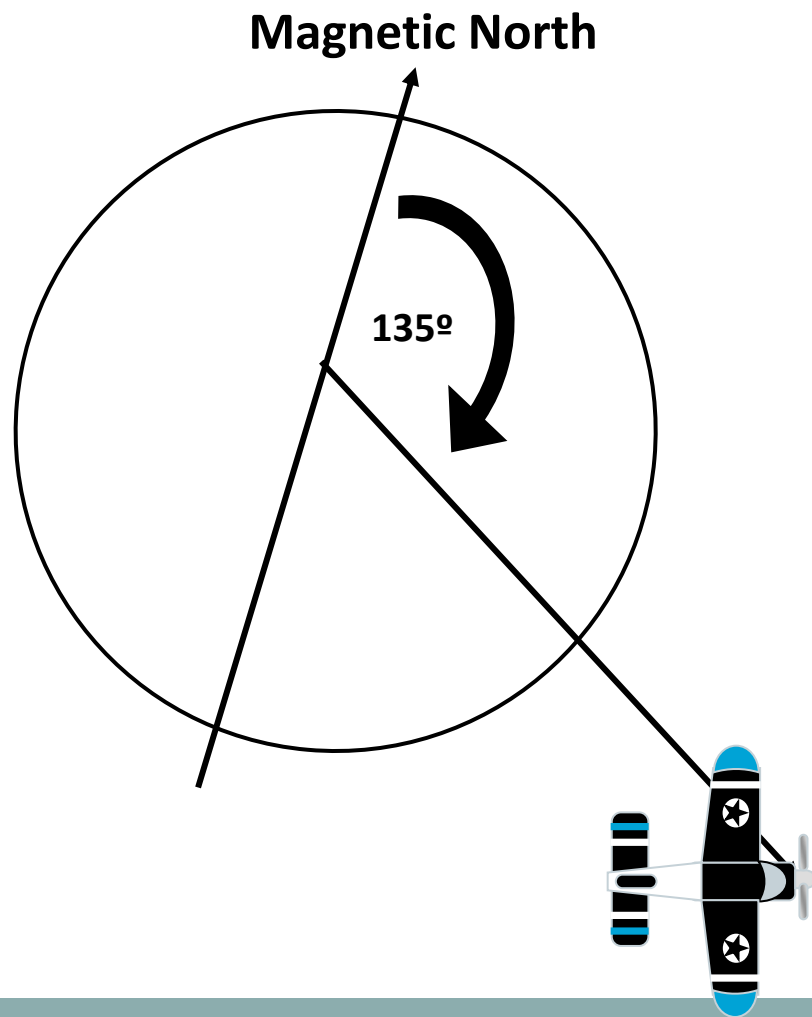
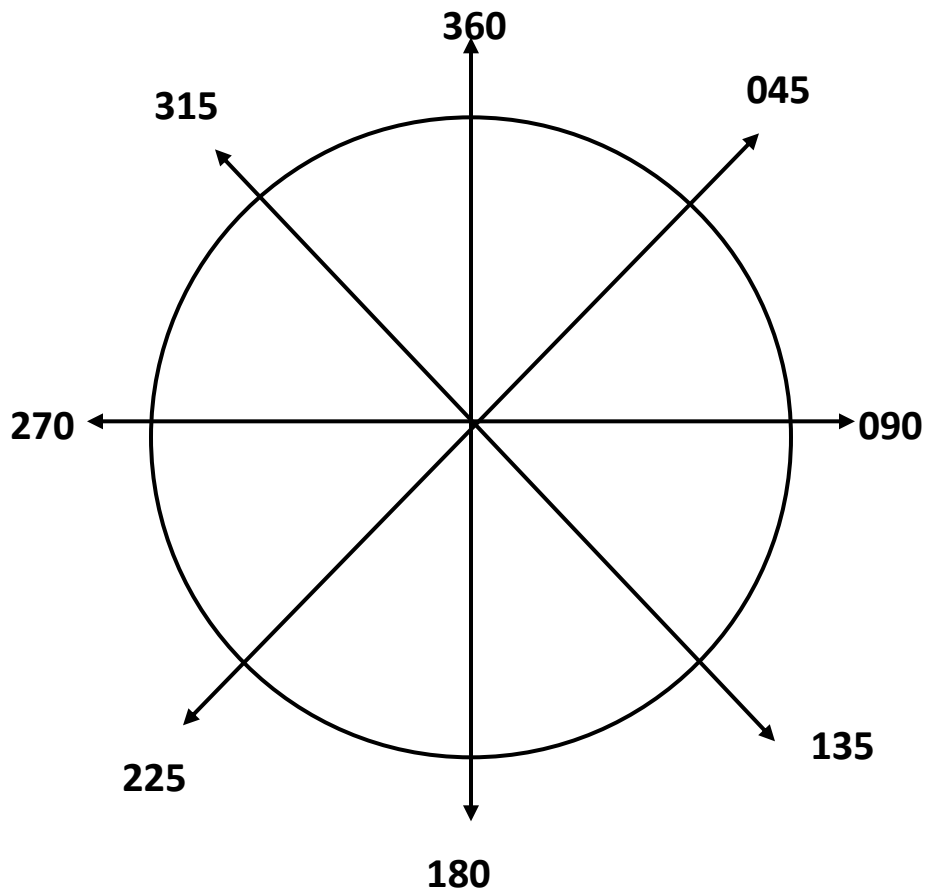


VOR ground antenna



- The VOR ground antenna is oriented to magnetic north.
- Consists of :
 - **Single Stationary Antenna** at the centre
 - **Rotating antennas**
- It produces 360° radials/tracks at 1° spacing.
- These 360 bearings are known as **RADIALS**
- VOR ground installations are **strategically** located along air routes and airport to ensure continuity of **guidance**.

RADIALS



PRINCIPLE OPERATION OF VOR



How VOR works



- VOR receiver in the cockpit is tuning to the specific frequencies assigned for that VOR 's airport.
- It is VHF frequency which is between 108-117.95 MHz.
- After entering the frequency, the volume control should be turned up in order to confirm that the **three letter identification code (Morse Code)** is correct.
 - For example, KLIA airport has a VOR known as VKL-Victor Kilo Lima

How VOR works



- The VOR station on the ground **transmits two signals** at the same time; one signal is constant in all directions, while the other signal is rotated about a point.
- One from stationary antenna, while the other from rotating antenna.
- When aircraft receives these two signals, an aircraft VOR receiver electronically measures the **phase angle different** between these two signals.
- This phase angle different is translated as the **MAGNETIC BEARING** which tell the pilot the aircraft angle direction to the VOR station.
- This bearing angle also known as **RADIALS**.

VOR Indicator Display



VOR Indicator Display



A Display

A Rotating Course Card, calibrated from 0 to 360°, which **indicates the VOR bearing** chosen as the reference to fly TO or FROM. Here, the 345° radial has been set into the display. This VOR gauge also digitally **displays the VOR bearing, which simplifies setting the desired navigation track**

B Display

The Omni Bearing Selector, or OBS knob, used to **manually rotate the course card.**

VOR Indicator Display



C Display

The CDI, or **Course Deviation Indicator**. This needle swings left or right indicating the direction to turn to return to course. When the needle is to the left, turn left and when the needle is to the right, turn right, When centered, the aircraft is on course. Each dot in the arc under the needle represents a 2° deviation from the desired course.

VOR Indicator Display

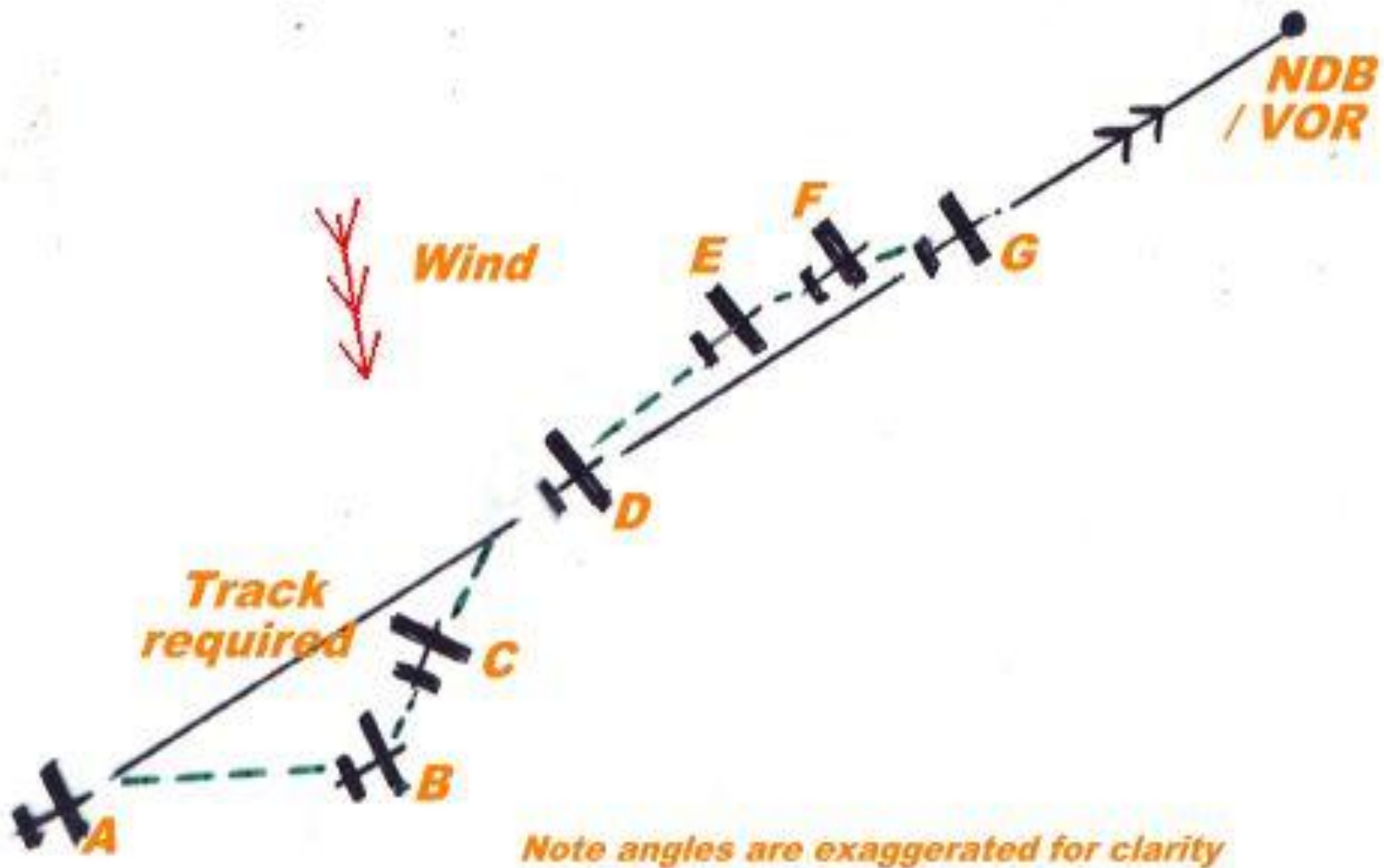


D Display

The TO-FROM indicator. This arrow will **point up**, or towards the nose of the aircraft, **when flying TO the VOR station**.

The arrow reverses direction, **points downward**, when **flying away FROM the VOR station**.

A **red flag** replaces these TO-FROM arrows when the VOR is **beyond reception range**, has **not been properly tuned in**, or the **VOR receiver is turned off**. Similarly, the flag appears if the VOR station itself is inoperative, or down for maintenance.



VHF OMNIDIRECTIONAL RANGE (VOR)

Advantages of VOR



- **More accurate & precise flying:**
 - The accuracy of course alignment of the VOR is excellent, being generally plus or minus 1 degree.
- **Reliable:**
 - Can be used day and night.
- **Multiple number of route :**
 - Provide multiple number of route 'towards' or away from each station.
 - These routes are like invisible highways , which the pilot can navigate to @ away from any location.

Disadvantages of VOR



- **Signals cannot be received at low altitudes** (below 1000ft)
- VORs are **sensitive to the interference of terrain**. The nearest mountains and buildings cause the VOR bearings to be stopped and interrupted.
- Other disadvantages is VOR equipments are **costly to maintain**.



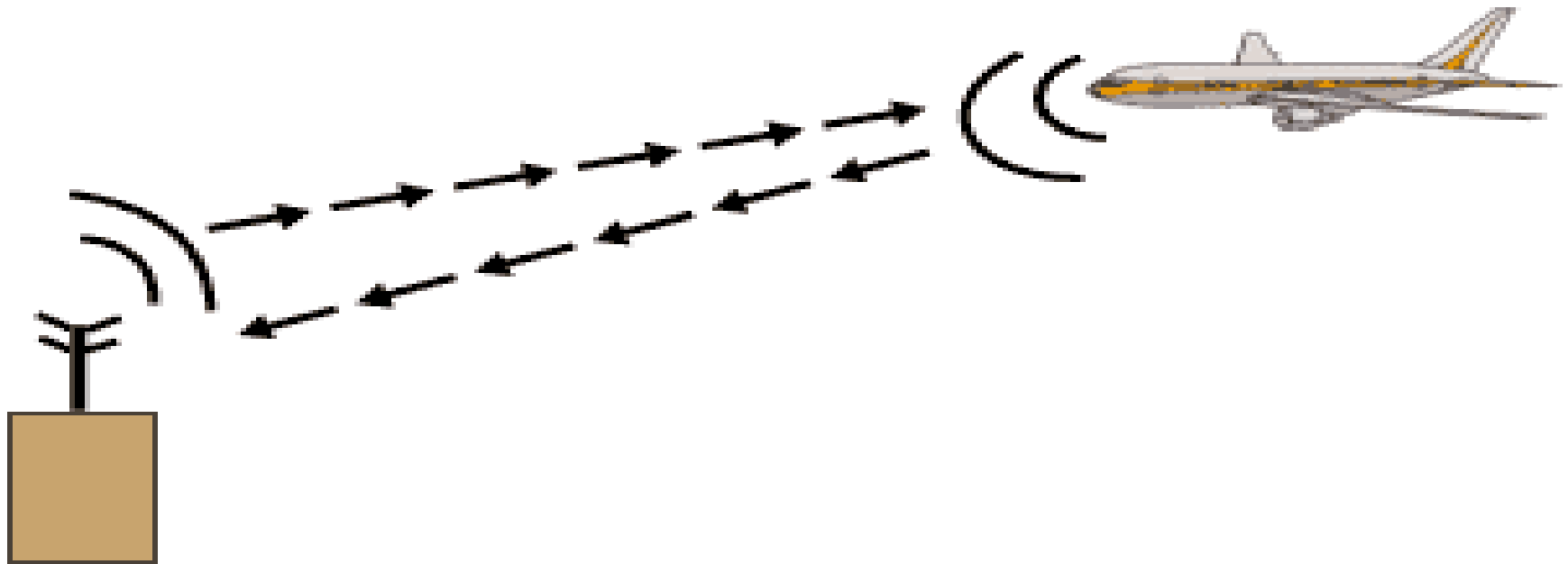
Distance Measuring Equipment (DME)

Definition



- **DME** is stand for **D**istance **M**easuring **E**quipment.
- DME is a type of en-route navigation system for aircraft.
- DME often installed near VOR stations so as to provide combined **bearing** and **distance**.
- When DME is installed with the VOR, it is referred to as a **VOR/DME**.





Airborne DME measures elapsed time required for exchange of signals and converts into distance and ground speed.

The uses of DME

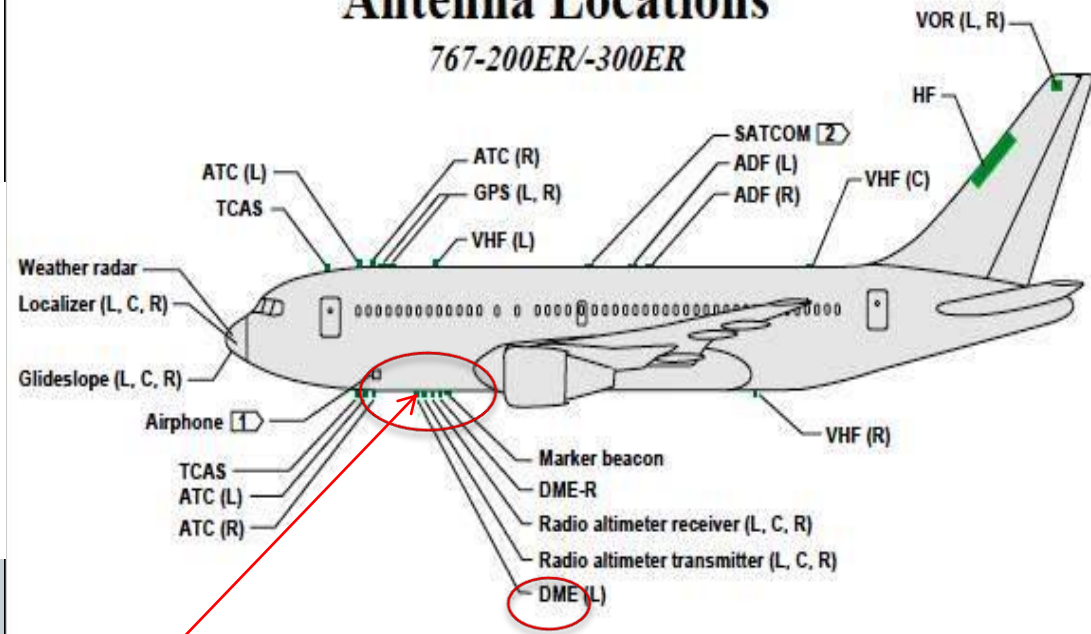


- DME provides the physical **distance from the aircraft to the ground DME transponder** expressed in Nautical Miles (NM).
- DME also calculates **ground speed and the time needed to reach the station** if the aircraft is fitted with appropriate computer.



Antenna Locations

767-200ER/-300ER



DME System Components:



The DME system consists of three basic components which are:

- DME antenna on the aircraft body
- DME navigation display unit in aircraft cockpit
- DME transmitter/receiver in the ground

DME INDICATOR IN THE COCKPIT



DME Indicator

- **DME** enables aircraft to establish its range to the ground station: Distance in nautical miles, Ground speed in knots, Flying time to the station in minutes



DME distance = 92.4 nm

Corresponding VHF frequency = 112.3 Mhz



DME distance = 107.9 nm

Ground speed = 250 kt

Time to station = 25 minutes

DME PRINCIPLE



How DME works?

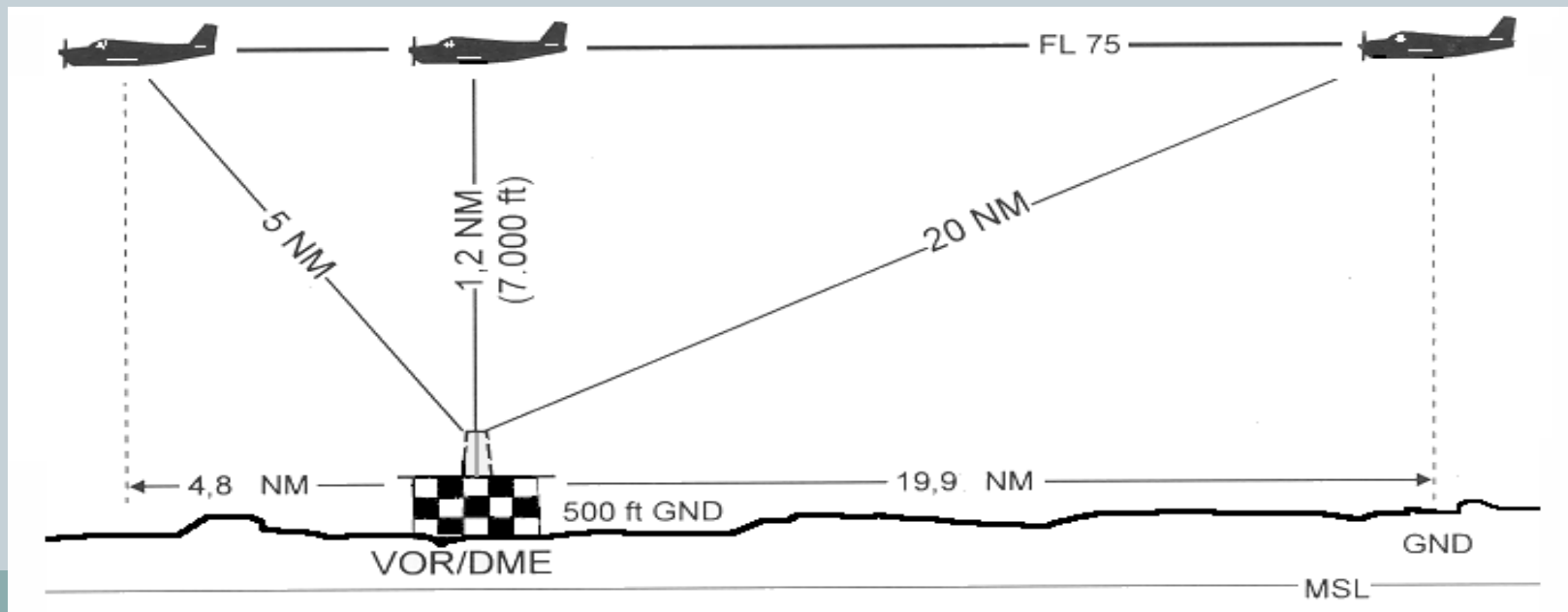


- DME provides **distance (slant range) from the aircraft to the ground DME.**
- DME operates on Ultra High Frequency (UHF) which is between 962 to 1213 MHz.
- DME works based on pulse techniques, where pulse means a single vibration of electric current.
- The aircraft's antenna sends out paired pulses at specific spacing.
- The ground DME station receives the pulses and then responds with paired pulses at the same spacing but a different frequency.

How DME works?



- The aircraft receiver measures the time taken to transmit and receive the signal which is transmitted into distance.
- Beside that, the distance formula is also used by the DME receiver to calculate the distance from DME station in Nautical Miles.



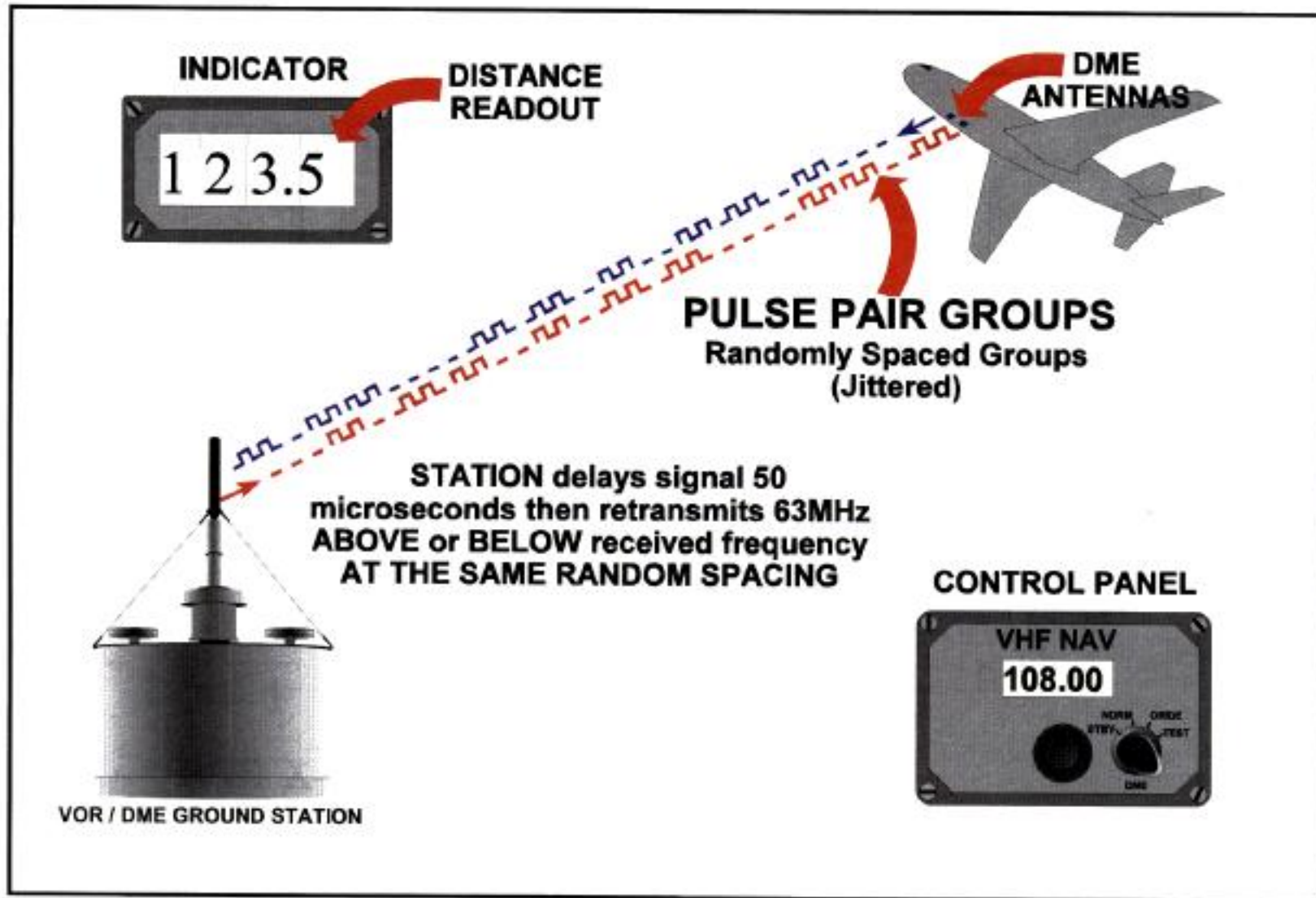


Figure 12.8. The Principle of Range Measurement.

Advantages of DME



- **DME is extremely accurate:** Provide continuous and accurate indication of the slant range distance.
- **Aircraft Handling Capability:** The transponder equipment should be capable of handling 100 to 200 aircrafts.
- **Large coverage:** DME facility provides coverage up to 200 NM.

Disadvantages of DME

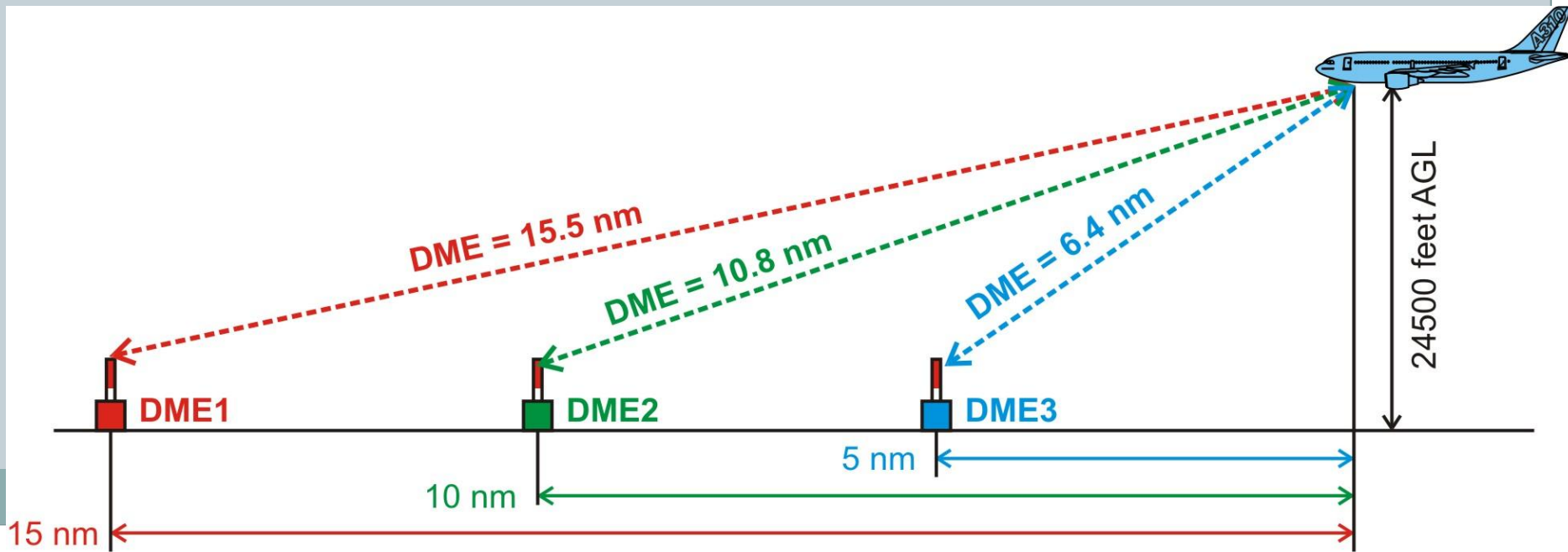


- As VOR the DME is **also restricted to line-of-sight transmission**. For example, the aircraft at altitude below 10'000 ft is unable to detect the DME signal.

Disadvantages of DME



- **Errors and abnormal indications:**
 - **Slant range**
 - **Speed and time calculation**
 - **Ground system saturation – 100 aircraft**
 - **System error**



Automatic Direction Finder
(ADF)

&

Non Directional Beacon (NDB)



INTRODUCTION TO NDB & ADF



Non Directional Beacon



Automatic Directional Finder

Definition

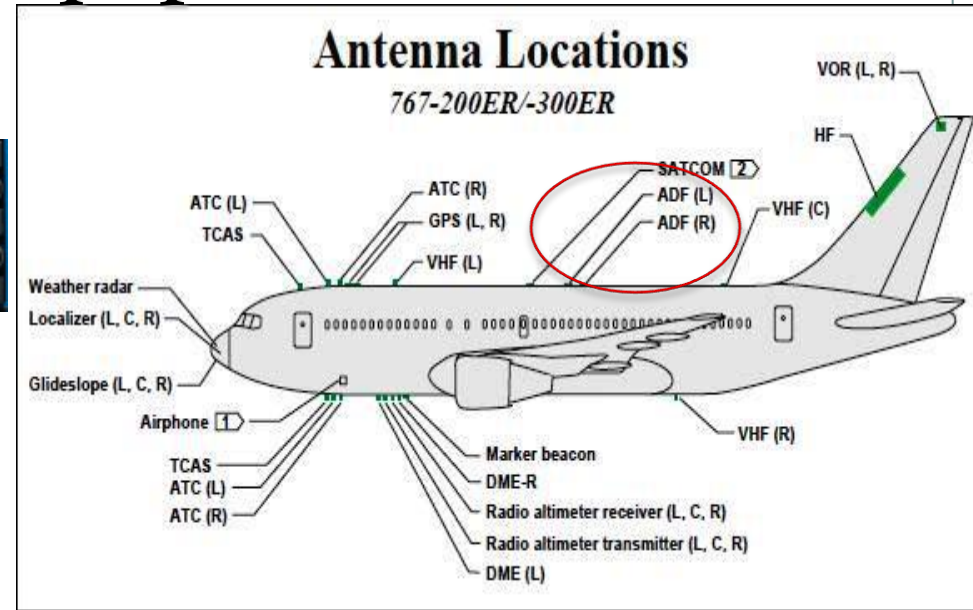
- **ADF** is stand for **A**utomatic **D**irection **F**inder.
- **NDB** is stand for **N**on **D**irectional **B**eacon.
- **ADF & NDB** is the **one of the older types of radio navigation system** that still in use today.
- They still in use today because of its simplicity.
- As it name, the signal transmitted by NDB does not included directional information, but ADF automatically searching for NDB signal.

ADF & NDB Equipments



- **N**on **D**irectional **B**eacon (**NDB**) is used in conjunction with **A**utomatic **D**irection **F**inder (**ADF**) in the cockpit.
- ADF equipments consists of 1) **ADF antenna** (transmitter & receiver) **outside aircraft's body**, 2) an **ADF indicator inside the cockpit**.
- NDB equipment only consist of **ground NDB antenna** located near the airport (airfield area).
- ADF determines the direction to ground NDB station.

ADF & NDB Equipment



ADF indicator inside the cockpit

ADF antenna outside aircraft 's body



Ground NDB stations is the Tall antenna located near the airfield

Purpose



- The purpose of ADF/NDB is to provide aid for aircraft navigation by **provide bearing information of aircraft location** to the airport. (aircraft direction or heading to the airport in degrees(angle))
- **Bearing: the angle which measured in a clockwise direction.
- NDB bearings provide a consistent method for defining paths aircraft can fly. NDB can define "airways" in the sky.

NDB Frequencies



- ICAO has assigned **Low Frequency (LF)** and **Medium Frequency (MF)** band for NDB,
- It is **within 200 – 1750 KHz.**
- However, most of NDB equipments are found operating within frequency band of **200-525 KHz.**



How ADF & NDB works

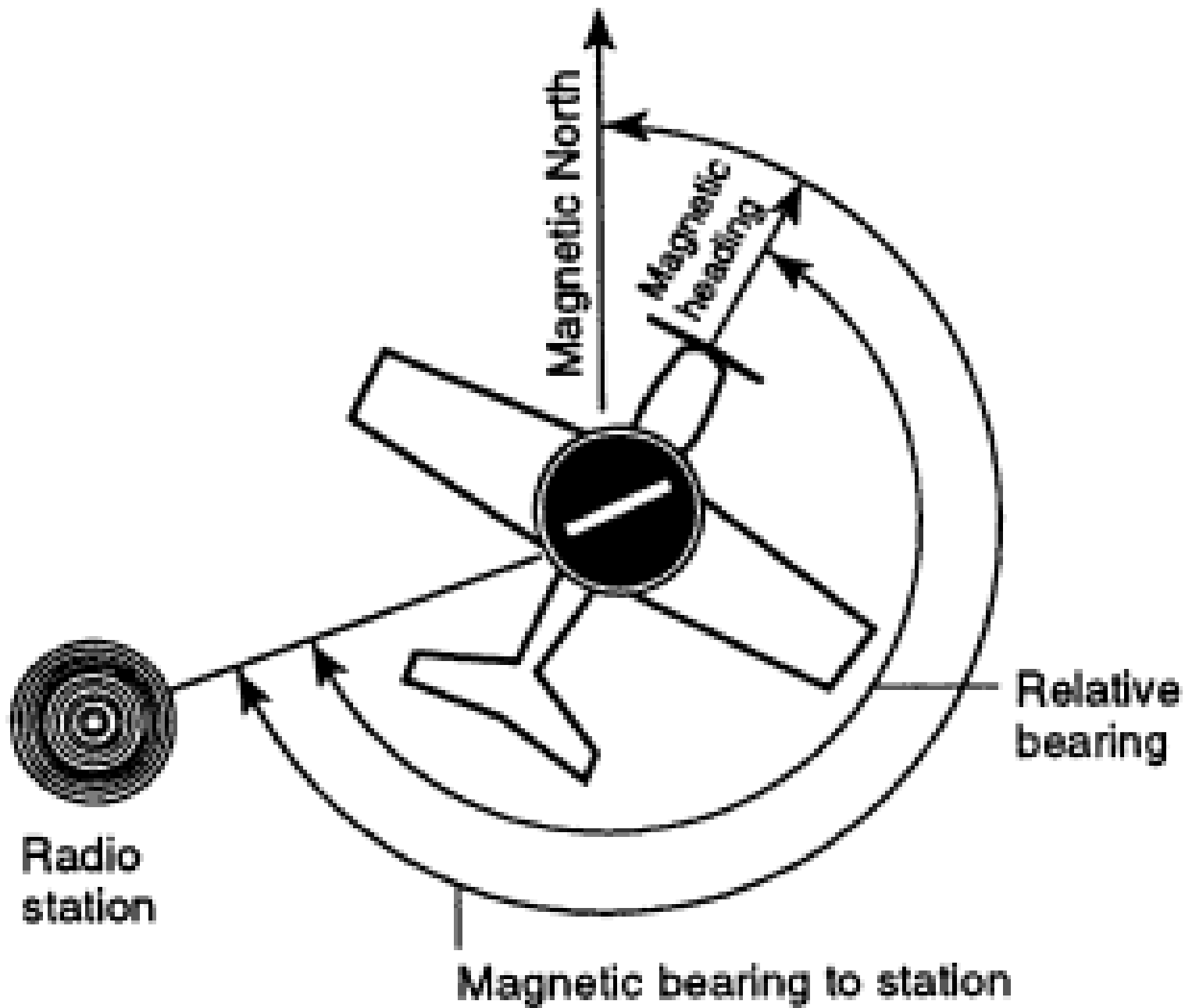
NDB station radiates a **non-directional signal** in all directions around its antenna (transmitter).

Station identification code(callsign) in the form **Morse code** is also transmitted by the NDB.

An **ADF selector** in aircraft will **tune to NDB's frequency in order to search its signals.**

After NDB call sign is identified, the **direction of aircraft in bearing to the NDB station will be indicated.**

ADF indicator in the cockpit will display the bearing to the NDB station *relative to the heading* of the aircraft.

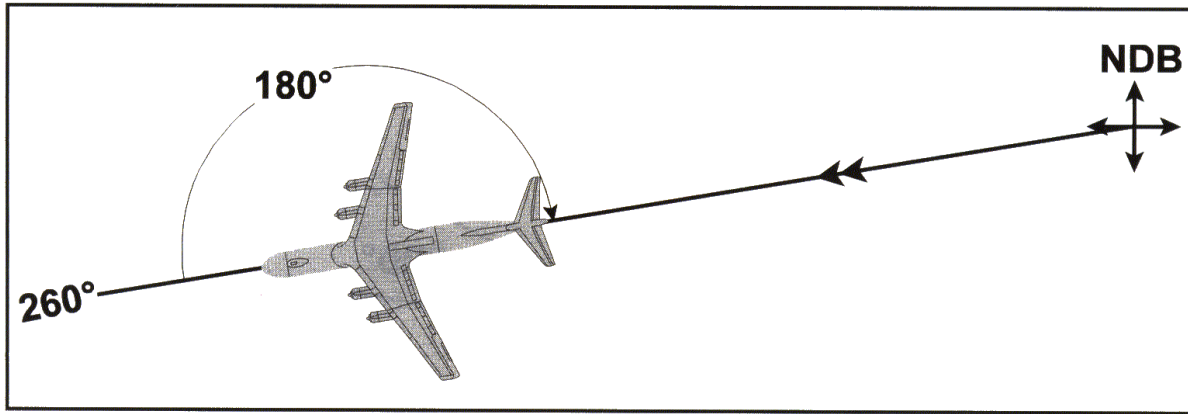


The uses of NDB



- Used for FLYING FROM NDB or HOMING TO NDB when maintaining airway centre-lines.
- Used for en-route navigational bearing
- Used for HOLDING system before landing.
- Used as markers for an **Instrument Landing System (ILS)** approach

FLYING FROM or HOMING TO NDB station



Flying From ←

Figure 4.14.

Homing To →

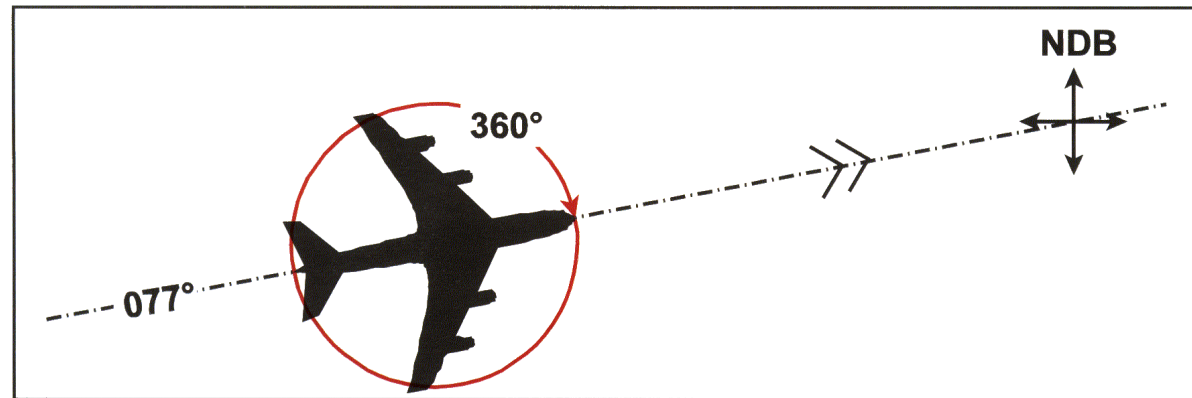
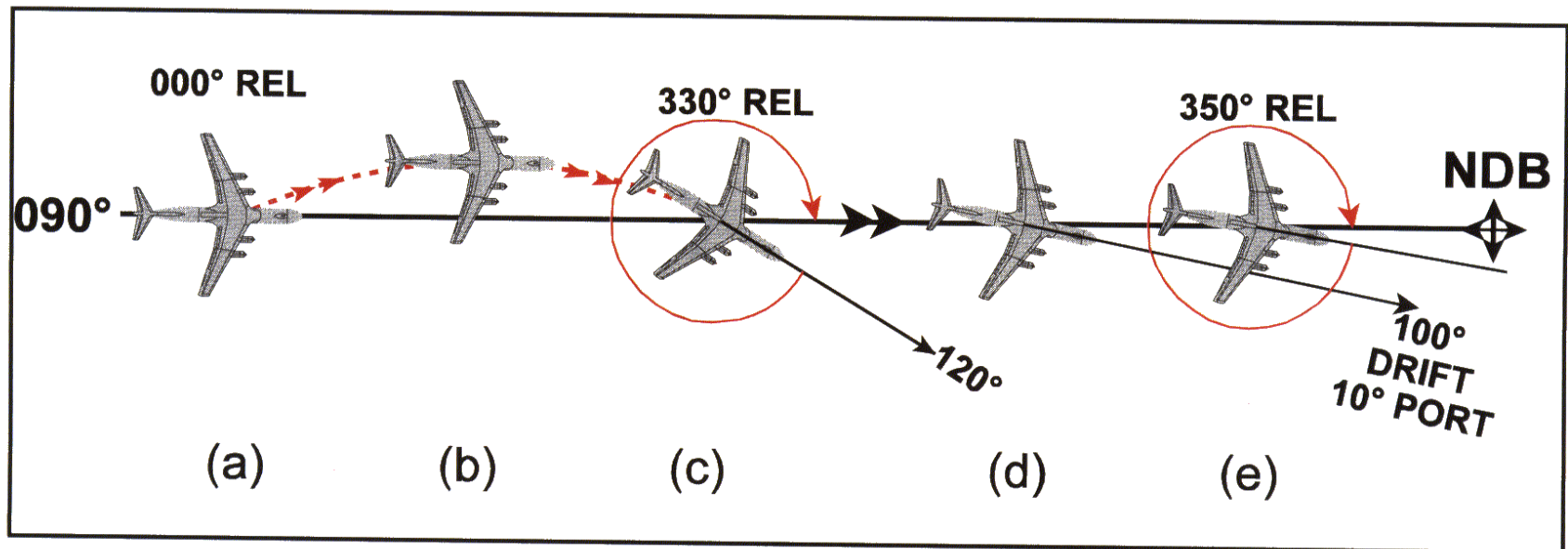


Figure 4.10 Homing in Zero Drift.

En-Route Navigation



- Aircraft must maintain their heading using the Automatic Direction Finding (ADF) in the cockpit.
- Pilot must always watch the relative bearing indicator to maintain the airway center line.



Holding System

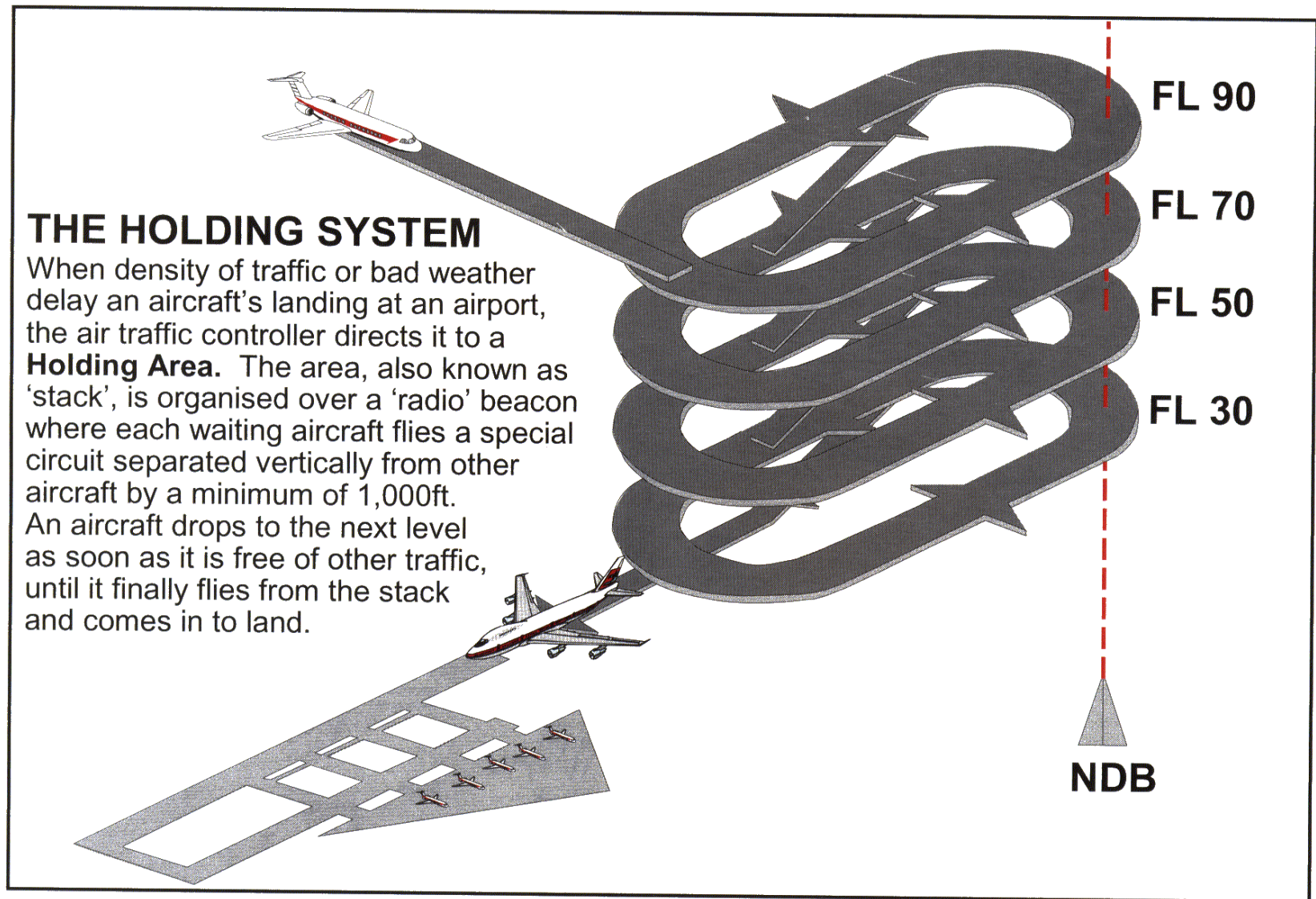


Figure 4.20 The Holding System.

Markers for an ILS approach



- NDB also can be used as the **markers for Instrument Landing System (ILS) approach**.
- This type of NDB is also known as LOCATOR.
- Locator is a low power NDB.
- It has a signal range within 10 to 25 Nautical Miles.

Advantages of NDB



- NDB signal can be received at low altitudes.
- This is because NDB signal is based on surface wave propagation (signal not limited to 'line of sight').
- NDB also can be used as the Back-Up system. For example, during no signal given by the VHF Omnidirectional Range (VOR) system.
- NDB system only requires low cost for their maintenances.
- NDB still important for many small airports.

Disadvantages of NDB



- Limited Signal because of several factors including:
 1. Interference Effect
 2. Thunderstorm Effect
 3. Mountain Effect
 4. Night Effect
 5. Coastal Refractions

Disadvantages of NDB



- **Interference Effect** –interference occurs if an ADF receives two or more signals radiated by NDB.
- **Thunderstorm Effect** – Thunderstorm have very powerful discharges of static electricity that can interrupt the NDB signal. Needle of ADF indicator sometimes points toward the storm.
- **Mountain Effect** – Mountain areas can cause reflections and diffractions and lead to the error direction reading by ADF.

Disadvantages of NDB



- **Night Effect** – Low signal or no signal during night time because contamination of radio wave.
- **Coastal Refractions** – Also known as **Shoreline Effect** . Surface wave travel in one direction over land, but another direction over water (refraction). This can cause error reading in ADF indicator.

Accuracy



- The accuracy of NDB is ± 5 degree for approach and ± 10 for en-route.
- The accuracy of an NDB at any given time is difficult to determine when considering all the factors creating error.

RADAR BEACON TRANSPONDER

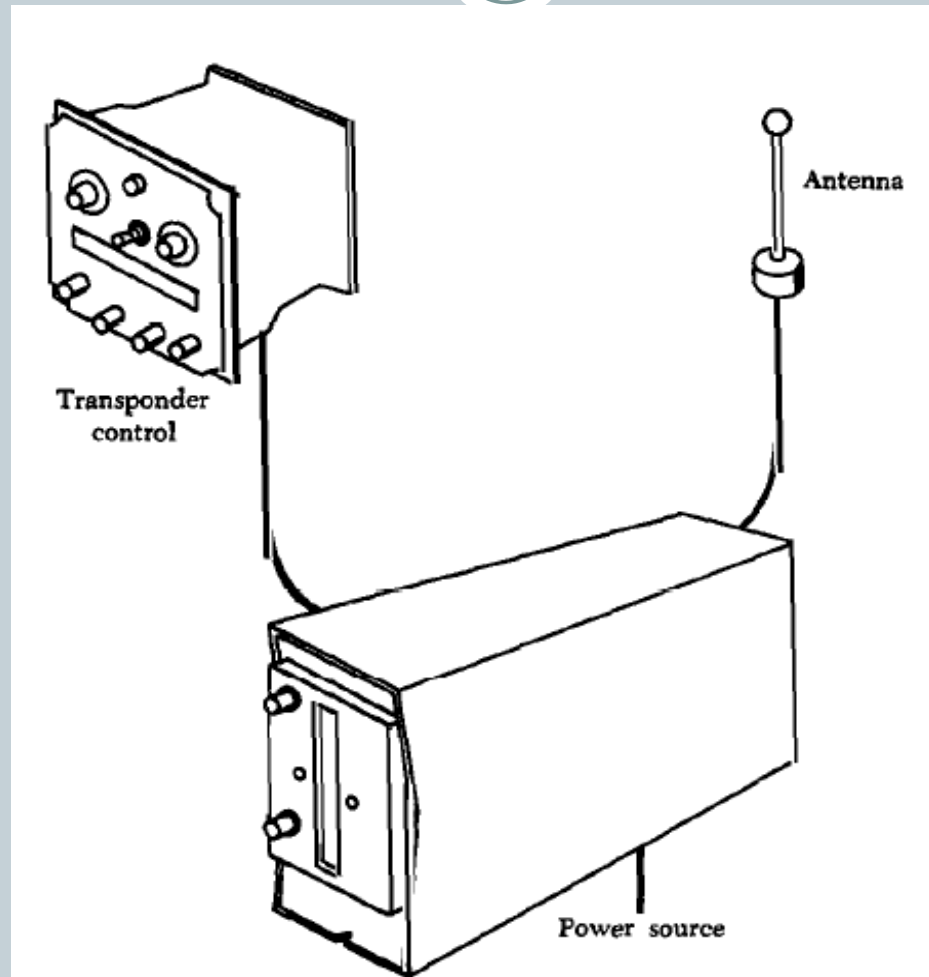


FIGURE 13-16. Typical transponder system.

DOPPLER NAVIGATION SYSTEMS

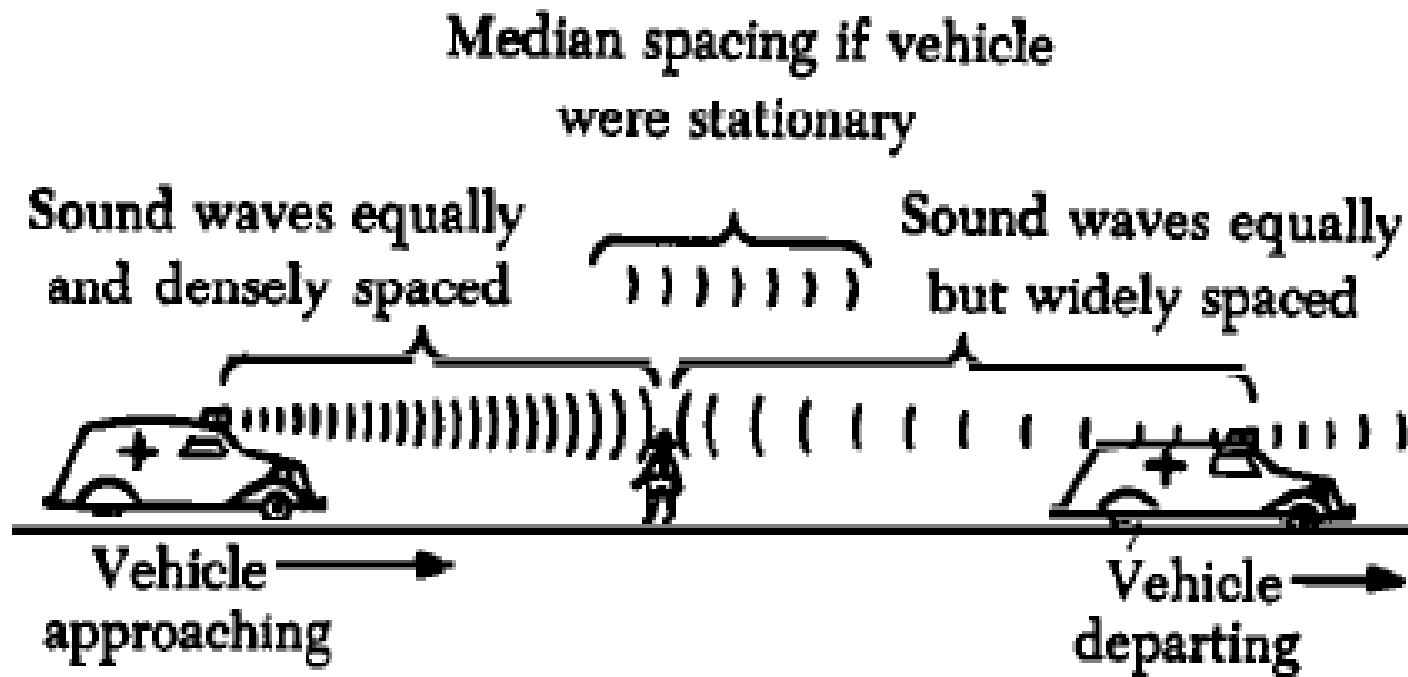


FIGURE 13-17. Doppler effect with sound waves.

INERTIAL NAVIGATION SYSTEM

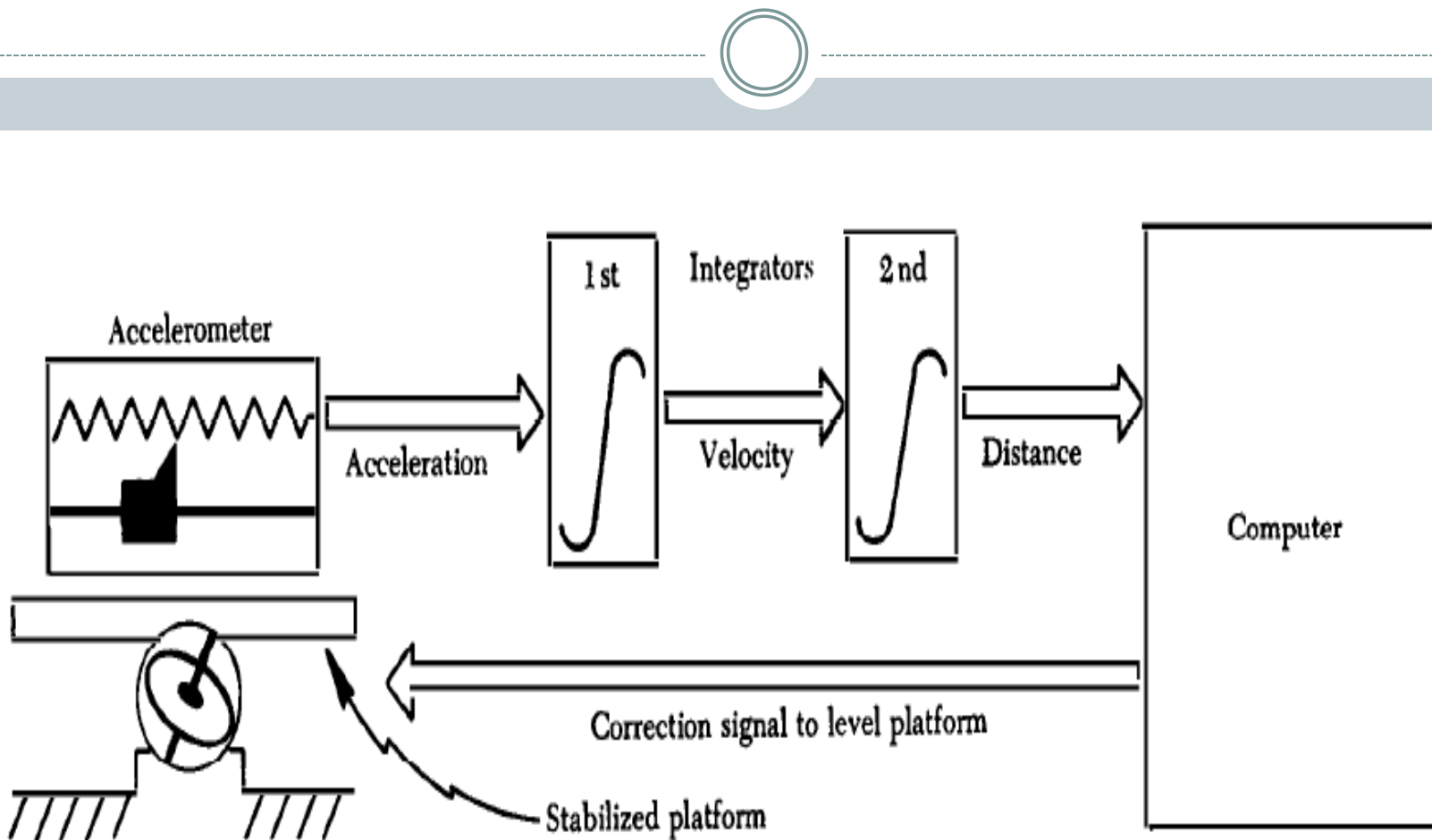


FIGURE 13-18. A basic inertial navigation system.

AIRBORNE WEATHER RADAR SYSTEM

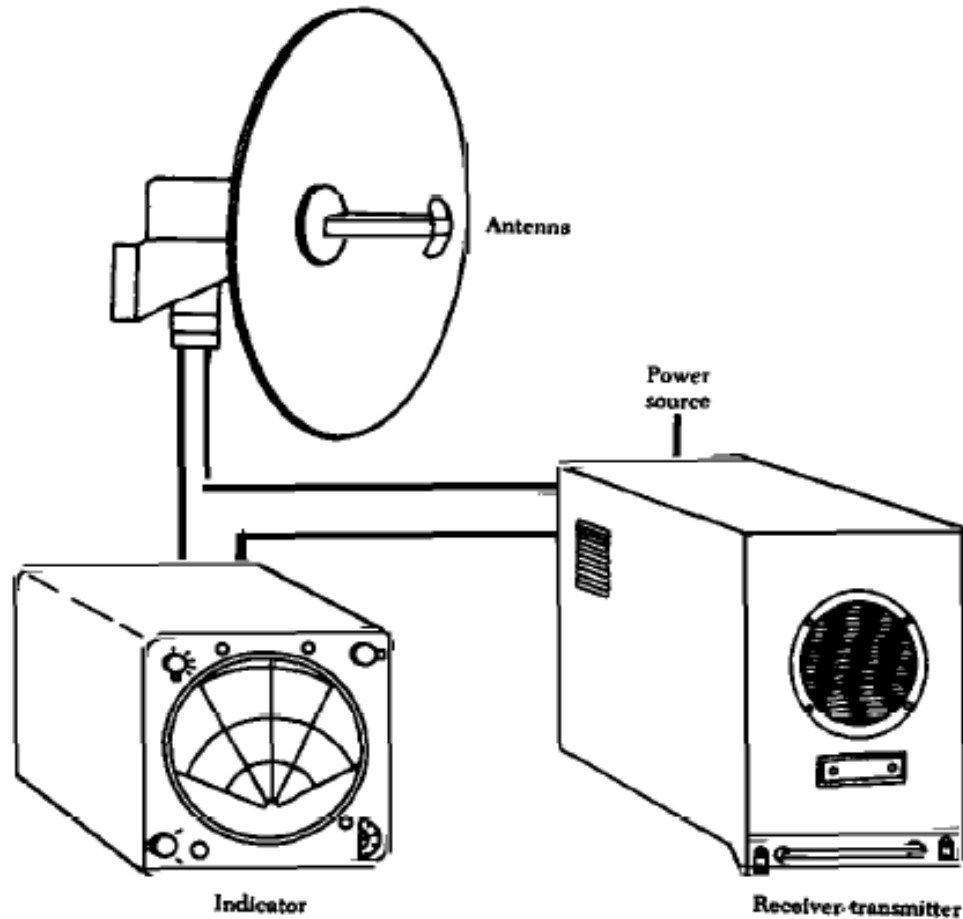


FIGURE 13-19. Weather radar system diagram.

RADIO ALTIMETER

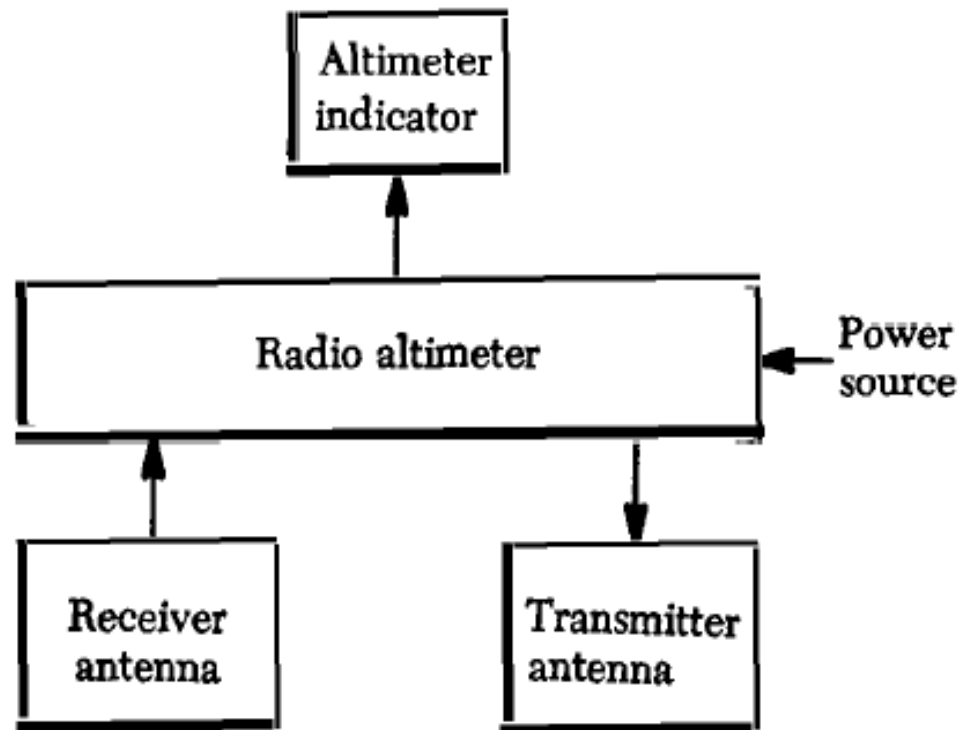


FIGURE 13-20. Typical radio altimeter system diagram.

EMERGENCY LOCATOR TRANSMITTER (ELT)

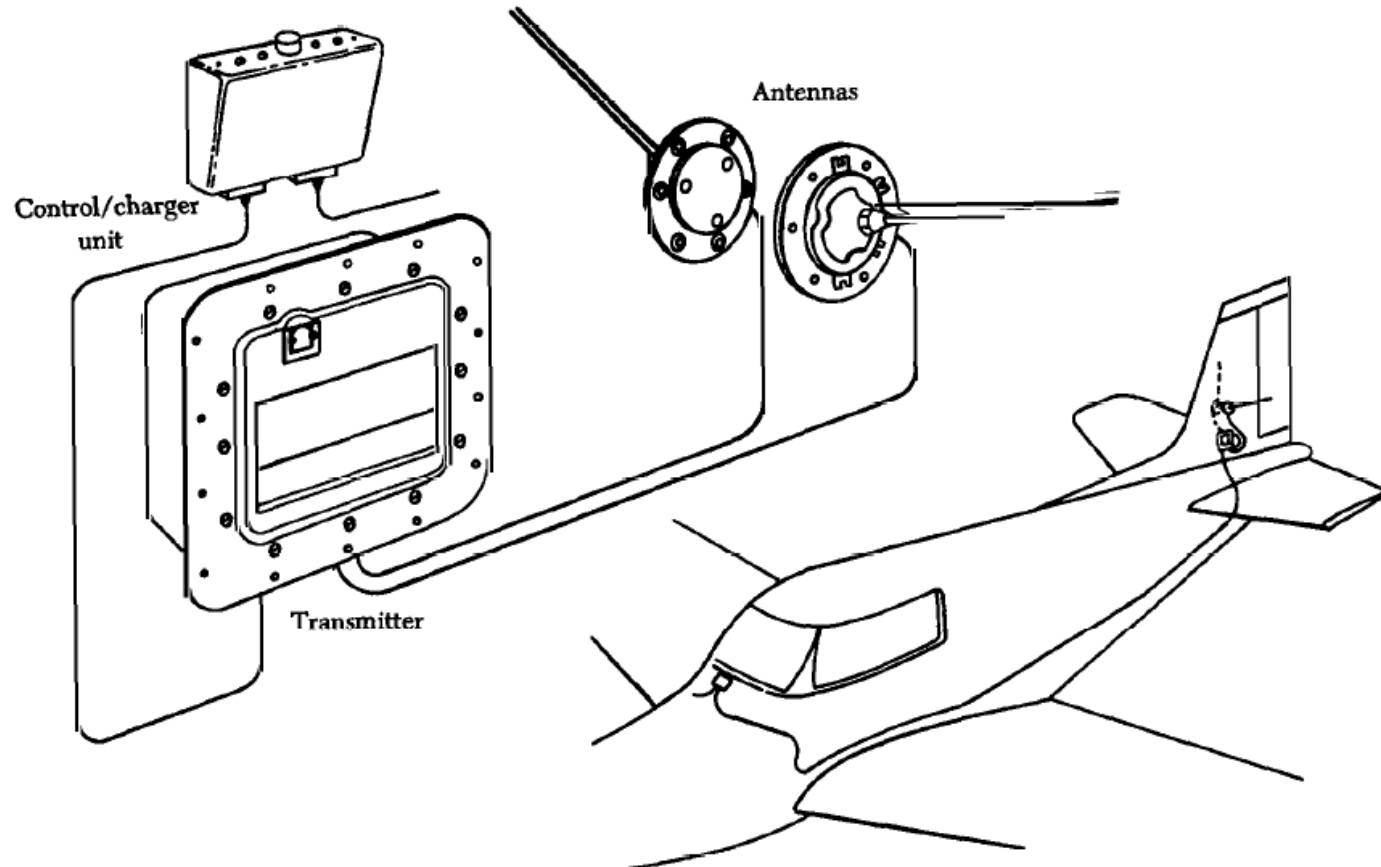


FIGURE 13-21. Emergency locator transmitter (ELT).