ATA2 仪表和电气笔记

Edited: 2026.2.28 – 查看最新版本

Contents

一种可取的学习方式作参考：

1. **首先阅读中文知识点/PPT/上课，建立对系统的感性认识；**
2. **之后，一边做题，一边找到英文笔记的对应知识点，发现题目考点对应的英文术语/解释方式，并作记忆。**

笔记正在整理完善中~~

Part I Electrical System

1. Battery

A battery is a device that converts chemical energy into electrical energy and vice versa. According to the type of electrolyte used, aircraft batteries are divided into three categories: **acid batteries, alkaline batteries, and organic-solution batteries.**

1) The most common **acid battery** is the **lead-acid battery(铅蓄电池)**, whose electrolyte is sulfuric acid (硫酸).

2) The most common **alkaline battery** is the **nickel-cadmium (Ni-Cd) (镉镍蓄电池)battery**, whose electrolyte is **potassium hydroxide** (氢氧化钾).

3) The most common **organic-solution** battery is the **lithium-ion battery** (锂离子电池).

Nickel-Cadmium Battery

Nickel-cadmium batteries have **high reliability** and can operate normally under severe vibration, acceleration, and pressure conditions. They also have a **long service life**, so they are widely used on civil transport aircraft.

The **negative electrode** (负极) is **cadmium** powder, and the **positive electrode** (正极) consists of **nickel** oxide or nickel hydroxide. The **electrolyte** is a **potassium hydroxide** solution.

During discharge, the **positive plate converts nickel hydroxide into nickelous hydroxide**, and the **negative plate converts cadmium into cadmium hydroxide**, while the electrolyte concentration remains essentially unchanged. **Therefore, the density and liquid level of the electrolyte hardly vary during charge and discharge.**

Functions of Aircraft Battery

1) The aircraft battery serves as a standby or emergency power source (备用电源或应急电源). 2) Large aircraft also have a dedicated battery for the APU (Auxiliary Power Unit). Before each flight, the voltage of the aircraft battery must be checked and must not be lower than the value required in the maintenance manual.

2. Types of AC Power Supply

Aircraft AC (Alternating Current 交流电) power systems include two main types: **Constant Frequency (CF) power supply and Variable Frequency (VF) power supply**. Constant Frequency systems are further divided into **Constant Speed Constant Frequency (CSCF 恒速恒频) and Variable Speed Constant Frequency (VSCF 变速恒频)**.

In the **variable frequency system, the AC generator is directly driven by the engine through a reduction gearbox**. In a constant speed constant frequency (CSCF) system, a Constant Speed Drive (CSD 恒速传动装置) keeps the generator speed constant to produce **400 Hz** AC power.

Constant Speed Drive (CSD)

An **Integrated Drive Generator (IDG** 组合传动发电机) combines a **CSD and an AC generator** into a single unit. The commonly used design is a hydro-mechanical differential type CSD with oil cooling. The system includes four major parts: the transmission system, oil system, speed control system, and protection system.

1) **Transmission** system: consists of a **hydraulic pump-motor set and differential gears**. Most of the generator's required power is transmitted mechanically through the gears, while the hydraulic system transmits only a small portion.

2) **Oil system**: provides lubrication and cooling for the gears and also acts as the **power transmission medium** between the pump and motor.

3) **Speed control system**: **adjusts the output speed of the hydraulic motor** to maintain constant generator speed.(If engine speed decreases → hydraulic system speeds up the motor. If engine speed increases → hydraulic system slows the motor)

4) **Protection system**: **disconnects the generator from the CSD** in case of a malfunction to prevent damage to the unit.

Variable Speed Constant Frequency (VSCF) Power Supply

The VSCF system is a new type of aircraft power supply. It uses an **electronic converter** to transform variable-frequency power from the engine-driven generator into **115/200 V, 400 Hz** three-phase AC. VSCF systems can be either AC–AC or AC–DC–AC types.

3. AC Generator

Modern transport aircraft commonly use brushless AC generators with rotating rectifiers. They come in two configurations: **two-stage and three-stage designs**.

1) A two-stage brushless generator consists of **an AC exciter and a main generator**. It is a self-excited type. To ensure reliable excitation, permanent magnets may be embedded in the exciter stator or rotor.

2) A three-stage brushless generator consists of an **auxiliary exciter, main exciter, main generator, and rotating rectifier**. It provides reliable excitation and strong short-circuit excitation capability.

Both types **adopt a rotating field structure and use rotating rectifiers**. Some aircraft also install an **air-driven turbine generator or hydraulically driven generator** as an **emergency AC power** source.

4. Voltage Regulation of AC Generator

Modern transport aircraft widely use **transistor-type voltage regulators**. A transistor (晶体管) is connected **in series** in the **excitation circuit**. By changing its **conduction ratio (导**通比**)**, the excitation current and hence the output voltage are adjusted.

5. Parallel Operation of AC Generators

Generators can only be connected in parallel when their output **voltage waveform, phase sequence, frequency, voltage, and phase** are all within specified limits. These parameters are automatically monitored by the paralleling control unit, which connects the generator when conditions are met.

Load balancing ensures that all generators share equal **active and reactive power loads**. **Reactive load balancing** is achieved by adjusting **excitation current**, while **active load balancing** is achieved by adjusting **output frequency**.

Advantages of parallel operation include improved power quality and reliability. Disadvantages include more complex control and protection circuits, and reduced power capability if load sharing is unbalanced.

6. Control of AC Power System

The AC power system on transport aircraft typically involves four main control functions:

1) **Generator excitation control**: connects or disconnects the excitation circuit, determining **whether the generator can produce power.**

2) **Generator output control**: **connects the generator to the bus** to deliver power to the system.

3) **conflux(合流) condition connect control**: determines whether power is **shared between buses or isolated.**

4) **External power control**: determines whether external power supplies the aircraft system.

7. Generator Faults and Protection

Common generator faults include voltage, frequency, and short-circuit faults.

1) Voltage faults: **overvoltage, undervoltage, and unstable voltage**. **Overvoltage protection uses anti-delay, undervoltage uses fixed delay.**

2) Frequency faults: over-frequency, under-frequency, and unstable frequency, typically using **fixed delay** protection.

3) Short-circuit faults: stator and feeder short circuits are protected by **differential protection** with very short delay (**tens of milliseconds**).

8. Transformer Rectifier Unit (TRU)

A TRU converts **115/200 V 400 Hz** or variable-frequency AC into **28 V** DC. It is mainly used in large and medium-sized aircraft powered primarily by AC systems.

A conventional TRU includes an input filter, step-down transformer, rectifier diodes, and an output filter. Some designs include cooling fans and overheat protection. Output voltage decreases slightly with increasing load current.

An electronic TRU first converts high-voltage AC into DC, then inverts it into high-frequency AC, steps it down via a transformer, and rectifies it into low-voltage DC. This design is compact and less sensitive to input or load variations.

9. Converter

1) **Rotary converter**: converts DC into AC using a motor–generator set, available in single-phase or three-phase versions. These are heavy, inefficient, and have mostly been replaced by static converters.

2) **Static converter**: converts aircraft DC power into 400 Hz single- or three-phase AC. It consists of a DC–DC converter and a DC–AC inverter. **The first stage raises voltage and provides isolation; the second stage generates 400 Hz sinusoidal AC**.

10. Typical Aircraft Power Distribution

Power distribution forms of typical independent power supply systems

A typical twin-engine aircraft has **one 115/200 V 400 Hz AC system and one 28 V DC system.** The AC system consists of **two engine-driven generators and one APU-driven generator**. Part of the AC power is converted to DC through **TRUs**. If AC power fails, the

battery supplies DC power and can feed **essential AC equipment** via the **static inverter**. Normally, **AC systems operate independently, while DC systems operate in parallel**. Some aircraft are also equipped with **emergency generators that supply AC** to essential buses when the main AC fails, and supply DC through **TRUs**. On the ground, external power can energize the entire aircraft electrical network.

In an independent distribution system, even if a short-circuit fault occurs, it only affects the faulty power grid, thereby enhancing the reliability of operation. However, if the power **generation capacity of each independent system** is not large enough, it will cause significant **voltage fluctuations** in this system when starting a **large load**.

After a group of power supplies fail, it takes a certain amount of time for the electrical equipment to switch back to the normal channel, which will cause a power supply interruption.

Power distribution forms of typical parallel power supply systems

It is often used in aircraft with more than two engines. The constant-frequency AC power supply is provided by several generators, and the DC power supply is provided by several transformer rectifiers. Under normal circumstances, the AC power supply system is connected in parallel, and so is the DC power supply system. When a certain generator does not meet the parallel connection conditions, it can also supply power independently.

11. Electrical Loads

Aircraft electrical equipment is classified into three categories according to importance: **flight-essential equipment (飞行关键设备), mission-essential equipment (任务关键设备), and general electrical equipment (一般用电设备)**.

1) Flight-essential equipment ensures safe flight and landing. It is powered by the essential bus and automatically transfers to the emergency source upon main power failure.

2) Mission-essential equipment supports mission tasks and may be shed during emergencies to preserve essential loads.

3) General electrical equipment is non-critical and can be disconnected under limited power conditions to prioritize essential loads.

DC Motors

DC motors on aircraft are classified by excitation type: **series, shunt, and compound**. **Series motors** are used for short, frequent starts; **shunt motors** for steady-speed applications; **compound motors** are commonly used as engine starters.

AC Motors

AC motors do not require rectifiers or brushes and are used in AC-powered aircraft. The most common type is the asynchronous (induction) motor, available in three-, two-, and single-phase versions. Three-phase induction motors are efficient and produce high torque, used in drive systems and gyros. Two-phase induction motors are used as servos, and single-phase ones for low-power applications.

Part II Engine Instruments

1. EPR Indicator

The thrust of a jet engine is related to the total pressure at the compressor inlet, the total pressure at the turbine outlet, and the flight speed. **When the Mach number remains constant, the engine thrust depends mainly on pressure**. **The EPR (Engine Pressure Ratio 发动机压力比) i**ndicator shows engine thrust by measuring **the ratio of turbine exhaust total pressure to compressor inlet total pressure**.

Two pressure sensors are used: one senses turbine **exhaust total pressure**, the other senses **compressor inlet total pressure.** The computer calculates the ratio and sends the result to the EPR indicator for display.

Before takeoff, the pilot **determines the required takeoff EPR based on field pressure, ambient temperature, and aircraft gross weight**, and sets the **thrust reference cursor** accordingly. During takeoff, when the **indicator pointer** aligns with the **thrust reference cursor**, the engines have reached takeoff thrust. During flight, the pointer continuously shows the actual EPR.

2. Torque Indicator

The torque indicator reflects the power output of a **turboprop engine.** Using the **helical gear spiral teeth in the reduction gearbox**, the **axial thrust** can be measured on a **counter shaft** (**secondary shaft),** which is proportional to the transmitted **torque**. This axial force creates an **oil pressure** known as **torque pressure**, which is proportional to the engine power and is displayed in **PSI** on the cockpit gauge. **(PSI or LB*ft)**

3. Tachometer (RPM Indicator)

The tachometer measures the rotational speed of the **engine's crankshaft or turbine shaft(not propeller shaft).** Two main types are used:

1) **Magnetic-induction type**: uses a tachometer generator that converts engine speed into a **three-phase AC signal, the frequency** of which is proportional to rotational speed.

2) **Magnetoelectric typ**e: uses a magnetoelectric sensor that converts rotational speed into an **induced electromotive force**, the **frequency** also proportional to the rotational speed.

For **piston engines**, RPM is expressed in **revolutions per minute (r/min)**. For **jet engines,** the speed is extremely high, so it is **expressed as a percentage**, where 100% represents the rated rotational speed.

4. Exhaust Gas Temperature (EGT) Indicator

The exhaust gas temperature indicator measures the temperature of the jet exhaust at the nozzle. The measurement principle is based on the **pyroelectric/thermoelectric effect (热电效应) of a thermocouple.** The thermocouple's **hot junction senses exhaust temperature**, while the cold junction is kept at a constant reference temperature. The **electromotive force** produced is proportional to the hot-junction temperature, thus indicating the exhaust temperature.

5. Fuel Flow and Fuel Quantity Indicators

Fuel flow indicators **measure** fuel consumption and help monitor fuel use and remaining quantity. Two main types of flowmeters are used:

1) **impeller type**: converts **fuel flow into rotational speed** using a small impeller, which is then measured to **indicate volumetric flow rate (e.g., L/h).**

2) **Angular-momentum type**: measures fuel mass flow by relating the fluid's **angular momentum to flow rate**; the torque produced is converted into an electrical signal indicating **mass flow (e.g., lb/h)**.

Fuel quantity indicators measure the remaining fuel volume in tanks. Two types are common:

1) **Float-type**: converts the height of the fuel level into **electrical resistance** for indication. This type is prone to **attitude errors** *(And the electrical resistance has temperature errors.)*

2) **Capacitance-type**: converts the fuel level into **capacitance changes** measured by the indicator. It is subject to **temperature and fuel-density errors.**

6. Oil Pressure and Temperature Indicators

Oil temperature is measured using the principle that the electrical resistance of a conductor or semiconductor varies with temperature. Thus, the **temperature is converted into an electrical resistance** value for measurement.

Oil pressure is measured using a pressure sensor that converts the sensed pressure into an **electrical signal/power** through a **diaphragm or capsule** (膜片或膜盒). (normally senses the oil pump outlet pressure)

7. Vibration Indicator

The vibration indicator monitors the vibration amplitude of the engine to ensure smooth operation. The **ratio of vibration acceleration amplitude to gravitational acceleration** is called the **vibration load factor** (振动载荷系数).

There are two main vibration measurement methods:

1) **Speed magnetoelectrical vibration measurement**: converts **vibration velocity** into an **electromotive force** proportional to it.

2) **Accelerated speed electrical vibration measurement**: converts **vibration acceleration** into a proportional **voltage.**

Vibration is indicated in **'g'** for the **vibration load factor** and in **'mil'** (1 mil = 10^{-3} inch) for **vibration amplitude**. Under normal operation, civil aircraft engines typically **show 3–4 g or 2–3 mil.**

EPR			
EGT		**pyroelectric/thermoelectric effect, hot side**	**EMF**
Torquemeter		**Axial thrust on counter shaft** **Using helical gear spiral teeth in the reduction gearbox in**	**Oil pressure**
Tachometer		**Magnetic-induction**	**Three phase AC frequency**
		Magnetoelectric type	**EMF frequency**
Fuel	**FF**	**Impeller**	**Volume**
		Angular momentum	**Momentum**
	FQ	**Float type**	**Resistance**
		Capacitive	**Capacitive**
Oil	**Temp**		**Resistance**
	P		**Diagram capsule->electrical power/signal**
Vib	**Amplitude**	**Speed magnetoelectrical**	**EMF Electromotive force**
		Accelerated speed electrical	**V voltage**

Part III Flight Instrument Systems

1. Air Data Instruments

Machmeter

The Machmeter operates according to the relationship between Mach number, total pressure, and static pressure: **M = A × (Pt / Ps)^0.5**, where Pt is total pressure and Ps is static pressure. It uses diaphragm capsules to sense both pressures, indirectly indicating the Mach number.

If the total or static pressure systems are blocked: a blocked pitot tube causes the instrument to overread during climb, while a blocked static port causes it to underread.

Total Air Temperature (TAT) Indicator

As the aircraft moves through the air, airflow decelerates and compresses adiabatically, increasing temperature. This increase is known as **'ram rise'** (动力温升). The **total air temperature (TAT，总温) equals the static temperature plus ram rise**.

TAT is measured by a total temperature probe installed at positions where airflow disturbance is minimal, such as the **wingtip, vertical fin top, or the nose side.** The probe's recovery factor indicates how much of the ram rise is measured. A **recovery factor of 1** means true total temperature is measured.

SAT(static): true air temperature; RAT/TAT: true total outside air temperature

2. Air Data Computer (ADC)

The Air Data Computer (ADC 大气数据计算机) **receives total pressure, static pressure to computer altitude, speed, vertical speed, Mach number, air density etc. It receives TAT for computing temperature, TAS etc. It uses AOA to calibrate static source error.**

Inputs: Pt and Ps from pitot-static systems, TAT from probes, and AOA (angle of attack) from sensors. Outputs: altitude, IAS, TAS, vertical speed, Mach number, and temperature to systems such as Flight **Data Recorder(FDR), Flight Management System (FMS), Automatic Flight Control System (AFCS 自动飞行控制系统), Transponder (XPDR 应答机), and Ground Proximity Warning System (GPWS 近地警告系统), Power Management Computer(PMC), Flight Director System(FDS) etc.**

(注意：考试可能说，output 有 Heading、AOA，不是。AOA 是 input 不是 output)

(考试的 pitot 有 drain，如果 pitot 堵了,drain 没堵，IAS will decrease to zero)

Most aircraft have **two ADCs** for redundancy. Normally, each pilot's display uses its own ADC. If one fails, data can be switched to the other side.

Working Principle

The ADC may be **analog or digital**, but modern aircraft use **digital ADCs**. Digital ADCs convert analog inputs from pressure, temperature, and AOA sensors into digital signals via A/D conversion, then compute and output flight parameters to the respective systems and indicators.

The ADC includes internal monitoring logic to detect sensor or interface malfunctions. If a fault is detected, it alerts the crew and records data for maintenance use.

3. Electronic Flight Instrument System (EFIS)

The **Electronic Flight Instrument System (**电子飞行仪表系统) displays attitude, airspeed, heading, and navigation data using CRT or LCD screens. Information is integrated and color-coded to reduce pilot workload and improve situational awareness.

EFIS includes **two identical systems** (captain and first officer). Each has two display units. Each system has a **Symbol Generator (SG 符号发生器)(the core of EFIS)**, and a **Display Control Panel (DCP 显示控制板)**. The SG processes navigation and flight control data, generates symbols, and sends them to the display. (there are standby SG in case of failure)

The main displays are the **EADI(electronic attitude direction indicator)** or **PFD (Primary Flight Display 主飞行显示器)** and the **EHSI(Electronic Horizontal Situation Indicator) or ND (Navigation Display 导航显示器).** The PFD shows attitude (from **IRS**), airspeed, altitude, flight director, and mode annunciations. The ND displays navigation route, track, groundspeed, and distance information in either **full-compass or arc mode.**

4. ECAM (Electronic Centralized Aircraft Monitoring)

The **ECAM (机载电子集中监控系统)** assists the crew in monitoring aircraft systems under both normal and abnormal conditions. It consists of the **2 displays: E/WD** (Engine/Warning **Display**) and **S/SD** (System/Status **Display**), System Data Acquisition Concentrators (**SDAC**), Flight Warning Computers (**FWC**), Display Management Computers (**DMC**), and the ECAM Control Panel (**ECP**) etc.

SDAC collects and processes system data, sending them to the **DMC and FWC**.

DMC (the core of ECAM system) outputs the engine working parameters and system page data.

FWC outputs alarm information and corresponding program information. FWC can generate red warning messages based on direct information from aircraft sensors and systems, and also produce amber alert messages through system information from SDAC.

Under abnormal circumstances, the ECAM system attracts the attention of the flight crew through **visual attention acquisition devices** (red main warning light and amber main alert light) and **audio attention acquisition devices.**

The S/SD has four display modes: flight-phase, advisory, failure, and manual/system diagram.

flight-phase mode, ECAM automatically shows data relevant to each flight phase.

Advisory mode(status mode) displays system condition summaries **automatically on S/SD**;

failure mode shows fault details and procedures;

manual mode allows the crew to **manually display on S/SD** systems like ENG, HYD, ELEC, FUEL, or DOOR. The manual mode has the highest priority

5. EICAS (Engine Indication and Crew Alerting System)

The **EICAS (发动机指示与机组警告系统)** displays key engine parameters and system warnings or advisories. It usually consists of two displays: a **primary display** showing essential engine parameters (**EPR, N1, EGT, etc**.) and a **secondary display** showing **N2, fuel flow, oil data, and system advisories.**

Two computers provide data for each of the EICAS for redundancy; if one fails, the other takes over automatically.

The **EICAS system has three display modes**:

(1) **operation mode**: provide the main engine parameter display, if there is abnormal, alarm information display and the details of the abnormal situation, the model is used for during the flight.

(2) **status mode:** mainly used in the plane during the preparation, display the system status and flight plane readiness.

(3) **maintenance mode:** used in fault diagnosis maintenance personnel.

On the EICAS display control panel, the operation mode and status mode can be selected

EICAS system continuously monitor a large number of input information from the sensors in the engine and aircraft systems, if a system failure is detected, produced a suitable alarm message and display in the main display.

Class A: warning, need **immediate action** unit. This information is displayed in **red**. When this message appears, the main warning light is on and the central warning system gives an **audible warning.**

Class B: alert information, need the crew **to be aware of immediately**, but **don't need to take immediate action**. This information is displayed in **amber color**. When this message appears, the warning light lights up and is accompanied by an **audio message.**

Class C: consulting information, need the crew **to be aware of**. This information is also displayed in **amber color**. To distinguish the warning information, display one character back. (no audible warning)

6. Flight Management Computer System (FMCS)

The Flight Management Computer System (FMCS 飞行管理计算机系统) is the central component of modern aircraft avionics. It integrates navigation, performance, and guidance functions to optimize flight efficiency and reduce pilot workload.

Composition and Functions

The FMCS consists of **two Flight Management Computers (FMC) and two Control Display Units (CDU**). The crew enters flight route, waypoint, and performance data through the CDU. Based on these inputs and data from onboard sensors, the FMCS performs three major functions: navigation, performance, and guidance.

Navigation Function

The FMC uses the **Navigation Database** to establish and manage the flight route. During flight, it continuously updates the aircraft position using data from the **Inertial Reference System (IRS 惯性基准系统)**, **radio navigation aids**(DME, VOR, ADF)**, and GPS**. The calculated position is compared with the programmed route and displayed on the EFIS. The FMC can also automatically tune radio navigation equipment as required.

When entering a flight plan into the Flight Management Computer (FMC),

a **blue dashed line** indicates that the route has **not been activated**.

When the blue dashed line becomes a **solid magenta(red purple) line**, it means the route is **active.**

If a **white dashed line** appears over the magenta route, it indicates that the route has been **modified and is awaiting confirmation.**

Performance Function

The FMC's **Performance Database** contains aircraft aerodynamic and engine data. Using crew inputs such as **aircraft gross weight, cruise altitude, and cost index**, it computes **optimal speed, climb and descent profiles, and target thrust settings** to achieve fuel-efficient operation.

Guidance Function

The guidance function **sends control commands** to the Autopilot (**AP**) and Autothrottle (**AT**). In **LNAV (Lateral Navigation) mode**, the FMC computes roll commands to follow the programmed lateral route.

In **VNAV (Vertical Navigation) mode**, it calculates target speeds and vertical rates, transmitting these to the AP and AT to maintain the desired vertical flight profile.

Modern aircraft usually have dual FMCS units cross-linked for redundancy. Data entered through one CDU are automatically available to both FMCs, allowing monitoring and verification.

Databases

The FMCS contains two primary databases: **the Navigation Database and the Performance Database.**

1) Navigation Database: Includes **waypoints, navigation aids, airways, airports, and procedures such as Standard Instrument Departures (SIDs 标准仪表离场程序) and Standard Terminal Arrivals (STARs 标准终端进场程序)**. The database is updated not **less than every 28 days** and includes both current and revision datasets.

2) Performance Database: There are two performance databases in FMC: the **default performance database** and the **aircraft/engine performance database**.

The default database performance is part of the flight procedures, is a series of aircraft aerodynamic model and a particular engine fuel flow/thrust model. This data is used to predict the optimal vertical profile performance of the aircraft.

Aircraft/engine performance database with the default database performance with the same type of information and the same function. However, the aircraft/engine performance database is the data required for a more specific series of aircraft.

7. Inertial Navigation System (INS)

Laser Gyro

A Laser Gyro (激光陀螺) is an **optical device** that measures an object's **rotation angle** or **angular velocity** relative to inertial space using laser technology. It consists of a **laser generator** and a **photoelectric detector.** The generator contains a **laser tube, two mirrors, and one semi-transparent mirror** forming a closed light path. The laser tube emits two beams of high-energy light that propagate in opposite directions **(relative motion)** within a sealed cavity. Any rotation of the cavity causes a difference in the optical path length of the two beams, which results in a **frequency difference proportional to the angular velocity**. By measuring this frequency difference, the system determines the **rotation rate and angle**.

Basic Functions and Characteristics

1) Functions of the Inertial Navigation System (INS 惯性导航系统):

The INS continuously provides navigation information such as aircraft attitude, true heading, magnetic heading, vertical speed, position, acceleration, angular rate, wind direction and velocity, and ground speed. The system's accuracy depends on the precision of **initial data input and alignment with true north**.

2) Advantages and Disadvantages of INS:

Advantages: (1) Fully **autonomous** system; not affected by weather conditions, with strong concealment; (2) Once aligned, provides high **short-term** positional accuracy.

Disadvantages: (1) Positioning error increases continuously with time, resulting in **cumulative error** (积累误差).

3) Sources of Error:

Errors are divided into **deterministic** and **random** categories.

Deterministic errors arise from **installation misalignment, scale factor deviation, initial condition errors, and computational inaccuracies**, and can be compensated through **calibration**.

Random errors mainly result from zero point bias of **gyro drift** (陀螺漂移) and **accelerometer zero point bias** (加速度计零位偏置), which are the **primary sources** of long-term accuracy degradation.

Composition and Classification

The INS consists mainly of the **inertial navigation unit, control/display unit, and mode selector**. The inertial navigation unit includes **accelerometers, gyros, platform assembly**, navigation **computer,** electronic **circuits,** and **power** supply. A **backup battery** provides emergency power in case of main power failure.

According to the presence or absence of a physical stabilized platform, INS is divided into **Platform-type INS** (平台式惯导系统) and **Strapdown INS** (捷联式惯导系统). The platform-type system includes a gyro-stabilized platform**(gimbaled)** on which accelerometers and gyros are mounted. The strapdown system eliminates the mechanical platform; accelerometers and gyros are directly fixed to the airframe, and the concept of a 'platform' is realized by a computational model called the mathematical platform (数学平台).

Basic Principle

In a **Platform-type INS**, three accelerometers and gyros are mounted on a stabilized platform. The gyros stabilize the platform and measure rotation rates, while the accelerometers measure linear acceleration along the east-west, north-south, and vertical directions. The computer integrates these measurements with the initial data to compute position, velocity, and attitude. The system also determines the aircraft's orientation relative to the platform to output attitude and heading angles.

In a **Strapdown Inertial Reference System** (IRS 惯性基准系统), accelerometers and gyros are mounted along the aircraft's three body axes. The accelerometers measure acceleration along these axes, and the laser gyros measure angular rates about them. The navigation computer performs coordinate transformations, converting body-axis accelerations into **Earth-reference axes**, and then integrates them to obtain navigation parameters such as position, velocity, and attitude.

The '**attitude matrix**' (姿态矩阵) in the navigation computer describes the relationship between the body coordinate system and the navigation coordinate system. If the navigation frame represents geographic coordinates, the accelerations measured along the aircraft's axes can be transformed into **Earth-referenced** accelerations, which are then integrated to calculate velocity and position. The 'mathematical platform' performs these transformations and continuously updates the attitude matrix based on gyro data to compute attitude angles.

the **position change** of the aircraft is determined by **common changes of strapdown inertial navigation system and aircraft**

(Note: platform need to be earth-referenced, while the nature of gyros is inertial space referenced)

Modes of Operation

The INS operates in three main modes: NAV, ATT, and ALIGN.

1) ALIGN Mode (Alignment Mode):

In ALIGN mode, the system performs initial alignment to establish reference orientation. During this mode, the aircraft must remain stationary.

For strapdown systems, the gyros detect Earth's rotation to determine **true north and latitude (注意：not determine position),** while accelerometers sense gravity to determine the aircraft's **static attitude**. The computer **compares the entered latitude with the calculated value**. If there is a difference between the entered and stored positions, an alignment error message is displayed. After successful **verification**, the system builds a '**mathematical platform**.'

Typical alignment times:

platform-type INS takes approximately **15–20 minutes**;

Strapdown INS normally completes alignment in **less than 10 minutes**. If the heading remains unchanged, a rapid alignment can be accomplished in about **30 seconds**.

2) NAV Mode (Navigation Mode):

In NAV mode, the system provides the aircraft's position, heading, velocity, and attitude. After alignment is complete, switching to NAV mode enables continuous navigation data output.

3) ATT Mode (Attitude Reference Mode):

In ATT mode, **navigation capability is lost,** and only pitch, roll, and heading information is provided. If navigation mode fails, ATT mode can still supply continuous **attitude and heading** outputs to the EFIS and AFCS.

Initial Alignment

Purpose: For Platform-type INS, alignment adjusts the platform to coincide with the reference coordinate frame. For Strapdown INS, it establishes the navigation coordinate system and defines measurement references for accelerometers and gyros.

Alignment Process for **Strapdown INS**: (1) **Determination of True North**: When stationary on the ground, laser gyros detect Earth's rotation rate, which is used to calculate the aircraft's **true heading and latitude**. (2) **Determination of Aircraft Attitude**: Accelerometers sense gravity, allowing calculation of the aircraft's pitch and roll angles. (3) Comparison and Verification: The computer **compares entered latitude and computed**

latitude to verify accuracy. (4) Mathematical Platform Construction: After successful **latitude verification**, the computer establishes the mathematical platform for navigation.

Alignment should be completed before aircraft movement. The process is not significantly affected by gusts, refueling, or passenger boarding.

For an air carrier that elects to use a dual Inertial Navigation System (INS) on a proposed flight, only one INS is required to be operative, if a **Doppler Radar is substituted for the other INS.**

Part IV Automatic Flight Control System

1. Automatic Pilot (AP 自动驾驶仪)

1.1 Basic Functions and Classification

Basic function: During flight, the Automatic Pilot (AP 自动驾驶仪) substitutes for the pilot in controlling the aircraft control surfaces so as to keep the aircraft stabilized in a specific state or to transition the aircraft from one state to another automatically.

Classification by controlled axes: **single-axis autopilot, two-axis autopilot, and three-axis autopilot.**

① Single-axis autopilot: provides control about the roll axis via the ailerons (副翼).

② Two-axis autopilot: provides control about the roll and pitch axes via the ailerons and the elevator (升降舵) respectively. Its basic function is to provide stability about these axes. It also **supplies signals directly to the Flight Director (FD 飞行指引仪)** so that the selected flight path can be followed either manually or automatically.

③ Three-axis autopilot: provides control about the pitch, roll, and yaw axes via the elevator, ailerons, and rudder (方向舵).

1.2 Control Channels and Channel Composition

The autopilot controls the aircraft through three automatic control loops that respectively drive the ailerons, elevator, and rudder. Each automatic control loop is called a control channel. The loop that controls the elevator is the **Pitch Channel** (俯仰通道); the one that controls the ailerons is the **Roll Channel** (横滚通道); and the one that controls the rudder is the **Yaw Channel** (航向通道/偏航通道). The three channels are both independent and mutually responsive, working together to control the aircraft.

On some aircraft, the autopilot controls only the ailerons and elevator, while the rudder is stabilized by the Yaw Damper (YD 偏航阻尼器). Therefore, **when the autopilot is engaged, the yaw damper engages automatically.**

Each channel of the autopilot consists of: **sensing/measurement devices, an automatic-pilot computer, amplifier, a servo (舵机), a feedback device, and control/annunciation displays.**

• **Measurement devices:** include a **primary sensor** to sense the **angular displacement** from the initial state, and **auxiliary sensors** to sense **angular rate and angular acceleration**. **Introducing angular-rate feedback reduces oscillations and enhances system stability**.

• **Automatic-pilot computer**: receives all AP inputs, computes the required control law, and sends commands to the amplifiers.

• **Amplifier:** amplifies small control signals from the computer and drives the servo(s).

• **Servo(s)**: the actuators driving the control surfaces—either electric or hydraulic types.

• **Feedback device**: feeds back control-surface deflection and deflection rate to complete the closed loop and to command surface recentering when appropriate.

• **Control/annunciation display unit:** used to engage/disengage the AP, select operating modes, and display mode status.

1.3 Basic Working Principle (Inner-Loop Stabilization 内环稳定)

The three channels work on similar principles; only the measured signals and controlled surfaces differ. Taking the pitch channel as an example: during normal operation the AP maintains the aircraft pitch attitude existing at engagement. If aerodynamic disturbances or trim imbalance change the attitude (e.g., a pitch-down deviation), the attitude/rate sensors detect the deviation and send an error signal to the AP computer.

The computer commands the servo to deflect the elevator upward to counter the deviation. At the same time, the feedback device reports control-surface deflection back to the computer. When the feedback equals the error, the surface stops moving. As the aircraft response reduces the deviation, the residual error reverses the servo command, allowing the surface to recenter progressively. This cyclic process continues until the deviation becomes zero—surface neutral and aircraft stabilized at the reference attitude.

1.4 Outer-Loop Control (Command Modes 指令模式)

While inner loops stabilize the aircraft, feeding reference data such as heading, airspeed, altitude, radio bearing, Lateral Navigation (LNAV 横向导航) and Vertical Navigation (VNAV 纵向导航) enables the system to accomplish guidance tasks. This is called **outer-loop control, or AP command mode (CMD)**.

Modes are selected on the **Mode Control Panel** (MCP 模式控制板) and coupled to the associated AP channels. AP modes fall into two categories: **roll (lateral) modes and pitch (vertical) modes.**

• Roll (lateral) modes include: Heading (HDG/HDG SEL 航向模式), Navigation (NAV 导航模式), and LNAV (lateral FMS-guided route tracking) etc.

• Pitch (vertical) modes include: Altitude (ALT 高度保持), Speed (SPD 速度), Vertical Speed (V/S 垂直速度), and VNAV (vertical FMS profile tracking) etc.

1.5 Engagement and Disengagement

The AP may be used in all phases of flight **except takeoff**. Once the aircraft reaches the prescribed engagement altitude and other conditions are met, press the AP ENGAGE switch to connect the AP. After engagement, select the required operating modes; mode switching in flight is permitted as needed.

Disengagement: the most common method is **pressing the AP disengage switch on the control column**. Other methods include **switching off the AP master switch**, or applying sufficient **manual force on the controls to override and disconnect.** Modern aircraft provide distinctive aural and visual warnings for AP disconnects, whether manual or fault-induced.

During multi autopilot approaches, power supply bus isolation(隔离) occurs at 1500AGL.

（Flight Director, autothrottle(N1 mode) can be used for all phase of flight, autopilot can only be engaged after takeoff）

2. Flight Director (FD 飞行指引仪)

2.1 Functions and Command-Bar Forms

Function: According to the selected mode, the Flight Director (FD 飞行指引仪) computes control commands to guide the pilot in maneuvering the aircraft so that it captures and maintains the commanded flight path. The FD is available throughout takeoff, climb, cruise, descent, approach, and go-around.

Command-bar forms:

• **Cross-pointer bars** (十字指引针): a **vertical bar** for pitch guidance and a **horizontal bar** for roll guidance. When the bars are centered over the aircraft symbol, the target condition is achieved. If the vertical bar is above the symbol, pitch up; if below, pitch down. If the horizontal bar is left of the symbol, bank left; if right, bank right.

• “**V-bar**” (八字/“V”形指引针): use the relative up/down of the V-bar to command pitch and left/right tilt for roll. When the V-bar encloses the aircraft symbol, the target state is achieved; if the V-bar appears above the symbol, pitch up; if it tilts to the right relative to the symbol, bank right, etc.

2.2 Basic Working Principle

The FD comprises a **Flight Director Computer, Mode Selector Panel, Mode Annunciations, an Attitude/Command Indicator, and input devices.** Within the computer, the roll-command computation forms the roll channel, and the pitch-command computation forms the pitch channel. Inputs include lateral and vertical navigation sources, manual control selections, and the vertical gyro (垂直陀螺) attitude reference.

The FD compares the aircraft's actual trajectory against the preselected targets according to the selected mode, computes the required attitude, compares it with actual attitude, and sends the command to the bar-servo so that the command bars deflect away from the aircraft symbol, indicating both magnitude and direction of the required pitch and bank commands.

2.3 Basic Operating Modes

Typical FD basic modes include: ALT (altitude hold), HDG (heading select/hold), NAV (VOR radial capture), APP (approach), GA (go-around), and TO (takeoff).

• ALT: command to maintain the selected altitude.

• HDG: command to steer to and hold the selected heading.

• **NAV: command to intercept and track a VOR radial.**

• **APP: command to execute the selected approach mode.**

• **GA: go-around guidance.**

• **TO: takeoff guidance.**

3. Automatic Flight Director System (AFDS 自动驾驶飞行指引系统)

The AFDS integrates the Autopilot (AP) and Flight Director (FD), incorporating the functions of both. **Its core is the Flight Control Computer (FCC 飞行控制计算机),** which performs **both FD and AP computations**. The **Mode Control Panel (MCP 模式控制板)** is used to **engage/disengage AP/FD and to select modes.**

When the aircraft reaches the autopilot engagement altitude and other engagement conditions are met (some aircraft also require the aircraft to be in trim), pressing the autopilot engagement switch will engage the autopilot. The autopilot can be disengaged either manually or automatically, and an aural and visual warning system will provide alerts. Normally, the **autopilot will automatically disengage under the following conditions**: stall warning activation; electrical power failure; flight control system malfunction; when the CWS button is pressed and the roll rate or pitch rate exceeds the autopilot operating limits; excessive fuel imbalance between the two sides.

3.1 Lateral (Roll) Modes

Typical AFDS lateral modes include: HDG (航向), VOR (VOR 径向), LOC (本场航向道), and LNAV (FMS-lateral path).

• HDG: command AFDS to turn to and maintain the preselected heading.

• VOR: command AFDS to intercept and maintain a specified VOR radial.

• LOC: command AFDS to capture and track the localizer (LOC 航向道).

• LNAV: command AFDS to fly the lateral route as commanded by the FMS (飞行管理系统).

3.2 Vertical (Pitch) Modes

Typical AFDS vertical modes include: ALT, V/S, GS (glideslope 下滑道), VNAV, and FL CH (Flight Level Change 高度层改变模式).

• ALT: command AFDS to capture and maintain the selected altitude.

• V/S: command AFDS to climb or descend at a given vertical speed to a target altitude.

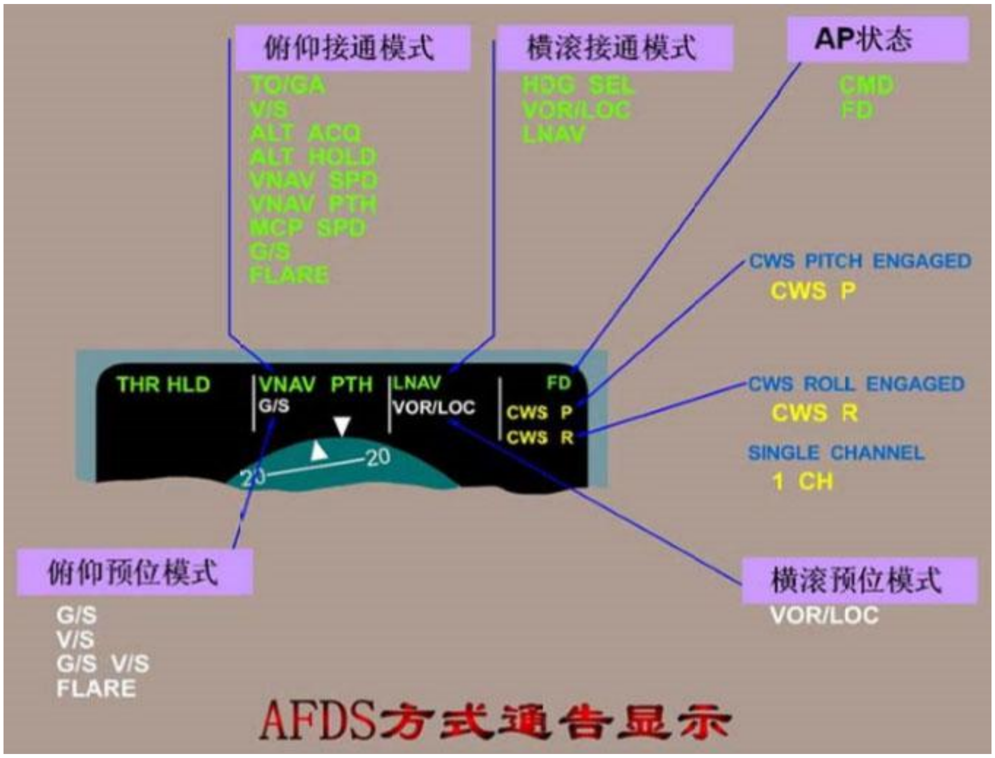
• GS: command AFDS to capture and track the ILS glideslope.

• VNAV: command AFDS to fly the programmed vertical profile from the flight plan.

• FL CH: command AFDS to climb or descend at a target airspeed to a preselected altitude.

3.3 Flight Mode Annunciator (FMA 模式信号牌)

AFDS mode annunciations are shown on the FMA (often on the EFIS/PFD). Different colors distinguish active and armed states. Typical annunciations include: HDG SEL, LNAV, VOR, LOC, V/S, ALT ACQ, ALT HOLD, VNAV PATH, VNAV SPD, MCP SPD, GS, TO, and FLARE (平飘).



4. Autothrottle (AT 自动油门系统)

4.1 Function and Basic Principle

The Autothrottle (AT 自动油门系统) is a computer-controlled electromechanical system that maintains engine thrust within design limits and provides automatic thrust and speed control throughout all flight phases. It is controlled by the **Thrust Management Computer (TMC 推力管理计算机)** or the **Flight Management Computer** (FMC 飞行管理计算机).

The TMC **computes thrust commands** based on mode inputs from the autothrottle control panel and thrust mode control panel, signals from the FMC, and airspeed, Mach number, pressure altitude, and total air temperature from the Air Data Computer (ADC 大气数据计算机), as well as N1 or EPR signals from engine sensors. Computation results are sent to the EFIS for mode and speed indications and to the autothrottle servo amplifier, which drives throttle servos and fuel control units to automatically adjust thrust. Feedback from throttle position sensors returns to the TMC for closed-loop management.

4.2 Basic Operating Modes

The autothrottle system has two basic operating modes: **Thrust Mode (**推力模式/N1 模式) and **Speed Mode** (速度模式/SPD).

1) **Thrust Mode (N1 mode or EPR mode)**: in this mode, AT maintains engine thrust at the set value of N1 (fan speed) or EPR (Engine Pressure Ratio 发动机压气比).

2) **Speed Mode (SPD mode):** in this mode, AT maintains the aircraft speed by moving the thrust levers as required. **After takeoff, the SPD mode can be used** in all subsequent flight phases.

4.3 Disengagement and Warning

The AT system can be disengaged by:

(1) switching the AT arm switch to OFF;

(2) pressing the AT disengage button on the throttle levers;

(3) automatic disengagement upon detection of AT system failure; or

(4) automatic disengagement after landing.

Disengagement, whether manual or automatic, triggers aural and visual warnings **(the exact format varies by aircraft).**

!!(AP disengagement： aural and visual warnings; A/T disengagement: varies by aircraft)

4.4 Mode Annunciation

The **autothrottle mode annunciations** appear on the EFIS (Electronic Flight Instrument System 电子飞行仪表系统), displaying the active AT mode such as N1, EPR, SPD, or ARM.

5. Autoland (自动着陆系统)

5.1 Basic Terms

For a fully automatic approach and landing, at least two autopilots and one autothrottle system are required to ensure redundancy. This guarantees that if one major autopilot component fails, the aircraft remains safely controlled.

1) Alert Height (警告高度): a specified radio altitude. If a failure occurs **above the alert height, the approach must be discontinued and a go-around performed**. If a failure occurs **below the alert height, the approach continues.**

2) Fail-Operational (失效-工作): when a failure occurs **below alert height but remaining systems can still complete the landing automatically.**

3) Fail-Passive (失效-被动): when a failure occurs below alert height, the aircraft **remains trimmed and stable but automatic landing cannot be completed.**

5.2 Operating Logic and Status Annunciations

On aircraft equipped with three autopilots, autoland operation is indicated as LAND2 or LAND3 depending on the number of engaged autopilots:

- **LAND2** – two autopilots engaged: **fail-passive** capability.
- **LAND3** – three autopilots engaged: **fail-operational** capability.

Normally, only one autopilot is used during cruise and initial approach. As the aircraft nears the airport, the crew selects APP mode on the AFDS control panel; the remaining autopilots arm automatically. At about **1500 feet radio altitude**, when **localizer (LOC) and glideslope (GS) are captured,** the other autopilots engage automatically and **LAND3** is annunciated**. (bus isolation occurs to supply power independently)**

If a fault occurs b**etween 200 and 1500 feet**, the system automatically **degrades to LAND2**. **At 330 feet, pitch trim is adjusted nose-up** for landing attitude. **Below 200 feet**, **failures are inhibited**, and LAND2 indication remains until **below 40 knots after touchdown.**

At 45 feet, flare mode automatically engages, reducing descent rate to approximately **2 ft/sec at touchdown**. **At 5 feet, flare disengages and rollout mode** maintains runway tracking until manual disconnect.

6. Flight Envelope Protection (飞行包线保护)

Flight envelope protection ensures the aircraft remains within the normal safe operating envelope during all flight phases. Protection types include: **angle of attack (迎角保护), high-speed (高速保护), pitch attitude (俯仰姿态保护), bank angle (坡度保护), and load factor (载荷因素保护).**

1) **Angle-of-Attack Protection**: allows pilots to perform **emergency pitch-up maneuvers** (e.g., collision avoidance) at the maximum allowable angle of attack without overcontrolling. When the aircraft exceeds normal limits, auto trim is disabled and manual input is required.

2) **Overspeed Protection**: allows pilots to descend rapidly by **pushing the control column forward without exceeding speed limits**; requires ADC to provide airspeed and Mach number signals for elevator control.

3) **Pitch-Attitude Protection**: **complements AOA and overspeed protections** using attitude gyro pitch signals to control the elevator.

4) **Bank-Angle Protection**: prevents excessive bank angles **(normally above 30°)** but still allows effective roll maneuvers.

5) **Load-Factor Protection**: based on **accelerometer G-load measurements**, preventing aircraft structural overload. It is interrelated with high-AOA protection.

7. Yaw Damper (YD 偏航阻尼器) and Automatic Pitch Trim System

7.1 Yaw Damper

Modern aircraft are equipped with a Yaw Damper (YD 偏航阻尼器) **to eliminate Dutch roll.** It uses **airspeed and yaw-rate** feedback to **generate rudder inputs opposite the oscillation, thereby increasing damping. (higher airspeed, less deflection required)**

The yaw-rate gyro senses aircraft motion around the vertical axis, sending angular-rate signals to a band-pass filter that removes low-frequency turns and high-frequency vibrations. The filtered signal is amplified and drives a hydraulic actuator that moves the rudder. Feedback from the actuator cancels the yaw-rate signal as the oscillation ceases, returning the rudder to neutral.

The yaw-damper signal gain is inversely proportional to airspeed, requiring ADC airspeed input. Flap-position signals also adjust gain for different configurations. The yaw damper It is usually **connected before takeoff on the ground, remains active throughout flight** and **disconnects automatically if hydraulic pressure fails**. **In AFCS-integrated systems, engaging AP automatically engages YD; for manual flight, YD must be engaged manually.**

7.2 Automatic Pitch Trim System

During automatic flight, **changes in speed, configuration, or aircraft weight alter the center of gravity**. The Automatic Pitch Trim System (自动俯仰配平系统) maintains pitch equilibrium by **adjusting the horizontal stabilizer trim angle**. It uses a dedicated trim servo motor operating in parallel with the AP pitch channel servo and **becomes effective whenever AFCS is engaged**.

7.3 Mach Trim System

At high subsonic or transonic speeds, airflow near the **wing root reaches sonic velocity, causing shock waves and a rearward movement of the pressure center**. This transonic effect induces a **nose-down tendency (Mack Tuck)**. The Mach Trim System (马赫配平系统)

automatically **commands elevator-up trim** proportional to Mach number to counteract this tendency.

The Mach trim coupler receives **Mach number from the ADC**; when it exceeds the threshold, a motor drives the elevator upward to restore pitch balance. The system is inhibited on the ground, when flaps are extended, or when Mach number is low. Internal monitoring circuits provide cockpit failure indication in case of malfunction. ***Automatically connect, has nothing to do with autopilot.***

（Flight Director, autothrottle can be used for all phase of flight, autopilot can only be engaged after takeoff）	
Yaw Damper	when the autopilot is engaged, the yaw damper engages automatically. connected before takeoff on the ground, remains active throughout flight and disconnects automatically if hydraulic pressure fails
Automatic Pitch Trim	becomes effective whenever AFCS is engaged.
Mach trim	Automatically connect, has nothing to do with autopilot.

Part V Warning and Recording Systems

1. Terrain Awareness and Warning System (TAWS 地形提示与警告系统)

1.1 Function and Regulatory Requirements

Controlled Flight Into Terrain (CFIT 可控飞行撞地) is a major cause of fatal transport accidents. **TAWS prevents CFIT** by issuing visual and aural alerts when unsafe proximity to terrain is detected. During takeoff, go-around, and approach with **radio altitude (RA 无线电高度) below ~2,450 ft**, TAWS evaluates aircraft configuration and terrain; upon detecting risk, it prompts corrective action.

Regulatory (CCAR-91 §91.207): **Transport-category turbine aircraft or turbine aircraft with ≥9 passenger seats(excluding any pilot seat)** must be equipped with TAWS.

All turbine powered airplanes are required to be equipped with a **ground proximity warning/glide slope deviation** warning system.

ground proximity warning/glide slope deviation	**All turbine powered**
GPWS	**Transport-category turbine aircraft or turbine aircraft with ≥9 passenger seats**
Thunderstorm	10
ACAS/intercomm	**Transport-category turbine airplanes with ≥19 seats require ACAS II/TCAS II v7.1** **Transport CAT A**

MTOW > 5700: CAT A TAWS; below, CAT B

1.2 Basic Modes and Trigger Conditions(GPWS)

Mode 1 – **Excessive Descent Rate**（过大的下降率）: **Active below ~2,500 ft RA**. If descent rate exceeds limits:

• Caution: **amber light + “SINK RATE”.**
• Warning: **“WHOOP WHOOP PULL UP”.**
Ends when leaving alert region.

Mode 2 – **Excessive Terrain Closure Rate**（过大的地形接近率）: Approaching rising terrain too fast:
• Caution: **“TERRAIN, TERRAIN”.**
• Warning: **“WHOOP WHOOP, PULL UP”.**
Based on closure rate vs RA thresholds.

Mode 3 – **Altitude Loss After TO/GA**（起飞/复飞后高度下掉）: If significant altitude loss occurs after takeoff or during low go-around:
• Alert: **“DON’T SINK, DON’T SINK”**. Stops with positive rate.

Mode 4 – **Unsafe Terrain Clearance in Non-Landing Configuration**（非着陆形态越障高度不安全）:
• 4A (Cruise/Approach): gear & flaps not in landing config → **“TOO LOW TERRAIN” / “TOO LOW GEAR”.**
• 4B (Cruise/Approach): gear DOWN, flaps not in landing config → **“TOO LOW TERRAIN” / “TOO LOW FLAPS”**.
• 4C (Takeoff): either gear or flaps not in landing config → **“TOO LOW TERRAIN”**.

Mode 5 – **Below Glideslope**（低于下滑道）: **GS tuned/valid, gear down, RA<1000 ft.**
Triggers when below GS with:
• RA 1000–30 ft and deviation > 1.3 dots → **“GLIDESLOPE”**.
• RA 300–30 ft and deviation > 2.0 dots → **“GLIDESLOPE”**.

Audio intensity scales with deviation.

Mode 6 – Callouts/Bank Angle（高度喊话/坡度过大）: Decision altitude/height → **“MINIMUMS, MINIMUMS”**; excessive bank → **“BANK ANGLE”**.

Mode 7 – **Low-Level Windshear**（低空风切变）: Below ~1,500 ft RA during TO or final approach, entry into windshear warning region triggers **red WINDSHEAR light + horn + “WINDSHEAR” voice**.

1.3 Terrain Display (Color Logic)

EFIS terrain may be manually selected or auto-displayed during alerts. Colors reflect terrain height relative to aircraft altitude:

• **Light green: 1,000–2,000 ft below.**

• Medium green: 500–1,000 ft below.

- **Medium yellow: 500 ft below to 1,000 ft above.**
- **Bright yellow:** 1,000–2,000 ft above.
- **Red: >2,000 ft above.**
- Magenta: not in database.

Terrain >2,000 ft below aircraft is suppressed (black background). Colors shift with climb/descent. **Forward-Looking Terrain/Obstacle Cautions/warnings enhance to solid yellow/red patches**. TCF/GPWS alerts do not change the terrain picture.

1.4 Forward-Looking Terrain/Obstacle Alerting(FLTA)

Databases: (1) **airports** (paved runways ≥3,500 ft), (2) **terrain/obstacles** (higher resolution near airports), (3) **envelope adjustments** (approach/departure profiles).

Inputs: **GPS/IRS for position; ADC** (Air Data Computer 大气数据计算机) **for pressure altitude**. TAWS compares against forward terrain to compute closure and clearance, then applies alert criteria.

Geometry/thresholds: Two alert levels—**Caution ~40–60 s prior**; **Warning ~20–30 s prior**. Look-ahead distance scales with **groundspeed** (地速). A supplemental +6° up-look doubles forward range for very high terrain. Vertical floor: ~700 ft below aircraft; lateral: ±1/8 NM (0.23 km) each side. Envelopes shrink as the aircraft nears an airport.

1.5 Terrain Clearance Floor (TCF 离地间隔保护包线)

Non-precision approach safeguard based on radio altitude. Example profile for runways ≥3,500 ft:
- Begins ~1.5 NM prior to threshold; rises ~100 ft/NM to 400 ft at 5 NM.
- Holds 400 ft to 12 NM; then rises ~100 ft/NM to 700 ft at 15 NM; thereafter holds 700 ft.

Caution annunciation when triggered: **“TOO LOW TERRAIN” + amber NEAR TERRAIN light**.

1.6 Cockpit Alerting (Caution/Warning)

Caution (~40–60 s): **“CAUTION TERRAIN”**; terrain display turns **solid yellow**; **amber NEAR TERRAIN light**. Escalates to **warning** if no crew response within **~7 s**.

Warning (~20–30 s): **“TERRAIN TERRAIN, PULL UP!”**; terrain display **solid red**; **master warning and PULL UP lights**. Cancels when climb/avoidance removes the threat; voice stops if turning away while red terrain remains lateral.

1.7 Operation and Integrity Test

During takeoff or approach and landing, if the system issues a warning, the pilot should operate the aircraft correctly according to the **voice** message.

When approved procedures require using a **flap setting less than normal landing flaps or require the landing gear to remain retracted**, the landing gear or flap override switch may be used to inhibit or cancel the warning.

When it is confirmed that the **terrain database is unavailable,** the terrain inhibit switch may be set to the INHIBIT position, and **forward-looking terrain alerts and TCF alerts will be unavailable.**

When conducting an approach below the glideslope, the glideslope inhibit switch may be used to inhibit or cancel Mode 5 alerts.

Press the TEST button to test the system’s warning lights and aural alerts.

2. Airborne Collision Avoidance System (ACAS/TCAS 机载防撞系统)

2.1 Function and Classification

Warns of potential conflicts between transponder-equipped aircraft sharing the same airspace. U.S.: **TCAS**; Europe: **ACAS**—functionally identical. **Transport-category turbine airplanes with ≥19 seats** require ACAS II/TCAS II v7.1.

• TCAS I: **TA (Traffic Advisory) only** (visual acquisition aid).
• TCAS II: **TA + RA (Resolution Advisory, vertical only)** with Mode S coordinated complementary RAs.

（TCAS III 和IV可以水平机动）

2.2 Protection Zones (TA/RA) and Timing Gates

Zones are time-based to CPA (closest point of approach) and vary with altitude, speed, and closure rate:
• TA: **20–48 s**; vertical gate **±850 ft (below FL420), ±1,200 ft (above).**
• RA: **15–35 s**; vertical gate **~±600–800 ft** (altitude-dependent). TA typically precedes **RA by 5–20 s**; rare direct-RA cases exist.

2.3 Basic Principle and Protection Levels

Components: TCAS computer (interrogator/transceiver), antennas, ATC/TCAS control panel, cockpit display, Mode S transponder. Interrogations elicit replies with identity and altitude (Mode C/S). Relative altitude and rate computed from altitude/time; bearing via directional antenna (not required).

Protection level **depends on intruder capability**: **Mode A (TA only), Mode C/S (TA+RA), TCAS II↔TCAS II (coordinated RA). No transponder → not detected.**

2.4 Cockpit Display Symbology (Partial)

Threat symbology:
■ Red filled square — **RA target** (entered warning zone).
● Orange filled circle — **TA target** (entered caution zone).
◆ Blue/white filled diamond — **Proximity traffic** (PT 接近交通): **range < 6 NM or |Δh| < 1,200 ft; not a threat.**
◇ Blue/white hollow diamond — **Other traffic** (OT 其他交通): **|Δh| ≥ 1,200 ft or range ≥ 6 NM.**

Altitude tags: **two-digit value with "+" (above) or "–" (below) shows relative altitude (hundreds of feet)**. If **vertical speed ≥ 500 ft/min, an up/down arrow** is shown. Off-scale traffic is indicated by "**OFF SCALE**" or a **half-symbol** at the display edge. If bearing is unknown, TCAS still shows threat level, range, and relative altitude.

2.5 Resolution Advisory (RA) Visual Indications

RA indications appear on the Vertical Speed Indicator (VSI) and EFIS (Electronic Flight Instrument System 电子飞行仪表系统). Red and green arcs on the VSI indicate unsafe and safe vertical speed regions, respectively.

• Red narrow arcs: unsafe climb/descent rates.
• Green wide arcs: recommended maneuver range.

On EFIS, RA commands are displayed as red trapezoids. For **corrective RAs**, the aircraft symbol is currently inside the trapezoid, thus must move outside the trapezoid; for **preventive RAs**, it must remain outside.

2.6 Voice Annunciations

Aural messages accompany TCAS advisories:
• TA: "**TRAFFIC, TRAFFIC**."
• Preventive RA: "**MONITOR VERTICAL SPEED**."
• Corrective RA: "**CLIMB, CLIMB, CLIMB.**" or "**DESCEND, DESCEND, DESCEND**." (~1500 ft/min).
• Crossing RA: "**CLIMB, CROSSING CLIMB**." / "DESCEND, CROSSING DESCEND."
• Adjust RA: "**ADJUST VERTICAL SPEED, ADJUST.**"
• Strengthened RA: "**CLIMB NOW." / "DESCEND NOW.**" or "INCREASE CLIMB/DESCENT."

(~2500 ft/min).
• Clear-of-Conflict: “**CLEAR OF CONFLICT**.”

2.7 Operating Modes and Inhibition Logic

Operating Modes:
• **TA/RA** mode: normal mode, both advisories provided.
• **TA-only** mode: used when operating close to other traffic, e.g. parallel runways.

If ATC and TCAS commands conflict, **pilots must follow TCAS and report to ATC** promptly.

Each pilot, who deviates from an ATC clearance in response to a TCAS advisory, is expected to notify ATC and expeditiously return to the ATC clearance in effect prior to the advisory, after the conflict is clear.

Inhibition Logic:
1. “CLIMB” inhibited when **climb capability limited**.
2. “INCREASE DESCENT” inhibited **below 1450 ft RA.**
3. “DESCEND” inhibited **below 1000 ft RA**.
4. All RA inhibited **below 500 ft RA**.
5. “TRAFFIC, TRAFFIC” voice inhibited **below 400 ft RA.**
6. During **GPWS or Windshear** warnings, TCAS aural messages inhibited.

Aural warning priority: stall>windshear>GPWS>TCAS

3. Overspeed Warning System (超速警告系统)

When the aircraft exceeds the **maximum operating speed (VMO/MMO),** the overspeed warning system issues an **aural alert**. It uses **two independent Mach/Airspeed channels driven by the Central Air Data Computer (CADC 中央大气数据计算机).** If indicated speed exceeds the red pointer value on the Mach/Airspeed indicator, **a continuous warning tone activates until speed decreases below VMO/MMO.**

4. Stall Warning System (失速警告系统)

The Stall Warning System provides warnings when **approaching or entering stall**. It has **two independent computers** using inputs from **AOA (Angle of Attack 迎角), flap position, and thrust**. **As airspeed nears stall(not “already stalled”)**, motors on the control columns activate **to vibrate the yoke (stick shaker)** simulating buffet; **stall indications also appear on the EFIS.**

5. Takeoff Configuration Warning System (起飞形态警告系统)

When the aircraft is on the ground and thrust levers are advanced for takeoff, the system monitors configuration. If unsafe, it triggers an aural warning. Conditions include:

• Speedbrake not retracted.
• Parking brake set.
• Leading-edge devices not extended.
• Trailing-edge flaps not in takeoff position.
• Stabilizer trim out of takeoff range.

6. Flight Data Recorder (FDR 飞行数据记录器)

6.1 Function

The FDR automatically records parameters such as altitude, speed, attitude, and engine data (about 300 flight parameters) in time sequence for at **least 25 hours (airplanes) or 10 hours (helicopters).** Used for **accident investigation** and aircraft system monitoring. For aircraft using data link, all communications are recorded and correlated with CVR data. The FDR automatically starts recording data **before the aircraft moves by its own power and stops recording data once the aircraft can no longer move by its own power**. During the flight, the pilot was unable to turn off the recorder. The recorded data cannot be erased even after landing. **Since 2005, ACFT certified TOW > 5700kg must have FDR.**

FDR	TOW > 5700kg (Since 2005)	**25h** airplanes; 10h helicopters
CVR	Since 1 Jan 2022 MTOW >27,000 kg require at least **25 hours**	Minimum duration **2 hours** Last 30min cannot erase

Cockpit voice recorder and flight recorder data kept 60 days

6.2 Features

• **Bright orange/yellow** casing.
• **Reflective** surface.
• Equipped with **Underwater Locator Beacon** (ULB 水下定位信标) **active for 30 days**.

Recording starts when aircraft moves under own power and stops when stationary; crew cannot disable or erase.

7. Cockpit Voice Recorder (CVR 驾驶舱话音记录器)

7.1 Function

Records crew communications, intercoms, ATC, and ambient cockpit sounds. Recording spans from s**tart of 'Before Starting Engine' checklist to completion of final checklist after flight.**

Minimum duration 2 hours; aircraft certificated after 1 Jan 2022 with MTOW >**27,000 kg** require **at least 25 hours**. Combination units (CVR/FDR) may be used if meeting all standards. Under the condition that all recording requirements are met, **two sets of combined flight recorders (flight data recorder/cockpit voice recorder)** can be installed to respectively replace the independent flight data recorder and the independent cockpit voice recorder.

Cockpit voice recorder and flight recorder data kept 60 days, in the event of accident or occurrence resulting in terminating the flight.

CVR Record 4 tracks: between Pilots, Pilots and ATC, Pilots/Crew Pax broadcast, Cockpit

7.2 Features

• **Bright orange/yellow** casing.
• **Reflective** surface.
• Equipped with **under water positioning ULB active 30 days.**

8. Master Warning System (主警告系统)

The system comprises **red and amber lights** linked to aircraft subsystems.

Red lights indicate immediate action required;

Amber lights indicate attention required as soon as possible/in time.

Red Master Warning activates for **serious faults**; **amber Master Caution** for less critical issues.

9. Predictive Windshear Warning System (PWS 风切变预警系统)

9.1 Function

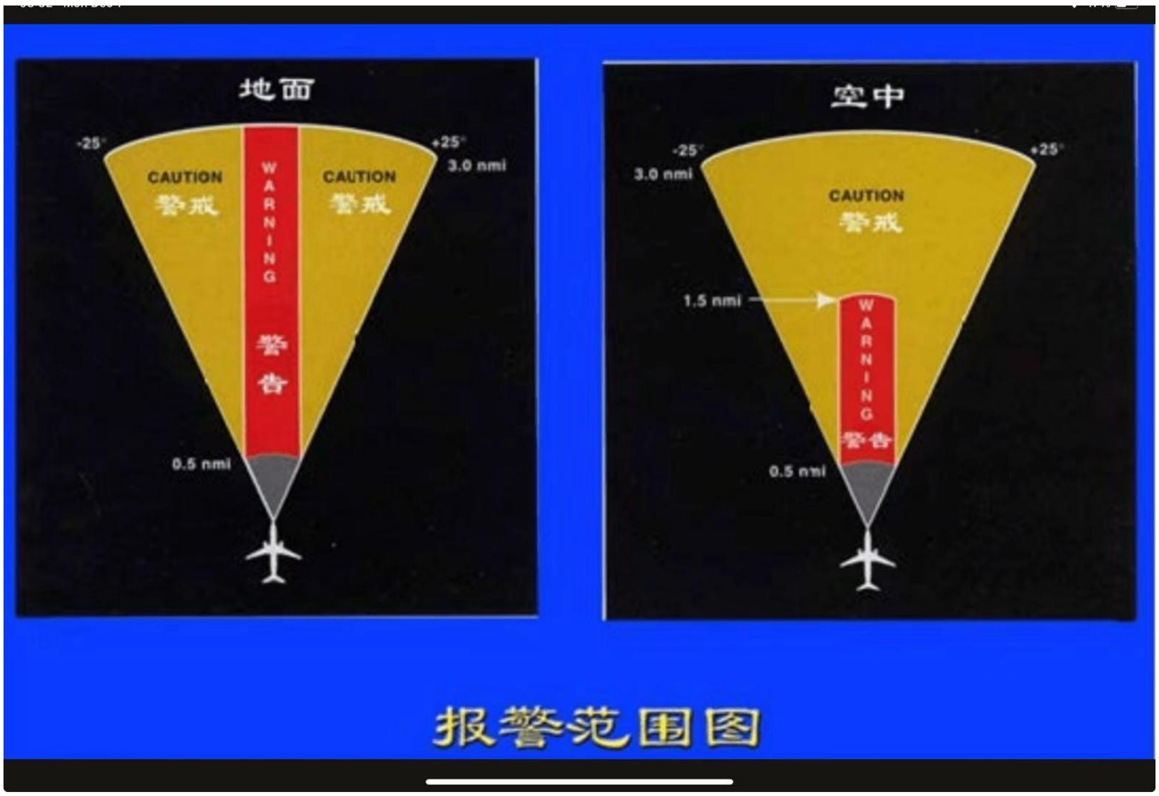
Detects **microbursts or windshear** ahead using Doppler weather radar, providing alerts before entry. Two levels: **Caution and Warning**, depending on distance and intensity.

9.2 Operation

Activates automatically **below 2300 ft AGL during approach and before takeoff** via air/ground logic and thrust lever position, or manually by AUTO switch.

9.3 Principle and Range

PWS analyzes radar returns**(wind direction, wind speed)** for velocity gradients, detecting windshear **3**–5 NM ahead. (25degree each side)



Caution range: 0.5-3

Warning range: 0.5 – 1.5(air) 3(ground)

9.4 Alerts

• Caution: '**MONITOR RADAR DISPLAY' when wind shear in caution area** + **amber WINDSHEAR on EFIS + red icon showing position of windshear.** Allowing crew **more time to respond.**
• Warning (Takeoff): '**WINDSHEAR AHEAD**' (2×) + **EFIS red WINDSHEAR** + **master warning light.**
• Warning (Approach): '**GO-AROUND, WINDSHEAR AHEAD**' + **EFIS red WINDSHEAR** + **master warning light.**

10. Altitude Alert System (高度警告系统)

Alerts crew when approaching or deviating from selected altitude on MCP (Mode Control Panel 模式控制面板). Comparison between selected and actual altitude triggers warnings if deviation exceeds thresholds.

Example (B737NG):

• **Approach alert**: starts **900 ft** before reaching target and **ends 200 ft before**; **1-sec tone + white box on PFD altitude.**

• **Deviation alert**: when **±200 ft** off target; **1-sec tone + amber box;** ends within ±200 ft or new selection.

No alert if G/S captured or flaps >20°.

Part VI Airborne Weather and Surveillance Radar Systems

1. Airborne Weather Radar (机载气象雷达)

1.1 Basic Functions and Cautions

Frequency Band: Weather radar operates in the **X-band** (X 波段), presenting **meteorological and terrain informatio**n on cockpit displays.

Functions:
1) Primary function is to **detect weather conditions(rain)** ahead and display plan-view images of moisture-laden weather formation areas so that the crew can select safe routes and avoid hazardous weather.
2) Secondary function is to observe terrain features ahead and below the aircraft. By tilting the antenna downward appropriately, large-scale terrain contours such as rivers, coastlines, major mountains, and cities can be displayed to assist navigation.

Cautions:
• Weather radar is used to **avoid severe weather**—not to penetrate it. Whether to enter a radar echo area depends on echo intensity, spacing between echoes, aircraft performance, and crew experience.
• The detection capability and positional accuracy for mountains or other aircraft **do not meet terrain-avoidance or collision-avoidance requirements.** Therefore, weather-radar images must not be used as the basis for terrain or airborne collision avoidance.

1.2 Operating Principle and System Composition

Composition: **Transmitter/Receiver (收发机), Antenna (天线), Control Panel (控制盒), and Display (显示器).**

Operating Principle: The transmitter generates high-energy X-band RF pulses that are radiated by the antenna. Moisture-laden clouds or terrain reflect part of the energy back to the antenna; the receiver processes the echoes and displays them as color-coded radar returns.

Scanning and Tilt: The antenna scans a needle-shaped beam **±90° in azimuth** relative to the nose and can be tilted **±15° in elevation.** When pointed at a particular azimuth, the **directional** beam illuminates targets in that direction within detection range. Continuous azimuth scanning successively illuminates different bearings, covering the entire fan-shaped sector ahead.

1.3 Detectable Meteorological Targets and Reflectivity

• **Rain areas** with relatively large raindrops reflect X-band energy sufficiently to create radar echoes detectable by the system.
• **Wet hail** (表面包裹水层的冰雹) is readily detected because the surface water layer reflects radar energy effectively.
• **Dry hail** (干冰雹) without a surface water layer **reflects poorly and is difficult to detect**; only when its diameter approaches roughly eight-tenths of the radar wavelength can it be detected reliably.
• Severe rain, moderate-or-greater turbulence regions containing raindrops, wet hail, and large-diameter dry hail all produce strong echoes and can be effectively detected.
• Small-diameter **dry hail, dry snow,(ice crystal) and clean/transparent turbulence** produce very weak reflections and generally **cannot be detected effectively**.
• Turbulence detection is based on the Doppler effect produced when **water particles mixed in turbulence** reflect the radar beam. Airborne weather radar typically detects and displays moderate-or-greater turbulence (velocity variation about 6–12 m/s) when accompanied by precipitation. **Clear-air turbulence is normally not detected due to insufficient reflectivity.**

1.4 Display Colors and Operating Modes

Color Coding (precipitation rate representation):
• **Red – heavy rain / severe cells.**
• **Yellow – moderate rain.**
• **Green – light rain.**
• **Magenta/Purple/White – turbulence** (in specific turbulence modes).

Main Operating Modes:
• **WX** (Weather 模式): **Basic weather mode** showing plan-view distribution of airborne weather targets; the antenna scans the fan-shaped sector ahead and to both sides of the aircraft.
• **MAP** (地图模式): **Common basic mode** on all systems; displays ground features ahead/below (e.g., mountains, rivers, lakes, coastlines, large cities). Use **downward** antenna tilt to illuminate the ground area.
• **TEST** (测试模式): Provides a built-in test pattern for quick performance check.
• **TURB** (湍流探测模式): Displays **only turbulence areas in purple/white**; red/yellow/green rain areas are suppressed.
• **WX/T** (气象与湍流模式): Displays standard precipitation colors plus highlighted purple/white turbulence areas.

1.5 Antenna Tilt (TILT) – Basic Principles

The TILT control sets the vertical pointing angle of the antenna beam and significantly affects the detectable target volume. Tilt must be adjusted considering operating mode, flight altitude, and selected display range. Proper tilt management is essential for accurate interpretation and for avoiding ground clutter. *Climb->tilt down. Descent->tilt up.*

1.6 Gain (GAIN) – Basic Principles

MAP Mode Gain Adjustment: **Manually reducing receiver gain can remove weak-reflectivity ground areas to reveal high-reflectivity regions**, **clarifying terrain contours** for easier recognition.

WX / WX+T Gain Adjustment: **Gain is normally set to AUTO**. For analyzing the **strongest part** of a thunderstorm core, gradually reduce manual gain until red areas turn yellow and then green—the l**ast area to change to yellow is the most intense core**. After analysis, return gain to AUTO. When flying over or near heavy rain areas, **dry hail** may produce weak echoes under AUTO gain; using manual gain at a **higher level can make otherwise invisible dry-hail echoes appear** more clearly to aid identification.

MAP Mode: manually reduce to show weak reflectivity ground contours. WX/ WX+T: AUTO. Dry hail: manually increase.

1.7 Ground Use Precautions

• Do not operate the radar in transmit mode when the aircraft is **being refueled or other aircraft nearby are refueling,** to avoid igniting **fuel vapors**. Similarly, avoid powering the radar when **gasoline is used extensively for cleaning on the ramp**.

• Do not operate the radar in transmit mode **in a hangar** or with the **nose pointed toward nearby buildings or large metallic reflectors**, unless the transmitter is inhibited or RF energy is directed into an absorber—otherwise the entire area may be exposed to radiation.

• Do not power the radar when **personnel are in front of the aircraft**, to avoid harmful radiation exposure.

• For **ground checks**, use the built-in **test mode** whenever possible. **If transmit mode** must be used, set **antenna tilt UP** to avoid illuminating nearby ground targets.

2. Radio Altimeter (无线电高度表)

2.1 Function

Most airborne Radio Altimeters (RA 无线电高度表) use the **Frequency-Modulated Continuous Wave (FM-CW 调频等幅波)** method to measure the aircraft's true altitude above the terrain directly beneath it. Typical **measurement range is 0–2500 ft, display**

range is -20~2500ft. In modern transport-category aircraft, radio altitude data are displayed on the EFIS (Electronic Flight Instrument System 电子飞行仪表系统) and integrated with the Flight Director or Autopilot systems for approach and automatic landing operations.

2.2 Operating Principle

The radio altimeter transmits a frequency-modulated signal downward toward the ground. After reflection, the return signal is received by a separate antenna. Because the transmitted frequency is continuously modulated (usually linearly increasing with time), there exists a frequency difference (Δf) between the transmitted and received signals proportional to the signal's **round-trip time delay (Δt)**. Since Δt corresponds to the distance between aircraft and ground, **this frequency difference is proportional to true altitude**.

In typical systems, the transmitted carrier frequency is approximately **4300 ± 50 MHz** (operating range **4250–4350 MHz**). The system measures Δf continuously and converts it to an altitude output, which drives cockpit indicators or electronic displays.

2.3 System Composition

A standard Radio Altimeter installation consists of:
1) **Transmitter-Receiver** (收发机): generates, transmits, receives, and processes the frequency-modulated signal.
2) **Indicator** (指示器): provides a cockpit display of height above terrain and also supplies output signals to other systems such as Autopilot, Flight Data Recorder, and Ground Proximity Warning System (GPWS 近地警告系统).
3) **Transmitting and Receiving Antennas** (收发天线): installed on the lower fuselage, radiating the downward signal and receiving ground reflections.

2.4 Measurement Accuracy and Indication

Measurement **accuracy** specifications:
• **From 0–500 ft: ±3 ft or ±3 %** of the indicated value, whichever is greater.
• **Above 500 ft: ±5 %** of the indicated value.

When the aircraft is on the ground, the radio altimeter is calibrated so that the **indicated altitude equals zero when the main landing gear (主起落架) is in contact with the ground during a landing**. Due to system tolerances or antenna geometry, a small negative indication (e.g., −5 ft) may appear during taxi, which is normal.