R-22

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

MRCET CAMPUS

(AUTONOMOUS INSTITUTION – UGC, GOVT. OF INDIA)

DEPARTMENT of AERONAUTICAL ENGINEERING

AVIONICS

Prepared by:

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Assistant Professor
Department of ANE

AVIONICS

DIGITAL NOTES B.TECH (R-22 Regulation)(III YEAR – I SEM) (2025-2026)

DEPARTMENT OF AERONAUTCAL ENGINEERING

MALLAREDDY COLLEGE OF ENGINEERING &TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

Recognized under 2(f) and 12 (B) of UGC ACT 1956

(Affiliated to JNTUH, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015 Certified)

Maisammaguda, Dhulapally (Post Via. Hakimpet), Secunderabad – 500100, Telangana State, India

MRCET VISION

To become a model institution in the fields of Engineering, Technology and Management. To have a perfect synchronization of the ideologies of MRCET with challenging demands of International Pioneering Organizations.

MRCET MISSION

To establish a pedestal for the integral innovation, team spirit, originality and competence in the students, expose them to face the global challenges and become pioneers of Indian vision of modern society.

MRCET QUALITY POLICY.

To pursue continual improvement of teaching learning process of Undergraduate and Post Graduate programs in Engineering & Management vigorously. To provide state of art infrastructure and expertise to impart the quality education.

PROGRAM OUTCOMES
(PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design / development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainabledevelopment.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.
12. **Life- long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

DEPARTMENT OF AERONAUTICALENGINEERING

VISION

Department of Aeronautical Engineering aims to be indispensable source in Aeronautical Engineering which has a zeal to provide the value driven platform for the students to acquire knowledge and empower themselves to shoulder higher responsibility in building a strong nation.

MISSION

The primary mission of the department is to promote engineering education and research. To strive consistently to provide quality education, keeping in pace with time and technology. Department passions to integrate the intellectual, spiritual, ethical and social development of the students for shaping them into dynamic engineers.

QUALITY POLICY STATEMENT

Impart up-to-date knowledge to the students in Aeronautical area to make them quality engineers. Make the students experience the applications on quality equipment and tools. Provide systems, resources and training opportunities to achieve continuous improvement. Maintain global standards in education, training and services.

PROGRAM EDUCATIONAL OBJECTIVES – Aeronautical Engineering

1. **PEO1 (PROFESSIONALISM & CITIZENSHIP):** To create and sustain a community of learning in which students acquire knowledge and learn to apply it professionally with due consideration for ethical, ecological and economic issues.
2. **PEO2 (TECHNICAL ACCOMPLISHMENTS):** To provide knowledge based services to satisfy the needs of society and the industry by providing hands on experience in various technologies in core field.
3. **PEO3 (INVENTION, INNOVATION AND CREATIVITY):** To make the students to design, experiment, analyze, and interpret in the core field with the help of other multi disciplinary concepts wherever applicable.
4. **PEO4 (PROFESSIONAL DEVELOPMENT):** To educate the students to disseminateresearch findings with good soft skills and become a successful entrepreneur.
5. **PEO5 (HUMANRESOURCEDEVELOPMENT):** To graduate the students in building national capabilities in technology, education and research

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

1. To mould students to become a professional with all necessary skills, personality and sound knowledge in basic and advance technological areas.
2. To promote understanding of concepts and develop ability in design manufacture and maintenance of aircraft, aerospace vehicles and associated equipment and develop application capability of the concepts sciences to engineering design and processes.
3. Understanding the current scenario in the field of aeronautics and acquire ability to apply knowledge of engineering, science and mathematics to design and conduct experiments in the field of Aeronautical Engineering.
4. To develop leadership skills in our students necessary to shape the social, intellectual, business and technical worlds.

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

IV Year B. Tech, ANE-I Sem

L	T/P/	C
3	/-/- /	3

(R20A2146) AVIONICS

(PROFESSIONAL ELECTIVE-IV)

Objectives:

To introduce the students with functioning and principle of operation of various avionics systems including sensors installed on a modern passenger and fighter aircraft.

UNIT I: INTRODUCTION TO AVIONICS

Importance and role of Avionics in modern aircraft- systems which interface directly with pilot,aircraft state sensor systems, outside world sensor systems, task automation systems. The avionics equipment and system requirement, environmental, weight, reliability. Standardization and specification of avionics equipment and systems, ARINC and MIL specification. Electrical and optical data bus systems. Integrated modular avionics architectures.

UNIT II: DISPLAY &MAN- MACHINE INTERACTION AND COMMUNICATION SYSTEM

Introduction to displays- head- up displays(HUD)- basic principles, Helmet mounted displays, Head tracking systems. Head down displays- Civil cockpit, Military cockpit, Solid state standby display systems, Data fusion in displays- Intelligent display systems. Introduction to voice and data communication systems- HF,VHF,UHF and Satellite communications, Flight datarecorders.

UNIT III: INERTIAL SENSORS, ATTITUDE DERIVATION AND AIR DATA SYSTEMS

Basic principles of gyroscope and accelerometers. Introduction to optical gyroscope, ring laser gyros, principles. Stable platform system,strap down systems, error in inertial systems and corrections.Air data Information and its use, derivation of Air Data Laws and relationship, altitude,static pressure relationship, variation of ground pressure, Speed of sound, Mach Number, CAS, TAS, Pressure error. Air data sensors and computing

UNIT IV: NAVIGATION (INS AND GPS) AND LANDING SYSTEM

Principles of Navigation, Types of Navigation systems, Inertial Navigation System,Initial alignment and Gyro compassing, Strap down INS computing. Landing System, localizer and glide slope,marker systems. Categories of ILS. Global navigation satellite systems,GPS,description and basic principles. Integration of GPS and INS, Differential GPS.

UNIT V: SURVEILLANCE AND AUTO FLIGHT SYSTEMS

Traffic alert and collision avoidance systems(TCAS),Enhanced ground proximity warning system.Weather radar. Autopilots,Basic principle, height control, heading control, ILS coupled autopilot control, satellite landing system, speed control and auto throttle. Flight management systems,principles,flight planning, navigation and Guidance, performance prediction and flight path optimization.

TEXT BOOKS

1. Collinson, R.P.G., Introduction to Avionics Systems, second edition, Springer,2003,ISBN 978- 81- 8489- 795- 1
2. Moir, I. and Seabridge, A., Civil Avionics Systems, AIAA education Series, AIAA, 2002, ISBN 1- 56347589- 8

REFERENCE BOOKS

1. Kayton, M., & Fried, W.R, Avionics Navigation Systems, Wiley, 1997,ISBN 0- 471- 54795- 6Z

Outcomes:

1. The student would gain understanding of the basic principles of avionics system

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DEPARTMENT OFAERONAUTICAL ENGINEERING

SESSION PLANNER

SUB: Avionics **YEAR:IVYR** **SEMESTER: I SEM**

UNIT NO	TOPIC	No of Classes Planned
UNIT-1	**INTRODUCTION TO AVIONICS**	
	Importance and role of Avionics in modern aircraft- systems which interface directly with pilot	3
	aircraft state sensor systems, outside world sensor systems, task automation systems. The avionics equipment and system requirement, environmental, weight, reliability. Standardization and specification of avionics equipment and systems	3
	ARINC and MIL specification. Electrical and optical data bus systems. Integrated modular avionics architectures.	3
UNIT- II	**UNIT II: DISPLAY &MAN-MACHINE INTERACTION AND COMMUNICATION SYSTEM**	
	Introduction to displays-head-up displays(HUD),basic principles, Helmet mounted displays, Head tracking systems. Head down displays	3
	Civil cockpit, Military cockpit, Solid state standby display systems,	2
	Data fusion in displays- Intelligent display systems. Introduction to voice and data communication systems	2
	HF,VHF,UHF and Satellite communications, Flight data recorders	3
UNIT III	**UNIT III: INERTIAL SENSORS, ATTITUDE DERIVATION AND AIR DATA SYSTEMS**	
	Basic principles of gyroscope and accelerometers. Introduction to optical gyroscope, ring laser gyros, principles.	3
	Stable platform system- strap down systems, error in inertial systems and corrections.	3
	Air data Information and its use, derivation of Air Data Laws and relationship,altitude,static pressure relationship, variation of ground pressure, Speed of sound, Mach Number, CAS, TAS, Pressure error. Air data sensors and computing	3
UNIT-IV	**UNIT IV: NAVIGATION (INS AND GPS) AND LANDING SYSTEM**	
	Principles of Navigation, Types of Navigation systems- . Inertial Navigation System- Initial alignment and Gyro compassing,	3
	Strap down INS computing.	2
	Landing System- localizer and glide-slope,marker systems. Categories of ILS. Global navigation satellite systems	3
	GPS, description and basic principles. Integration of GPS and INS, Differential GPS.	2
UNIT-V	**UNIT V: SURVEILLANCE AND AUTO FLIGHT SYSTEMS**	
	Traffic alert and collision avoidance systems(TCAS)- Enhanced ground proximity warning system.Weather radar.	3
	Autopilots,Basic principle, height control, heading control, ILS coupled autopilot control, satellite	2
	landing system, speed control and auto throttle. Flight management systems- principles- flight planning	3
	Navigation and Guidance, performance prediction and flight path optimization.	3
	Total	**60**

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IV B.TECH. I SEMESTER AERONAUTICAL ENGINEERING

AVIONICS

MODEL PAPER – I

Time: 3 Hours **Max marks: 75**

Note: This question paper contains two parts A and B.

Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B contains of 5 units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART –A (25 Marks)

1. (a) Enumerate core avionics systems in modern aircraft. (3)

(b) List few aircraft state sensors. (2)

(c) List components of Head-up display (HUD). (3)

(d) List the limitations of VHF communications against HF Communication system. (2)

(e) Draw a neat block diagram of a ring laser gyro illustrating various parts. (3)

(f) List the errors in inertial systems. (2)

(g) Illustrate the purpose of VHF Omni-range and distance measuring equipment. (3)

(h) How is the inertial navigation system aligned? (2)

(i) Explain the principle of autopilot. (3)

(j) Explain the purpose of flight management system. (2)

PART- B

2. (a) Discuss the importance and role of Avionics in modern aircraft.

(b) Illustrate the function of ARINC and MIL-STD-1553 B data bus.

OR

3. (a) Explain the method for protecting avionics systems against environmental conditions.

(b) Differentiate between electrical and optical data bus system.

4. (a) Discuss the solid state standby display systems.

(b) Explain Head down displays in military fighter aircraft cockpit.

OR

5. (a) With the help of a neat diagram, explain the principle of radio voice communication.

(b) Explain the principle of satellite communications.

6. (a) Explain the principle of mechanical gyroscopes.

(b) Explain the functioning of differential global positioning system.

OR

7. (a) Explain the functioning of spring restrained pendulous accelerometers.

(b) Explain the requirement and process of integration of GPS and INS.

8. (a) Discuss the principle of strap-down inertial navigation system.

(b) With neat diagram explain the purpose and functioning of attitude and heading reference system.

OR

9. (a) Explain the purpose and functioning of Kalman filters.

(b) Explain the functioning of automatic direction finders in an aircraft.

10. Write short notes on.

(a) Traffic collision and avoidance system (TCAS)

(b) Enhanced ground proximity warning system (EGPWS)

OR

11. Explain the principle of following auto pilot.

(a) Height control (b) Heading control.

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IV B.TECH. I SEMESTER – AERONAUTICAL ENGINEERING

AVIONICS (R15)

MODEL PAPER – II

Time: 3 Hours **Max marks: 75**

Note: This question paper contains two parts A and B.

Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B contains of 5 units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART –A

1. (a) Enumerate various outside world sensors. (2)

(b) List the purpose and method of avionics packaging. (3)

(c) List the purpose of helmet mounted display. (2)

(d) List the various head down displays in fighter aircraft. (3)

(e) Explain the basic principle of accelerometer as sensor. (2)

(f) Differentiate between strap-up and strap-down inertial navigation system. (3)

(g) What do you mean by gyro compassing with respect to inertial navigation system? (2)

(h) Discuss the functioning of localizer with a diagram in landing system. (3)

(i) Discuss the role of Mode S transponder. (3)

(j) Explain the purpose of ILS coupled autopilot control. (2)

PART-B

2 Explain the requirement of Avionics equipment and systems with respect to

(i) Environment

(ii) Reliability

OR

3 (a) Discuss how various avionics systems are interfaced with the pilot.

(b) Discuss the functioning of MIL-STD-1553B data bus.

4. (a) Discuss intelligent display management systems in modern aircraft.

(b) Explain the functioning of data recorder systems in an aircraft.

OR

5. (a) Explain ACARS data communication systems.

(b) Write short notes on

(i) Audio management system

(ii) In-flight entertainment system

6 (a) Explain the functioning of micro machined vibrating mass rate gyro.

(b) Discuss the principle and functioning of torque balancer pendulous accelerometer.

OR

7. With the help of neat diagram explain the principle and various segments of a global positioning system.

8. (a) Discuss the principle and components of Radio-navigation system.

(b) How are the angular rate and acceleration corrections provided in inertial navigation system?

OR

9(a) Explain the principle of strap-down INS computing.

(b) Explain the functioning of glide-slope and marker systems in ILS.

10. (a) Discuss the principle of weather radar systems.

(b) How is auto-stabilization achieved in an aircraft?

OR

11. (a) Explain the functioning of speed control and auto throttle control systems.

(b) Write short note on flight management system.

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IV B.TECH. I SEMESTER – AERONAUTICAL ENGINEERING

AVIONICS (R15)

MODEL PAPER – III

Time: 3 Hours **Max marks: 75**

Note: This question paper contains two parts A and B.

Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B contains of 5 units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART –A (25 Marks)

1. (a) Enumerate core avionics systems. (3)

(b) What are the reliability requirements of avionics system? (2)

(c) List the components of head tracking system. (3)

(d) What is the purpose and meaning of data fusion in displays? (2)

(e) List the basic principles of gyroscope. (3)

(f) What is the purpose of integration of INS with GPS? (2)

(g) How is INS aligned? (3)

(h) List the categories of Instrument landing systems. (2)

(i) Enumerate the functioning of air traffic control systems. (3)

(j) Draw the block diagram of speed control system. (2)

PART-B

2. (a) Explain the purpose and functioning of electrical data bus systems.

(b) What are the various task automation systems? How do they function?

OR

3. (a) Discuss briefly ARINC specifications.

(b) Write short note on avionics packaging.

4. (a) Explain the display systems in modern military aircraft.

(b) Discuss the functioning of helmet mounted displays.

OR

5. (a) With neat diagram explain the functioning of data communication system.

(b) Discuss the role and functioning of audio management system in a modern civil aircraft.

6. (a) Discuss the principle of ring laser gyro with the help of a diagram.

(b) Discuss the purpose and functioning of differential GPS.

OR

7. (a) Write short note on augmented satellite navigation system.

(b) What are the sources of errors in inertial systems? Explain.

8. (a) Explain the purpose and operation of attitude and heading reference system.

(b) How is angular rate correction done in inertial system?

OR

9. Explain the principle of instrument landing system including localizer, glide slope and marker systems.

10. (a) Explain the operation of airborne weather warning radar system and associated display.

(b) Discuss the purpose and functioning of stability augmentation system.

OR

11. (a) Explain the principle and operation of height hold autopilot with the help of neat diagram.

(b) How is the response of an aircraft determined due to longitudinal control? Briefly explain.

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IV B.TECH. I SEMESTER – AERONAUTICAL ENGINEERING

AVIONICS (R15)

Time: 3 Hours **Max marks: 75**

MODEL QUESTION PAPER- IV

Note: This question paper contains two parts A and B.

Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B contains of 5 units. Answer anyone full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART –A

1. (a) List core avionics systems. (2)

(b) What are the main types of dead reckoning navigation systems? (3)

(c) List the main advantages of head-up display in civil aircraft. (3)

(d) Draw the block diagram of an intelligent display management system. (2)

(e) Elaborate multi-path error in GPS. (2)

(f) Discuss the requirement of integration of INS and GPS. (3)

(g) List various range and bearing radio navigation aids. (3)

(h) What are the various angular rate correction terms? (2)

(i) Write the purpose of stability augmentation system. (2)

(j) List the functions performed by flight management system. (3)

PART-B

2. (a) Discuss various task automation systems in modern aircraft.

(b) Briefly explain electrical data bus systems.

OR

3. (a) Discuss integrated avionics system architecture in a civil aircraft.

(b) Discuss environment and reliability requirements of avionics equipment.

4. (a) Briefly explain the working of head tracking systems.

(b) Discuss the functions of solid state standby display systems.

OR

5. (a) Discuss the components of voice communication systems in an aircraft.

(b) Explain the functioning and purpose of data recorder systems in an aircraft.

6. (a) Explain the principle of micro electro-mechanical systems (MEMS) technology rate gyros.

(b) Explain the functioning of simple spring restrained pendulous accelerometer.

OR

7. (a) Write short notes on

(i) Differential GPS

(ii) Augmented satellite navigation systems.

(b) Discuss various errors in inertial systems.

8. (a) Discuss the basic principle and attributes of inertial navigation.

(b) Discuss the effect of accelerometer bias and Gyro drift on the errors in inertial navigation system.

OR

9. Explain the functioning of aided INS and Kalman filters.

10. (a) Discuss the purpose and functioning of speed control and auto-throttle systems.

(b) Explain how performance prediction and flight path optimization is achieved.

OR

11. (a) Discuss the purpose and process of flight planning.

(b) Discuss how a coordinated turn is achieved in an aircraft. Derive the necessary relation between bank angle,rate of turn and aircraft velocity.

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IV B.TECH. I SEMESTER – AERONAUTICAL ENGINEERING

AVIONICS (R15)

Time: 3 Hours **Max marks: 75**

MODEL QUESTION PAPER- V

Note: This question paper contains two parts A and B.

Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B contains of 5 units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART –A (25 Marks)

1. (a) List various aircraft state sensors. (2)

(b) List the task performed by flight management system. (3)

(c) Write the advantages of HF communication systems. (2)

(d) What are the components of HUD electronics? (3)

(e) Explain the purpose of gyro and accelerometer in inertial system. (3)

(f) What is the purpose of INS and GPS integration? (2)

(g) Explain the purpose of initial alignment in INS. (3)

(h) Explain the purpose of markers in instrument landing system. (2)

(i) Write the purpose of mode S transponder. (3)

(j) Draw the block diagram of a height control autopilot. (2)

PART-B

2. Discuss the requirements of avionics equipment with respect to following:

(i) Environment (ii) Weight (iii) Reliab

OR

3. Discuss the purpose and functioning of various data bus systems in civil and military aircraft.

4. Write short notes on

    (i) Data fusion in displays.

    (ii) Head down displays in military cockpit.

OR

5. Write short notes on

    (i) In-flight entertainment system

    (ii) ACARS data communication system.

6.(a) Explain the functioning and components of global positioning system.

(b) Explain the functioning of differential GPS.

OR

7. Explain various errors and their compensation methods in inertial navigation systems.

8. Write short notes on

    (i) VHF omni-range (ii) Distance measuring equipment (iii) Automatic direction finding.

OR

9. Explain the function of instrument landing system including localizer, glide slope and marker beacons.

10. Write short notes on

    (i) TCAS (ii) EGPWS

OR

11. Discuss in detail longitudinal and lateral control and response of aircraft.

UNIT-I

Introduction to Avionics

Sl No	Name of the topic
1	Importance and Role of Avionics
2	Core Avionics System
3	Aircraft State Sensors
4	Outside world Sensors
5	Requirement of Avionics Equipment
6	Standardization & Specifications
7	Electrical & Optical data Bus
8	Integrated Modular Avionics architecture

UNIT 1: INTRODUCTION TO AVIONICS

MRCET

UNIT 1: INTRODUCTION TO AVIONICS

Avionics = Aviation+Electronics

- Used in USA in early 1950's.
- Avionic System / Avionic subsystem: – any system in the aircraft which is dependent on electronics for itsoperation.
- Fly by wire Flight control system, Fly-by-wire (FBW) is a system that replaces the conventional manual flight controls of an aircraft with an electronic interface.

Thehighagilityandmaneuverability requirement ofamodernfighter leadstothechoiceof afly-by-wire design for the flight control system in which the on-board computer performs the central function. Integrated avionics is the key to itsmission effectiveness and reliability. The advent of powerful digital processors, data buses, synthetic displays and artificial intelligence in the cockpit promises to revolutionize the way military aviation will develop in future. Dramatic advances in airborne radar and electronic warfare systems and electro-optic sensors have made them key elements of modern fighter aircraft, even more than the speed and agility features of these machines. The development of unmanned air vehicles makes special demands on technologies related to telemetry, tele-command, secure data link, navigation and mission sensors. Major DRDO accomplishments in this critical field of avionics technology arereviewed.

Advanced avionics systems can automatically perform many tasks that pilots and navigators previously did by hand. For example, an area navigation (RNAV) or flight management system (FMS) unit accepts a list of points that define a flight route, and automatically performs most of the course, distance, time, and fuel calculations. Once en route, the FMS or RNAV unit can continually track the position of the aircraft with respect to the flight route, and display the course, time, and distance remaining to each point along the planned route. An autopilot is capable of automatically steering the aircraft along the route that has been entered in the FMS or RNAV system.

Advanced avionics perform many functions and replace the navigator and pilot in most procedures. However, with the possibility of failure in any given system, the pilot must be able to perform the necessary functions in the event of an equipment failure. Pilot ability to perform in the event of equipment failure(s) means remaining current and proficient in accomplishing the manual tasks, maintaining control of the aircraft manually (referring only to standby orbackup instrumentation), and adhering to the air traffic control (ATC) clearance received or requested. Pilots of modern advanced avionics aircraft must learn and practice backup procedures to maintain their skills and knowledge. Risk management principles require the flight crew to always have a backup or alternative plan, and/or escape route. Advancedavionics aircraft relieve pilots of much of theminute-to-minute tediumof

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everydayflights, but demandmuchmoreinitialandrecurrent trainingtoretaintheskills andknowledge necessary to respond adequately to failures and emergencies.

The FMS or RNAV unit and autopilotofferthe pilotavariety of methods of aircraft operation. Pilots can perform the navigational tasks themselves and manually control the aircraft, or choose to automate both of these tasks and assume a managerial role as the systems perform their duties. Similarly, information systems now available in the cockpit provide many options for obtaining data relevant to the flight. Advanced avionics systems present three important learning challenges as you develop proficiency:

1. How to operate advanced avionics systems

2. Which advanced avionics systems to use and when

3. How advanced avionics systems affect the pilot and the way the pilot flies How To Operate Advanced Avionics Systems The first challenge is to acquire the "how-to" knowledge needed to operate advanced avionics systems. This handbook describes the purpose of each kind of system, overviews the basic procedures required to use it, explains some of the logic the system uses to perform its function, and discusses each system's general limitations. It is important to note that this handbook is not intended as a guide for any one manufacturer's equipment. Rather, the aim is to describe the basic principles and concepts that underlie theinternal logicand processes and the use of each type of advanced avionics system.

These principles and concepts are illustrated with a range of equipment by different manufacturers. It is very important that the pilot obtain the manufacturer's guide for each system to be operated, as only those materials contain the many details and nuances of those particular systems. Many systems allow multiple methods of accomplishing a task, such as programming or route selection.

Aproficient pilot tries allmethods, and chooses themethodthat works best forthatpilotfor the specific situation, environment, and equipment. Not all aircraft are equipped or connected identically for the navigation system installed. In many instances, two aircraft with identical navigation units are wired differently. Obvious differences include slaved versus non-slaved electronic horizontal situation indicators (EHSIs) or primary flight display (PFD) units.

Optional equipment is not always purchased and installed. The pilot should always check the equipment list to verify what is actually installed in that specific aircraft. It is also essential for pilots using this handbook to be familiar with, and apply, the pertinent parts of the regulations and the Aeronautical Information Manual (AIM). Advanced avionics equipment, especially navigation equipment, is subject to internal and external failure. You must always be ready to perform manually the equipment functions which are normally accomplished automatically, and should always have a backup plan with the skills, knowledge, and training to ensure the flight has a safe ending. Which Advanced Avionics Systems To Use

UNIT 1: INTRODUCTION TO AVIONICS

and When The second challenge is learning to manage the many information and automation resources now available to you in the cockpit.

Specifically, you must learn how to choose which advanced cockpit systems to use, and when. There are no definitive rules. In fact, you will learn how different features of advanced cockpit avionics systems fall in and out of usefulness depending on the situation.

In many systems, there are multiple methods of accomplishing the same function. The competent pilot learns all of these methods and chooses the method that works best for the specific situation, environment, and equipment.

Importance and role of Avionics

- Systems which interface directly with pilot
- Aircraft state sensor systems
- Navigation systems
- External world sensor systems
- Task automation systems.
- Million dollarbusiness , 30% of totalcost of aircraft --- avionics equipments
- 40% - maritime/patrol/anti submarine aircraft
- 75% - Airborne early warning aircraft.
- The avionic systems are essential to enable the flight crew to carry out the aircraft mission safely and efficiently.
- Mission: Carrying the passengers totheir destination, intercepting a hostile aircraft, attacking a ground target, reconnaissance or maritime patrol. – In military operations, reconnaissance is the exploration outside anareaoccupiedby friendlyforcesto gaininformation about natural features and enemypresence.
- By automation of tasks, the crew s workload can be minimized.
- The reduction in weight is also significant and can be translated into more passengers or longer range on lessfuel.
- The crew comprises of two members namely, the first pilot/ captain and thesecond pilot.

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UNIT 1: INTRODUCTION TO AVIONICS

- The elimination of second crew member (navigator/observer/radar operator) has also significant benefits in terms of reduction in training costs.

Goal of Avionic systems is

- increased safety
- Air traffic controlrequirements
- All weather operation
- Reduction in fuelconsumption
- Improved aircraft performance and control
- Handling and reduction of maintenance costs

Main avionic subsystems can be grouped into five layers according to their role and function.

- Systems which interface directly with the pilot.
- Aircraft state sensorsystems
- Navigation systems
- External world sensorsystems
- Task automation systems

i. Systems which interface directly with the pilot

- **Displays:** Provide visual interface between pilot and the aircraft systems.
  - ✓ **Helmet Mounted Displays (HMDs)**: - HUD on the helmet.
    Major advantage--- Informationcanbepresentedto thepilot whenlookingin any direction as opposed to the relatively limited forward field of HUD.
    Night viewing Goggles can also be integrated.

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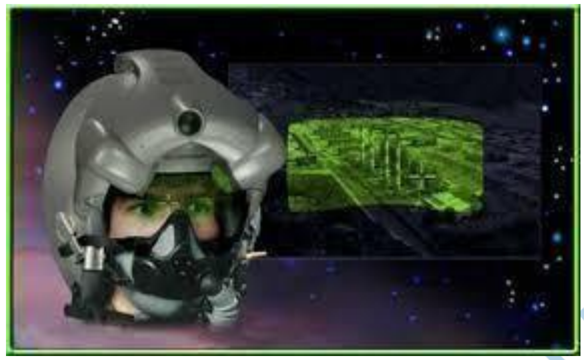

- ✓ **Head up Displays (HUDs)**: HUD can also display a forward looking infrared (FLIR) video picture one to one with the outside worldfrom afixed FLIR imaging sensor installed in aircraft.

- ✓ **Head Down Displays (HDDs)**:

- ✓ **Color head down displays, multi-function color displays**

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Height, air speed, Mach number, vertical speed, artificial horizon, pitch angle, bank angle and heading and velocity vector Navigation displays, Horizontal situation indication (HIS) displays, weather radar displays, engine data, aircraft systems, electrical power supply system, hydraulic power supply system, cabin pressurization system and fuel management system

- **Communications:** Two way communication between ground bases andthe aircraft or between aircraft - air traffic control.
  - ✓ High frequency radios---- 2 to 30 MHz.
  - ✓ Veryhighfrequency ------ 30to100MHz.
  - ✓ Ultrahighfrequency------250 to 400 MHz.
  - ✓ SATCOM systems Short for Satellite Communications and used frequently in the context of VSAT (Very Small Aperture Terminal) Communications satellites or comsats. Satcom(satellite), a fleet of early geostationary communications satellites.
- **Data entry and control:**
  - ✓ Crew avionic systems.
  - ✓ Keyboards, touch panels, direct voice input control.
- **Flight control:** Auto stabilization/ Stability Augmentation. FBW flight control systems Auto stabilization systems are requiredfor achieving acceptable control and handling motion characteristics across flight envelope. FBW flight control systems provide continuous automatic stabilization of the aircraft by computer control of the control surfaces from appropriate motion sensors.

ii. Aircraft State Sensor Systems:

1. **Air Data systems:** Accurate information of air data quantities sensed by accurate sensors are computed by air data computing system for control and navigation of aircraft.

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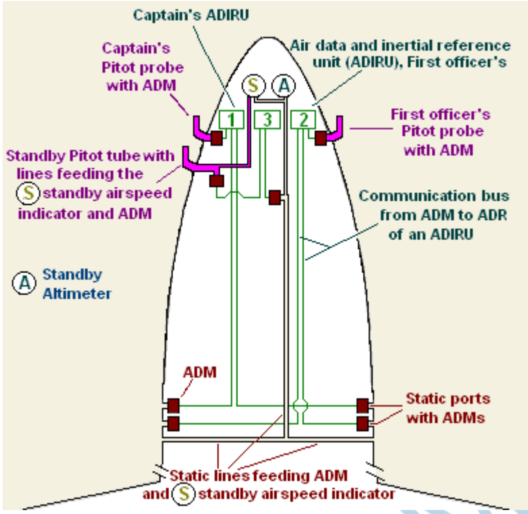
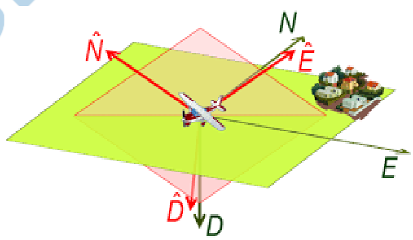
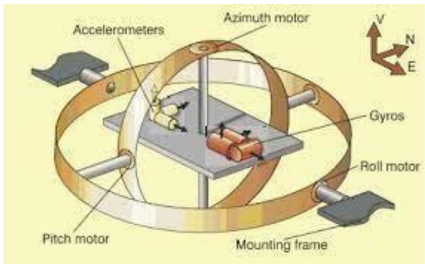


2. **Inertial Sensor Systems**: The use of veryhighaccuracy gyros andaccelerometers to measure the aircrafts motion enables an inertial navigation system (INS) to be mechanized which provides very accurate attitude and heading information together with the aircrafts velocity and position data

iii. **Navigation systems:** Accurate navigation information like aircraft position, ground speed and track angle (direction of motion of the aircraft to true North) is essential for the aircraft's mission whether civil or military. Navigation systems are divided into

- **Dead Reckoning system:** DR navigation derives the vehicles present position by estimating the distance traveled from a known position's speed and direction of motion of vehicle. They are of 3 types
  - ✓ Inertial navigation systems
  - ✓ Doppler/heading reference system,
  - ✓ Air Data/headingreferencesystem.





- **Position Fixed SystemsorRadio Navigationsystem:**The Positionfixingsystems usedat present are mainly radio navigation systems based on satellite or ground based transmitters. Asuitable receiver in theaircraft withasupporting computer is thenused

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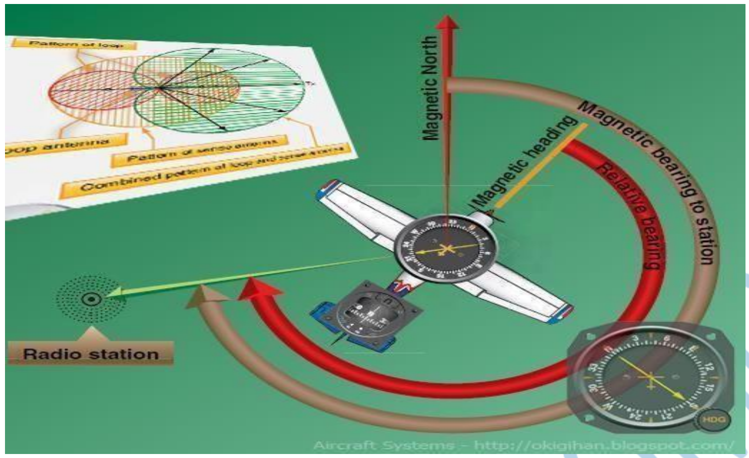
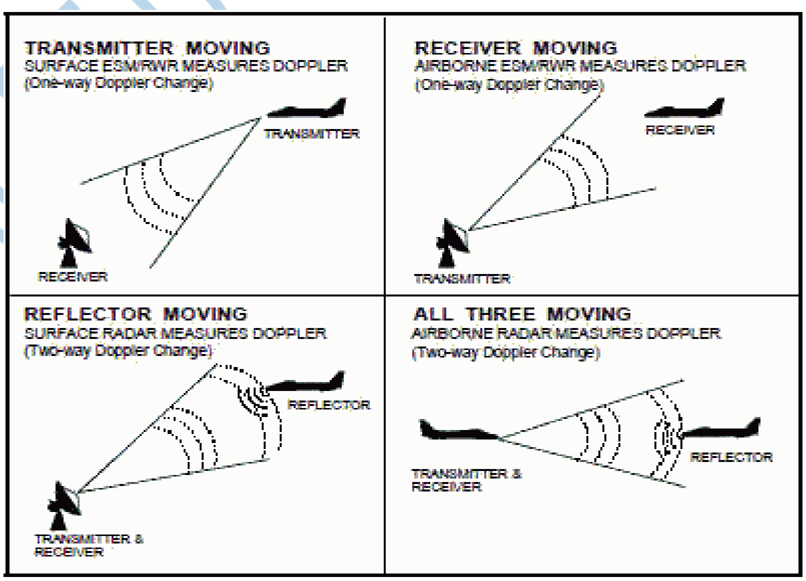
toderive theaircrafts positionfromthe signals receivedfromthetransmitters. Ex: INS, GPS, VOR/DME, ILS MLS can be included for full navigation.



iv. **External world sensor systems:**

These comprise both radar and infrared sensor. Systems enable all weather and night time operations and transform the operational capability of the aircraft.

- Radar Systems: Weatherradar is installed in all civil airliners andalso in manygeneral aviation aircraft. The radar looks ahead of the aircraft and is optimized to detect water droplets and provide warning f storms, cloud turbulence and severe precipitation so thattheaircraft canalter course andavoidturbulence, the violence of the vertical gusts can subject the aircraft structure to very high loads and stresses. These radars can also generally operate in ground mapping and terrain avoidance modes.



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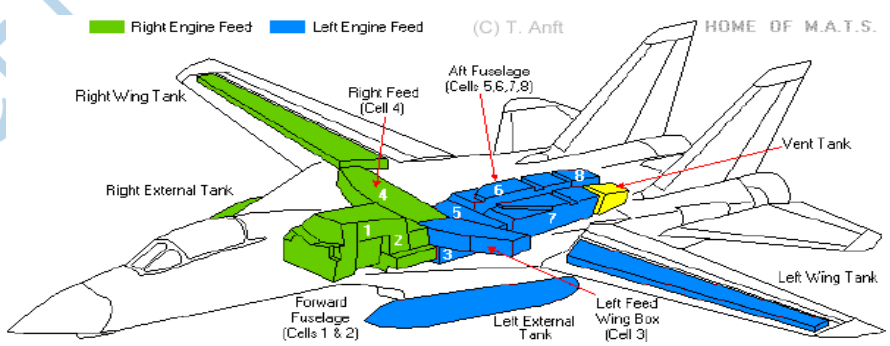
- Infrared Sensor Systems: Have major advantage of being entirely passive systems. Used to provide video picture of the thermal image scene of the outside world either using fixed FLIR sensor, or alternatively gimbaled IR imaging sensor.

v. **Task Automation Systems**: These comprisethe systems which reduce the crew workload and enable minimum crew operation by automating and managing of tasks.

- ✓ **Navigation management system:** operation of all radio navigation aid systems and the combination of the data from all the navigation sources.
- ✓ **Autopilots and Flight Management Systems:**
  - i. Flight planning
  - ii. Navigation management
  - iii. Engine control to maintain the planned speed or mach number
  - iv. Control of the aircraft path to follow the optimized planned route
  - v. Control of the vertical flight profile
  - vi. Ensuring the aircraft is at the planned 3D position at planned time slot: often referred as 4D navigation. Very important for ATC
  - vii. Flight envelop monitoring
  - viii. Minimizing fuel consumption
- ✓ **Engine control and Management:** Full Authority Digital Engine Control System (FADEC) -
  -- flow of fuel, temperature, engine speed, acceleration, engine health monitoring system
  - Performance deterioration.
- ✓ **House Keeping Management:** automation of background tasks - aircrafts safe and efficient operation.

  --- Fuel management: This embraces fuel flow and fuel quantity measurement and control of fuel transfer from the appropriate fuel tanke to minimize changes in the aircraft trim



--- Electrical power supply system management

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--- Cabin / cockpit pressurization systems

--- Environmental control systems

--- Warning Systems

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--- Maintenance and Monitoring Systems: These comprise monitoring and recording systems which integrated into an onboard maintenance computer system. This provides the information toenable speedy diagnosis and rectification of equipment and system failures by pin-pinting faulty units and providing all the information, such as part numbers etc., for replacement units to module level in some cases.

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Avionic Environment

Avionic systems equipment is very different in many ways from ground based equipment carrying similar functions. The reasons are:

- Achieving minimum weight
- Adverse operating environment particularly in military a/c in terms of operating temp range, acceleration, shocks, vibration, humidity range and electro-magnetic interference.
- Importance of very high reliability, safety and integrity.
- Space constraints so may require miniaturization and high packaging densities.

i. Minimum weight:

Thereisagearingeffectunnecessary weightwhichis oftheorderof 10:1.Forexampleaweight saving of 10 kg enablesanincrease in thepayload capability of theorder of 100 kg. theprocess of theeffect of additionalweight is a vicious circle. Anincrease in theaircraft weight dueto, say ,anincreaseinweightoftheavionicsequipment,requirestheaircrfaftstructuretobeincreased I the strength, and therefore made heavier, In order to withstand the increased loads during maneuvers. (assuming the same maximum normal acceleration, or G , and the same safety margins on maximum stress levels aremaintained). This increase in aircraft weight meanthat more lift is required from the wings and the accompanying drag is thus increased. An increase in engine thrust is therefore required to counter the increase in drag and the fuel consumption is thus increased. For the same range it is thus necessary to carry more fuel and the payload has to becorrespondingly reduced, or, ifthepayloadis keptthesame,therangeis reduced. Forthese reasons tremendous efforts are ,made to reduced the equipment weight to a minimum and weight penalties can be imposed if equipment exceeds the specified weight.

ii. Environmental Requirements:

The environment in whichavionic equipmenthas to operate can beavery severe andadverse one in military aircraft; the civil aircraft environment is generally much more benign but is still an exacting one.

Considering just the military cockpit environment alone , such as that experienced by the HUD and HDD. The operating temperature range is usually specified from -40°C to +70°C. clearly, the pilot will not survive at these extremes but if the aircraft is left out in the arctic cold or soaking in the middle-east sun, for ex, the equipment may well reach such temperatures. Typical specifications can demand full performance at 20000 ft within 2 min of takeoff at any temperatures within the range.

Vibration is usually quite severe, and in particular, airframe manufacturers tend to locatethe gun right underthedisplays. Powerspectralenergylevels of 0.04 g^2 per HZ are

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encountered in aircraft designed in the 1970^s andlevels of 0.7 g^2per HZat very lowfrequencies are anticipated in future installations it is worth noting that driving over cobblestones will give about 0.01 g^2 per HZ.

The equipment must also operate under the maximum acceleration or g to whichtheaircraftis subjectedduringmaneuvers.Thiscanbe9ginamodernfighter aircraftand the specification for the equipment would call up at least 20g.

The electromagnetic compatibility (EMC) requirements are also very demanding. The equipment must not exceed the specified emission levels for a very wide range of radio frequencies and must not be susceptible to external sources of very high levels of RF energy over a very wide frequency band.

The equipment must also be able to withstand lightening strikes and the very high electromagneticpulses (EMP) which can beencountered during such strikes.

Design of electronic equipment to meet the EMC requirements is in fact a very exacting discipline and requires vey careful attention to detail design.

iii. Reliability:

The over-riding importance of avionic equipment reliability can be appreciated in the view of the essential roles of this equipment in the operation of the aircraft. It is clearly not possible to repair equipment in aircraft so that equipment failure can be in aborting the mission or a significant loss of performance or effectiveness in carrying out the mission. The cost of equipmentfailures in airline operation can be very high interrupted schedules , loss of income during ‘ aircraft on the ground ’ situations etc. in military operations , aircraft availability is lowered and operational capability lost.

Every possible care is taken in the design of avionic equipment to achieve maximum reliability. The quality assurance (QA) aspects are very stringent during the manufacturing processesandalsoveryfrequentlycallforwhatisreferredtoas‘reliability shakedowntesting‘ , or RST, before the equipment has accepted for delivery. RST is intended to duplicate the most severe environmental conditions to which the equipment could be subjected, in order to try to eliminate the early failure phase of the equipment life cycle.

A typical RST cycle requires the equipment to operate satisfactorily through the cycle described below:

- Soaking in an environmental chamber at a temperature of +70^0C for a given period.
- Rapidly cooling theequipment to-55^0C in 20 min, and soaking at that temperature fora given period.
- Subjectingtheequipmenttovibration,forexample0.5gamplitudeat50HZ,forperiods during the hot and cold soaking phases.

A typical specification would call for 20 RST cycles without a failure before acceptance of the equipment. If a failure should occur at the n^{th} cycle, the failure must be rectified and the remaining (20-n) cycles repeated.

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Introduction and Background:

Major avionic systems generally comprise a number of smaller sub-systems which are combined to form an overall system. The combination, interconnection and control of the individual sub-systems so that the overall system can carry out its tasks effectively is referred to as 'systems integration'. The number of sub-systems which need to be integrated to form a major system can be appreciated from the previous chapter on flight management systems. It is instructive to review the development of avionic systems and their integration into overall systems in the light of the technology available and the circumstances prevailing at the time.

The object is to put the development of today's advanced systems and the even more advanced systems currently under development in perspective. In many cases the current concepts and philosophy are not new - often the originators of particular system developments in the past were far sighted in their concepts, but, as always, were limited by the technology available at the time. World War 2 (WW2) resulted in amajor growth in theelectronic equipment installed in aircraft andthe birth of avionics, with the very rapid development of airborne radar systems and associated displays, radar warning systems and ECM, and more advanced autopilot systems exploiting electronics. Installation of the electronic equipment (or 'black boxes'), however, was very much on an ad hoc basis due to the very rapid developments and time scale pressures in war time.

Some very limited degree of integration between sub-systems was introduced, for example coupling the bomb sight to the autopilot - as readers who have seen the film 'Memphis Belle' may have noted. In general, however, the systems were 'stand alone' systems and their integration into an overall system was carried out by specific crew members such as the navigator, bomb aimer or radar operator. The 1950s period saw the emergence of a number of avionic sub-systems (some of which were initiated during WW2) which have since undergone continual development and now form part of the avionic equipment suite of most civil and military jet aircraft and helicopters. For example, auto-stabilisers (or stability augmentation systems), ILS, VOR/DME, TACAN, Doppler, air data computers, attitude heading reference systems, reference systems, inertial navigation systems.

The first major step towards integrating avionic systems was taken in the mid- 1950s with the establishment of the 'weapon system' concept. These concepts were incorporated in the 1960s generation of aircraft, some of which are still in service. The concept requires a total system approach to thetask of carrying outthemission effectively withahighprobability of success. The aircraft, weapons and the avionic systems required by the crew to carry out the mission effectively must thus be considered as an integrated combination. It should be appreciated, of course, that the total system approach is applicable to any project, military or civil. As with many methodologies, however, military applications provided the spur and the initial funding.

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The very widely used 'program evaluation review technique', or 'PERT' networks, and 'critical path analysis', for example, were originally developed on the POLARIS missile program. As an example of the overall system approach, consider the requirements for a naval strike aircraft. The aircraft must be able to operate from an aircraft carrier in all weathers and be able to find the target and attack it with a suitable weapon (or weapons) with a high probability of success.

Operational analysis shows that to minimize the probability of detection and alerting the enemy's defenses, the aircraft needs to approach the target at high subsonic speeds (550-600 knots) at very low level at a height of 100 ft or so above the sea so as to stay below the radar horizon of the target as long as possible. The avionic sub-system specifications can then be determined from the overall system requirements with an aircraft crew comprising pilot and observer/navigator.

Hence in the above example, the avionic equipment fit would comprise:

- Radar – target acquisition in all weather conditions.
- Doppler – accurate ((4 knots) velocity sensor for DR navigation. (Note: IN systems capable of accurate initial alignment at sea on a moving carrier were still under development in the early 1960s.)
- Attitude heading reference system (or master reference gyro system – UK terminology) – attitudeand heading information for pilot's displays, navigation computer, weapon aiming computer, autopilot.
- Air data computer – height, calibrated airspeed, true airspeed, Mach number information for pilot's displays, weapon aiming, reversionary DR navigation, autopilot.
- Radio altimeter – very low level flight profile during attack phase and all weather operation.
- Navigation computer – essential for mission.
- Autopilot – essential for reduction of pilot work load.
- Weapon aiming computer – essential for mission.
- HUD – all the advantages of the HUD plus weapon aiming for low level attack; for example, 'toss' bombing.
- Stores management system – control and release of the weapons.
- Electronic warfare (EW) systems – radar warning receivers, radar jamming equipment. Essential for survivability in hostile environment

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DataBuses:

The " Bus " is a contraction of Greek word " Omnibus " means " to all " .

Hencethe computers and digital domain the communication or data interchange forall components got defined as BUS. A Bus in generally is a set wires which carry electrical pulses, but with each BUS a definition ofProtocol or methodof data transmission is defined. Aircraft Data bus system allows number of instruments andsensor tosharethedatawith eachotheror withthe centralFlight ManagementSystemcomputer.TheBusarchitecturedefinesaprotocoltosend/receivedataaswellasacommoninterface.

The dedicated aerospace data buses used within the military aerospace community are:

A Tornado serial data bus;

B ARINC ;

C MIL-STD-1553B and derivatives;

D STANAG 3910.

Other bus standards such as the JIAWG high-speed data bus (HSDB), the IEEE1394B and fibre channel buses are all commercial standards that have beenadoptedfor military useor commercial use

Electromagnetic compatibility)

Criterion	Selected Evaluation Factors
Safety	Availability and reliability, Partitioning, Failure detection, Common cause/mode failures, Bus expansion strategy, Redundancy management
Data Integrity	Maximum error rate, Error recovery, Load analysis Bus capacity, Security
Performance	Operating speed, Bandwidth, Schedulability of messages, Bus length and max. load, Retry capability, Data latency
Electromagnetic Compability	Switching speed, Wiring, Pulse rise and fall times,
Design Assurance	Compliance with standards (such as DO-254 & DO-178B)
Configuration Management	Change control, compliance with standards, documentation, interface control, etc.

A. Tornado Serial

The Tornado serial data bus was the first to be used on a UK Fighter aircraft. The bus was adopted for the Tornado avionics system and also used on the Sea Harrier integrated head-up display/ weapon-aiming computer (HUD/WAC) system. This is a half-duplex serial bus operating at a rate of 64 Kbit/s and is used to pass data between the avionics main

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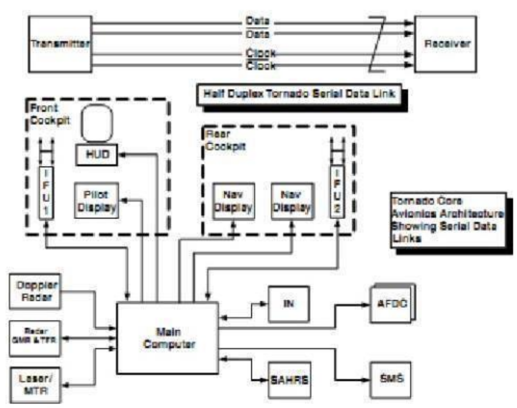
computer and other sensors, computers and displays within the Tornado Nav attack and weapon-aiming system, as shown in Figure 2. The bus

Comprised four wires implemented as a twisted screened quad format. The lines carried clock and complement and data and complement respectively. Fig 2shows the main computer interfacing via the Tornado serialbus withmajor avionics subsystems:

- Doppler radar;
- Radar (ground-mapping radar (GMR) and terrain-following radar (TFR);
- Laser range finder/marked target receiver (MTR);
- Attitude Sources
- inertial navigation system (INS) and secondary attitude and headingreference system (SAHRS);
- Autopilot/flight director system (AFDS);
- Stores management system(SMS);
- Front cockpit:



B. ARINC : Means Aeronautical Radio Incorporated.

Overview of ARINC: ARINC stands for Aeronautical Radio, Inc., a private corporation organized in 1929, and is comprised of airlines, aircraft manufacturers and avionics equipment manufacturers as corporate shareholders. ARINC was developed to produce specifications and standards for avionics equipment outside the government for domestic and overseas manufacturers.

ARINC copy writes and publishes standards produced by the Airlines Electronic Engineering Committee (AEEC). Although ARINC 429 (A429) bus is a single-source -multiple sink type which facilitates a source to talk to many sinks at a time for data transmission. However, if any of the sink equipment needs to reply, then each piece of equipment will require its own transmitter and a separate physical bus to do so, and cannot reply down the same wire pair. This half-duplex modeof operationhascertaindisadvantages.Ifit isdesiredtoaddadditionalequipment,anew set of buses may be required up to a maximum of eight new buses in this example if each new link needs to operate in bidirectional mode. The physical implementation of the A429 data bus is a screened, twisted wire pair with the screen earthed at both ends and at all intermediate breaks. The transmitting element shown below in Figure 3 is embedded in the source equipment and may interface with up to 20 receiving terminals in the sink equipment. Information may be transmitted at a low rate of 12- 14 Kbit/s or a higher rate of 100 Kbit/s; the higher rate is by far the most commonly used. The modulation technique is bipolar return to zero (RTZ), having three signal levels High , Null and Low. Information is transmitted downthe bus as 32 bit words, as shown in Fig The standard embraces many fixed labels and formats, so that a particular type of equipment always transmits data in a particular way. This standardization has the advantage that all manufacturers of particular equipment know what data to expect.Where necessary, additionsto thestandard may also be implemented.

ARINC publishes the AEEC produced standards under three types of documents:

1. ARINC Characteristics: Characteristics are definitions of the form, fit and function of avionics equipment. These documents are equipment specific and define how a unit will operate. The ARINC 500 Series of Characteristics define older analog avionics equipment where the ARINC 700 Series are more current documents and are typically digital versions of the analog specs. 400 Series documents are general design and support documentation for the 500 Series avionics equipment characteristics. 600 Series documents are general design and support documentation for the 700 Series avionics equipment characteristics.

2. ARINC Specifications: Specifications are used to define Physical packaging and mounting of avionics equipment Data communications standards High level computer languages The ARINC 429 Specification, Mark 33 Digital Information Transfer System falls under the Specification document category.

3. ARINC Reports: Reports provide general information and best practice guidelines for airlines. Reports predominately refer to maintenance and support procedures.

There are different series like:

a. **Arinc429:** ARINC 429 is a single-source, multiple-sink, half-duplex bus that operates at two transmission rates; mostcommonlythehigher rate of 100 Kbit/s is used. Althoughthedata bus has itsorigins in the civil marketplace, it is also used extensively on civil platforms that have been adopted for military use, such as the Boeing 737, Boeing 767 and A330. High-performance business jets such as the Bombardier Global Express and Gulfstream GV that are frequently modified as electronic intelligence (ELINT) or reconnaissance platforms also employ A429

b. History: The ARINC 429 Specification developed out of the original commercial aviation digital communication spec, the ARINC 419 Specification. The ARINC 419, first released in 1966 and last revised in 1983, describes fourdifferent wiringtopologies, including a serial, twisted shielded pair interface used by the Digital Air Data System (DADS), known as the ARINC 575 or DADS 575 Spec.

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This serial topology evolved into the ARINC 429 Specification, first released as ARINC 429-1 in April 1978, and currently exists as ARINC 429-15. ARINC 429-15 was adopted by the AEEC in 1995 and is comprised of 3 parts:

ARINC Specification 429 Part 1-15: Functional Description, Electrical Interface, Label Assignments and Word Formats

ARINC Specification 429: Part 2-15: Discrete Word Data Standards. Part 2 defines the formats of words with discrete word bit assignments.

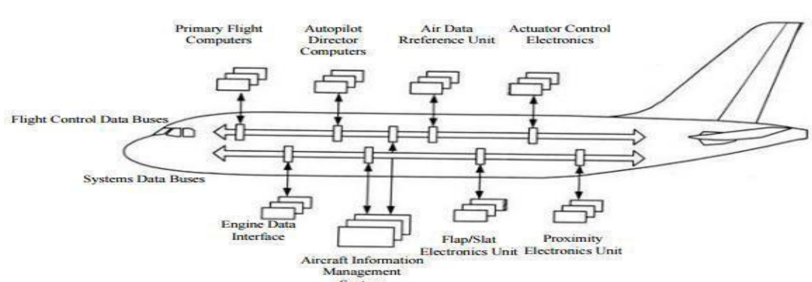
ARINC Specification 429: Part 3-15: File Data Transfer Techniques Part 1 addresses the buses physical parameters, label and address assignments, and word formats. Part 3 defines link layer file data transfer protocol for data block and file transfers.

The ARINC 429 Specification The ARINC 429 Specification establishes how avionics equipment and systems communicate on commercial aircraft. The specification defines electrical characteristics, word structures and protocol necessary to establish bus communication. ARINC 429 utilizes the simplex, twisted shielded pair data bus standard Mark 33 Digital Information Transfer System bus.

ARINC 429 defines both the hardware and data formats required for bus transmission. Hardware consists of a single transmitter - or source - connected to from 1-20 receivers - or sinks - on one twisted wire pair. Data can be transmitted in one direction only - simplex communication - with bi-directional transmission requiring two channels or buses. The devices, line replaceable units or LRUs, are most commonly configured in a star or bus-drop topology. Each LRU may contain multiple transmitters and receivers communicating on different buses. This simple architecture, almost point-to-point wiring, provides a highly reliable transfer ofdata.

A transmitter may 'talk only' to a number of receivers on thebus, up to 20 on one wire pair, with each receiver continually monitoring for its applicable data, but does not acknowledge receipt of thedata.

A transmitter may require acknowledgement from areceiver when large amounts of data have been transferred.



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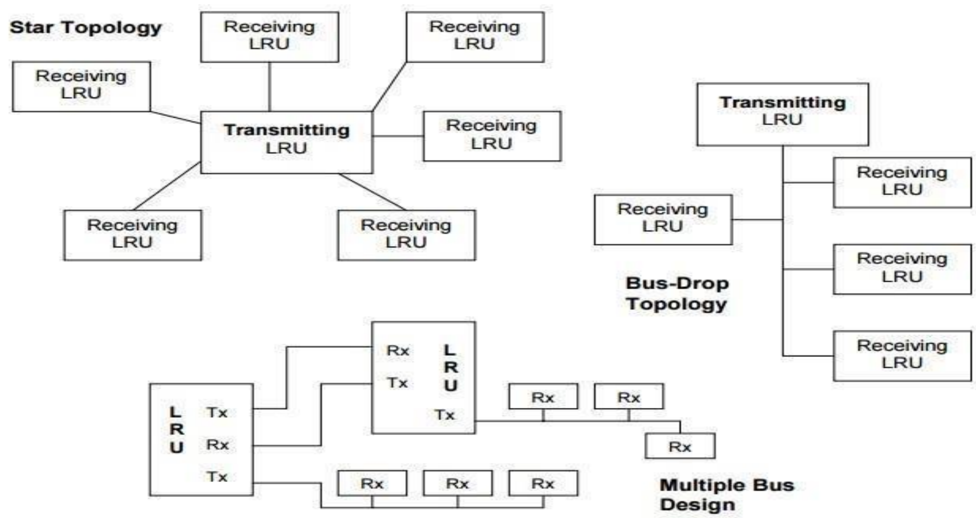
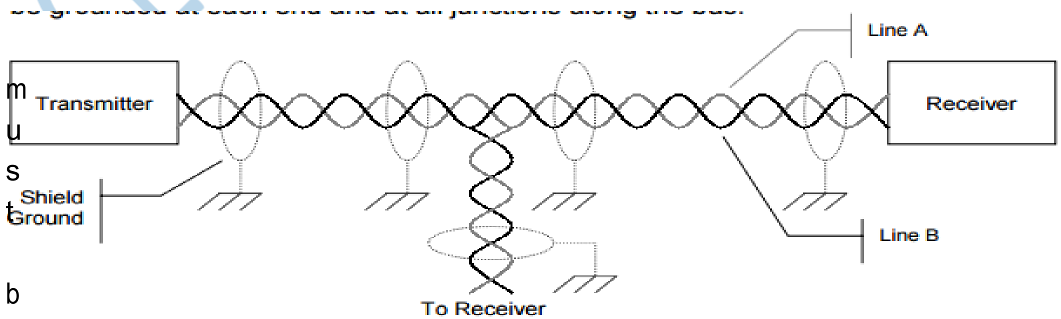


This handshaking is performed using a particular word style, as opposed to a hard wired handshake. When this two way communication format is required, two twisted pairs constituting two channels are necessary to carry information back and forth, one for each direction.

Transmission from the source LRU is comprised of 32 bit words containing a 24 bit data portioncontainingtheactualinformation, andan 8 bit labeldescribing thedataitself. LRUs have no address assigned through ARINC 429, but rather have Equipment ID numbers which allow grouping equipment into systems, which facilitates system management and file transfers.

Sequentialwordsareseparated byat least 4 bittimes of nullor zero voltage. Byutilizing this null gap between words, a separate clock signal is unnecessary. Transmission rates may be at either a low speed - 12.5 kHz - or a high speed - 100kHz.

Cable Characteristics: The transmission bus media uses a 78 Ω shielded twisted pair cable. The shield must be



grounded at each end and at all junctions along the bus. The transmitting source output impedanceshouldbe75Ω± 5Ω divided equally between Line A and Line B. This balanced output should closely match the impedance of the cable. The receiving sink must have an effective input impedance of 8k Ω minimum.

Maximum length is not specified, as it is dependent on the number of sink receivers, sink drain and source power. Most systems are designed for under 150 feet, but conditions permitting, can extend to 300 feet and beyond.

Transmission Characteristics: ARINC 429 specifies two speeds for data transmission. Low speedoperationisstatedat 12.5kHz, withanactualallowablerangeof 12to14.5kHz. High speed operation is 100 kHz ± 1% allowed. These two data rates can not be used on the same transmission bus.

Data is transmitted in a bipolar, Return-to-Zero format. This is a tri-state modulation consisting of HIGH, NULL and LOW states.

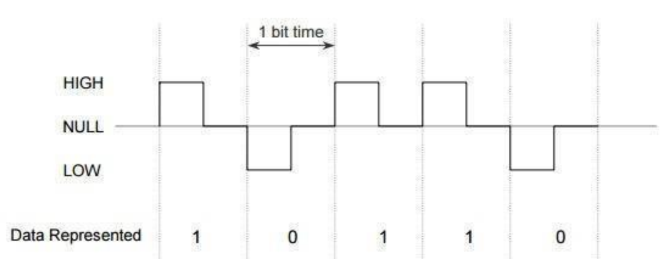
Transmission voltages are measured across theoutput terminals of the source. Voltages presented across the receiver input will be dependent on line length, stub configuration and the number of receivers connected. The following voltage levels indicate the three allowable states:

TRANSMIT	STATE	RECEIVE
+10.0 V ± 1.0 V	HIGH	+6.5 to 13 V
0 V ± 0.5V	NULL	+2.5 to-2.5 V
-10.0 V ± 1.0 V	LOW	-6.5 to -13 V

In bipolar, Return-to-Zero – or RZ – format, a HIGH (or 1) is achieved with the transmission signal going from NULL to +10 V for the first half of the bit cycle, then returning to zero or NULL.

A LOW (or 0) is produced by the signal dropping from NULL to –10 V for the first half bit cycle, then returning to zero.

Witha Return-to-Zero modulationformat, eachbit cycle time ends withthe signal level at 0 Volts, eliminating the need for an external clock, creating a self-clocking signal. An example of the bipolar, tri-state RZ signal is shown here:



Waveform Parameters: Pulse rise and fall times are controlled by RC circuits built into ARINC 429transmitters. Thiscircuitry minimizesovershootringing common withshortrisetimes.

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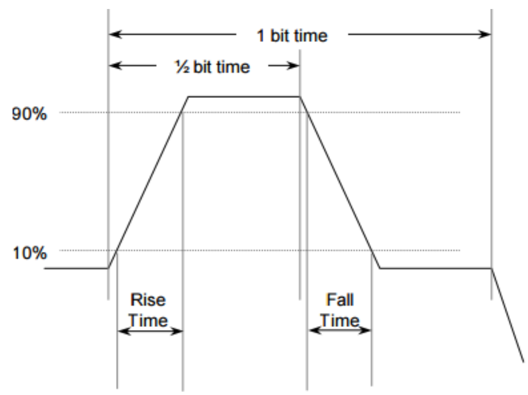
Allowable rise and fall timesare shown belowfor bothbit rates. Bitand ½bittimesarealso defined.



	High Speed	Low Speed
Bit Rate	100 kbps ± 1%	12 - 14.5 kbps ± 1%
1 bit time	10 µsec ± 2.5%	(1/Bitrate)µsec±2.5%
½ bit time	5 µsec ± 5%	(1 bit time/2) ± 5%
Rise Time	1.5 µsec ± 0.5 µsec	10 µsec ± 5 µsec
Fall Time	1.5 µsec ± 0.5 µsec	10 µsec ± 5 µsec

Word Formats ARINC 429 protocol uses a point-to-point format, transmitting data from a single source on thebustoupto 20 receivers. Thetransmitter is always transmitting, either data words or the NULL state. Most ARINC messages contain only one data word consisting ofeither Binary(BNR), Binary Coded Decimal(BCD) or alphanumeric data encoded using ISO Alphabet No. 5. File datatransfers that send more than one wordare also allowed. ARINC 429 data words are 32 bit words made up of five primary fields: Parity - 1 bit Sign/Status Matrix (SSM) - 2 bits Data- 19 bits Source/Destination Identifier (SDI) - 2 bits Label - 8 bits The

C. MIL-STD-1553

Digital Internal Time Division Command/Response Multiplex Data Bus, is a military standard (presently in revision B), which has become one of the basic tools being used today by the DoD for integration of weapon systems. The standard describes the method of communication and the electrical interface requirements for subsystems connected to the data bus.

The 1 Mbps serial communication bus is used to achieve aircraft avionic (MIL-STD-1553B) and stores management (MILSTD-1760B) integration. In the future it will be used to extend the systems integration to flight controls, propulsion controls, and vehicle management

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system (electrical, hydraulic, environmental control, etc.). Several other documents exist, which are related to MIL-STD-1553. MIL-HDBK-1553 describes the implementation practices for this standard including: design considerations, examples of applications, and guidelines for implementations. Portions of MIL-STD-1553 are also the foundation of the MIL-STD-1773 (Fiber-optics), and MIL STD-1760B (Stores Management).

In addition, MIL-STD-1553 is embodied in or referenced by the following international documents: NATO STANAG 3838, ASCC Air Standard 50/2, and UK DEF STAN 00-18 (Part 2)/Issue 1.

MIL-STD-1553 Key Elements: Some of the key MIL-STD-1553B elements are

- Bus controller,
- Embedded remote terminal (a sensor or subsystem that provides its own internal 1553 interface),
- Stand-alone remote terminal,
- Bus monitor,
- Twisted shielded pair wire data bus and the isolation couplers that are optional.

The buscontroller'smainfunction istoprovidedataflowcontrolfor alltransmissions on the bus. In this role, thebus controller is the sole source of communication. The systemusesa command /response method. The embedded remote terminal consists of interface circuitry locatedinside a sensoror subsystem directly connectedtothedatabus. Itsprimary jobisto performthetransfer of data in andout of the subsystem ascontrolledbythebus controller.

Thistype of terminalusuallydoesnothavebuscontroller capability. However, if thesensor itself is fairly intelligent, it can become a candidate for the backup bus controller function. Generally, an intelligent subsystem (i.e., computer based) can become a backup bus controller if a second computer, equal in function to the primary, is unavailable.

The stand-alone remote terminal is the only device solely dedicated to the multiplex system. It is used to interface various subsystem(s), which are not 1553 compatible with the 1553 data bus system. Its primary function is to interface and monitor transmission in and out of these non-1553 subsystem(s).

The bus monitor listens to all messages, and subsequently collects data, from the data bus. Primary applications of this mode of operation include: collection of data for on board bulk storage or remote telemetry; or use within a "hot" oroff-line back-up controller to observe the state and operational mode of the system and subsystems.

The fourth item is the data bus itself. The standard defines specific characteristics for the twisted pair shielded cable. Notice 2 tightens these requirements and adds adefinition for connector polarity. The last item to be discussed is the data bus coupler unit that isolates the main bus from the terminals. MIL-STD-1553B allows two types of data bus interface

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techniques; direct coupling and transformer coupling. Subsystems and 1553 bus elements are interfaced to the main data busby interconnection buses (called "stubs").

These stubs are either connected directly to the main bus or interfaced via data bus couplers. The data bus couplers contain two isolation resistors (one per wire) and an isolation transformer (with a ratio of 1 to the square root of 2). The purpose of the data bus couplersistoprevent ashort onasinglestubfrom shortingthemaindatabus.Theselection of the value of the resistors, the transformer's turn ratio, and the receiver impedance are such thatthe stub appearstothemainbusasa"clean interface" (i.e., highimpedance). This technique reduces the distortion caused on the main data bus by the termination.

The characteristics of the data bus couplers are discussed in paragraph 4.2.4. Main buses utilizing direct coupled stubs must be designed to withstand the impedance mismatch of the stubs. This can be reduced by minimizing stub length(less thanonefoot) and"tuning" the bus by terminal spacing. Designs not using data bus couplers should be carefully analyzed and tested to determine if waveform distortion is significant enough to cause receiver problems.

The other risk associated with direct coupled stubs is a short on a stub will cause the main bustofail. The obvious advantage todirect coupled stubs isthe elimination of thelogistical problems associated with another device and the installation problem of locating these small devices (approximately 1 inch cube) in the aircraft.

Today, data bus couplers and line terminating resistors are available in molded packages, which can become part of the wiring harness, thus eliminating some of theinstallation problems. Also, multiple data bus couplers and data bus line terminating resistors are available in single packages, which reduce the number of unique units installed per aircraft. Message Types MIL-STD-1553 is a serialdata busbased onmessage transmission.

Therefore, considerable emphasis is placed on the term "information transfer formats," which describe each of the 10 message types. Within these 10 message types are the formats used to achieve communication, the primary function of the data bus system. Each message format is made up of control words called command and status.

Data words are used to encode communication between system elements. Both control words and data words are used in system communication as well as data bus system control. These message formats have been subdivided into two groups by 1553B and are shown in figure I-1.1; the "information transfer formats" and the "broadcast information transfer formats."

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These two groups can be easily segregated because the broadcast group does not conform directly to the command/response philosophy of the other (nonbroadcast) message formats. This command/response philosophy requires that all error free messages received by aremote terminal be followed bythetransmissionof aremoteterminal status word. This handshaking process validates error free message completion. Since broadcast message formats are transmitted to multiple receivers, a more detailed scheme is required to validate error free message reception. Also, since address 31 is used by all terminals receiving a broadcast message, sub addressing needs to be managed on a data bus system basis rather than on a remote terminal basis.

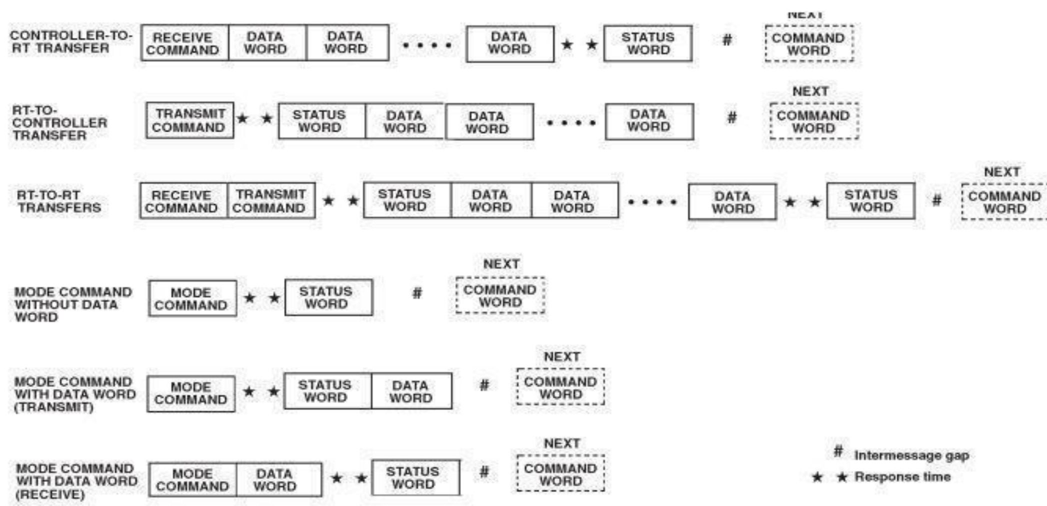

Figure: Information Transfer Formats

The information transferformats allow communications between twoelements in thedata bus system thebuscontroller andtheremoteterminal(RT). In 1553, the bus controller is in controlof all communication and it isthe sole deviceallowed totransmit command words.

Notice that all messages are initiated by the bus controller using command word(s). Messages to a device (remote terminal) from the bus controller are issued using a command word (see figure II1.2) containing the remote terminal's address, direction of message transmission (transmit/receive bit), sub address (destination within the specific remote terminal or subsystem), and the word count.

The command word is immediately followed by the appropriate number of data words specified in the command word. Thereceiving terminal validateserrorfreemessage

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Reception by transmitting a status word (see figure I-1.3), which contains information about its health. Using this technique, the bus controller can transmit data to any terminal attached tothe databus. In a similar manner, thebus controller can initiate acommandtoa remote terminal, which requires the remote terminal to transmit a specific message to the bus controller.

This is accomplished using the RT to bus controller message format. Similarly communication can be established between two unique remote terminals, when the bus controller commands one terminal to receive data and the other terminal to transmit data. Neitherthereceiving northetransmitting terminal knows wherethemessage originatedor destined. Both will transmit status words in the proper formats.

Each status word is evaluated by the bus controller to verify error free message completion. In addition tothese threemessage formats, three control message formatsareprovided to support data bus system management. These formats are mode code formats allowing the transmission of a command word and up to one data word from the bus controller to a unique remote terminal. The remote terminal's response involves the transmission of a status word and up to one data word upon receipt of the mode command.

3. Word Types: The standard allows for only three types of words as discussed in the previous message format section; command word, status word, and data word. 1553 requires each word to consist of 16 bit of data plus, a sync pattern (3 bit times long), and a one bit parity providing a 20 bit word format.

- The command word provides the definition of the message format to be transmitted and can only be transmitted by the bus controller As seen in the message format section, the command word may be followed by data, another command word, or a response time gap prior to status word transmission by the remote terminal. The command word sync pattern is a unique invalid Manchester waveform, which cannot be duplicated by data (see figure I-1.3). The command word sync and the status word sync are identical and the inverse of the data word sync pattern. Therefore, command and status words, which initiate a sequence, can always be distinguished from data word sync patterns
- The command word address is always the address of the remote terminal being com-mended; a bus controller does not have an address while in the active bus controller mode (backup bus controllers canfunction as an RT with a unique address oras a bus monitor with no address until they become an active bus controller). The transmit/receive (T/R) bit indicates the direction of flow of data words (i.e., receive means data to be received by the remote terminal). The subaddress/mode code field has two purposes. When a unique terminal is to receive or transmit data, the

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subaddress acts as an internal address to pointtothetype of datadesired, the location of a data pointer in memory, subsystem interface, etc.

- Whenthesubaddressfieldis 00000or11111,it indicatesthatthenextfieldcontainsthe number of the mode code. The next field (word count/mode number) contains the number of data word(s) in the message or the number of the mode code. Odd parity is established for all words based on the 16 bits of data plus parity bit.
- The data word contains a unique sync (three bit times long), 16 data bits, and a one bit parity. No restrictions are placed on the encoding of the data field, except that the "most significant bit shall be transmitted first." Once again, parity is odd and established on the 16 bits of data plus the parity bit.

4. Status bits The optional status bits are; instrumentation, service request, broadcast command received, busy, subsystem flag, dynamic buscontrol acceptance and terminal flag.

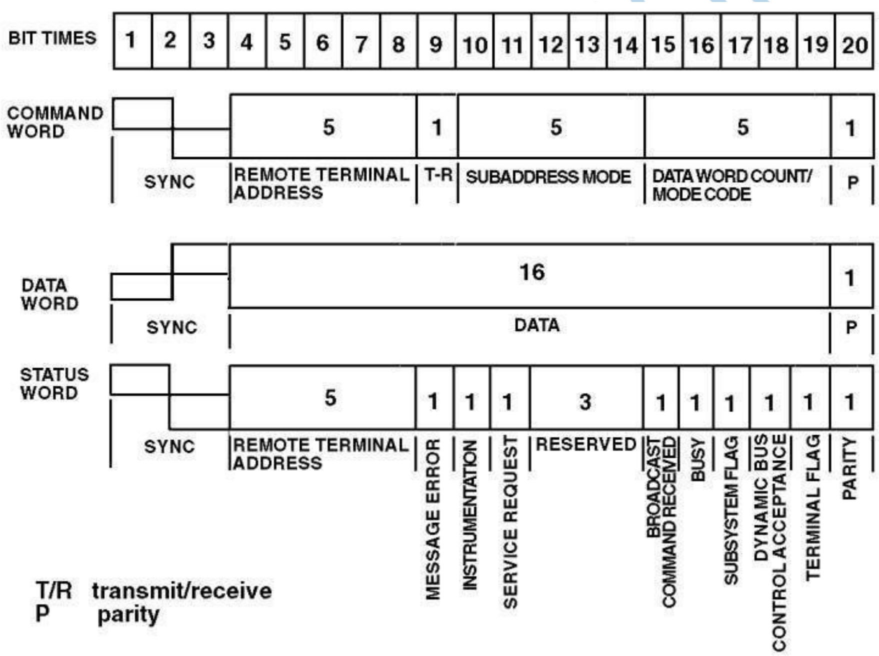

Figure I-1.2 Word Formats

UNIT 2: DISPLAYS –MAN MACHINE INTERATION AND COMMUNICATION SYSTEM:

Displays – Man Machine Interaction and Communication

UNIT 2: DISPLAYS –MAN MACHINE INTERATION AND COMMUNICATION SYSTEM:

The **Cockpit display systems** (or CDS) provides the visible (and audible) portion of the Human Machine Interface (HMI) by which aircrew manage the modern Glass cockpit and thus interface with the aircraft avionics. They also provide a visual presentation of the information data from the aircraft sensors and systems to the pilot (and crew) to enable the pilot to fly safely and carry out the mission. The vital information that is provided is like:

- **Primary flight information,**
- **Navigation information,**
- **Engine data,**
- **Airframe data,**
- **Warning information.**

The military pilot has also a wide array of additional information to view, such as.,

- **Infrared imaging sensors,**
- **Radar,**
- **Tactical Mission data,**
- **Weapon aiming,**
- **Threat warnings.**

History

Prior to the 1970s, cockpits did not typically use any electronic instruments or displays. Improvements in computer technology, the need for enhancement of situational awareness in more complex environments, and the rapid growth of commercial air transportation, together with continued military competitiveness, led to increased levels of integration in the cockpit.

The average transport aircraft in the mid-1970s had more than one hundred cockpit instruments and controls, and the primary flight instruments were already crowded with indicators, crossbars, and symbols, and the growing number of cockpit elements were competing for cockpit space and pilot attention.

Architecture

Glass cockpits routinely include high-resolution multi-color displays (often LCD displays) that present information relating to the various aircraft systems (such as flight management) in an

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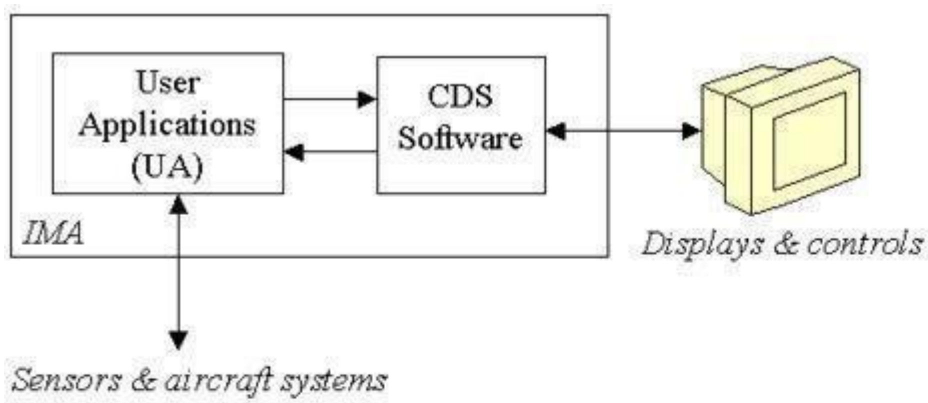
integratedway.Integrated Modular Avionics(IMA)architecture allows for theintegration ofthe cockpit instruments and displays at the hardware and software level to be maximized.



CDS software typically uses API code to integrate with the platform (such as OpenGL to access the graphics drivers for example). This software may be written manually or with the help of COTS tools such as GL Studio, VAPS, or SCADE Display .

Standards such as ARINC 661 specify the integration of the CDS at the software level with the aircraft system applications (called User Applications or UA).

During early military Head-Up Display (HUD) development, it was found that pilots using HUDs could operate their aircraft with greater precision and accuracy than they could with conventional flight instrument systems.

This realization eventually led to thedevelopment of thefirst HUD systems intended specifically toaid thepilotduring commercial landing operations. This was first accomplished by Sextant Avionic for the Dassault Mercure aircraft in 1975, and then by Sundstrand and Douglas Aircraft Company for the MD80 series aircraft in the late 1970s (see Figure 2.1).

In the early 1980s, Flight Dynamics developed a holographic optical system to display an initially derived aircraft flight path along with precision guidance, thus providing the first wide field-of-view (FOV) headup guidance system. Subsequently, Alaska Airlines became the first airline to adopt this technology and perform routine fleet-wide manually flown CAT IIIa operations on B-727-100/200 aircraft using the Flight Dynamics system (see Figure 2.2).

Once low-visibility operations were successfully demonstrated using a HUD in lieu of a fail passive auto land system, regional airlines opted for this technology to help maintain their schedules when the weatherfell below CAT II minimums, and to help improve situational awareness. By the end of the century, many airlines had installed head-up guidance systems, and thousands of pilots were fully trained in their use. HUD-equipped aircraft had logged more than 6,000,000 flight hours and completed over 30,000 low-visibility operations. HUDs are now well-established additions to aircraft cockpits, providing both additional operational capabilities and enhanced situational awareness, resulting in improved aircraft safety.

HUD Fundamentals: All head-up displays require an image source, generally a high-brightness cathode-ray tube, and an optical system to project the image source information at optical infinity. The HUD image is viewed by the pilot after reflecting from a semitransparent element referred to as the HUD combiner.

Head-up display systems are comprised of two major subsystems:

The pilot display unit (PDU): The PDU interfaces electrically and mechanically with the aircraft structure andprovides theoptical interface tothepilot. The HUD processor interfaceselectronically withaircraft sensors and systems, runs a variety of algorithms related to data verification and formatting, and generates the characters and symbols making up the display.

HUD processor or HUD computer: Modern HUD processors are capable of generating high integrity guidance commands and cues for precision low-visibility take-off, approach, landing (flare), and rollout. The interface between the HUD processor and the PDU can be either a serial digital display list or analog X and Ydeflection and Z-axis video bright-up signals for controlling the display luminance.

- The PDU is located within the cockpit to allow a pilot positioned at the cockpit Design Eye Position (DEP) to view HUD information which is precisely positioned with respect to the outside world.

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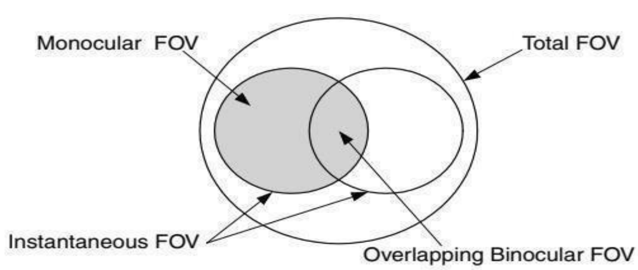
- This allows, for example, the computer-generated and displayed horizon line to overlay the real-world horizon in all phases of flight.
- The cockpit DEP is defined as the optimum cockpit location that meets the requirements of FAR 25.7734 and 25.777.5 from this location the pilot can easily view all relevant head-down instruments and the outside world scene through the aircraft windshield, while being able to access all required cockpit controls.
- The HUD "eyebox," is always positioned with respect to the cockpit DEP, allowing pilots tofly the aircraft using the HUD from the same physical location as a non-HUD-equipped aircraft would be flown.

1. **Optical Configurations.** Theoptics inhead-updisplay systems are used to "collimate" the HUD image so that essential flight parameters, navigational information, and guidance are superimposed on the outside world scene.
   - ✓ Total FOV (TFOV) – The maximum angular extent over which symbology from the image source can be viewed by the pilot with either eye allowing vertical and horizontal head movement within the HUD eyebox.
   - ✓ Instantaneous FOV (IFOV) – The union of the two solid angles subtended at each eye by the clear apertures of the HUD optics from afixedheadposition within the HUD eyebox.
   - ✓ Binocular overlapping FOV –The binocular overlapping FOV is the intersection of the two solid angles subtended at each eye by the clear apertures of the HUD optics from a fixed head position within the HUD eye box.
   - ✓ Binocular FOV Monocular - The solid angle subtended at the eye by the clear apertures of the HUD optics from a fixed eye position. Note that the monocular FOV size and shape may change as a function of eye position within the HUD eyebox.



Reflective Optical Systems

In the late 1970s, HUD optical designers looked at ways to significantly increase the display total and instantaneous FOVs. It illustrates the first overhead-mounted reflective HUD optical system (using a holographically manufactured combiner) designed specifically for a commercial transport cockpit. As in the classical refractive optical system, the displayed image is generated on a small CRT, about 3 in. in diameter. The reflective optics can be thought of as two distinct optical subsystems. Thefirst is a relay lens assembly designed to re-image and pre-aberrate the CRT image source to an

UNIT 2: DISPLAYS –MAN MACHINE INTERATION AND COMMUNICATION SYSTEM:

intermediateaerial image, located at onefocal lengthfrom theoptically powered combiner/collimator element.

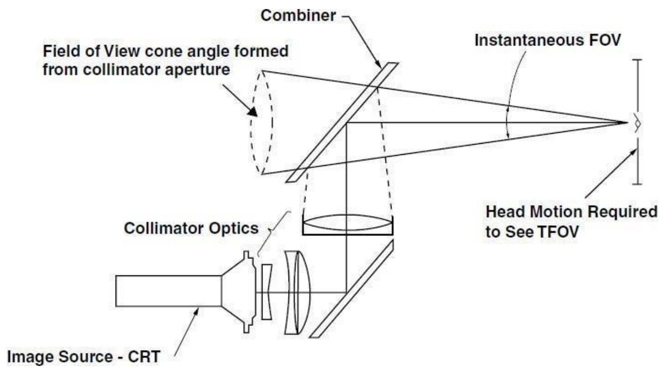


FIGURE 2.4: Refractive optical systems.

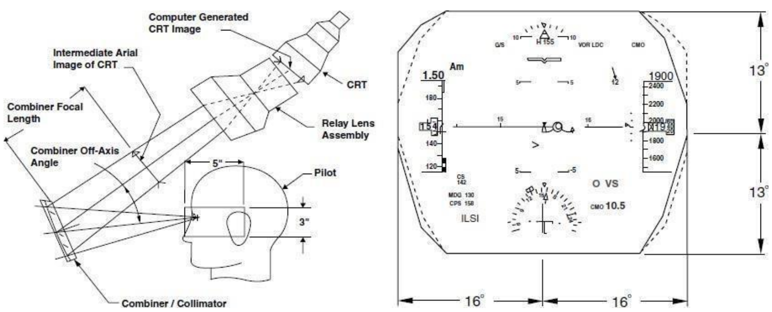


Figure 2.5: Reflective optical systems (overhead mounted).

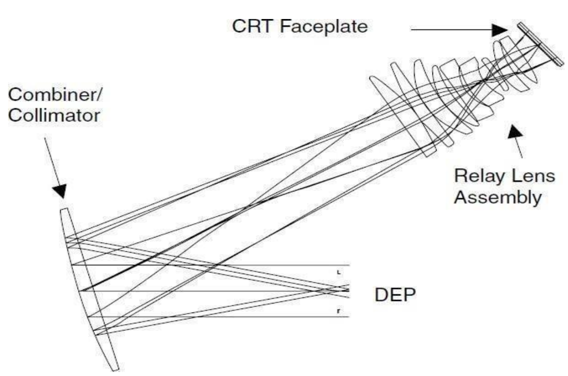


FIGURE 2.6 Reflective optical system raytrace.

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The second optical subsystem is the combiner/collimator element that re-images and collimates the intermediate aerialimagefor viewing bythepilot. As in therefractive systems, thepilot'seyes focusat optical infinity, looking through the combiner to see the virtual image. To prevent the pilot's headfrom blocking rays from the relay lens tothe combiner, the combiner is tilted off-axis withrespect totheaxial chief ray from the relay lens assembly. The combiner off-axis angle, although required for image viewing reasons, significantly increases the optical aberrations within the system, which must be compensated in the relay lens to have a well-correlated, accurate virtual display.

Figure 2.6 illustrates the optical raytrace of a typical reflective HUD system showing the complexity of the relay lens assembly. (This is the optical system used on the first manually flown CAT IIIa HUD system ever certified.)

The complexity of the relay lens, shown in Figure 2.6, provides alarge instantaneous FOVover afairly large eyebox, while simultaneously providing low display parallax and high display accuracy. The reflective optical system canprovide an instantaneous andbinocular overlapping FOVthat is equal to the total FOV, allowing the pilot to view all of the information displayed on the CRT with each eye with no head movement. Table 2.1 summarizes typical field-of-view performance characteristics for HUD systems. All commercially certified HUD systems in airline operation today use reflective optical systems because of the improved display FOV characteristics compared with refractive systems.

Basic Principles

The basic configuration of a HUD is shown schematically in Figure 2.4. The pilot views the outside world through the HUD combiner glass (and windscreen). The combiner glass is effectively a 'seethrough' mirror with a high optical transmission efficiency so that there is little loss of visibility looking through the combiner and windscreen. It is called a combiner as it optically combines the collimated display symbology with the outside world scene viewed through it.

The display symbology generated from the aircraft sensors and systems (such as the INS and air data system) is displayed on the surface of a cathode ray tube (CRT). The display images are then relayed through a relay lens system which magnifies the display and corrects for some of the optical errors which are otherwise present in the system.

The relayed display images are then reflected through an angle of near 90◦ by the fold mirror and thence to the collimating lens which collimates the display images which are then reflected from the combiner glass into the pilot's forward field of view.

The virtual images of the display symbology appear to the pilot to be at infinity and overlay the distant world scene, as they are collimated. The function of the fold mirror is to enable a compact optical configuration to be achieved so that the HUD occupies the minimum possible space in the cockpit.

A collimator is definedasan optical system of thefinite focallength with an image source atthe focal plane. Rays of light emanating from a particular point on the focal plane exit from the collimating system as a parallel bunch of rays, as if they came from a source at infinity.

Figures 2.5(a) and (b) showa simple collimating lenssystem withtheraystraced froma source at the centre, O, and a point, D, on the focal plane respectively. A ray from a point on the focal plane which goes through the centre of the lens is not refracted and is referred to as the 'non-deviated ray'. The other rays emanating from the point are all parallel to the non-deviated ray after exiting the collimator.

IFOV = 2 tan-1 D/2L

TFOV = 2 tan-1 A/2F

The constraints involved in the HUD design are briefly outlined below.

1) For a given TFOV, the major variables are the CRT display diameter and the effective focal length of the collimating lens system.
2) For minimum physical size and weight, a small diameter CRT and short focal length are desired. These parameters are usually balanced against the need for a large diameter collimating lens to given the maximum IFOV and a large focal length which allows maximum accuracy. The diameter of the collimating lens is generally limited to between 75 mm and 175 mm (3 inches and 7 inches approximately) by cockpit space constraints and practical considerations. Large lenses are very heavy and liable to break under thermal shock.
3) The HUD combiner occupies the prime cockpit location right I the centre of the pilot'sforward line of view at the top of the glare shield.
4) The size of the combiner is determined by the desired FOV and the cockpit geometry, especially the pilot's seating position.
5) The mainbody of the HUD containingtheoptics andelectronics must be sunk downbehindthe instrument panel in order to give an unrestricted.
6) The pilot's design eye position for the HUD is determined by pilot comfort and thye ability to view the cockpit instruments and head down displays and at the same time achieve the maximum outside worldvisibility.
7) In the case of a combat aircraft, there is also the ejection line clearance to avoid the pilot being 'kneecapped' by the HUD on ejecting, which further constraints the design eye position.
8) Typical IFOVs range fromabout 13◦ to 18◦ with a corresponding TFOV of about 20◦ to 25◦. The total vertical FOV of a HUD can be increased to around 18◦ by the use of a dual combiner configuration rather like a venetian blind. Effectively two overlapping portholes are provided, displaced vertically.

Theeffect of thecockpitspaceandgeometryconstraints isthattheHUDdesignhastobe'tailor made' for each aircraft type and a 'standard HUD' which would be interchangeable across a range of different aircraft types is not a practical proposition.

The conventional combiner glass in a refractive HUD has multi-layer coatings which reflect a proportion of collimated display imagery and transmit a large proportion of the outside world, so that the loss of visibility is fairly small. A pilot looking through the combiner of such a HUD sees the real world at 70% brightness upon which is superimposed the collimated display at 30% of the CRT brightness (taking typical transmission and reflection efficiencies). The situation is shown in Figure 2.9 and is essentially a rather lossy system with 30% of the real world brightness thrownaway,(equivalentto wearingsunglasses) as is 70% of the CRT displaybrightness.

9) Inordertoachieveanadequatecontrastrationsothatthedisplaycanbeseenagainsttheskyat high altitude or against sunlit cloud it is necessary to achieve a display brightness of 30,000 Cd/m² (10,000 ft L) from the CRT. In fact, it is the brightness requirement in particular which assures the use of the CRT as the display source for some considerable time to come, even with the much higher optical efficiencies which can be achieved by exploiting holographic optical elements.

10) The use of holographically generated optical elements can enable the FOV to be increased by a factor of two or more, with the instantaneous FOV equal to the total FOV. Very much brighter displaystogether withanegligible lossin outsideworldvisibility canalso be achieved, aswillbe explained in thenext section. Highopticaltransmission throughthecombiner is required so as not to degrade the acquisition of small targets at long distances.

It should be noted, however, that the development of 'Rugate' dielectric coatings applied to the combiners of conventional refractive HUDs hasenabled very bright displays withhigh outside world transmission to be achieved, comparable, in fact, with holographic HUDs. A Rugate dielectric coating is a multi-layer coating having a sinusoidally varying refractive index with thickness which can synthesise a very sharply defined narrow wavelength band reflection coating, typically around 15 nm at the CRT phosphor peak emission. The coating exhibits similar high reflection and transmission values to holographic coatings but is not capable of generating optical power. The IFOV of arefractive HUD using a combiner witha Rugate dielectric coating still suffers from the same limitations and cannot be increased like a holographic HUD. It can, nevertheless, provide a very competitive solution for applications where a maximum IFOV of up to 20◦ is acceptable.

Significant Optical Performance Characteristics

This section summarizes other important optical characteristics associated with conformal HUD systems. It is clear that the HUD FOV, luminance, and display line width characteristics must meet basic performance requirements.

However, optical system complexity and cost are driven by HUD eyebox size, combiner off-axis angle, display accuracy requirements, and optical parallax errors. Without a well corrected optical system, conformal symbology will not properly overlay the outside world view and symbology will not remain fixed with respect to the real-world view asthe head is moved around within the HUD eyebox.

Display Luminance and Contrast Ratio

The HUD should be capable of providing a usable display under all foreseeable ambient lighting conditions, including a sun-lit cloud with a luminance of 10,000 foot-Lamberts (ft-L)(or 34,000 cd/m and a night approach to a sparsely lit runway. HUD contrast ratio is a measure of the relative luminance of the display with respect to the real-world background and is defined as follows:

The display luminance is the photopically weighted CRT light output that reaches the pilot's eyes. Realworld luminance is the luminance of the real world as seen through the HUD combiner. (By convention, the transmission of the aircraft windshield is left out of the real-world luminance calculation.)

It is generallyagreedthatacontrast ratio(CR) of 1.2 is adequatefordisplay viewing, butthata CR of 1.3 is preferable. A HUD contrast ratio of 1.3 against a 10,000-ft-L cloud seen through a combiner with an 80% photopic transmission requires a display luminance at the pilot's eye of 2400 ft-L, a luminance about 10 times higher than most head-down displays. (This luminance translates to a CRT faceplate brightness of about 9000 ft-L, aluminanceeasily metwith high-brightness monochrome CRTs.)

Head Motion Box

The HUD head motion box, or "eyebox," is a three-dimensional region in space surrounding the cockpit DEP in which the HUD can be viewed with at least one eye. The center of theeyebox canbe displayed forward or aft, or upward or downward, with respect to the cockpit DEP to better accommodate the actual sitting position of the pilot. The positioning of the cockpit eye reference point or DEP is dependent on a number of ergonomically related cockpit issues such as head-down display visibility, the over-the nose down-lookangle, and the physical location of various controls such as the control yoke and the landing gear handle.

The HUD eyebox shouldbeaslargeas possible toallowmaximum headmotion without losing display information. The relay lens exit aperture, the spacing between the relay lens and combiner and the combiner to DEP, and the combiner focal length all impact the eyebox size. Modern HUD eyebox dimensions aretypically 5.2 in lateral, 3.0 in vertical, and 6.0 in longitudinal. Inall HUDs, themonocular instantaneous FOV is reduced (or vignettes) with lateral or vertical eye displacement, particularly near the edge of the eyebox. Establishing a minimum monocular FOV from the edge of the eyebox thus ensures that even when the pilot's head is de-centered so that one eye is at the edge of the eyebox, useful display FOV is still available.

FOV generally can be used to define the eyebox limits. In reflective HUDs, relatively small head movements (1.5 in laterally) will cause one eye to beoutside of the eyebox and see no display. Under these conditions, the other eye will see the total FOV, so no information is lost to the pilot.

HUD Display Accuracy

Displayaccuracy isameasure of howprecisely theprojected HUD imageoverlays thereal-world view seen through the combiner and windshield from any eye position within the eyebox. Display accuracy is a monocular measurement and, for a fixed display location, is numerically equal to the angular difference between a HUD-projected symbol element and the corresponding real-world feature as seen through the combiner and windshield. The total HUD system display accuracy error budget includes opticalerrors, electronic gainandoffseterrors, errors associated withthe CRT and yoke, Overhead to Combiner misalignment errors, windshield variations, environmental conditions (including temperature), assembly tolerances, andinstallationerrors. Optical errorsarebothhead-position and field-angle dependent. The following display accuracy values are achievable in commercial HUDs when all the error sources are accounted for:

The boresight direction is used as the calibration direction for zeroing all electronic errors. Boresight errors include the mechanical installation of the HUDhardpoints to the airframe, electronic drift due to thermal variations, and manufacturing tolerances for positioning the combiner element. Refractive HUDs with integrated combiners (i.e., F-16) are capable of achieving display accuracies of about half of the errors above.

HUD Parallax Errors

Within the binocular overlapping portion of the FOV, the left and right eyes view the same location on the CRT faceplate. These slight angular errors between what the two eyes see are binocular parallax errors orcollimation errors. The binocular parallax error for afixedfield point within the total FOV is the angular difference in rays entering two eyes separated horizontally by the inter pupillary distance, assumed to be 2.5 in. If the projected virtual display image were perfectly collimated at infinity from all eyebox positions, the two ray directions would be identical, and the parallax errors would be zero. Parallax errors consist of both horizontal and vertical components.

Holographic HUDs

The requirements for a large FOV is driven by the use of the HUD to display a collimated TV picture of the FLIR sensoroutput to enablethepilotto'see' throughthe HUD FOV in conditions of poor visibility, particularly night operations. It should be noted that the FLIR sensor can also penetrate through haze and many cloud conditions and provide 'enhanced vision' as the FLIR display is accurately overlaid one to one with the real world. The need for a wide FOV when manoeuvring at night at low level can be seen in Figures 2.10 and 2.11. The wider azimuth FOV is essential for the pilot to see into the turn. (The analogyhas been made of trying todrive a car round Hyde Park Corner with a shattered opaque windscreen with your vision restricted to a hole punched through the window.

Inamodern wide FOV holographic HUD, the display collimation is carried out by the combiner which is givenoptical power (curvature) such that it performs the display image collimation.

Figure 2.12 shows the basic configuration of a modern single combiner holographic HUD. The CRT display is focused by the relay lens system to form an intermediate image at the focus of the powered combiner. This acts as a collimator as the tuned holographic coating on the spherical surface of the combiner reflects the green light from the CRT displayed and forms a collimated display image at the pilot's design eyeposition.

Because the collimating element is located in the combiner, the porthole is considerably nearer tothepilotthanacomparable refractive HUD design. The collimating elementcanalso be mademuch larger thanthe collimating lens of arefractive HUD, within the same cockpit constraints. The IFOVcan thus be increased by a factor of two or more and the instantaneous and total FOVs are generally the same, as the pilot is effectively inside the viewing porthole.

This type of HUD is sometimes referred to as a 'Projected Porthole HUD' and the image is what is known as pupil forming. Modern holographic HUDs are designed to have a reasonably sized head motion box so that the pilot is not unduly constrained.

The combiner comprises a parallel-faced sandwich of plano-convex and plano-concave glass plates with a holographic coating on the spherical interface between them.

The holographic coating is formed on the spherical surface of the plano-convex glass plate and the concave surface glass forms a cover plate so that the holographic coating can be hermetically sealed within the combiner.

The holographic coating is sharply tuned so that it will reflect the green light of one particular wavelength from the CRT display with over 80% reflectivity but transmit light at all other wav elengths with around 90% efficiency. (The CRT p0hosphors generally used are P43 or P53 phosphors emitting green light with a predominant wavelength of around 540 nm, and the hologram is tuned to this wavelength.) This gives extremely god transmission of the outside world through the combiner. (The outerfaces of thecombinerglass areparallel so thatthere isno optical distortion of theoutside scene.) The outside world viewed through the combiner appears very slightly pink as the green content of the outside world with a wavelength of around 540nm is not transmitted through the combiner. Holographic HUDs, in fact, are recognisable by the green tinge of the combiner.

Holography was invented in 1947 by Denis Gabor, a Hungarian scientist working in the UK. Practical applications had to wait until the 1960s, when two American scientist, Emmet Leith and Joseph Upatnieks, used coherent light from the newly developed laser to record thefirst hologram.

The bandwidth of theangular reflection range is determined bythe magnitude of the change in refractive index. This variable can be controlled during the developing process and is specified as the hologram modulation.

The process for producing the powered holographic combiner is very briefly out-lined below.

The process has three key stages:

- Design and fabricate the Computer Generated Hologram(CGH)
- Produce masterhologram
- Replicate copies for the holographic combiner elements.

The basic functional elements of a modern HUD electronic system are shown in Figure 2.19. These functional elements may be packaged so that the complete HUD system is contained in a single unit, as in the Typhoon HUD above.

The systemmayalso be configured astwo units, namelythe Display Unitandthe Electronics Unit. The Display Unit contains the HUDoptical assembly, CRT, displaydrive electronics, high andlow voltage power supplies. The Electronics unit carries out the display processing, symbol generation and interfacing to the aircraft systems

The display processor processes this input data to derive the appropriate display formats, carrying out tasks such as axis conversion, parameter conversion and format management. In addition the processor also controls the following functions:

- Self test,
- Brightness control (especially important at low brightness levels),
- Mode sequencing,
- Calibration,
- Power supply control.

Civil Aircraft HUDs

The application of HUDs in civil aircraft has been mentioned earlier in the chapter. This section explains their potential and importance in greater detail and covers the progress that has been made in producing viable systems for civil aircraft operation.

The use of HUDby civilaviation operators is still arelatively novelpractice and it wasestimated in 2009 that there were about 2,000 HUD installations in revenue service worldwide. This compares with over 15,000 military HUD systems in service worldwide.

The main advantages of a HUD in a civil aircraft are:

1. Increased safety providing a better situational awareness for the pilot to control the aircraft by the head up presentation of the primary flight information symbology so that it is conformal with the outside world scene.
2. The problems of severe wind shear conditionshavebeen mentioned earlier in theintroduction to this chapter. Figure 2.23 shows how wind shear arises and the introduction to this chapter. Figure 2.23 shows how wind shear arises and the problems it creates. Over 700 passengers were killed in the USA alone in accidents in recent years caused by wind shear.
3. The HUD can also provide aflightpathdirectordisplay which allowsfortheeffect of wind shear from a knowledge of the aircraft's velocity vector, airspeed, height and aerodynamic behaviour.
4. The HUD can also increase safety during terrain, or traffic avoidance manoeuvres.
5. Ground proximity Warning Systems (GPWS) are a very valuable aid in avoiding terrain and enhanced GPWS will extend this protection still further.
6. In circumstances, however, during a terrain escape manoeuvre where the terrain is visible, the flight path vector (FPV) displayed on the HUD provides an unambiguous presentation on whetherornottheterrain will be missed. If the FPV is overlaid on terrainahead, theaircraft will

hit it and in this situation the crew must decide on another decide on another course of action as opposed to 'holding on' to see what happens.

7. Traffic Collision Avoidance Systems (TCAS) provide traffic conflict and escape guidance and are of great benefit in preventing mid air collisions. Guidance, however, is provided head down so the pilot is manoeuvring on instruments while trying to acquire conflicting traffic visually. The HUD enablestheescape manoeuvre and search fortraffictobeaccomplished headup.
8. Safety improvements in the course of each stage of a typical flight were predicted in a study published by Flight Safety Foundation (see Further Reading). The study concluded that a HUD would likely have had a positive impact on the outcome of 30% of the fatal jet transport incidents documented over the period 1958 to 1989.
9. Increased revenue earning ability by extending operations in lower weather minima. The HUD is used to monitor the automatic landing system and to enable the pilot to take over on aircraft which are not equipped to full Category III automatic landing standards.
10. Use of the HUD as part of an enhanced vision system to enable operations in lower weather minima at airfields not equipped with automatic landing aids (ILS/MLS). For example, the number of Type II and Type III ILS facilities in the US is very limited - typically less than 70. The revenue earning potential of enhanced vision systems is thus very considerable. As explained earlier, the HUD displays a video image of the real world ahead of the aircraft derived from a millimetric wavelength radar sensor anda FLIR sensor installed in theaircraft togetherwiththe overlaid primary flight information and flight path parameters.
11. The use of the HUD for displaying ground taxiway guidance is being actively investigated, and is considered a likely extension to the HUDs roles. Ground taxiway guidance could be provided by differential GPS.

Symbology Sets and Modes

To optimize the presentation of information, the HUD has different symbology sets that present only the information needed by the pilot in that phase of flight. For example, the aircraft pitch information is not important when the aircraft is on the ground. These symbology sets are either selected as modes by the pilot or are displayed automatically when a certain condition is detected.

Primary Mode

The HGS Primary (PRI) mode can be used during all phases of flight from take-off to landing. This mode supports low-visibility take-off operations, all en route operations, and approaches to CAT I or II minimums using FGS Flight Director guidance.

The HGS Primary mode display is very similar to the Primary Flight Display (PFD) to enhance the pilot's transition fromheaddowninstruments to headup symbology. Figure 4.16 showsa typical in flight

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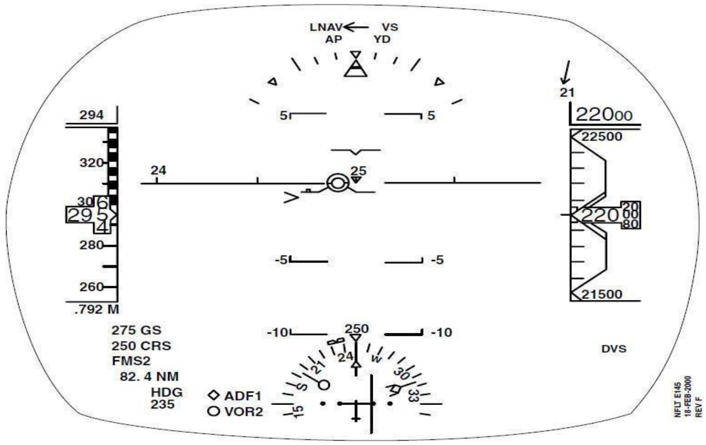

FIGURE 2.16: HGS primary mode symbology: in-flight.

Primary mode display that includes the following symbolic information:

- Aircraft Reference (boresight) symbol
- Pitch — scale and horizon relative to boresight
- Roll — scale and horizon relative to boresight
- Heading — horizon, HIS, and digital readouts
- Speeds — CAS (tape), vertical speed, ground speed, speed error tape

- Altitudes — barometric altitude (tape), digital radio altitude
- Flight Path (inertial)
- Flight Path acceleration
- Slip/Skid Indicators
- FGS Flight Director (F/D) guidance cue and modes
- Flight Director armed and capture modes
- Navigation data — ILS, VOR, DME, FMS, marker beacons
- Wind — speed and direction

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- Selected parameters — course, heading, airspeed, and altitude
- Attitude
- Altitude
- Airspeed
- Navigation Data
- Warning and Advisory

When the aircraft is on the ground, several symbols are removed or replaced as described in the following sections. Aftertake-off rotation,thefull, in-flight set of symbolsisrestored. The Primarymode is selectable at the HCPorbypressing thethrottlego-around switch duringany mode of operation.

Primary Mode: Low-Visibility Take-off (HGS Guidance)

The Primary mode includes special symbology used for a low-visibility take-off as shown in Figure 4.17. The HGS guidance information supplements visual runway centerline tracking and enhances situational awareness. For take-off operation, the HSI scale is removed from the Primary display until the aircraft is airborne.

Additional symbols presented during low-visibility take-off operation are

- Ground Roll Reference Symbol (fixed position)
- Ground Localizer Scale and Index
- Ground Roll Guidance Cue (HGS-derived steering command)
- TOGA Reference Line

The Ground Localizer Scale and Index provide raw localizer information any time the aircraft is on the ground. For a low-visibility take-off, the general operating procedure is to taxi the aircraft into take-off position over the runway centerline. The selected course is adjusted as necessary to overlay the elected Course symbol on the actual runway centerline at the furthest point of visibility. Take-off roll is started and the captain uses rudder control to center the Ground Roll Guidance Cue in the Ground Roll Reference symbol (concentric circles). If the cue is to the right of the Ground Roll Reference symbol then thepilot would need toapply right ruddertoagain center thetwo symbols. (At rotation, the Ground Roll Reference and Guidance Cue symbols are replaced by the Flight Path symbol and the Flight Director Guidance Cue.)

Primary Mode: Climb

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At rotation, anumber of changes takeplace on thedisplay (see Figure 4.16). Flight Path Acceleration, now positioned relative to Flight Path controlling the aircraft, is particularly useful in determining a positive climb gradient and in optimizing climb performance. With the appropriate airspeed achieved, to null Flight Path Acceleration will maintain airspeed. Alternately, the Flight Director commands can be followed.

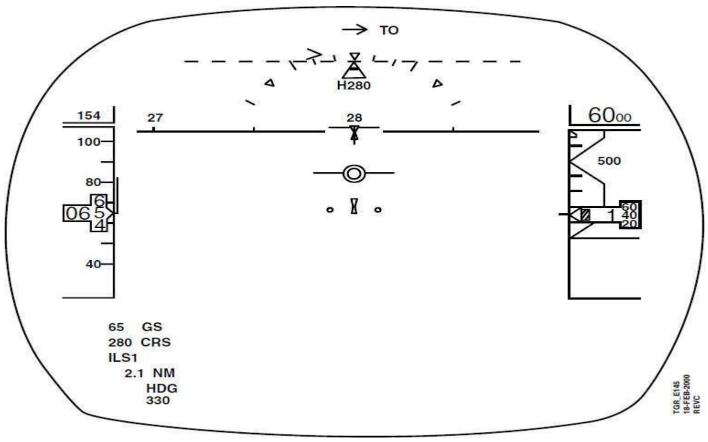

FIGURE 4.17 HGS primary mode: low-visibility take-off.

Primary Mode: Cruise

Figure2.16showsatypical HGSdisplayfor anaircraft instraightandlevelflightat 22,000ft, 295kn,and Mach .792. Ground Speed is reduced to 275 kn as a result of a 21-kn, right-quartering headwind indicated by the wind arrow. The aircraft is being flown by the autopilot with LNAV and VS modes selected. Holding the center of the Flight Path symbol level on the horizon, and the Flight Path Acceleration symbol (_) on the Flight

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Radio Communication: Developing an understanding of radio communications begins with the comprehension of basic electromagnetic radiation. Radio waves belong to the electromagnetic radiation family, whichincludes x-ray, ultraviolet, and visible light — forms of energy we use everyday. Much like the gentle waves that form when a stone is tossed into a still lake, radio signals radiate outward, or propagate, from a transmitting antenna. However, unlike water waves, radio waves propagate at the speed of light.

We characterize a radio wave in terms of its amplitude, frequency, and wavelength (Figure 1-1).

Radiowaveamplitude, orstrength, can be visualized asits height— thedistance between its peakand its lowest point. Amplitude, which is measured in volts, is usually expressed in terms of an average value called root-mean-square, orRMS.

The frequency of a radio wave is the number of repetitions or cycles it completes in a given period of time. Frequency is measured in hertz (Hz); one hertz equals one cycle per second. Thousands of hertz areexpressed as kilohertz (kHz), and millions of hertz as megahertz (MHz). You would typically see a frequency of 2,182,000 hertz, for example, written as 2,182 kHz or 2.182 MHz.

Radio wavelength is the distance between crests of a wave. The product of wavelength and frequency is a constant that is equal to the speed of propagation. Thus, as the frequency increases, wavelength decreases, and viceversa.

Since radio waves propagate at the speed of light (300 million meters per second), you can easily determine the wavelength in metersfor anyfrequency by dividing 300 by the frequency in megahertz. So, the wavelength of a 10-MHz wave is 30 meters, determined by dividing 300 by 10.

The Radio Frequency Spectrum In the radio frequency spectrum (Figure 1-2), the usable frequency range for radio waves extends from about 20 kHz (just above sound waves) to above 30,000 MHz. A wavelength at 20 kHz is 15 kilometers long. At 30,000 MHz, the wavelength is only 1 centimeter.

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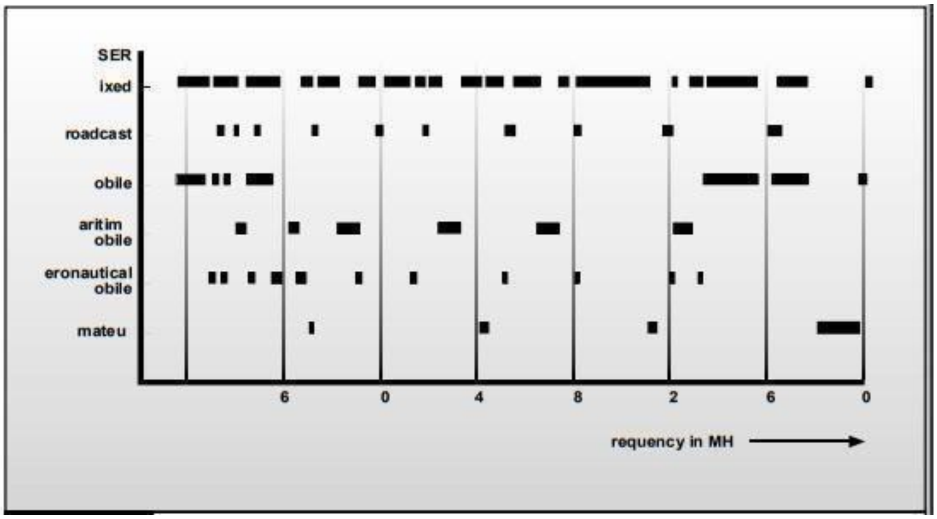
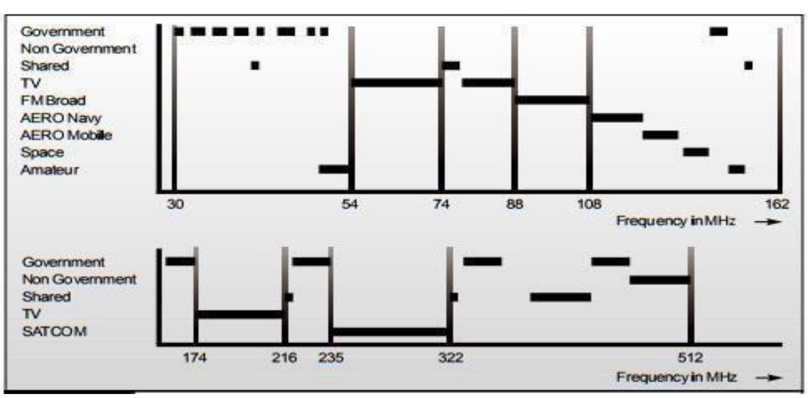
The High Frequency (HF) Band: The HF band is defined as the frequency range of 3 to 30 MHz. In practice, most HF radiosuse the spectrumfrom 1.6 to 30 MHz. Most long-haul communications in this bandtakeplacebetween 4 and 18 MHz. Higherfrequencies (18 to 30 MHz) may also be availablefrom time to time, depending on ionospheric conditions and the time of day (see Volume One, HF Technology).



Very High Frequency (VHF) Band The VHF frequency band is defined as the frequency range from 30 to 300 MHz. From the previous discussion about the relationship between frequency and wavelength, it should be noted that VHF wavelengths vary from 10-meters at the low end to one meter at the high end. This meansthatthe size of antennasandtuningcomponents used in VHFradioaremuch smaller and lighter than those of HF radios. This is a big advantage for manpack radios.

Ultra High Frequency (UHF) Band: The UHF band goes from 300 MHz to 2450 MHz, although TACSAT manpack UHF radios do not utilize frequencies above 512 MHz. The wavelengths associated with 300 to 512 MHz rangefrom one meter to 0.58 meters (58 centimeters). The very small antennas requiredfor these wavelengths make them ideal for use on high-speed aircraft.



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Frequency Allocations: Within the HF spectrum, groups of frequencies are allocated to specific radio services — aviation, maritime, military, government, broadcast, or amateur. Frequencies are further regulated according to transmission type: emergency, broadcast, voice, Morse code, facsimile, and data. International treaty and national licensing authorities govern frequency allocations. Frequencies within the VHF/UHF bands are similarly allocated (Figure 1-4).

Modulation The allocation of a frequency is just the beginning of radio communications. By itself, a radio wave conveys no information. It's simply a rhythmic stream of continuous waves (CW). When we modulate radio waves to carry information, we refer to them as carriers. To convey information, a carriermust be varied so thatitsproperties— itsamplitude, frequency, orphase (themeasurement of a complete wave cycle) — are changed, or modulated, by the information signal.

The simplest method of modulating a carrier is by turning it on and off by means of a telegraph key. In the early days of radio, On-Off keying, using Morse code, was the only method of conveying wireless messages. Today's common methods for radio communications include amplitude modulation (AM), which varies the strength of the carrier in direct proportion to changes in the intensity of a source such asthehumanvoice(Figure 1-5a). In other words, information is contained in amplitude variations. The AMprocess creates a carrier andapair of duplicate sidebands — nearbyfrequencies aboveandbelow the carrier (Figure 1-5b). AM is a relatively inefficient form of modulation, since the carrier must be continually generated.

The majority of the power in an AM signal is consumed by the carrier that carries no information, with the rest going to the information-carrying sidebands. In a more efficient technique, single sideband (SSB), the carrier and one of the sidebands are suppressed (Figure 1-5c). Only the remaining sideband, upper (USB) or lower (LSB), is transmitted. An SSB signal needs only half the bandwidth of an AM signal and is produced only when a modulating signal is present.

Thus, SSB systems are more efficient both in the use of the spectrum, which must accommodate many users, and of transmitter power. All the transmitted power goes into the information-carrying sideband.

One variation on this scheme, often used by military and commercial communicators, is amplitude modulation equivalent (AME), in which a carrier at a reduced level is transmitted with the sideband. AME lets one use a relatively simple receiver to detect the signal.

Another important variation is independent sideband (ISB), in which both an upper and lower sideband, each carrying different information, is transmitted. This way one sideband can carry a data signal and the other can carry a voice signal.

Frequency modulation (FM) is a technique in which the carrier's frequency varies in response to changes in the modulating signal (Figure 1-5d). For a variety of technical reasons, conventional FM generally produces a cleaner signal than AM, but uses much more bandwidth. Narrowband FM, which is sometimesused in HFradio, provides animprovement in bandwidth utilization, butonlyatthe costof

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signalquality. It is intheUHFand VHFbandsthat FM comesintoitsown. RememberthattheHF bandis generallydefined asoccupying the spectrumfrom 1.6 MHzto 30 MHz. This is a span of only 28.4 MHz. The VHFband covers thespan of from 30 MHzto 300 MHz, which is a span of 270 MHz; nearly 10 times the span of HF. This extra room means that a channel bandwidth of 25 kHz is used to achieve high signal quality.

Radio Wave Propagation describes how radio signals radiate outward from a transmitting source. The action is simple to imagine for radio waves that travel in a straight line (picture that stone tossed into the still lake). The true path radio waves take, however, is often more complex.

There are two basic modes of propagation: ground waves and sky waves. As their names imply, ground waves travelalongthe surface of theearth, while skywaves "bounce" backtoearth. Figure 1-6 shows the different propagation paths for radio waves.

Ground waves consist of three components: surface waves, direct waves, and ground-reflected waves. Surface waves travel along the surface of the earth, reaching beyond the horizon. Eventually, the earth absorbs surface wave energy. The frequency and conductivity of the surface over which the waves travel largelydetermine the effective range of surface waves. Absorption increases with frequency.

Transmitted radio signals, which use a carrier traveling as a surface wave, are dependent on transmitter power, receiver sensitivity, antenna characteristics, and the type of path traveled. For a given complement of equipment, the range may extend from 200 to 250 miles over a conductive, all-sea-water path. Over arid, rocky, non-conductive terrain, however, the range may drop to less than 20 miles, even with the same equipment.

Direct waves travel in a straight line, becoming weaker as distance increases. They may be bent, or refracted, by the atmosphere, which extends their useful range slightly beyond the horizon. Transmitting and receiving antennas must be able to "see" each other for communications to take place, so antenna height is critical in determining range. Because of this, direct waves are sometimes known as line-of-sight (LOS) waves. This is the primary mode of propagation for VHF and UHF radio waves. Ground-reflected wavesaretheportion of thepropagated wave that is reflectedfromthe surface of the earth between the transmitter and receiver.

Sky waves make beyond line-of-sight (BLOS) communications possible. At frequencies below 30 MHz, radio waves are refracted (or bent), returning to earth hundreds or thousands of miles away. Depending on frequency, time of day, and atmospheric conditions, a signal can bounce several times before reaching a receiver.

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Electronic Flight Instrument System (EFIS)

An Electronic Flight Instrument System (EFIS) is a flight deck instrument display system in which the display technology used is electronic rather than electromechanical.

Early EFIS systems portray information using cathode ray tube (CRT) technology. Later instrument displays are presented on multi-colour liquid-crystal display (LCD) screens, which replace some or all of the conventional flight instruments for both pilots.

A typical EFIS system comprises a Primary Flight Display (PFD) (Electronic Attitude Direction Indicator (EADI)) and an Electronic Horizontal Situation Indicator (EHSI) (Navigation Display). In some designs the two displays are integrated into one.

An electronic flight instrument system (EFIS) is a flight deck instrument display system in which the display technology used is electronic rather than electromechanical. EFIS normally consists of a primary flight display (PFD), multi-function display (MFD) and engine indicating and crew alerting system (EICAS) display. Although cathode ray tube (CRT) displays were used at first, liquid crystal displays (LCD) are now more common. The complex electromechanical attitude director indicator (ADI) and horizontal situation indicator (HSI) were the first candidatesfor replacement by EFIS.
EFIS installations vary greatly. A light aircraft might be equipped with one display unit, on which flight and navigation data are displayed. A wide-body aircraft is likely to have six or more display units. An EFIS installation will follow the sequence:

- Displays
- Controls
- Data processors

A basic EFIS might have all these facilities in the one unit.

Display Units

- Primary flight display(PFD)
- Multi-function display (MFD) / Navigation display (ND)
- Engine indicationsand crewalerting system (EICAS)/ electronic centralized aircraft monitoring (ECAM)

Control Panels The pilots are provided with controls, with which they select display range and mode (for example, mapor compass rose) and enter data (such as selected heading).
Where inputs by the pilot are used byother equipment, data buses broadcast the pilot's selections so thatthepilotonlyneedstoenterthe selection once. For example, thepilotselects thedesired level-off

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altitude on a control unit. The EFIS repeats this selected altitude on the PFD and by comparing it with the actual altitude (from the air data computer) generates an altitude error display. This same altitude selection is used by the automatic flight control system to level off, and by the altitude alerting system to provide appropriatewarnings.

Data Processors: The EFIS visual display is produced by the symbol generator. This receives data inputs from the pilot, signals from sensors, and EFIS format selections made by the pilot. The symbol generator can go by other names, such as display processing computer display electronics unit, etc. The symbol generator does more than generate symbols. It has (at the least) monitoring facilities, a graphics generator and a display driver (this is a hardware not a software). Inputs from sensors and controls arrive via databuses, andare checked for validity. The required computations are performed, andthe graphics generator and display driver produce the inputs to the display units.

Example of a flight deck with electronic flight information displays

Primary Flight Display (PFD)

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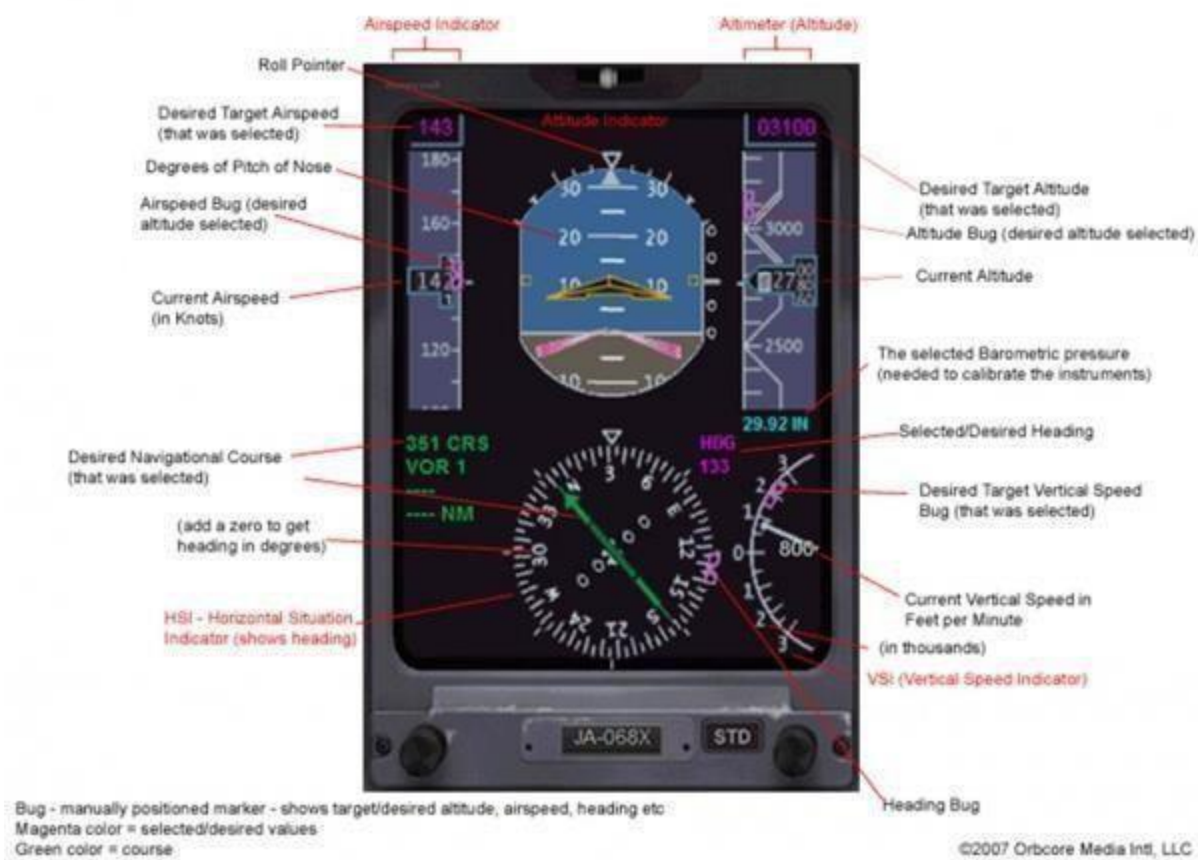
Primary Flight Display.

The Primary Flight Display (PFD) is an instrument which integrates and depicts, on a single display, all of the information that was historically presented on a number of individual electromechanical instruments. The PFD has evolved from a basic attitude indicator/flight director combination, presented electronically on a CRT, to an Electronic Attitude Direction Indicator (EADI) which, variable by manufacturer, added additional information such as heading, altitude and airspeed. The modern PFD displays virtually all of the information that the pilot requires to determine basic flight parameters (altitude, attitude, airspeed, rate of climb, heading, etc) plus autopilot and auto-throttle engagement status, flight director modes and approach status. Depending upon the phase of flight and pilot selections, the flight director will provide appropriate lateral guidance to maintain the selected track, heading or approach and missed approach track and vertical guidance for climb and descent, level off, approach and missed approach. This greatly reduces pilot workload while in manual flight and facilitates flight monitoring with the autopilot engaged as all required information is displayed on a single instrument.



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Integrated PFD / EHSI, *Source*: Orbcore Media Intl., LLC

In most cases, guidance is provided on the PFD to assist the pilot in folowing an ACAS RA.

Electronic Horizontal Situation Indicator (EHSI)

The Electronic Horizontal Situation Indicator (EHSI), often referred to as the Navigation Display (ND), replacesanumber of differentinstruments found ona conventional aircraft instrument panel, andmay be used to depict some or all of the following information:

- heading flown;
- heading or trackselected;
- bearing to or from a navigation beacon (VOR, DME);
- lateral deviation from a selected track;
- ground speed, distance and time to go;
- aeronautical map;
- weather information;

plus much more information according to design.

Figure illustrating the use of a typical EHSI in navigation mode and in weather mode.

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Monitoring

Likepersonal computers, flightinstrument systemsneed power-on-self-test facilities and continuous self-monitoring. Flightinstrument systems, however, need additional monitoring capabilities:

- Input validation – verify that each sensor is providing valid data
- Data comparison – cross check inputs from duplicated sensors
- Displaymonitoring – detect failures within the instrument system

Former Practice

Traditional (electromechanical) displays were equipped with synchro mechanisms which would transmit, to an instrument comparator, the pitch, roll and heading that were actuallybeing shown on the Captain's and First Officer's instruments. The comparator warned of excessive differences between the Captain and First Officer displays. Even a fault as far downstream(Downstream and upstream refer to the direction of data flow; from sensor, to processor, to display) as a jam in, say, the roll mechanism of an ADI would trigger a comparator warning.

The instrument comparator thus provided both comparator monitoring and display monitoring.

Comparator Monitoring

With EFIS, the comparator function isassimple asever. Is the roll data (bank angle) from sensor 1 the same astherolldatafrom sensor 2? If not, putawarning caption (such as CHECK ROLL) onboth PFDs.

Comparison monitors will give warnings for airspeeds, pitch, roll and altitude indications. The more advanced EFIS systems, more comparator monitors will be enabled.

Display Monitoring

An EFIS display allows no easy re-transmission of what is shown on the display. What is required is a new approachto displaymonitoring thatprovides safetyequivalent to thatofthetraditionalsystem.Onesolution is to keep the display unitas simple as possible, so thatitisunable to introduce errors. The display unit either works or does not work. A failure is always obvious, never insidious. Now the monitoring function can be shifted upstream to the output of the symbol generator. In this technique, each symbol generator contains two display monitoring channels. One channel, the internal, samples the output from its own symbol generator to the display unit and computes, for example, what roll attitude should produce that indication. This computed roll attitude is then compared with the roll attitude input to the symbol generator from the INS or AHRS (Attitude and Heading Reference System). Anydifference hasprobably been introduced by faulty processing, andtriggers awarning ontherelevant display. The external monitoring channel carries out the same check on the symbol generator on the other side of the flight deck: the Captain's symbol generator checks the First Officer's, the First Officer's checks the Captain's. Whichever symbol generator detects a fault, puts up a warning on its own display. The external monitoring channel also checks sensor inputs (to the symbol generator) for reasonableness. A spurious input, such as a radio height greater than the radio altimeter's maximum, results in a warning.

B737 NG FlightInstruments

The NG'shave 6Display Units(DU's), thesedisplaytheflightinstruments; navigation,engineand some system displays. They are controlled by 2 computers

Display Electronics Units(DEU's). Normally DEU

1controlstheCaptainsand theUpper DU's whilst DEU

2 controls the F/O's and the lower DU's.

The whole system together is known as the Common Display System(CDS). The DU's normally display the PFD's outboard, ND's inboard, engine primary display centre (upper) and engine secondary display lower. Although they can be switched around into almost any other configuration with the DU selector. The CDS FAULT annunciation will only occur on the ground prior to the second engine start, it is probably a DEU failure butisinany case a no-go item. If a DEUfails in-flight, the remaining DEUwill automatically power all 6 DU's and a DSPLY SOURCE annunciation will appear on both PFD's. The nomenclature requirements for these annunciations were developed by Boeing Flight Deck Crew Operations engineers during the early design phase of the 737NG program.

The intent of the design function is as follows:

- The CDS FAULT message is intended to be activated on ground to tell the maintenance crew or air crew that the airplane is in a non-dispatch able condition.

- The DISPLAY SOURCE message is annunciated in air to tell the crew that all the primary display information is from one source and should be compared with all other data sources (standby instruments, raw data, etc.) to validate its accuracy. Since the DISPLAY SOURCE message is intended to be activated in air and CDS FAULT is intended to be activated on ground, air/ground logic is used by CDS to determine which message is appropriate. The air/ground logic system uses a number of inputs to determine airplane state. One of the inputsused is"engines running". CDS uses the "engines running" logic as the primary trigger for changing the CDS FAULT message to its in-air counterpart. The "engines running" logic is used in case the air/ground data isn't correct as a result of other air/ground sensing faults.

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In-flight entertainment (IFE) refers to the entertainment available to aircraft passengers during a flight. IFE was delivered in the form of food and drink services, along with an occasional projector movie during lengthy flights. In 1985 the first personal audio player was offered to passengers, along with noise cancelling headphones in 1989.[2] Duringthe 1990sthedemandforbetter IFE wasamajorfactor in the design of aircraft cabins. Before then, the most a passenger could expect was a movie projected on a screen at thefront of a cabin, which could be heard via a headphone socket at his or her seat. Now, in most aircraft, private IFE TV screens are offered on most airlines.

The current European trend is to implement bring your own device systems that provide internet connectivity, allowing the user to stream a predefined range of multimedia content. Following this trend, companies such as Immfly are advancing at a fast pace to deliver on-board entertainment on short-haul commercial flights.

Design issues for IFE include system safety, cost efficiency, software reliability,hardware maintenance, and user compatibility.

The in-flight entertainment onboard airlines is frequently managed by content service providers.

History

The first in-flight film screened during the 1921 Parade of Progress Exposition in Chicago

The first in-flight movie was in 1921 on Aeromarine Airways showing a film called*Howdy Chicago* to its passengers as the amphibious airplane flew around Chicago.[3] The film *The Lost World* was shown to passengersofanImperialAirwaysflight inApril1925between London(CroydonAirport) andParis.[4] Eleven years laterin 1932, thefirst in-flight television called 'mediaevent' was shownonaWestern Air Express Fokker F.10aircraft.[3]

The post-WWII British Bristol Brabazon airliner was initially specified with a 37-seat cinema within its hugefuselage; this was later reduced toa 23-seat cinema sharingthe rear of the aircraft with a lounge and cocktail bar. The aircraft never entered service.[5]

However, it was not until the 1960s that in-flight entertainment (other than reading, sitting in a lounge and talking, or looking out the window) was becoming mainstream and popular. In 1961, David Flexer of

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Inflight Motion Pictures developed the 16mm film system using a 25-inch reel for a wide variety of commercial aircraft. Capable of holding the entire film, and mounted horizontally to maximize space, this replaced the previous 30-inch-diameter film reels. In 1961, TWA committed to Flexer's technology and wasfirst to debut afeaturefilm in flight.[3] Interviewed by the New Yorker in 1962, Mr Flexner said, "an awful lot of ingenuity has gone into this thing, which started from my simply thinking one day, in flight, that air travel is both the most advancedform of transportation and themost boring."[6] Amerlon Productions, a subsidiary of Inflight, produced at least one film, *Deadlier Than the Male*, specifically for use on airplanes.

In 1963, AVID Airline Products developed and manufactured the first pneumatic headset used on board the airlines and provided these early headsets to TWA. These early systems consisted of in-seat audio that could be heard with hollow tube headphones.[3] In 1979 pneumatic headsets were replaced by electronic headsets. The electronic headsets were initially available only on selected flights and premium cabins whereas economy class still had to make do with the old pneumatic headsets.[*citation needed*] In the United States, the last airline to offer pneumatic headphones was Delta Air Lines, which switchedto electronic headphones in 2003, despitethe fact that all Deltaaircraft equippedwithin-flight entertainment since the Boeing 767-200 have included jacks for electronic headphones.

Throughout the early to mid-1960s, some in-flight movies were played back from videotape, using early compact transistorized videotape recorders made by Sony (such as the SV-201 and PV-201) and Ampex (such as the VR-660 and VR-1500), and played back on CRT monitors mounted on the upper sides in the cabin abovethepassenger seats with several monitors placedafew seats apartfromeachother. The audio was played back through the headsets.

In 1971, TRANSCOM developed the 8mm film cassette. Flight attendants could now change movies in-flight and add short subject programming.

In the late 1970s and early 1980s, CRT-based projectors began to appear on newer widebody aircraft, such as the Boeing 767. These used LaserDiscs or video cassettes for playback. Some airlines upgraded the old film IFE systems to the CRT-based systems in the late 1980s and early 1990s on some of their older widebodies. In 1985, Avicom introducedthefirst audioplayer system, based on the Philips Tape Cassette technology. In 1988, the Airvision company introduced the first in-seat audio/video on-demand systems using 2.7 inches (69 mm) LCD technology for Northwest Airlines. The trials, which were run by Northwest Airlines on its Boeing 747 fleet, received overwhelmingly positive passenger reaction. As a result, this completely replaced the CRT technology.

Today, in-flight entertainment is offered as an option on almost all wide body aircraft, while some narrow body aircraft are not equipped with anyform of In-flight entertainment at all. This is mainly due to the aircraft storage and weight limits. TheBoeing 757 was the first narrow body aircraft to widely feature bothaudio and video In-flight entertainment and today it is rare to find a Boeing 757 without an In-flight entertainment system. Most Boeing 757s feature ceiling-mounted CRT screens, although some newer 757s may feature drop-down LCDs or audio-video on demand systems in the back of each seat. ManyAirbus A320 series and Boeing 737 Next Generation aircraft are also equipped with drop-down LCD screens. Some airlines, such asWestJet, United Airlines, andDelta Air Lines, have equipped some narrow body aircraft with personal video screens at every seat. Others, such as Air Canada and JetBlue, have even equipped some regional jets with AVOD.

For the introduction of personal TVs onboard jetBlue, company management tracked that lavatory queuingwentfar down. They originally had twoplanes, onewithfunctioningIFEand one withnone, the functioning one later was called "the happy plane".

System safety and regulation

Onemajorobstacle in creating an in-flight entertainment system is system safety. Withthesometimes miles of wiring involved, voltage leaks and arcing become a problem. This is of more than theoretical concern. The IFE system was implicated in the crash of Swissair Flight 111 in 1998. To contain any possible issues, the in-flight entertainment system is typically isolated from the main systems of the aircraft. In the United States, for a product to be considered safe and reliable, it must be certified by the FAA and pass all of the applicable requirements found in the Federal Aviation Regulations. The concerning section, ortitle, dealing withthe aviation industry andtheelectronic systems embedded in theaircraft, is CFR title 14 part 25. Contained inside Part 25 are rules relating to theaircraft's electronic system.

There aretwomajor sections of the FAA"s airworthiness regulations that regulate flight entertainment systemsandtheir safety in transport category aircraft: 14 CFR25.1301 which approvestheelectronic equipmentforinstallation anduse, byassuring thatthe system in question is properlylabeled, andthat its design is appropriate to its intended function. 14 CFR 25.1309 states that the electrical equipment must not alter the safety or functionality of the aircraft upon the result of a failure. One way for the intended IFE system to meet this regulatory requirement is for it to be independent from the aircraft's main power source and processor. By separating the power supplies and data links from that of the aircraft's performanceprocessor, intheevent of afailure thesystem is self-sustained, andcan not alter the functionality of the aircraft. Upon a showing of compliance to all of the applicable U.S. regulationsthe in-flight entertainment system is capable of being approved in the United States. Certain U.S. design approvals for IFE may be directly accepted in other countries, or may be capable of being validated, under existing bilateral airworthiness safety agreements.

Cost efficiency

The companies involvedare in aconstant battletocut costs ofproduction, without cutting the system's quality and compatibility. Cutting production costs may be achieved by anything from altering the housing for personal televisions, to reducing the amount of embedded software in the in-flight entertainmentprocessor. Difficulties with cost are also present withthe customers, orairlines, looking to purchase in-flight entertainment systems. Most in-flight entertainment systems are purchased by existing airlines as an upgrade package to an existing fleet of aircraft. This cost can be anywhere from $2 million to $5 million for a plane to be equipped with a set of seat back LCD monitors and an embedded IFE system. Some of the IFE systems are being purchased already installed in a new aircraft, such as the Airbus A320, which eliminates the possibility of having upgrade difficulties. Some airlines are passing the cost directly into thecustomers ticket price, while some are charging auserfee based on anindividual customers use. Some are also attempting to get a majority of the cost paid for by advertisements on, around, and in their IFE.

The largest international airlines sometimes pay more than $90,000 for a licence to show one movie over aperiod of twoorthreemonths. These airlines usually featureup to 100 movies at once, whereas 20 years ago they would have only 10 or 12. In the United States, airlines pay a flat fee every time the movie is watchedbya passenger. Some airlines spend up to$20 million per yearon content.[13]

Software reliability

Software for In-flight entertainment systems should be aesthetically pleasing, reliable, compatible, and also must be user friendly. These restrictions account for expensive engineering of individually specific software. In-flight entertainment equipment is often touch screen sensitive, allowing interaction between each seat in the aircraft and the flight attendants, which is wireless in some systems. Along with a complete aircraft intranet to deal with, the software of the in-flight entertainment system must be reliable when communicating to and from the main In-flight entertainment processor. These additional requirements not only place an additional strain on the software engineers, but also on the price.Programmingerrors canslipthroughthetestingphasesofthesoftwareandcauseproblems.[14]

Varieties of in-flight entertainment

Moving-map systems

Simplified version of Airshow

A moving-map system is a real-time flight information video channel broadcast through to cabin project/video screens and personal televisions (PTVs). In addition to displaying a map that illustrates the position and direction of the plane, the system gives the altitude, airspeed, outside air temperature, distance to the destination, distance from the origination point, and local time. The moving-map system information is derived in real time from the aircraft's flight computer systems.[15]

The first moving-map system designed for passengers was named **Airshow** and introduced in 1982.[16] It was invented by Airshow Inc (ASINC), a small southern California corporation, which later became part of Rockwell Collins. KLMand Swissair were the first airlines to offer the moving map systems to their passengers.

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The latest versions of moving-maps offered by IFE manufacturers include AdonisOne IFE, ICARUS Moving Map Systems, Airshow 4200 by Rockwell Collins, iXplor2 by Panasonic Avionics and JetMap HD by Honeywell Aerospace. In 2013, Betria Interactive unveiled FlightPath3D, a fully interactive moving-map that enables passengers to zoom and pan around a 3D world map using touch gestures, similar to Google Earth.[17] FlightPath3D was chosen by Norwegian as the moving-map on their new fleet of Boeing787Dreamliners, runningon Panasonic's Androidbased touch-screen IFE system.[18]

After the attempted Christmas Day bombing of 2009, the United States Transportation Security Administration (TSA) brieflyordered the live-map shut-off on internationalflights landing in the United States. Some airlines complained that doing so may compel the entire IFE system to remain shut. After complaints from airlines and passengers alike, these restrictions were eased.

Audio entertainment

Audio entertainment covers music, as well as news, information, and comedy. Most music channels are pre-recorded and feature their own DJs to provide chatter, song introductions, and interviews with artists. In addition, there is sometimes a channel devoted to the plane's radio communications, allowing passengers to listen in on thepilot's in-flight conversations withotherplanesand ground stations.

In audio-video on demand (AVOD) systems, software such as MusicMatch is used to select music off the music server. Phillips Music Server is one of the most widely used servers running under Windows Media Center used to control AVOD systems.

This form of in-flight entertainment is experienced through headphones that are distributed to the passengers. The headphone plugs are usually only compatible with the audio socket on the passenger's armrest (and vice versa), and some airlines may charge a small fee to obtain a pair. The headphones provided can also be used for the viewing of personal televisions.

In-flight entertainment systems have been made compatible with XM Satellite Radio and with iPods, allowing passengers to access their accounts or bring their own music, along with offering libraries of full audio CDs from an assortment of artists.[19]

Video entertainment

iQ entertainment system on a Qantas A330

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Video entertainment is provided via a large video screen at the front of a cabin section, as well as smaller monitors situated every few rows above the aisles. Sound is supplied via the same headphones as those distributed for audio entertainment.

However, personal televisions (PTVs) for every passenger provide passengers with channels broadcasting new and classic films, as well as comedies, news, sports programming, documentaries, children's shows, and drama series. Some airlines also present news and current affairs programming, which are often pre-recorded and delivered in the early morning before flights commence.

PTVs are operated via an In flight Management System which stores pre-recorded channels on a central server and streams them to PTV equipped seats during flight.AVOD systems store individual programs separately, allowing a passenger to have a specific program streamed to them privately, and be able to control the playback.

Some airlines also provide video games as part of the video entertainment system. For example, Singapore Airlinespassengers on some flights have access to a number of Super Nintendo games as part of its *KrisWorld* entertainment system. Also Virgin America's and V Australia's new *RED* Entertainment System offers passengers internet gaming over aLinux-based operating system.[20]

Personal televisions

Panasonic eFX system installed on a Delta Air Lines Boeing 737-800

Some airlines have now installed personal televisions (otherwise known as PTVs) for every passenger on most long-haul routes. These televisions are usually located in the seat-backs or tucked away in the armrests for front row seats and first class. Some show direct broadcast satellite television which enables passengers to view live TV broadcasts. Some airlines also offer video games using PTV equipment. Fewer still provide closed captioning fordeaf andhard-of-hearing passengers.

Audio-video on demand (AVOD) entertainment has also been introduced. This enables passengers to pause, rewind, fast-forward, or stopaprogram that they havebeenwatching. Thisis in contrasttoolder entertainment systems where no interactivity is provided for. AVOD also allows the passengers to choose among movies stored in the aircraft computer system.

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In addition to the personal televisions that are installed in the seatbacks, a new portable media player (PMP) revolution is under way. There are twotypes available: commercial off the shelf (COTS) based players and proprietary players. PMPs can be handed out and collected by the cabin crew, or can be "semi-embedded" intotheseatbackor seat arm.Inboth of thesescenarios,thePMP canpopin andout of an enclosure built into the seat, oran armenclosure. Anadvantage of PMPs is that, unlike seatback PTVs, equipment boxes for the inflight entertainment system do not need to be installed under the seats, since those boxes increase the weight of the aircraft and impede legroom.

In-flight movies

Personal on-demand videos are stored in an aircraft's main in-flight entertainment system, from whence they can be viewed on demand by a passenger over the aircraft's built in media server and wireless broadcast system. Along with the on-demand concept comes the ability for the user to pause, rewind, fast forward, or jump to any point in the movie. There are also movies that are shown throughout the aircraft at one time, often on shared overhead screens or a screen in the front of the cabin. More modern aircraft are now allowing Personal Electronic Devices (PED's) to be used to connect to the on board in-flight entertainment systems.

Regularly scheduled in flight movies began to premiere in 1961 on flights from New York to Los Angeles.[21]

Closed-captioning

Closed captioning technology for deaf and hard-of-hearing passengers started in 2008 with Emirates Airlines. The captions are text streamed along with video and spoken audio and enables passengers to either enable or disable the subtitle/caption language. Closed captioning is capable of streaming various text languages, including Arabic, Chinese, English, French, German, Hindi, Spanish, and Russian. The technology is currently based on Scenarist file multiplexing so far; however, portable media players tend to use alternative technologies. A WAEA technical committee is trying to standardize the closed caption specification. In 2009, the US Department of Transportation ruled a compulsory use of captions of all videos, DVDs, and other audio-visual displays played for safety and/or informational purposes in aircraft should be high-contrast captioned (e.g., white letters on a consistent black background [14 CFR Part 382/ RIN 2105-AD41 /OSTDocket No. 2006-23999]). As of 2013, severalairlines, including

- United Airlines,
- Qantas
- Southwest
- and Emirates,

have closed-captioning provided on their AVOD systems.

In-flight games[

Video games are another emerging facet of in-flight entertainment. Some game systems are networked to allow interactive playing by multiple passengers. Later generations of IFE games began to shift focus from pure entertainment to learning. The best examples of this changing trend are the popular trivia

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gameseriesandthe Berlitz Word Travelerthat allows passengers tolearnanewlanguage in theirown language. Appearing as a mixture of lessons and mini games, passengers can learn the basics of a new language while being entertained. Many more learning applications continue to appear in the IFE market.

Islamic prayers and directions to Mecca

In several airlinesfrom the Muslim worldthe AVOD systems provide Qibla directions to allow Muslims to pray toward Mecca(e.g. Emirates, Etihad, Malaysia Airlines, Qatar Airways, Royal Jordanian and Saudia); Malaysia Airlines has built-in Qur'ane-books and Garuda Indonesia has a unique Qur'an channel.

Several Islamic airlines may also switch to a pre-flight Qur'an prayer prior to taking off, like Egypt Air, Etihad, Jazeera Airways, Kuwait Airways, Pakistan International Airlines, Royal Brunei, and Saudia.

In-flight connectivity

In recent years, IFE has been expanded to include in-flight connectivity—services such as Internet browsing, text messaging, cell phone usage (where permitted), and emailing. In fact, some in the airline industry have begun referring to the entire in-flight-entertainment category as "IFEC" (In-Flight Entertainment and Connectivity or In-Flight Entertainment and Communication).

The airline manufacturer Boeing entered into the in-flight-connectivity industry in 2000 and 2001 with an offshoot calledConnexion by Boeing. The service was designed to provide in-flight broadband service to commercial airlines; Boeing built partnerships with United Airlines, Delta, and American. By 2006, however, the company announced it was closing down its Connexion operation. Industry analysts cited technology, weight, and cost issues as making the service unfeasible at the time. The Connexion hardware that needed to be installed on an aircraft, for example, weighed nearly 1,000 pounds (450 kg), which added more"drag" (a force working against theforwardmovement of theplane) and weight than was tolerable for the airlines.

Since the shuttering of Connexion by Boeing, several new providers have emerged todeliver in-flight broadband to airlines—notably Row 44, OnAir and AeroMobile (who offer satellite-based solutions), and Aircell (which offers air-to-ground connectivity via a cellular signal).

In the past few years, many US commercial airlines have begun testing and deploying in-flight connectivity for their passengers, such as Alaska Airlines, American, Delta, and United. Industry expectations were that bythe end of 2011, thousands of planesflying in the US will offer some form of in-flight broadband to passengers. Airlines around the world are also beginning to test in-flight-broadband offerings aswell.

Satellite and internal telephony

Some airlines provide satellite telephones integrated into their system. These are either found at strategic locations in theaircraft or integrated into thepassenger remote controlusedfortheindividual in-flight entertainment. Passengers can use their credit card to make phone calls anywhere on the ground. A rate close to US$10.00/minute is usually charged regardless of where the recipient is located andaconnection feemaybeappliedeven if therecipient does notanswer. These systems areusually notcapable of receiving incoming calls. There arealso some aircraft thatallowfaxes to besentandthe rate is usually the same as the call rate, but at a per page rate. Some systems also allow the transmission of SMS.

More modern systems allow passengers to call fellow passengers located in another seat by simply keying in the recipient's seat number.

Data communication

IFE producers have begun to introduce Intranet type systems. Virgin America's and V Australia's *RED* Entertainment System allows for passengers to chat amongst one another, compete against each other in the provided games, talk to the flight attendants and request, and pay for in advance, food or drinks, and have full access to the internet and email.

Wi-Fi

Several airlinesaretesting in-cabin wi-fi systems. In-flight internet service is provided eitherthrougha satellite network or an air-to-ground network. In the Airbus A380 aircraft, data communication via satellite system allows passengers to connect to live Internet from the individual IFE units or their laptops via the in-flight Wi-Fi access.

Boeing's cancellation of the Connexion by Boeing system in 2006 caused concerns that inflight internet would not be available on next-generation aircraft such as Qantas' fleet of Airbus A380s and Boeing Dreamliner 787s. However, Qantasannounced in July 2007 that all service classes in its fleet of A380s would have wireless internet access as well as seat-back access to email and cached web browsing when the Airbuses started operations in October 2008. Certain elements were also retrofitted into existing Boeing747-400s.[29]

Sixteen major U.S. airlines now offerWi-Fi connectivity service on their aircraft. The majority of these airlines use the service provided by Gogo Wi-Fi service. The service allows for Wi-Fi enabled devices to connect to the Internet. Delta currently has the most Wi-Fi equipped fleet with 500 aircraft that now offer in-flight Wi-Fi.[30]

Mobile phone

As a general rule, mobile phone use while airborne is usually not just prohibited by the carrier but also by regulatoryagencies in the relevantjurisdiction (e.g. FAAand FCC in the US). However, withadded technology, some carriers nonetheless allowthe use of mobile phones on selected routes.

Emirates became the first airline to allow mobile phones to be used during flight. Using the systems supplied by telecom company AeroMobile, Emirates launched the service commercially on 20 March 2008.[31] Installed first on an Airbus A340-300, AeroMobile is presently operating on Emirates A340, A330, and B777 aircraft.[32] Emirates plannedto rollout the system over their entirefleet by 2010.

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Ryanair had previously aimed to become the first airline to enable mobile phone usage in the air, but instead ended up launching its system commercially in February 2009.[33] The system is set up on 22 737-800 jets based at Dublin Airport and wasfitted on Ryanair's 200+fleetoff 737-800 jets by 2010.

ACARS data Communication Systems

ACARS (an acronym for **aircraft communications addressing and reporting system**) is a digital datalink system for transmission of short messages between aircraft and ground stations via airband radio or satellite. The protocol was designed by ARINC and deployed in 1978, using the Telexformat. More ACARS radio stations were added subsequently by SITA.

History of ACARS

Prior to the introduction of datalink in aviation, all communication between the aircraft and ground personnel was performed by theflight crew using voice communication, using either VHFor HF voice radios. In many cases, the voice-relayed information involved dedicated radio operators and digital messages sent to an airline teletype system or successor systems.

Further, the hourly rates for flight and cabin crew salaries depended on whether the aircraft was airborne ornot, and if on the ground whether it was at the gate or not. The flight crews reported these times by voice to geographically dispersed radio operators. Airlines wanted to eliminate self-reported times to preclude inaccuracies, whether accidental or deliberate. Doing so would also reduce the need for human radio operators to receive the reports.

In an effort to reduce crew workload and improve data integrity, the engineering department at ARINC introduced the ACARS system in July 1978, as essentially an automated time clock system. Teledyne Controls produced the avionics and the launch customer was Piedmont Airlines. The original expansion of the abbreviation was "Arinc Communications Addressing and Reporting System".[2] Later, it was changed to "Aircraft Communications, Addressing and Reporting System". The original avionics standard was ARINC 597, which defined an ACARS Management Unit consisting of discrete inputsforthe doors, parking brake and weight on wheels sensors to automatically determine the flight phase and generate and send as telex messages. It also contained a MSK modem used to transmit the reports over existing VHF voice radios. Global standards for ACARS were prepared by the Airlines Electronic Engineering Committee (AEEC). The first day of ARINC operations saw about 4,000 transactions, but ACARSdidnotexperience widespread use bythemajor airlines untilthe 1980s.

Early ACARS systems were extended over the years to support aircraft with digital data bus interfaces, flight management systems, and printers.

Systemdescriptionandfunctions

ACARS as a term refers to the complete air and ground system, consisting of equipment on board, equipment on the ground, and a service provider.

On-board ACARS equipment consists of end systems with a router, which routes messages through the air-ground subnetwork.

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Ground equipment is made up of a network of radio transceivers managed by a central site computer called AFEPS (Arinc Front End Processor System), which handles and routes messages. Generally, ground ACARS units are either government agencies such as the Federal Aviation Administration, an airline operations headquarters, or, for small airlines or general aviation, a third-party subscription service. Usually government agencies are responsible for clearances, while airline operations handle gate assignments, maintenance, and passenger needs.

The ground processing system[edit]

Ground system provision is the responsibility of either a participating ANSP or an aircraft operator. Aircraft operators often contract out the function to either DSP or to a separate service provider. Messages from aircraft, especially automatically generated ones, can be pre-configured according to message type so that they are automatically delivered to the appropriate recipient just as ground-originated messages can be configured to reach the correct aircraft.[*citation needed*]

The ACARS equipment on the aircraft is linked to that on the ground by the datalink service provider. Because the ACARS network is modeled after the point-to-point telex network, all messages come to a central processing location to be routed.ARINC and SITA are the two primary service providers, with smaller operationsfrom others in some areas. Some areas have multiple service providers.

ACARS messagetypes**ACARSmessagesmaybeofthreebroadtypes:**

- Air traffic control messages are used to request or provide clearances.
- Aeronautical operational control
- Airline administrative control

Control messages are used to communicate between the aircraft and its base, with messages either standardized according to ARINC Standard 633, or user-defined in accordance with ARINC Standard 618.[5] The contents of such messages can be OOOI events, flight plans, weather information, equipment health, status of connecting flights, etc.

OOOI events

A major function of ACARS is to automatically detect and report the start of each major flight phase, called OOOI events in the industry (out of the gate, off the ground, on the ground, and into the gate).[6] These OOOI events are detected using input from aircraft sensors mounted on doors, parking brakes, and struts. At the start of each flight phase, an ACARS message is transmitted to the ground describing the flight phase, the time at which it occurred, and other related information such as the amountoffuelonboardortheflight originanddestination. Thesemessagesareusedtotrackthestatus of aircraft and crews.

Flight management system interface

ACARS interfaces with FMS flight management systems, acting as the communication system for flight plans and weather information to be sent from the ground to the FMS. This enables the airline to update the FMS while in flight, and allows the flight crew to evaluate new weather conditions or alternative flight plans.

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Equipment health and maintenance data

ACARS is usedto send information from theaircraft to ground stations aboutthe conditions of various aircraft systems and sensors in real-time. Maintenance faults and abnormal events are also transmitted to ground stations along with detailed messages, which are used by the airline for monitoring equipment health, and to better plan repair and maintenance activities.

Ping messages[edit]

Automated ping messages are used to test an aircraft's connection with the communication station.[7] In the event that the aircraft ACARS unit has been silent for longer than a preset time interval, the ground station can ping the aircraft (directly or via satellite). A ping response indicates a healthy ACARS communication.

Manually sent messages

ACARS interfaces with interactive display units in the cockpit, which flight crews can use to send and receive technical messages and reports to or from ground stations, such as a request for weather information or clearances or the status of connecting flights. The response from the ground station is received on the aircraft via ACARS as well. Each airline customizes ACARS to this role to suit its needs.

Communicationdetails

ACARS messages may be sent using a choice of communication methods, such as VHF or HF, either direct to ground or via satellite, using minimum-shift keying (MSK) modulation.

ACARS can send messages over VHF if a VHFground station network exists in the currentarea of the aircraft. VHF communication is line-of-sight propagation and the typical range is up to 200 nautical miles at high altitudes. Where VHF is absent, an HF network or satellite communication may be used if available. Satellite coverage may be limited at high latitudes (trans-polar flights).

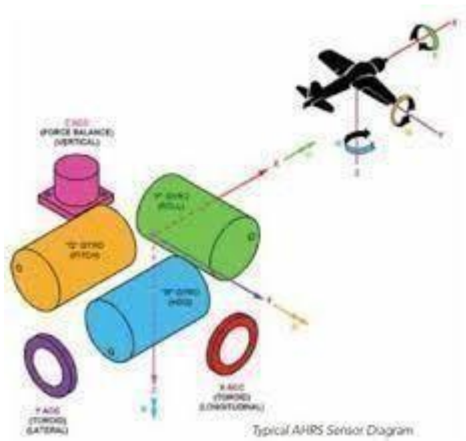
Roleof ACARSinairaccidentsandincidents

In the wake of the crash of Air France Flight 447 in 2009, there was discussion about making ACARS an "online-black-box" to reduce the effects of the loss of a flight recorder. However no changes were made to the ACARSsystem.

In March 2014, ACARS messages and Doppler analysis of ACARS satellite communication data played a verysignificant role in effortstotrace Malaysia Airlines Flight 370 to an approximate location.Whilethe primary ACARS system on board MH370 had been switched off, a second ACARS system called Classic Aero was active as long as the plane was powered up, and kept trying to establish a connection to an Inmarsat satellite every hour.

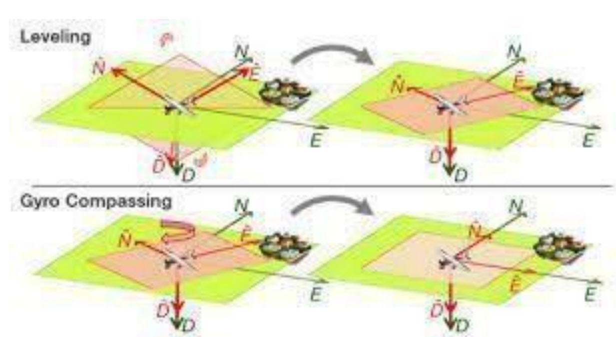
The ACARS on the Airbus A320 of EgyptAir flight 804 reported "irregularities" to ground staff on three separate occasions, which ledtothree emergency landings, in the 24 hours prior totheaircraft's crash into the Mediterranean Sea on May 19, 2016, which killed all 66 persons on board. The specific nature of the irregularities was not explained, but at each instance the aircraft was given clearance to continue its flight.

UNIT 3: INERIAL SENSORS AND GLOBAL POSIOTIONING SYSTEM



Inertial Sensorsand Global Positioning System

MRCET UGC AUTONOMOUS



UNIT 3: INERIAL SENSORS AND GLOBAL POSIOTIONING SYSTEM

Introduction: Gyroscopes and Accelerometers are known as inertial sensors. This is because they exploit the property of inertia, namely the resistance to a change in momentum, to sense angular motion in the case of the gyro and changes in linearmotion in the case of the accelerometer. They are fundamentaltothecontrolandguidanceofanaircraft. For example,inaFBWaircrafttherategyrosand accelerometers provide the aircraft motion feedback which enables a maneuvers command control to beachieved andanaerodynamically unstableaircraft tobestabilized by theflight control system.

Inertiashows itspresencein a varietyof waysonadaily basis. Being pressedbackinto your seat asyou godowntherunwayorhaving your coffee cup spillover asthepilotappliesmaximum braking. Inertia is almost always the property that contributes to the fact that any time a tool slips out of hand; it will end up in the most inconvenient placepossible. Sir Isaac Newton'sfirst law of motion states that anobject set in motion tends to stay in motion unless acted upon by external forces.

Sensors can be used to measure different types of motion and by applying some mathematics accurate position calculations can be made from a specific starting point. The two most conclusive types of motion are acceleration and rotation. Gyroscopic sensors are usedfor measuring degree of rotation, while rate gyros measure the speed of rotary motion.

Accelerometers on the other hand are devices used to measure acceleration. The "G" force is the main unitfor measurement of acceleration and is calculated as 1G = 32 feet per second persecond.

Both gyroscopes and accelerometers use an inertial reference frame, which is ameans of providing a fixed point from which measurements can be made. An accelerometer in free fall has no detectable input thereforenomeasurement canbemade. The input axis of aninertialsensingdevicedefineswhat it can measure and inertial navigation uses gyros and accelerometers to maintain an estimate of position. These inertial navigation systems (INS) not only provide a reliable means of position ensuing for aircraft but have also found uses in spacecraft, missiles, ships, submarines, and even surface vehicles. An Inertial Navigation System is comprised of some type of inertial measuring unit (IMU) or inertial reference unit (IRU). This type of navigational system includes a group of sensors including gyroscopes and accelerometers. All sensing devices contained within are secured to a common base which ensures all sensing devices have the same reference orientation. These sensing units supply acquired information to a microprocessor where integration of all available data is initiated and only then an estimated position is formulated based on applied motions and initial position.

Gyros and accelerometers are also the essential elements of the spatial reference system or attitude/heading reference system (AHRS) and the inertial navigation system (INS). They largely determine the performance and accuracy of these systems andaccount for amajor part of the system cost. The AHRS and INS share common technology and operating principles.

Gyros used in older designs of control and guidance systems are what is termed 'spinning rotor gyros' as theyexploit the angular momentum of a spinning rotor to sense angular motion. However their

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mechanical complexity and inherent failure modes constrain their cost and reliability and hence cost of ownership. Power consumption and run-up time are further limiting parameters of this technology. Gyros operating on 'solid state' principles have been developed because of their intrinsically higher reliability andlower cost of ownership. Optical gyros such astheringlaser gyro and thefiber optic gyro are rapidly displacing the spinning rotor types of gyro.

Gyroscope:

Gyroscope is a device for measuring and maintaining orientation based on principle of angular momentum. Gyroscopes are sensors for measuring rotation: rate gyroscopes measure rotation rate, and integrating gyroscopes also called whole-angle gyroscopes) measure rotation angle.

Mechanically, Gyroscope is spinning wheel/disc mounted on axle and axle is free to assume any direction.

Spinning object that is tilted perpendicularly to the direction of the spin will have a precession.

• The precession keeps the device oriented in avertical direction so theanglerelative to thereference surface can bemeasured.

Types of Gyros:

1. Ring Laser (RLG) and

The Ring Laser Gyros (RLG) can be used as the stable elements (for one degree of freedom each) in an inertial guidance system. The advantage of using a RLG is that there are no moving parts. Compared to the conventional spinning gyro, this means there is no friction, which in turn means there will be no inherent drift terms. Additionally, the entire unit is compact, lightweight and virtually indestructable, meaning it can be used in aircraft.

The basic principle of operation is that a single RLG can measure any rotation about its sensitive axis. This implies that theorientation in inertial space will be known at all times. The elements that measure actual accelerations can therefore be resolved into the appropriate directions.

The ring laser gyro uses laser light to measure angular rotation. Each gyro is a triangular-shaped, helium-neon laser that produces two light beams, one traveling in the clockwise direction and one in the counterclockwise direction. Production of the light beams, or lasing, occurs in the gas discharge region by ionizing the low pressure mixture of helium-neon gas with high voltage to produce a

glow discharge. Light produced from the lasing is reflected around the triangle by mirrors at each corner of the triangle to produce the clockwise and counterclockwise light beams.

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The pathlengtharoundthe cavity is carefully monitored andadjusted so that it is an integralmultiple of the peak power laser wavelength.

When the laser gyro is at rest, the frequencies of the two opposite travelling laser beams are equal. When the laser gyro is rotated about an axis perpendicular to the lasing plane, afrequency difference between thetwolaser beamsresults. Thefrequencydifference is created because thespeed of light is constant.Onelaser beam will thushave agreater apparent distancetotravelthantheother laser beam in completing one pass around the cavity.

A small amount of light from the two laser beams passes through one of the mirrors (less than 0.2%). The beams are combined by opticalfrequencies to produce a beatfrequency. This takes theform of a fringe (interference) pattern. This beat frequency of light is analogous to two different audio frequencies which combine to produce a third difference frequency.

When the laser beam frequencies differ, a fringe pattern of alternate dark and light stripes is created. Photodiodes sense the fringe pattern rate and direction of movement. The frequency and relative phase of the two diode outputs indicate magnitude and the direction of the gyro's rotation.

At lowrotation rates, the small frequency difference betweenthelaser beams leadstobeam coupling. This locks the frequencies together at a single false value. To compensate for this effect a peizoelectric dither motor is used to vibrate the laser block throughthe lock-in region. Dither vibration has anet zero average. It producesnonet inertial rotation. The dither motor vibration can be felt on the IRU case and produces an audiblehum.

Here's how a RLG can measure rotation about its sensitive axis:

The input laser beam is split into two beams that travel the same path but in opposite directions: one clockwise and the other counter-clockwise.

The beamsarerecombined and sent totheoutputdetector. Intheabsence or rotation, thepath lengths will be the same and the output will be the total constructive interfernence of the two beams.

If the apparatus rotates, there will be a difference (to be shown later) in the path lengths travelled by thetwobeams, resulting in anetphase difference anddestructive interference. Thenet signal will vary in amplitude depending on the phase shift, therefore the resulting amplitude is a measurement of the phase shift, and consequently, the rotation rate.

1. Amplitude of output signal: fortwoequalinputs(perfect beam splitter), theoutput voltage, Vout=Vincos(Df/2), where Df =the phasedifference of thebeamsuponrecombination.

2. Phase difference due to path length difference. If the two paths are different by Dx, then that corresponds to a phase difference of Df = 2p/l(Dx).

3. Pathlengthdifference duetorotation. Assume thepathsare circular, withradius = R. Intheabsence of rotation, the total path is 2pR for each beam. If the entire apparatus rotates and a constant rate (in

the clockwise direction) given by w (radians per second) the two beams will travel different path lengths.

(A) Clockwise beam (beam 1): the beam will have to travel an additional amount (depending on time).

Path length 1 = 2pR + wRt1, where t1 is the total time for path 1.

Since thebeamtravelsatthespeed of light (regardless of rotationrate, aprinciple of special relativity), the total distance travelled by the beam in that time is ct1. In other words

ct1 = 2pR + wRt1.

We can solve for the time:

t1 = 2pR/(c - wR).

Which corresponds to intuition, that it will take longer than if there was no rotation.

(B) Counter-clockwise beam (beam 2): By asimilar argument,

t2 = 2pR/(c + wR)

Note that the sign has changed in the denominator, and this will take less time that if there were no rotation.

4. Phase difference with rotation: since the beams take different times, there will be a net phase shift when they arerecombined.

Dx = cDt = c (t1 - t2)

= 2pcR{ 1/(c - wR) - 1/(c + wR) }

= 2pcR{2wR/(c2 - w2R2)}

= 4pcR2 w/(c2 - w2R2)

But, wR <<c(otherwise, theouter part of thering would be travelling anearthespeed of light!)

Therefore we can neglect the contribution of that term to the denominator:

Dx ~ 4pR2w/c2.

Now, conmpute the phase shift:

Df ~ 2p/l (4pR2w/c2) = (8p2lR2/c2)w

And the resulting affect on Vout:

Vout = Vin cos{(4p2lR2/c2)w}

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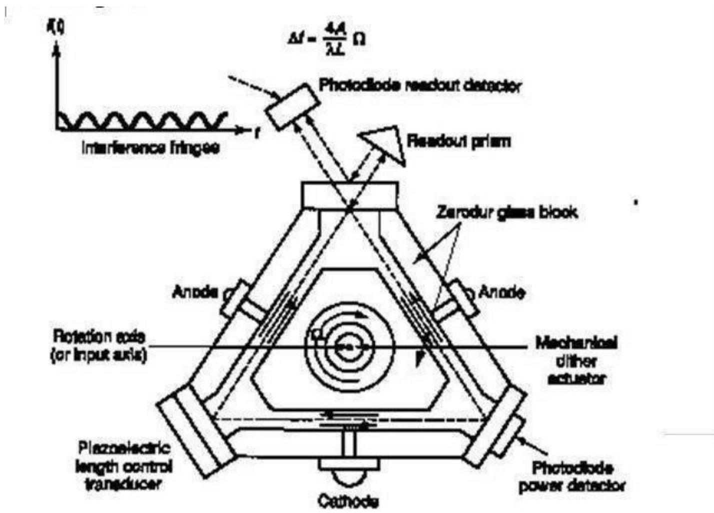
Since all the terms are constants, the output depends only on the rotation rate. The RLG therfore measures rotation rate about its sensitive axis.



Active optical resonator

Resonator is alaser itself (active) If gyro is rotatedcounter clock wisedirection, the counter-clock wise beam is travelling slightly longer than the opposite beam
The change in the path length is proportional to the rotation rate
In very small rotation rates there is a dead-band because of frequency lock-in

Ring laser gyroscopes may be classified as passive or active, depending upon whether the lasing, or gain, medium is external or internal to the cavity. In the active ring laser gyroscope the cavity defined by the closed optical path becomes an oscillator, and output beams from the two directions beat together to give a beat frequency that is a measure of the rotation rate. The oscillator approach means that the frequencyfiltering properties of the cavity resonatorare narrowed bymany orders of magnitude below the passive cavity and give very precise rotation sensing potential. To date the major ring laser gyroscope rotation sensor effort has been put into the active ring laser. Presently all commercially available optical rotation sensors are active ring laser gyroscopes.

When the rotation rate of the ring laser gyroscope is within a certain range, the frequency difference between the beams disappears. This phenomenon is called frequency lock-in, or mode locking, and is a major difficulty with the ring laser gyroscope because at low rotation rates the ring laser gyroscope produces a false indication that the device is not rotating. If the rotation rate of a ring laser gyroscope starts at a value above that where lock-in occurs and is then decreased, the frequency difference betweenthebeamsdisappearsata certain inputrotationrate. Thisinput rotation rate is called thelock-in threshold. The range of rotation rates over which lock-in occurs is the deadband of the ring laser gyroscope.

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Lock-in is beiieved to arise from coupling of light between the beams. The coupling results primarily from backscatter off the mirrors that confine the beams to the closed path. Backscatter causes the beam in each direction to include a small component having the frequency of the beam propagating in the other direction. The lock-in effect in a ring laser gyroscope is similar to the coupling that has been long been observed and understood in conventional electronic oscillators.

Upon reversal of the sign of the frequency difference between the two beams, there is a tendency for the beams to lock-in since at some point the frequency difference is zero. Since the output of the ring laser gyroscope is derived from the frequency difference, an error accumulates in the output angle. Since the periods in which the two beams are locked in are usually very short in duration, the error is very small. However, since the error is cumulative, in time the error can become appreciable in precision navigation systems. This error is called random walk or random drift.

In addition to causing erroneous rotation rate information to be output from a ring laser gyroscope, lock-in causes standing waves to appear on the mirror surfaces. These standing waves may create a grating of high and low absorption regions, which create localized losses that increase the coupling between the beans and the lock-in. The mirrors may be permanently distorfed by leaving a ring laser gyroscope operating in a lock-in condition.

Any inability to accurately measure low rotation rates reduces the effectiveness of a ring laser gyroscope in navigational systems. There has been substantial amount of research and development work to reduce oreliminate the effects of lock-in to enhance the effective use of ring laser gyroscopes in such systems.

There are several knownapproaches to solving the problems of lock-in. One such approach involves mechanically oscillating the ring laser gyroscope about its sensor axis so that the device is constantly sweeping through the deadband and is never locked therein. This mechanical oscillation of the ring laser gyroscope is usually called dithering. A typical ring laser gyroscope may be dithered at about 400 Hz with an angular displacement of a few arc minutes.

Mechanical dithering is accomplished by mounting the ring laser gyroscope frame on aflexure device that includes a plurality of vanes or blades extending from a central portion. Each blade has a pair of piezoelectric elements mounted on opposite sides thereof. Voltages are applied to the piezoelectric elements such that one piezoelectric element on each blade increases in length while the other piezoelectric element decreases in length. The effect of these length changes in the piezoelectric elements is transmitted to the blades through the mounting of the piezoelectric elements thereon. Increasingthe length of one side of eachblade while shorteningthe other side causes thebladestoflex or bend so that each blade experiences a small rotation about the ring laser gyroscope axis. The voltage is oscillatory so that the blades are constantly vibrating in phase, and the ring laser gyroscope frame mounted to the blades rotates about the axis.

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Body dither must be accomplished so that dither oscillations cause the ring laser gyroscope frame to rotate only about the sensing axis. Any small component of rotation about other axes causes the sensing axis to precess in a cone-shaped path about the direction in should point. This motion of the axis is called coning. Any change in the direction of the axis due to dithering introduces errors into the output of the ring laser gyroscope. Since a navigation system includes three ring laser gyroscopes mounted in an instrument block with the sensing axes being mutually orthogonal, mechanical coupling of the dither oscillations is likely.

To reduce coning, the plane of oscillation of the flexure is aligned perpendicular to the sensing axis, and the axis of the dither is collinear with the sensing axis to very close tolerances. To further minimize oscillations aboutother axes, theditherflexure should be as rigid as possible toresist anytendency to oscillate about other axes. Since all mechanical systems have natural frequencies of oscillation, there will in general be some small amount of osciilation about other axes. Typical prior art dither flexures have rotational and translational resonant frequencies below 1000 Hz and have relatively high compliances, which, when combined withrelatively low coning frequencies, leadto large system bias errors. These compliant flexures allow a relatively large amplitude frame input axis motion, which couples with system block motion to causeangleerrors that cannot be software compensated.

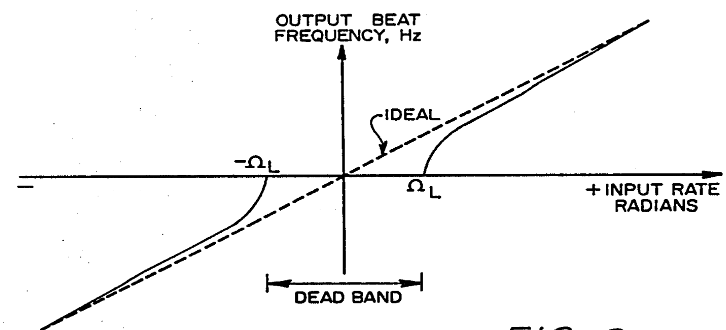


FIG. 8

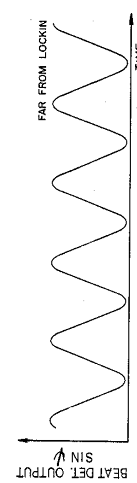


FIG. 10A

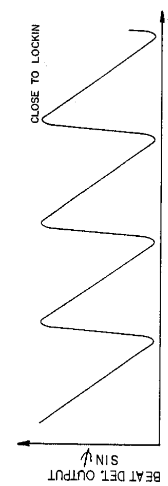
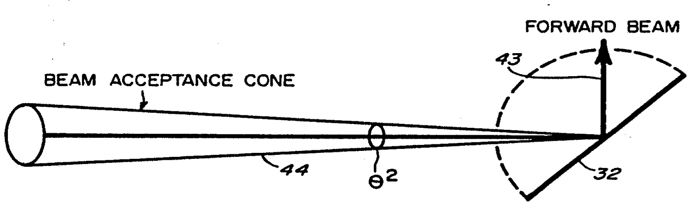


FIG. 10B



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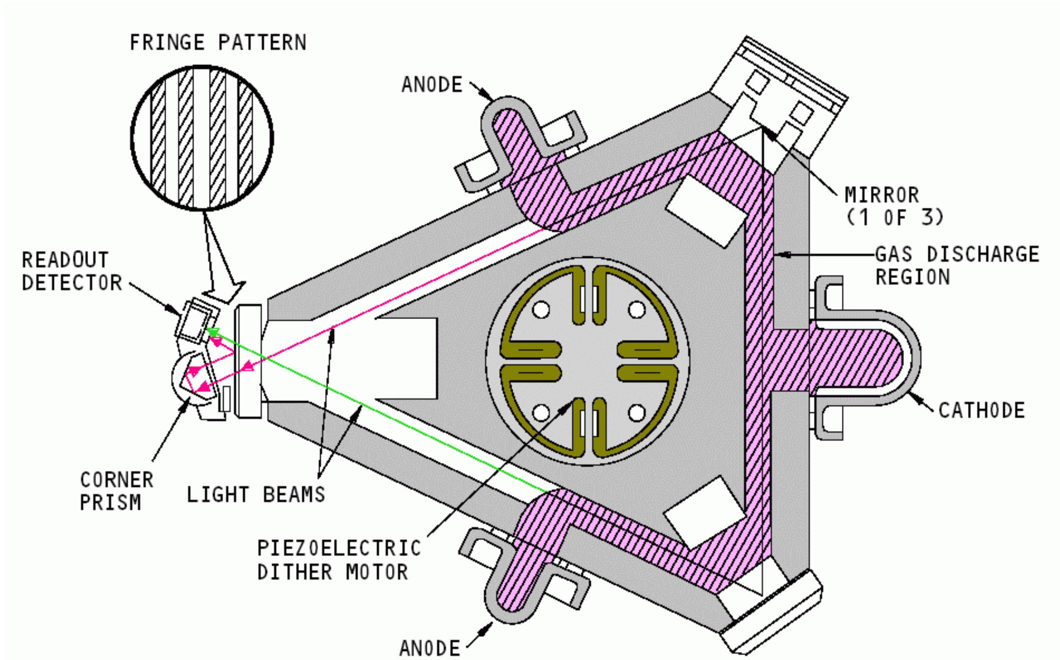

Laser Gyro

2. Fiber Optics Gyroscopes (FOG):

A **fibre optic gyroscope** (**FOG**) senses changes in orientation using the Sagnac effect, thus performing the function of a mechanical gyroscope. However its principle of operation is instead based on theinterference of light which has passed through a coil of optical fibre, which can be as long as 5 km.

A FOG provides extremely precise rotational rate information, in part because of its lackof cross-axis sensitivity to vibration, acceleration, and shock. Unlike the classic spinning-mass gyroscope, the FOG has no moving parts and doesn't rely on inertial resistance to movement. Hence, this is perhaps the most reliable alternative to the mechanical gyroscope. Because of their intrinsic reliability, FOGs are used for high performance space applications.
The FOG typically shows a higher resolution than aring laser gyroscope, but suffered from greater drift and worse scale factor performance until the end of the 1990s. FOGs are implemented in both open-loop and closed-loop configurations.

Time difference (sagnac effect) between CW and ACW paths is given by

$$\Delta A = \frac{4A}{c^2}A$$

Difference in path length

$$\Delta L = c\Delta A$$

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$$\Delta L = \frac{4A}{c} A$$

In absence of an input rate, the transit times of the two photons will be identical and equal to 2πR/c=T. consider the path rotating rate A

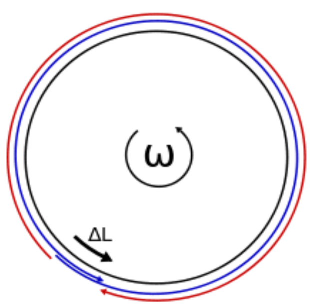
In time T,P has moved to P1 and the path length for CW photon is equal to (2πR+RAT), and the path length for the ACW photon is equal to (2πR+RAT).

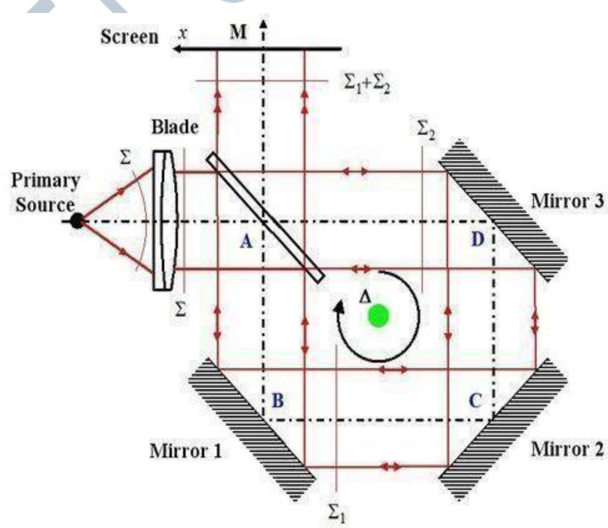
Difference transit time = $\frac{(2\pi R+RAT)-}{c}$ $\frac{(2\pi R-RAT)}{c}$

Substituting T=2πR/c, yields

$$\Delta A = \frac{4AA^2}{A c^2}$$

$$\Delta L = \frac{4AA^2}{A c}$$





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3. Dynamically tuned Gyroscopes (DTG):

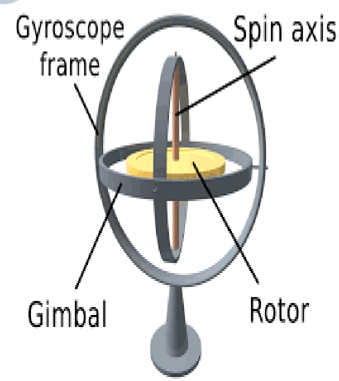
A dynamically tuned gyro is a mechanical gyroscope. It contains a rotor that is held betweenextremely freepivots. Ataparticular speedcalled thetuning speedthe rotor is free from torque due to rotation and can be used asa conventional or ideal gyroscope to measure rotation/rotary displacement from gimbal.

Based on conservation of momentum

1. Continuous angular movement flywheel gyroscope
2. Oscillatory angular momentum employ a torsionally suspended mass oscillating back and forth at its natural frequency
3. Continuous linear momentum Steady stream of fluid, plasma orelectrons, which tend to maintain its established velocity
4. Oscillatory linear momentum a set of discret masses moving back and forth along a straight line path (* or) (tuning-fork rate gyro)

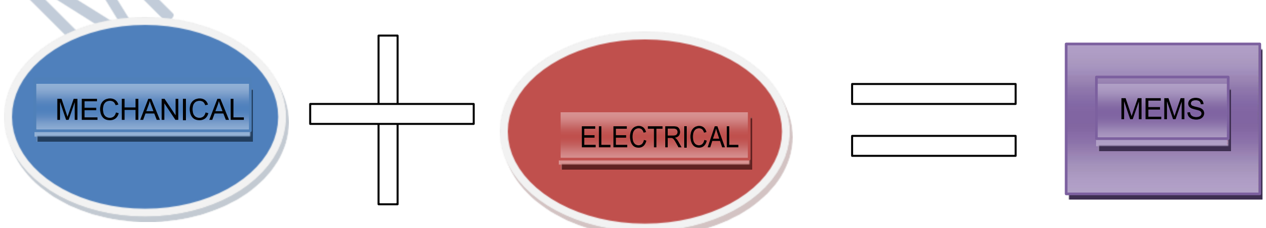
Applications of conventional mechanical gyroscopes:

- Aircrafts
- Ships
- Missiles
- Satellites



4. MEMS Gyroscopes:

The term MEMS stand for micro-electro-mechanical systems. Typically, MEMS sensing structures range from 1 micrometer to 100 micrometers. MEMS gyroscopes use a vibrating element for rate measurement. The underlying principle is, any vibrating body has a tendency to continue vibrating in its plane of vibration. As a consequence, if the orientation of the platform to which a vibrating body is attached is changed, the vibrating body will exert a force on the platform. This force can be measured and can be used to find out the output.



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Micro-electromechanical systems (MEMS) technology is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components.

• It combines conventional semiconductor electronics with beams, gears, accelerometers, gyroscopes, diaphragms levers, switches, sensors, and heat controllers; all of them microscopic in size.

MEMS Gyroscopes

• Micro-Electro-mechanical Systems (MEMS) gyroscope is a sensor that measures angle or rate of rotation.

• In recent years MEMS gyroscopes have gained popularity for use as rotation rate sensors in commercial products like ,

- Mobile Handsets
- Automobile
- Game consoles

Small size Low Cost Low Power consumption

Principle: Coriolis' Acceleration, It is an apparent acceleration that arises in rotating frame of reference. It is proportional to the rate of rotation Ω.

$$a_{cor} = 2(V \times \Omega)$$

• Coriolis Force : Thus the Coriolis force acting on particle of mass ' m ' is given by :

$$V_f = -2m (V \times \Omega)$$

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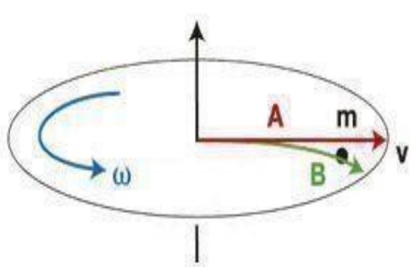

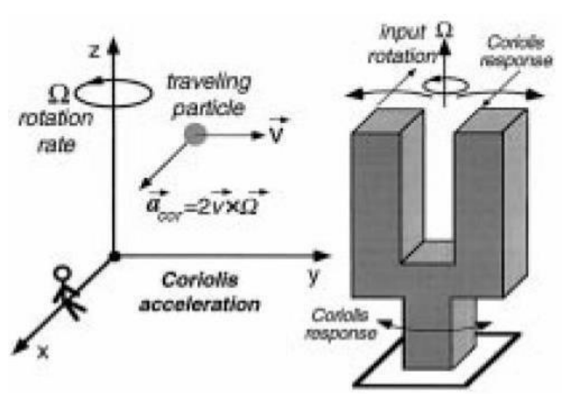

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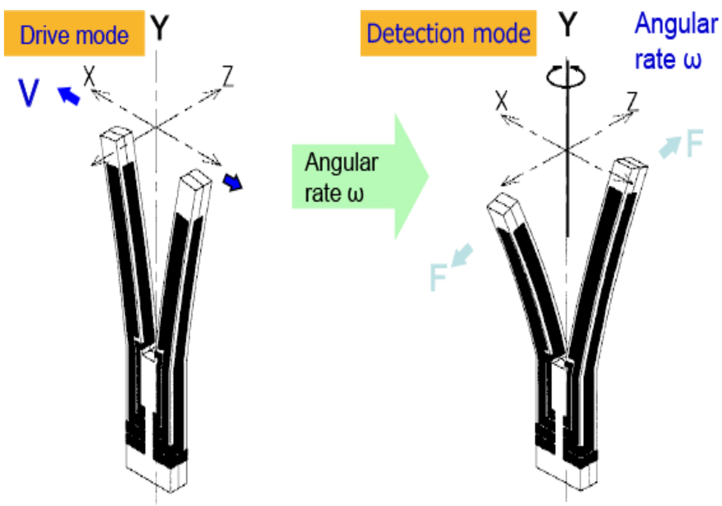

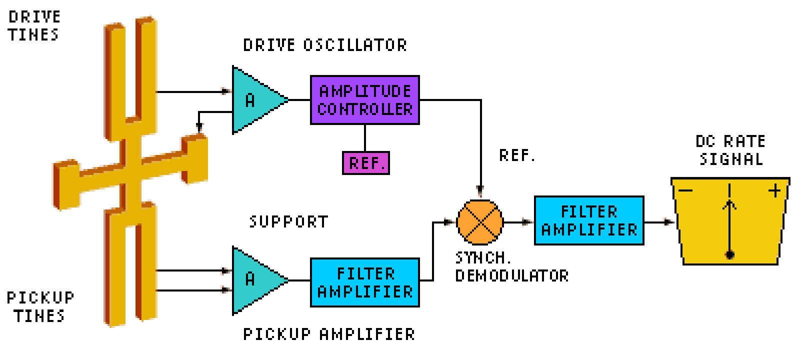

Advantages of MEMS gyroscopes over FOG/RLG:

- Extremely space efficient.
- Available in the form of chips, so can be fitted on electronic circuits.
- Adequate performance.
- As the technology is evolving, the performance accuracy of MEMS gyroscopes is also improving.
- No moving components unlike DTG/RLG and hence, completely maintenance free.
- Available at a fraction of the cost of FOG or RLG.

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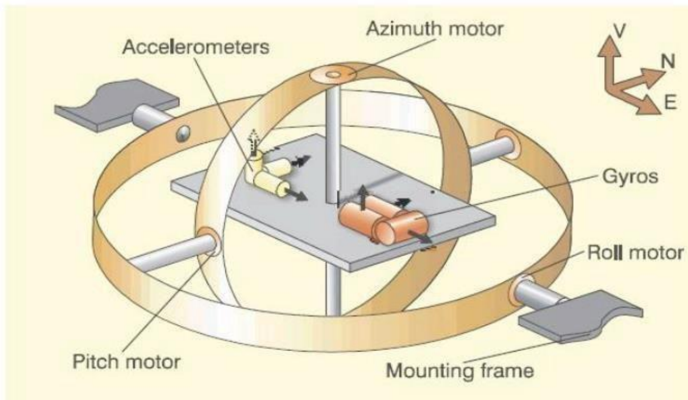
Accelerometers: Accelerometer is a sensor for measuring acceleration. However, accelerometers cannot measure gravitational acceleration. That is, anaccelerometer in freefall (or in orbit) hasnodetectable input.



Accelerometer can be designed to sense the acceleration about 1, 2, or 3 perpendicular axis.

Accelerometers are made up of three basic elements

1. A mass , often called the "proff mass".
2. A suspension, which locates the mass. This is the link between the mass and the accelerometer case.
3. A pick off, which measures the mass displacement with respect to the accelerometer case.
4. A forcer: An electric or magnetic force generator designed to oppose the inertia force created on themass.
5. An electric servo loop.

Accelerometer configuration: The spring - mass system

Alargenumber of accelerometers workontheprinciple asshown infigure, wherethecase of the sensor is fixed on the aircraft.

Acceleration can be determined by finding the force required to constrain a suspended force is F = mass x acceleration.

The vehicle acceleration is being produced by the vector sum of force on mass m

Thrust	= T.
Lift	=L
Drag	=D
Gravitationalforce	=mg

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$$A + A + L + NG = NA$$

Therefore $a = \frac{T+L+A}{A} + g$

Specific force = vector sum of external forces divided by the aircraft mass.

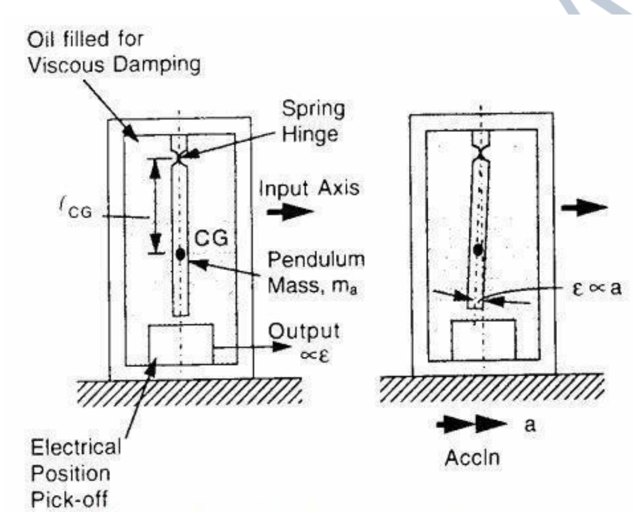
$$A_A + N_A g = N_A A$$

$$\frac{A_A}{N_A} + g = A = \frac{A + L + A}{N} + g$$

Only if accelerometer input axis is exactly orthogonal to the gravity vector (ie horizontal) so thatthereiszero gravitationalforcecomponentwilltheaccelerometermeasuretheaircraft acceleration component along its input axis.

A. Simple open loop spring restrained pendulous accelerometer:

- This Comprises an unbalanced pendulous mass which is restrained by the spring hinge so that it can only move in one direction, that is proportional to the angular deflection from the null position.
- Whenthecaseis acceleratedthependulumdeflectsfrom thenullposition until the spring torque is equal to the momentum required to accelerate the centre of the mass of the pendulum at the same acceleration as the vehicle



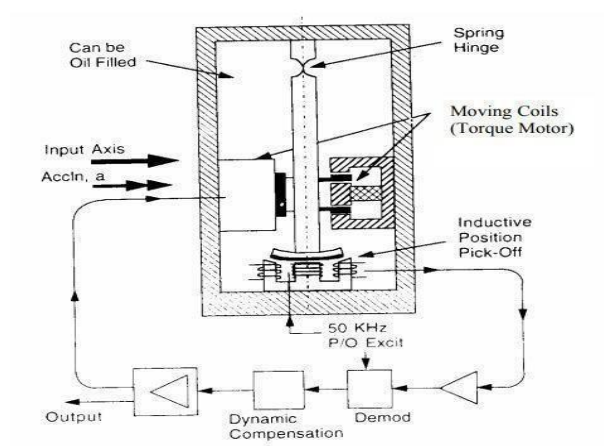


Figure: Simple open loop spring restrained pendulous accelerometer

Figure: Torque balanced pendulous

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Thetransferfunctionofthesimplestaccelerometeris $\frac{OUTPUT}{ANPUT} = \frac{K0}{A^2+A_0+2AA_{0A}}$

K_0 = AcceleRONEter scAle fActor A_0 = undANeed nAturAl frequencA

Maximum angle of deflection is ±2°

B. Closed loop Torque Balance Accelerometer:

The short comings in terms of accuracy and bandwidth can be overcome by closed loop. The deflection of the pendulum from its null position under an input acceleration is sensedbytheposition pick off andpickoff signal afteramplification and suitable dynamic compensation is used to control a precision torque exerted by the torque motor to balance inertia torque resulting fromaccelerating pendulous mass so that it has the same acceleration as the vehicle then enables the acceleration to be determined.

Construction: It consists of

1. Beam fabricated from fused quartz which is suspended within the case

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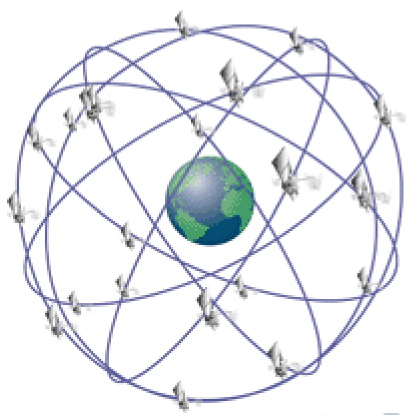
Global Positioning System (GPS): Satellite based navigation system, based on constellation of about 24 satellites which was developed by department of defense. It can provide accurate positioning 24 hours a day, anywhere in the world. No subscription or installation required. GPS satellite also called NAVSTAR the official US DOD.

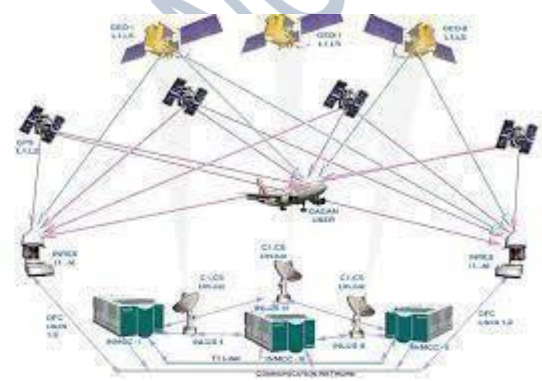
Satellites orbit the earth in 12 hrs. 6 orbital planes inclined at 55 degrees with the equator. This constellation provides 8 to 10 satellites from any point on the earth.

Satellites are located 12000 miles above earth. 5 ground stations manage & monitor the constellation. It offers two types of levels of service:

1. SPS (Standard Positioning)

2. PPS (Precise Positioning)





Basis of GPS technology is precise time & position information. It is accomplished through atomic clocks & location data.

HOW IT WORKS:

GPS satellites are orbiting the earth at an altitude of 11,000 miles. The orbits, and the locations of the satellites are known in advance. GPS receivers stores this orbit information for all of GPS satellites in an ALMANAC (File consists of positioning information's for all of the GPS satellites).

All 24 satellites aredivided into 6 parts. There are 4 satellites in each part. A definite orbit is defined for each part. Each of these is 3000 - 4000 - pound solar powered satellites. Position is measured by the timetaken by radio signal (GPS signal) totravel fromthe satellite to the receiver. Radio waves travel at thespeed of light, i.e. about 186,000 milesper sec. thedistance fromthe satellite tothereceiver can be determined by = d= speed xtime

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Atmospheric errors: Speed is affected by ionosphere and troposphere. Which cause a deviation of 0 to 30 m actual position of receiver.

Clock drift: Due to different code generations in satellite and receiver simultaneously. Which cause a deviation of 0 to 1.5 mfrom actual position of receiver.

Multi path: Bouncing of GPS signal due to a reflecting surface before reaching to receiver antenna. Which causes a deviation of 0 to 1m from actual position of the receiver.

GPS receiver receives these signals from three or more satellites. With this it determines the user position. Firstly it measures timeinterval between transmission & reception of satellite signals. Onthe basis of this it calculates the distance between theuser & satellites. For 2-Dfix, 3 satellites & for 3-Dfix 4 satellites arerequired.

ELEGANT CONVERGENCE Due its precise & stable frequency signals its used as synchronization sources for various applications. GPS was designed to minimize its vulnerability and make the satellites extremely difficult to reach. And its scope was expanded to include civil applications as well.

ACCURACY OF GPS

Measuring: the geometry of the constellation is evaluated by Dilution of Precision or DOP.

GPS receivers are accurate to within 15 meters. Due to parallel multi channel design receivers are extremely accurate. 12 parallel channel receivers lock onto the satellites. These locks are maintained even in dense foliage and urban buildings.

- Differential correction provides accuracy within 1-5m.
- Coarseacquisition receiver providesaccuracywithin 1-5m.
- Carrierphasereceiversprovidesaccuracywithin10-30cm,
- Dualfrequency receivers are capable of providing sub-centimeter GPS position accuracy.

SATELLITESYSTEM Satellites aretraveling at speedofroughly 7000 miles perhour. Theyarepoweredby solar energy. They have backup batteries onboard to keep them running in the absence of solar power. Small rocket boosters keep them flying in the correct path.

SOURCES OF ERRORS Ionosphere & troposphere delays Signal multipath Receiver clock errors Orbital errors Satellite geometry No. of satellites visible

Applications of GPS are growing. Cost of receivers is dropping & accuracy is improving.

LORAN, short for long range navigation: LORAN was a hyperbolic radio navigation system developed in the United States during World War II. It was similar to the UK's Gee system but operated at lower frequenciesinordertoprovideanimprovedrangeupto1,500miles(2,400km)with anaccuracyoftens

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of miles. It was first used for ship convoys crossing the Atlantic Ocean, and then by long-range patrol aircraft, but found its main use on the ships and aircraft operating in the Pacific theatre.

LORAN, in its original form, was an expensive system to implement, requiring a cathode ray tube (CRT) display. This limited use to the military and large commercial users. Automated receivers became available in the 1950s, but the same improved electronics led to new systems with higher accuracy. The US Navy begandevelopment of Loran-B, which offeredaccuracy ontheorder of afewtens of feet, but ran into significant technical problems. The US Air Force worked on a different concept, Cyclan, which the Navy took over as Loran-C. Loran-C offered longer range than LORAN and accuracy of hundreds of feet. The US Coast Guard took over operations of both systems in 1958.

In spite of the dramatically improved performance of Loran-C, LORAN, now known as Loran-A (or "Standard LORAN"), wouldbecome muchmorepopular duringthisperiod. This wasdue largelytothe large numbers of surplus Loran-A units released from the Navy as ships and aircraft replaced their sets with Loran-C. The widespread introduction of inexpensive microelectronics during the 1980s caused Loran-C receivers to drop in price dramatically, and Loran-A use began to rapidly decline. Loran-A was dismantled starting in the 1970s; it remained active in North America until 1980 and the rest of the worlduntil 1985. A Japanese chain remained on theair until 9 May 1997, anda Chinese chain was still listed as active as of 2000.

Loran-A used the same frequencies as the amateur radio 160-meter band, and radio operators were under strict rules to operate at reduced power levels; depending on their location and distance to the shore, US operators were limited to maximums of 200 to 500 watts during the day and 50 to 200 watts at night.

TACAN:

Introduction:

"Tacan" standsfor "Tactical Air Navigation" and is a system which, working in the UHF band, between 962 and 1,214 Mc/s, givesto apilot continuous information as to his rangeandbearingfrom abeacon. The airborne equipment consists of an interrogating transmitter and a receiver which includes suitable demodulating circuits to enable the information contained in the beacon's response to be extracted. The ground equipment consists of a beacon provided with a rotating aerial system.

In the absence of interrogating signals the beacon transmits a series of random pulses together with groups of marker or reference pulses which are locked to the aerial rotation. Bearing information can be obtained without interrogation since the beacon is continuously transmitting. In addition to transmitting arandomseries of pulsesthebeacon alsoperiodically transmits a signal bywhich it identifies itself.

- Tactical Air Navigation (TACAN) was developed to provide precise geographical fixing of the aircraft's position for the military where the Distance Measuring Equipment (DME) system is deemed unsuitable
    - This creates a system that is designed differently, but functions the same as VHF Omni-Directional Range (VOR) and DME

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- Like a VOR, provides 360 radials coming from the station
- VOR and TACAN systems collocated are called VORTACs
- An additional advantage is that TACAN ground equipment is compact and relatively easy to transport
- IDs every 35seconds
- The OFF position will disconnect the unit from the aircraft power supply
- STBY will receive magnetic bearing information only from ground TACAN navigation facilities
- In the T/R position, the TACAN receives magnetic bearing and distance information
- Cannot be used to transmit and receive voice
- Will identify itself with a Morse code identifier about every 37.5/32 seconds
- Transmittedonetime for each3or 4timesthat a VORsignal istransmittedwhenidentifyinga VORTAC

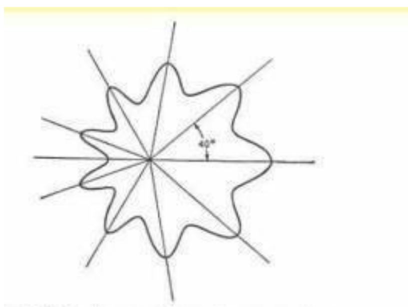

Figure 3.13: Polar diagram of TA

History:

- For reasons peculiar to military or naval operations (unusual siting conditions, the pitching and rolling of a naval vessel, etc.) the civil VOR/Distance Measuring Equipment (DME) system of air navigation was considered unsuitable for military ornaval use
- A new navigational system, TACAN, was therefore developed by the military and naval forces to more readily lend itself to military and naval requirements
- As a result, the FAA has integrated TACAN facilities with the civil VOR/DME program
- Although the theoretical, or technical principles of operation of TACAN equipment are quite differentfromthose of VOR/DMEfacilities, theendresult, asfar asthenavigating pilot is concerned, is thesame
- These integrated facilities are called VORTACs

Components:

- TACAN ground equipment consists of either a fixed or mobile transmitting unit
- The airborneunit in conjunctionwiththe ground unit reduces thetransmitted signal toavisual presentation of both azimuth and distance information
- TACAN is a pulse system and operates in the Ultrahigh Frequency (UHF) band of frequencies
- Its use requires TACAN airborne equipment and does not operate through conventional VOR equipment

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Passage:

1. DME decreases tominimum
2. Needle rotates 180°
3. CDI oscillates from side to side
4. TO/FORM indicator switches from TO to FROM

Frequencies:

- TACAN operates in the UHF (1000 MHz) band with 126 two-way channels in the operational mode (X or Y) for 252 total
- Air-to-ground DME frequencies are in the 1025 to 1150 MHz range
- Ground-to-airfrequencies are in the 962 to 1213 MHz range

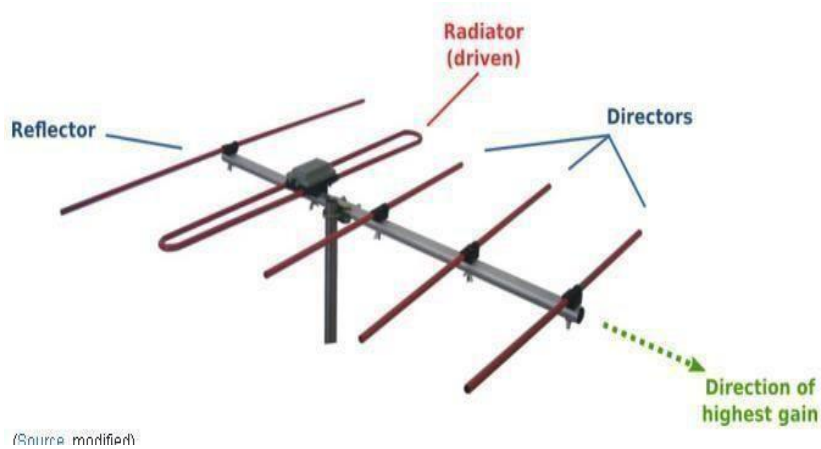
Ground Equipment:

- Consists of a rotating type antenna transmitting bearing and a receiver-transmitter (transponder) for transmitting distance information
- Ground stations are usually dual transmitter equipped
- One operational and the other standby
- Sometimes TACAN reception might be suspected of being in error or bearing/distance unlock conditions may be encountered in flight

TACAN bearing

A TACAN is based on a stationary antenna plus a rotating parasitic system. As already mentioned the base antenna is verticaland commonthe distance and bearing measurement instruments.

Parasitic elements in theaerialfield refer to passive antennaelementsaddedtotheactualactive radiator. A reflector decreases the gain on its side, a director increases the gain on its side (more). The well-known Yagi directional antenna (here in an horizontal polarization) has the two types of parasitic elements:



These elements are used in the TACAN, but they are rotating around the active element:

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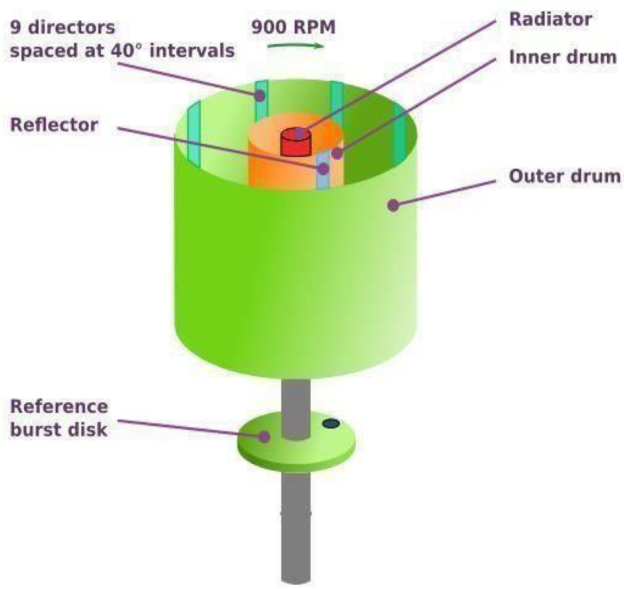
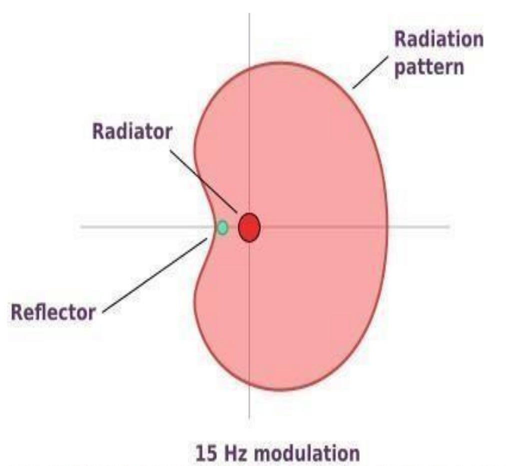


- The central element, which is the one also used for the DME portion, transmits a constant amplitude signal.
- Arotating drum withareflector electrically adjusts theradiation pattern, addinga signal dip (low gain) that rotates at 900 RPM, which is equivalent to a 15 Hz amplitude modulation. The radiation pattern in the horizontal plan takes the shape of a cardioid:



- Another drumwithaset of9 directors,mechanically linkedtothefirstone,creates a135Hz(9x15) additional amplitude ripple over the 15 Hz modulation:

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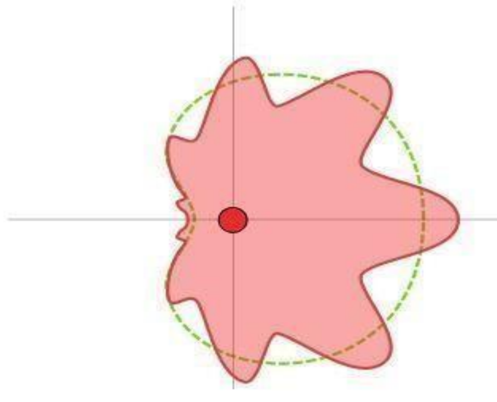


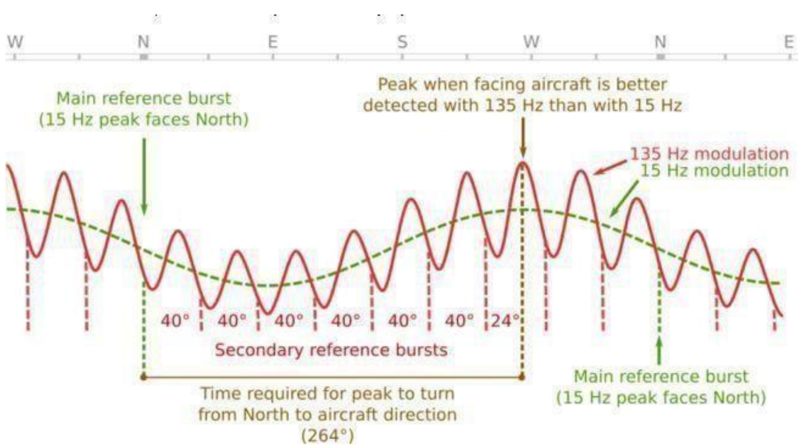
15 and 135 Hz modulation

Now we need to start again the reasoning taking into account that the TACAN signal isn't transmittedpermanently,but onlykeyed(switched on/off)byburstsof information. Burst areof two kinds:

- Reference bursts
- DME responses.

Reference bursts are generated according to the orientation of the modulation pattern:

- When the 15 Hz peak faces North a main reference burst is sent. The burst consists of 24 pulses with an asymmetric duty cycle.
- When any of the 135 Hz peaks faces East, an auxiliary reference burst is sent. The burst consists of 24 pulses with a symmetric duty cycle.



The duration of these bursts is only aportion of the 15 Hz cycle, meaning that if there isfew aircraft DME interrogations, most of the time the TACAN signal is not keyed, therefore not transmitted. This lack of transmission would create a difficulty for the aircraft receiver:

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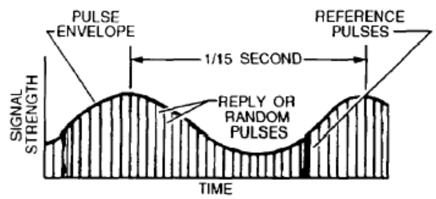
- To adjust its receiver gain (AGC) to counter fading.
- To identify the 15 Hz and 135 Hz modulations.

Tomaintainthecapabilityofreception,theTACANsignalisinsteadkeyedataconstantrateof 2,700 pairs of pulsespersecond, adding *squitterpulses* if necessary tofillthe blanks. The morethe DME interrogations are received by the TACAN, the more DME reply bursts are sent, the less squitter pulses are necessary (more in MIL-STD-291).



The 135 Hz modulation is used for thebearingdetermination. By comparing thetime betweenan auxiliary burst andthesubsequentreceptionofoneofthe9signalpeaks,itis possibletodeterminethe aircraft bearingrelativetotheground station. Themainburst (15Hz) is usedto disambiguate whichof the 9lobeswasused, andtherefore which of the 40°(360/9) sector is actually relevantforthebearing.

Intheorythe useofthetopendoftheUHF bandandthe135Hzrippleincreasethebearingaccuracyby oneorderof magnitude compared to the VOR. In practical this is less, but still better thanthe VOR.

In more modern TACAN, the mechanical rotations have been replaced by electronically scanned arrays:

To determine rangetheairbornetransmitter radiatesa series of pairs of pulses. These are received at the beacon and, after afixed delay, arere-transmitted in place of the particular random pulses that the beacon would have transmitted in the absence of interrogation. The time delay between the emission of any interrogating pulseand thereceipt of thereply ismeasured byone Tacan navigation system of the standard radar techniques To avoid mistakes arising from multiple interrogation the airborne transmitter emits its pairs of pulses at random intervals.

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The receiver only recognizes an exactly similar set of reply pulses all delayed by the same amount. The aerial polar diagram of the beacon is of the shape shown in Fig. 3.13. This is produced by placing parasitic radiators, comprising a single radiatorandaring of nine, in thepositions shown in Fig. 3.14.

By rotatingtheseparasiticelementsaroundtheradiator thepolar diagramis causedto rotatein space. The parasitic elements spin round the aerial at 900 r.p.m. so that the received signal is amplitude modulated at 15 c/s, caused by the rotation of the single radiator, and at 135 c/s caused bytherotation of the group of nine radiators. A marker signal is transmitted every time the main lobe of the polar diagram passes due magnetic East.

Somewhat misleadingly this is known as the "N " or north marker. Further marker signals are transmitted after every 40o of rotation of theaerialpattern. This system of markers provides reference signals at 15 and 135 c/s for phase comparison with the signals received in the aircraft. As the aircraft flies round the beacon the time of receipt of the marker signals with respect to the phase of the amplitude modulation of the received signal varies as shown in Fig. 3.15.

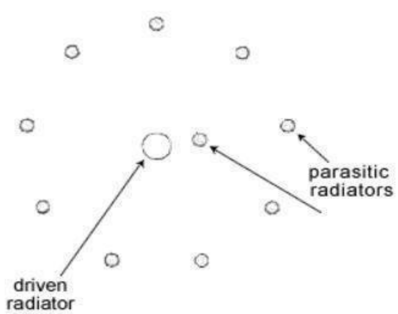

Figure 3.14: Plan of TACAN Beacon

The airborne receiver has five detectors. The first is an envelope detector whose output consists of a composite15 and135 c/s signal duetotherotation of the aerial pattern. The second andthird detectors areusedto isolatethe15and 135c/sreference signals respectively. Thefourthdetector is usedtofeed the rangemeasurement circuits andthefifthtoextract thebeacon identificationsignal. The signal from the envelope detector ispassed throughfilters toseparate the15 c/sand 135c/smodulations. A phase comparison circuit is used tomeasure the phase difference between the 15 c/s modulation andthe 15 c/s reference signal from detector number two. This circuit enables the bearing of the beacon to be measured to within ±20o A second phase comparison circuit compares the phase of the 135 c/s modulation with that of the 135 c/s reference signal from detector number three.

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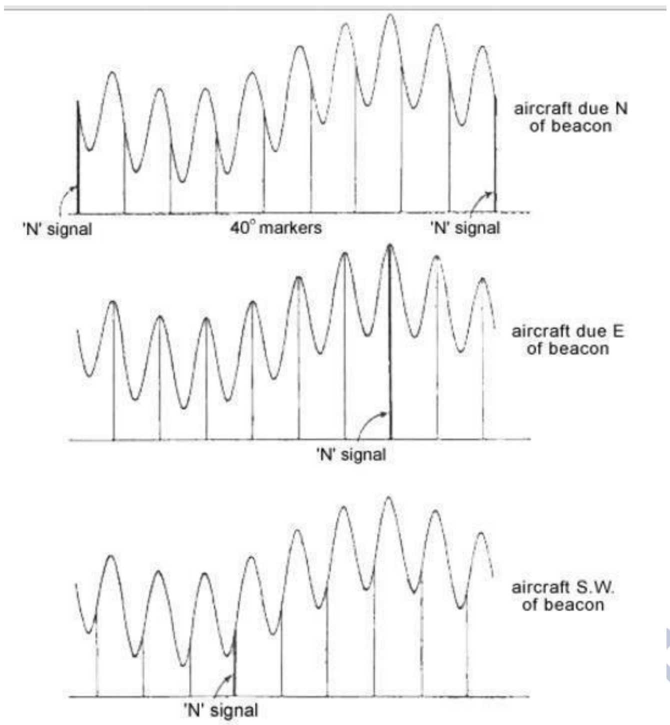

fig 3.15 Oscillograms of signals received by aircraft in various positions with respect to the beacon

Figure 3.15: Oscillograms of signals by aircraft in various positions w.r.t the beacon

This gives the bearing of the beacon to an accuracy of about ±1 o There is no limit to the number of aircraft which can simultaneously obtain bearing information from a Tacan beacon but no more than 100 aircraft at a time can obtain distance information. The major claim of the Tacan system is that by employing anantennapattern comprising amainlobeand "ninthharmonic" lobesanine-fold increase in accuracy is obtained. Whether such an accuracy can be obtained in varied conditions of siting has yet to be proved.

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UNIT IV

NAVIGATION (INS AND GPS) AND LANDING SYSTEM

Principles of Navigation

Navigation – The act, science or art of directing the movement of a ship or aircraft. Navigation thus involves both control of the aircraft's flight path and the guidance for its mission.

The measurement of the aircraft's attitude with respect to the horizontal plane in terms of the pitch and bank angles and its heading, that is the direction in which it is pointing in the horizontal plane with respect to North, is essential for both control and guidance. This information is vital for the pilot in order to fly the aircraft safely in all weather conditions, including those when the normal visibility of the horizon and landmarks is poor or not available, for example in haze or fog conditions, flying in cloud and night flying. Attitude and heading information is also essential for the key avionic systems which enable the crew to carry out the aircraft's mission. These systems include the autopilot system (e.g., Attitude and Heading Hold modes, Autoland, etc.) navigation system and the weapon aiming system. The information is also required for pointing radar beams and infrared sensors. Accurate knowledge of the aircraft's position in terms of its latitude/longitude coordinates, ground speed and track angle, height and vertical velocity is also equally essential for the navigation of the aircraft. The need for accurate and high integrity navigation is briefly summarised below. For civil aircraft, the density of air traffic on major air routes requires the aircraft to fly in a specified corridor or 'tube in the sky', these air routes being defined by the Air Traffic Control authorities. Not only must the aircraft follow the defined three dimensional flight path with high accuracy, but there is also a fourth dimension namely that of time, as the aircraft's arrival time must correspond to a specified time slot.

High accuracy navigation systems are thus essential and form a key part of the flight management system. For military operations, very accurate navigation systems are essential to enable the aircraft to fly low and take dvantage of terrain screening from enemy radars, to avoid known defences and in particular to enable the target to be acquired in time. The aircraft flies fast and very low so that the pilot cannot see the target until the aircraft is very near to it. There may be then only about six to ten seconds in which to acquire the target, aim and launch the weapons.

It is thus necessary to know the aircraft's position near the target area to within 100 m accuracy. This enables the target sight line to be continually computed (knowing the target coordinates, including target height, and the aircraft's height) and a target marker symbol to be displayed on the HUD. This should be near the target and the pilot then slews the marker symbol to exactly overlay the target. This corrects the errors and initializes the weapon aiming process.

The use of stand-off weapons which are released several kilometres away from the target also requires an accurate knowledge of the aircraft's position in order to initialise the mid-course inertial guidance system of the missile (the terminal homing phase is achieved with a suitable infrared or microwave radar seeker system). Clearly the integrity of the navigation system must be very high in both civil and military aircraft as large navigation errors could jeopardize the safety of the aircraft. There are two basic methods of navigation namely dead reckoning (DR) navigation and position fixing navigation systems. Both systems are used to achieve the necessary integrity.

Types of Navigation systems

The main types of airborne DR navigation systems are categorised below on the basis of the means used to derive the velocity components of the aircraft. In order of increasing accuracy these are:

1. Air data based DR navigation. The basic information used comprises the true airspeed (from the air data computer) with wind speed and direction (forecast or estimated) and the aircraft heading from the Attitude Heading Reference System, (AHRS).
2. ***Doppler/heading reference systems***. These use a Doppler radar velocity sensor system to measure the aircraft's ground speed and drift angle. The aircraft heading is provided by the AHRS.
3. ***Inertial navigation systems***. These derive the aircraft's velocity components by integrating the horizontal components of the aircraft's acceleration with respect to time. These components are computed from the outputs of very high accuracy gyroscopes and accelerometers which measure the aircraft's angular and linear motion.
4. ***Doppler inertial navigation systems***. These combine the Doppler and INS outputs, generally by means of a Kalman filter, to achieve increased DR navigation accuracy.

Inertial Navigation System

It is instructive to briefly review the reasons for the development of inertial navigation and its importance as an aircraft state sensor. The attributes of an ideal navigation and guidance system for military applications can be summarised as follows:

- High accuracy
- Self-contained
- Autonomous – does not depend on other systems
- Passive – does not radiate
- Unjammable
- Does not require reference to the ground or outside world.

In the late 1940s these attributes constituted a 'wish list' and indicated the development of inertial navigation as the only system which could be capable of meeting all these requirements. It was thus initially developed in the early 1950s for the navigation and guidance of ballistic missiles, strategic bombers, ships and submarines (Ships Inertial Navigation System, SINS). Huge research and development programmes have been carried out worldwide involving many billions of dollars expenditure to achieve viable systems. For instance, as mentioned earlier over three orders of magnitude improvement in gyro performance from 15◦/hour to 0.01◦/hour drift uncertainty was required. Precision accelerometers had to be developed with bias uncertainties of less than 50 μg. The major task of achieving the required computational accuracies had to be solved and in fact the first digital computers operating in real time were developed for IN systems. Once these problems had been solved, however, the INS can provide:

- Accurate position in whatever coordinates are required – e.g. latitude/ longitude, etc.
- Ground speed and track angle.
- Euler angles: heading, pitch and roll to very high accuracy.
- Aircraft velocity vector

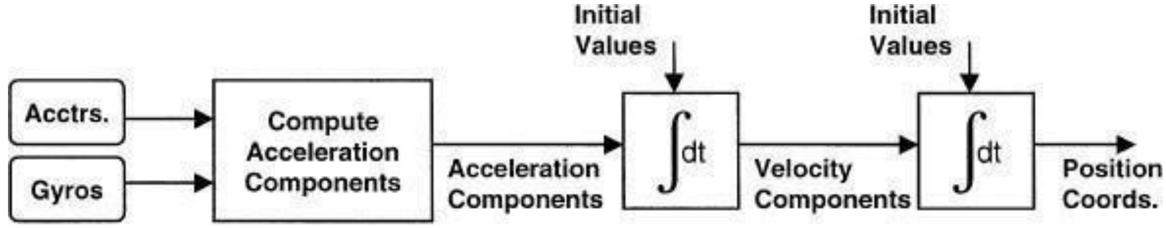


Fig. Basic principles of inertial navigation.

Accurate velocity vector information together with an accurate vertical reference are essential for accurate weapon aiming and this has led to the INS being installed in military strike aircraft from the early 1960s onwards as a key element of the navigation/weapon aiming system. The self-contained characteristics of an inertial navigation system plus the ability to provide a very accurate attitude and heading reference led to the installation of IN systems in long range civil transport aircraft from the late 1960s. They are now very widely used in all types of civil aircraft.

Initial Alignment and Gyro Compassing

Inertial navigation can only be as accurate as the initial conditions which are set in. It is therefore essential to know the orientation of the accelerometer measuring axes with respect to the gravitational vector, the direction of true North, the initial position and the initial velocity components to very high accuracy.

The two basic references used to align an inertial system are the Earth's gravitational vector and the Earth's rotation vector. The initial alignment process is basically the same in a stable platform and strapdown INS. The difference being that in a stable platform INS, the stable platform is physically rotated to bring it into alignment with the local NED axes by applying precession torques to the vertical and azimuth gyros on the platform. It is thus easier to visualise (literally). Whereas the strap-down system carries out the axis rotations within the system computer to create, in effect, a virtual stable platform as explained earlier.

The levelling operation takes place in two stages; a coarse levelling stage followed by a fine levelling stage using the horizontal accelerometer outputs. (In the case of a strap-down system, these are virtual horizontal accelerometers as the horizontal acceleration components are computed from the body mounted accelerometer outputs using the gyro derived attitude data.) These horizontal accelerometer outputs are directly proportional to the tilt angle from the horizontal of the accelerometer measuring axes when the aircraft is stationary on the ground. They also contain spurious accelerations and noise due to wind buffet, fuelling, crew and passengers moving about the aircraft, etc. The coarse levelling of a stable platform INS is achieved by feeding the horizontal accelerometer outputs directly into the appropriate torque motors of the vertical gyro(s).

The fine levelling stage, which filters out the noise and spurious accelerations, is achieved by filtering the accelerometer outputs before feeding them into the vertical gyro torque motors. The filtering process is basically the same as in a strap-down INS, which is covered below. It relies on the fact that the integrated horizontal acceleration components, which give the horizontal velocity components, should be zero as the aircraft is stationary on the ground. The accelerometers for an aircraft strap-down INS are generally mounted along the aircraft's principal axes so that the 'horizontal' accelerometers mounted along the forward and side-slip axes do not sense a large component of gravity. The pitch and bank angles of the aircraft are small as the aircraft is normally fairly level when stationary on the ground. The aircraft attitude integration process, using the incremental body angular rotations measured by the pitch, roll and yawstrap-down gyros, can be initialised by assuming the pitch and bank angles are both zero (if these are not known).

The fine levelling is carried out by using the fact that any tilt about the computed North and East axes will couple gravitational acceleration components into the East and North acceleration components derived from the accelerometers. The horizontal acceleration components are then integrated with respect to time to produce the horizontal velocity components of the aircraft.

These horizontal velocity components should be zero as the aircraft

is stationary on the ground. Any resulting horizontal velocity components that are measured are therefore fed back appropriately to correct the tilt and level the system. The levelling loops are generally third-order loops using the integrals of the velocity errors as well as the velocity errors as control terms. The feedback gains are also varied.

A coarse azimuth alignment with respect to true North is made to within a degree or so using, say, a magnetic reference. The fine alignment to achieve the required accuracy is accomplished by the process of gyro compassing. During the gyro compassing phase the computed heading is adjusted until the component of the Earth's rotation sensed by the gyros about the East axis is zero. As shown earlier, the components of the Earth's rate of rotation about the North, East and Down axes at a latitude of λ are:

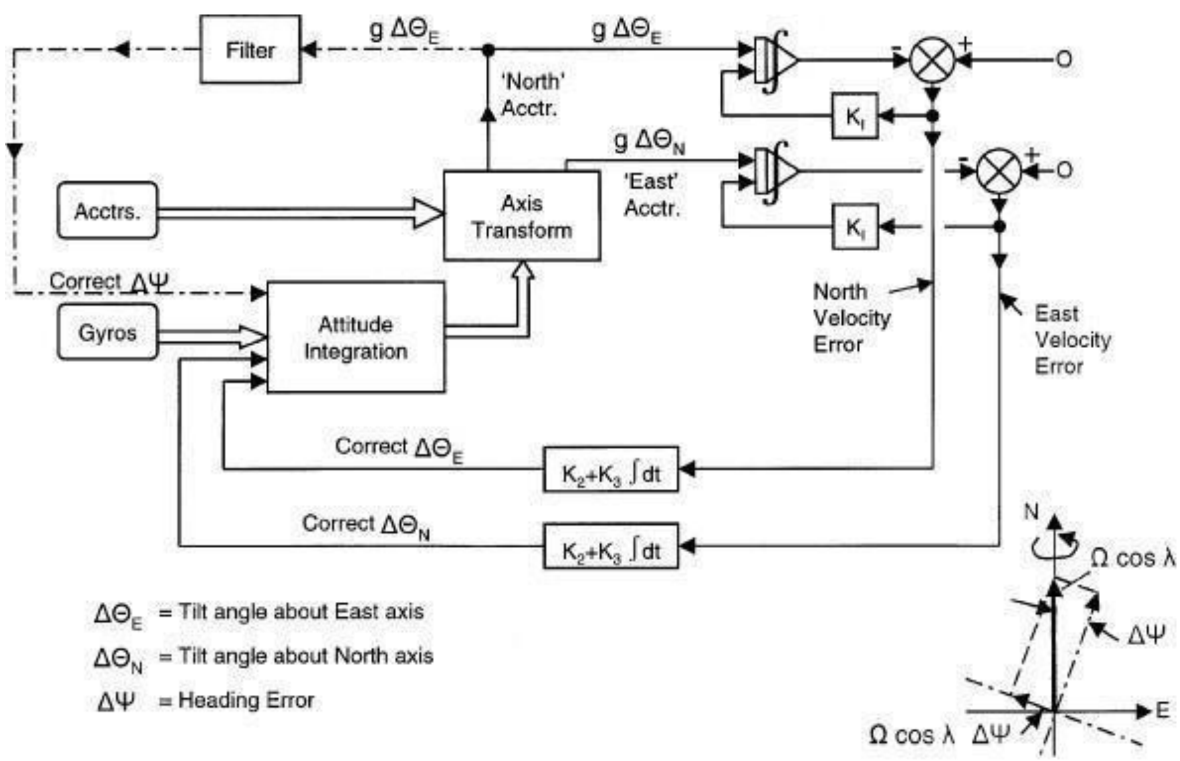
North axis	$\Omega \cos \lambda$
East axis	0
Vertical axis	$\Omega \sin \lambda$

The allowable gyro drift rate uncertainty can be determined from the accuracy required of the heading alignment. For example, if an accuracy of 0.1° is required for a latitude of 45°, then the component of the Earth's rate sensed at this latitude with a misalignment of 0.1◦ is equal to (0.1/57.3) sin 45◦ degrees per hour, that is 0.017 degrees per hour.

It can be seen that the magnitude of the component of Earth's rate to be sensed decreases with increasing latitude, so that gyro compassing is effectively restricted to latitudes below 80◦.

The major factors which affect alignment accuracy and alignment times are:

- Initial tilt.
- Aircraft movements, e.g., effect of wind gusts etc.
- Accelerometer bias errors and gyro drift rates.
- Change of the above quantities (c) with time as the system warms up.
- Accelerometer resolution and gyro threshold.



Fine levelling and gyro compassing loops.

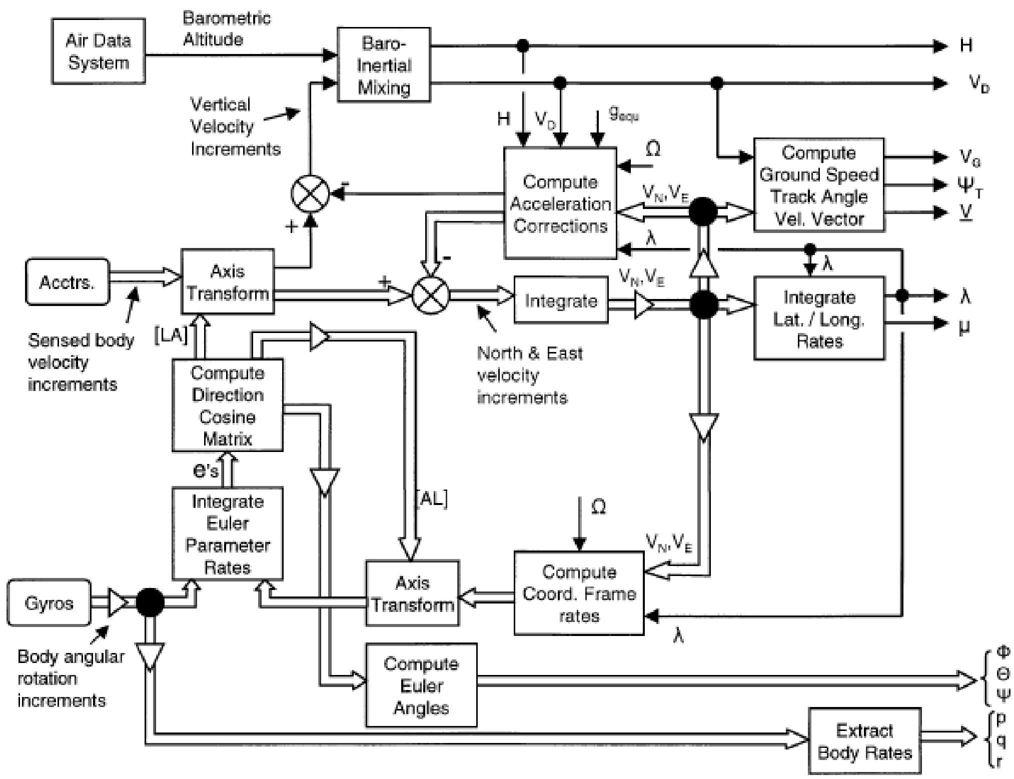
The loop gains in the levelling and gyro compassing loops are generally controlled by means of a Kalman filter to give an optimal alignment process. Typical alignment times are of the order of seven minutes for full accuracy IN performance. Reduced alignment times are sometimes used and the system corrected to give full IN accuracy by subsequent position fixes using a position fixing navigation system (e.g., GPS).

Strap down INS computing

The basic computing flow diagram for a strap-down INS is shown in Figure. A strap-down IN system carries out the same functions as a stable platform type. INS and many elements and functional areas are common to both systems. There are two crucial areas in the strap-down mechanisation. These are:

- Attitude integration whereby the vehicle attitude is derived by an integration process from the body incremental angular rotations measured by the gyros.
- Accelerometer resolution whereby the corrected outputs of the body mounted accelerometers are suitably resolved to produce the horizontal and vertical acceleration components of the aircraft.

Very high accuracy is required in the attitude integration process, the integration period should be as short as possible and accurate integration algorithms must be used (e.g., Runge–Kutta algorithms). The ortho-normalisation of the transition matrix is essential using the constraint equation for the Euler parameters, $(e_0^2 + e_1^2 + e_2^2 + e_3^2 = 1)$.



Strap-down INS computing flow diagram.

The implementation of a strap-down INS comprises:

1. The Inertial Measuring Unit (IMU) comprising three orthogonally mounted laser gyros and three orthogonally mounted accelerometers.
2. The Processor Module carrying out all the processing tasks just described, and also monitoring and self-test functions.
3. The Interface Module carrying out all the interfacing tasks.
4. The Power Supply Unit.

Instrument landing system

An instrument landing system (ILS) is a system that works by sending radio waves downrange from the runway end, with aircraft that intercept it using the radio waves to guide them onto the runway. It is defined by the International Telecommunication Union as a service provided by a station as follows:

A radio navigation system which provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing.

An instrument landing system operates as a ground-based instrument approach system that provides precision lateral and vertical guidance to an aircraft approaching and landing on a runway, using a combination of radio signals and, in many cases, high-intensity lighting arrays to enable a safe landing during instrument meteorological conditions (IMC), such as low ceilings or reduced visibility due to fog, rain, or blowing snow.

An instrument approach procedure chart (or 'approach plate') is published for each ILS approach to provide the information needed to fly an ILS approach during instrument flight rules (IFR) operations. A chart includes the radio frequencies used by the ILS components or navaids and the prescribed minimum visibility requirements.

Radio-navigation aids must provide a certain accuracy (set by international standards of CAST/ICAO); to ensure this is the case, flight inspection organizations periodically check critical parameters with properly equipped aircraft to calibrate and certify ILS precision.

An aircraft approaching a runway is guided by the ILS receivers in the aircraft by performing modulation depth comparisons. Many aircraft can route signals into the autopilot to fly the approach automatically. An ILS consists of two independent sub-systems. The localizer provides lateral guidance; the glide slope provides vertical guidance.

Localizer

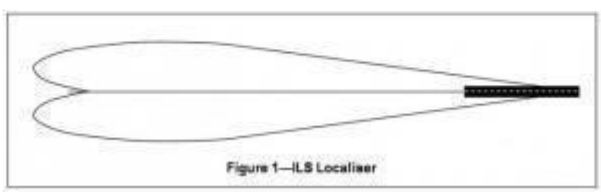
A localizer (LOC, or LLZ until ICAO standardisation[2]) is an antenna array normally located beyond the departure end of the runway and generally consists of several pairs of directional antennas. The localizer will allow the aircraft to turn and match the aircraft with the runway. After that, the pilots will activate approach phase (APP).

Glide slope (G/S)

The pilot controls the aircraft so that the glide slope indicator remains centered on the display to ensure the aircraft is following the glide path of approximately 3° above horizontal (ground level) to remain above obstructions and reach the runway at the proper touchdown point (i.e. it provides vertical guidance).

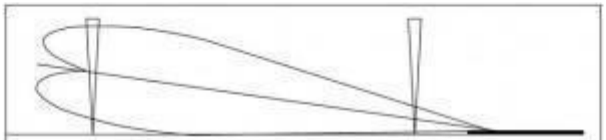
Categories of ILS

An Instrument Landing System is a precision runway approach aid employing two radio beams to provide pilots with vertical and horizontal guidance during the landing approach. The localiser (LOC)provides azimuth guidance, while the glideslope (GS) defines the correct vertical descent profile. Marker beacons and high intensity runways lights may also be provided as aids to the use of an ILS, although the former are more likely nowadays to have been replaced by a DME integral to the ILS or one otherwise located on the aerodrome, for example with a VOR.



Localiser

The ILS LOC aerials are normally located at the end of the runway; they transmit two narrow intersecting beams, one slightly to the right of the runway centreline, the other slightly to the left which, where they intersect, define the "on LOC" indication (see Figure 1). Airborne equipment provides information to the pilot showing the aircraft's displacement from the runway centreline.



Glide-slope

The ILS GS aerials are normally located on the aerodrome; they transmit two narrow intersecting beams, one slightly below the required vertical profile and the other slightly above it which, where they intersect, define the "on GS" indication (see Figure 2). Aircraft equipment indicates the displacement of the aircraft above or below the GS. The GS aerials are usually located so that the glide-slope provides a runway threshold crossing height of about 50 ft. The usual GS angle is 3 degrees but exceptions may occur, usually to meet particular approach constraints such as terrain or noise abatement.

If marker beacons are provided, they will be located on the ILS approach track at notified distances from touch-down (see Figure 2). Typically, the first marker beacon (the Outer Marker) would be located about 5 NM from touch-down while the second marker beacon (the Middle Marker) would be located about 1 NM from touch-down.

An approach may not normally be continued unless the runway visual range (RVR) is above the specified minimum. When an approach is flown, the pilot follows the ILS guidance until the decision height (DH) is reached. At the DH, the approach may only be continued if the specified visual reference is available, otherwise, a go-around must be flown.

Special categories of ILS approach are defined which allow suitably qualified pilots flying suitably equipped aircraft to suitably equipped runways using appropriately qualified ILS systems to continue an ILS approach without acquiring visual reference to a lower DH than the Category I standard of 200 feet above runway threshold elevation (arte) and do so when a lower reported RVR than the 550 metres usually associated with Category I:

- Category II permits a DH of not lower than 100 ft and an RVR not less than 300 m;
- Category IIIA permits a DH below 100 ft and an RVR not below 200 m;
- Category IIIB permits a DH below 50 ft and an RVR not less than 50 m;

- Category IIIC is a full auto-land with roll out guidance along the runway centreline and no DH or RVR limitations apply. This Category is not currently available routinely primarily because of problems which arise with ground manoeuvring after landing.

The special conditions which apply for Category II and III ILS operation cover aircraft equipment; pilot training and the airfield installations. In the latter case, both function, reliability and operating procedures are involved. An example of the latter is the designation of runway holding points displaced further back from the runway so as to ensure that aircraft on the ground do not interfere with signal propagation. Reliability requirements for Category II and III ILS include a secondary electrical power supply which should be fully independent of the primary one.

The transmission of ILS signals is continuously monitored for signal integrity and an installation is automatically switched off leading to the immediate display of inoperative flags on aircraft ILS displays selected to the corresponding frequency if any anomaly is detected. The reliability of this monitoring function is increased where approaches to minima lower than Category I are permitted and all ILS systems are subject to regular calibration flights to check that signals are being correctly transmitted. These checks only validate that the ILS is performing as intended and do not routinely investigate the indications which aircraft would receive if flown beyond signal validity.

It is very important to note that only a full ILS with LOC and GS signals is a precision approach. If only the LOC is transmitting then it can only support a Non-Precision Approach with increased minima, albeit this should be lower minima than an equivalent VOR would enable.

Global Positioning System

GPS is basically a radio navigation system which derives the user's position from the radio signals transmitted from a number of orbiting satellites. The fundamental difference between GPS and earlier radio navigation systems,

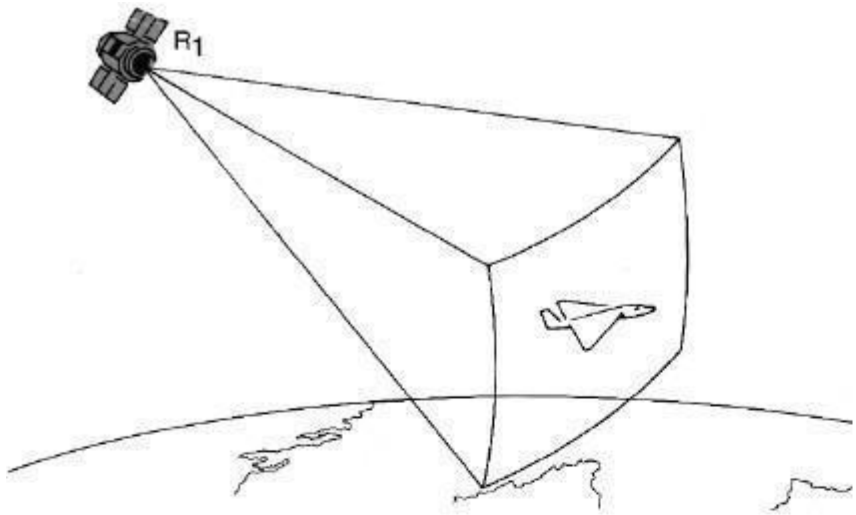
such as LORAN-C (now no longer in use), is simply the geometry of propagation from ground based transmitters compared with space borne transmitters. An orbiting satellite transmitter can provide line of sight propagation over vast areas of the world. This avoids the inevitable trade-offs of less accuracy for greater range which are inherent with systems using ground based transmitters. The satellite signals also penetrate the ionosphere rather than being reflected by it so that the difficulties encountered with sky waves are avoided.

GPS provides a superior navigation capability to all previous radio navigation systems. For these reasons and also space constraints, coverage of radio navigation systems has been confined to GPS. Satellite navigation can be said to have started with the successful launching by the Russians of the world's first orbiting satellite, SPUTNIK 1 in October 1957. The development of the first satellite navigation system TRANSIT 1, was triggered by observations made on the radio signals transmitted from SPUTNIK 1 and was initiated at the end of 1958. TRANSIT 1 resulted in a worldwide navigation system which has been in continuous operation since 1964. GPS started as a series of preliminary system concept studies and system design studies in the late 1960s. A Phase 1 'Concept and Validation Programme' was carried out from 1973 to 1979 followed by a Phase 2 'Full Scale Development and System Test Programme' from 1979 to 1985. The Phase 3 'Production and Deployment Programme' was initiated in 1985. Twelve development satellites were used to develop and prove the system and the first production satellite was launched in February 1989. Some delay to the program was incurred by the space shuttle CHALLENGER disaster in 1986, as it had been originally intended to insert all the production standard GPS satellites into orbit using the space shuttle. A DELTA 2 launch vehicle was used subsequently and deployment of the 24 production standard

GPS satellites was completed in the late 1990s

Basic Principles of GPS

The basic principle of position determination using the GPS system is to measure the spherical ranges of the user from a minimum of four GPS satellites. The orbital positions of these satellites relative to the Earth are known to extremely high accuracy and each satellite transmits its orbital position data. Each satellite transmits a signal which is modulated with the C/A pseudo-random code in a manner which allows the time of transmission to be recovered.



GPS spherical ranging.

The spherical range of the user from the individual transmitting satellite can be determined by measuring the time delay for the satellite transmission to reach the user. Multiplying the time delay by the velocity of light then gives the spherical range, *R*, of the user from the transmitting satellite. The user's position hence lies on the surface of a sphere of radius, *R*, as shown in Figure The system depends on precise time measurements and requires atomic clock

reference standards. The need for extremely high accuracy in the time measurement can be seen from the fact that a 10 ns (10−8 seconds) time error results in a distance error of 3 metres, as the velocity of light is 3 × 108 m/s.

Each GPS satellite carries an atomic clock which provides the time reference for the satellite data transmission. Assume for the moment that this time is perfect – the corrections required will be explained shortly. Given a perfect time reference in the user equipment, measurement of the spherical ranges of three satellites would be sufficient to determine the user's position. The user's equipment, however, has a crystal clock time reference which introduces a time bias in the measurement of the transit times of the satellite transmissions. The measurement of the time delay

is thus made up of two components. The first component is the transit time of the ranging signal and the second component is the time offset between the transmitter clock and the receiver clock due to the non-synchronisation of the clocks.

Integration of GPS and INS

GPS and INS are wholly complementary and their information can be combined to the mutual benefit of both systems. For example:

Calibration and correction of INS errors – the GPS enables very accurate calibration and correction of the INS errors in flight by means of a Kalman filter. The INS can smooth out the step change in the GPS position output which can occur when switching to another satellite because of the change in inherent errors.

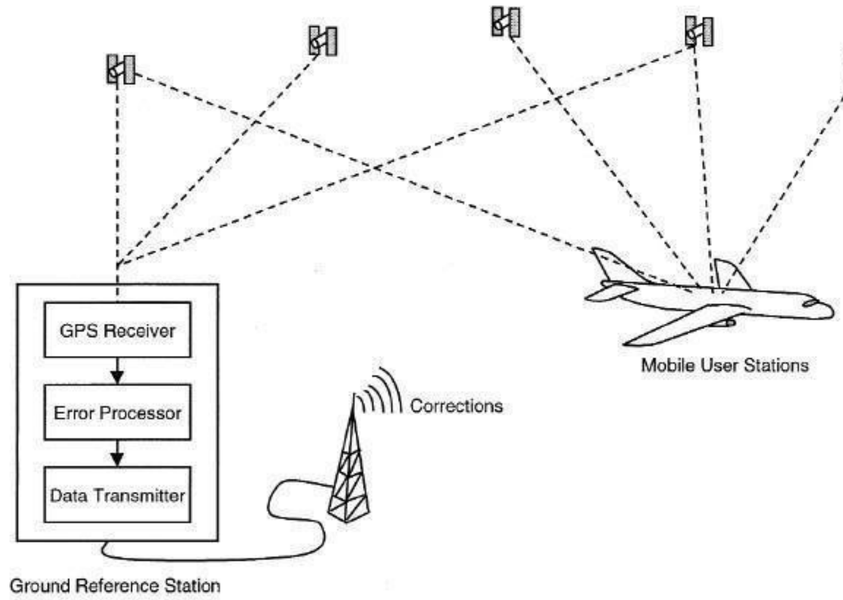
Jamming resistance – like any radio system, GPS can be jammed, albeit over a local area, although it can be given a high degree of resistance to jamming. The INS, having had its errors previously corrected by the Kalman filter, is able to provide accurate navigation information when the aircraft is flying over areas subjected to severe jamming.

Antenna obscuration – GPS is a line of sight system and it is possible for the GPS antenna to be obstructed by the terrain or aircraft structure during manoeuvres.

Antenna location corrections – the GPS derived position is valid at the antenna and needs to be corrected for reference to the INS location. The INS provides attitude information which together with the lever arm constants enables this correction to be made.

Differential GPS

As explained in the preceding section the horizontal position accuracy available to all GPS users (civil and military) is now 16 m. This was not the case, however, until 2000 when the restriction of 'Selective Availability' was removed. Concerns about potential enemies using GPS to deliver missiles and other weapons against the US had led to a policy of accuracy denial, generally known as Selective Availability. The GPS ground stations deliberately introduced satellite timing errors to reduce the positioning accuracy available to civil users to a horizontal positioning accuracy of 100 m to a 95% probability level. This was deemed adequate for general navigation use, but in practice it did not satisfy the accuracy or integrity requirements for land or hydrographic surveying, coastal navigation or airborne navigation. It should be noted that even the 16 m accuracy, now available, is insufficiently accurate for many applications. For example, positioning of off-shore oil drilling rigs or automatic landing in the case of airborne applications. A supplementary navigation method known as *Differential GPS* (DGPS) has therefore been developed to improve the positioning accuracy for the growing number of civil applications.



The differential GPS concept.

DGPS can be defined as:

The positioning of a mobile station in real-time by corrected (and possibly Doppler or phase smoothed) GPS pseudo ranges. The corrections are determined at a static 'reference station' and transmitted to the mobile station. A monitor station may be part of the system, as a quality check on the reference station transmissions.

The success of DGPS can be seen from its application to new markets such as locating land vehicles used by the emergency services. Successful trials for automatic landings and taxi-way guidance have also been conducted. It is now widely used in land and hydrographic surveying applications.

The errors present in a GPS system are discussed below.

GPS satellite clocks. GPS satellites are equipped with very accurate atomic clocks and corrections are made via the Ground Stations, as explained in the preceding section. Even so, very small timing errors are present and so contribute to the overall position uncertainty. Selective Availability deliberately introduced noise equivalent to around 30 m in the individual satellite clock signals.

Satellite ephemeris errors. The satellite position is the starting point for all the positioning computations, so that errors in the Ephemeris data directly affect the system accuracy. GPS satellites are injected into very high orbits and so are relatively free from the perturbing effects of the Earth's upper atmosphere. Even so, they still drift slightly from their predicted orbits and so contribute to the system error.

Atmospheric errors. Radio waves slow down slightly from the speed of light in vacuo as they travel through the ionosphere and the Earth's atmosphere. This is due respectively to the charged particles in the ionosphere and the water vapour and neutral gases present in the troposphere. These delays translate directly into a position error.

The use of different frequencies in the L1 and L2 transmissions enables a significant correction to be made for ionospheric delays. (It should be appreciated that this facility was not available to civil users prior to 2000.)

Future Augmented Satellite Navigation Systems

The advent of satellite navigation systems and satellite communication links has provided new capabilities for aircraft precision navigation, particularly in civil operations. Providing the integrity and accuracy requirements can be met, satellite navigation systems are able to support all phases of flight including all-weather precision

approaches to airports not equipped with ILS (or MLS) installations. Successful concept proving trials were, in fact, conducted by the UK Air Traffic Control authorities in conjunctionwith British Airways around 1996. The trials used the on-board GPS receivers and SAT COM radios in a British Airways Boeing 747 airliner to monitor the aircraft flight paths on normal commercial flights to theWest Indies. Detail changes in the aircraft flight path over theWest Indies were accurately monitored from the UK, over 3000 miles away. The potential for more flexible air traffic control systems can be seen and it is only a matter of time before they are introduced.

Some reservations exist as to whether the integrity of the present GPS systems is sufficiently high to meet the navigation integrity requirements in safety critical phases of the flight and adverse weather conditions.Although the probability of GPS receivers producing erroneous position data is very low, there have been recorded instances of erroneous GPS position data in flight.

There have also been reservations about total reliance on GPS, as it is a military system which is completely under the control of the US military command, although it is freely available to any user. The accuracy available to civil users during the 1990s was also limited to 100 m by the policy of Selective Availability, as already explained, and this was inadequate for precision approaches. An augmented satellite navigation system provided by additional satellites under international civil control was therefore proposed and studied in detail by the European civil authorities from the late 1990s. The additional ranging signals and monitoring will enable the integrity requirements to be met and will also provide increased accuracy

UNIT V

SURVEILLANCE AND AUTO FLIGHT SYSTEMS

Traffic alert and Collision Avoidance Systems (TCAS)

A **traffic collision avoidance system** ACAS or **traffic alert and collision avoidance system** (But both abbreviated as **TCAS**) is an aircraft collision avoidance system designed to reduce the incidence of mid-air collisions between aircraft. It monitors the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision (MAC). It is a type of airborne collision avoidance system mandated by the International Civil Aviation Organization to be fitted to all aircraft with a maximum take-off mass (MTOM) of over 5,700 kg (12,600 lb) or authorized to carry more than 19 passengers. CFR 14, Ch I, part 135 requires that TCAS I be installed for aircraft with 10-30 passengers and TCAS II for aircraft with more than 30 passengers. ACAS/TCAS is based on secondary surveillance radar (SSR) transponder signals, but operates independently of ground-based equipment to provide advice to the pilot on potentially conflicting aircraft.

In older glass cockpit aircraft and those with mechanical instrumentation, such an integrated TCAS display may replace the mechanical IVSI (which indicates the rate with which the aircraft is descending or climbing).

Research into collision avoidance systems has been ongoing since at least the 1950s, and the airline industry has been working with the Air Transport Association of America (ATA) since 1955 toward a collision avoidance system. ICAO and aviation authorities such as the Federal Aviation Administration were spurred into action by the 1956 Grand Canyon mid-air collision

It was not until the mid-1970s, however, that research centered on using signals from ATCRBS airborne transponders as the cooperative element of a collision avoidance system. This technical approach allows a collision avoidance capability on the flight deck, which is independent of the ground system. In 1981, the FAA announced a decision to implement an aircraft collision avoidance concept called the Traffic Alert and Collision Avoidance System (TCAS). The concept is based upon agency and industry development efforts in the areas of beacon based collision avoidance systems and air-to-air discrete address communications techniques utilizing Mode S airborne transponder message formats.

A short time later, prototypes of TCAS II were installed on two Piedmont Airlines Boeing 727 aircraft, and were flown on regularly scheduled flights. Although the displays were located outside the view of the flight crew and seen only by trained observers, these tests did provide valuable information on the frequency and circumstances of alerts and their potential for interaction with the ATC system. On a follow-on phase II program, a later version of TCAS II was installed on a single Piedmont Airlines Boeing 727, and the system was certified in April 1986, then subsequently approved for operational evaluation in early 1987. Since the equipment was not developed to full standards, the system was only operated in visual meteorological conditions (VMC). Although the flight crew operated the system, the evaluation was primarily for the purpose of data collection and its correlation with flight crew and observer observation and response.

Later versions of TCAS II manufactured by Bendix/King Air Transport Avionics Division were installed and approved on United Airlines airplanes in early 1988. Similar units manufactured by Honeywell were installed and approved on Northwest Airlines airplanes in late 1988. This limited installation program operated TCAS II units approved for operation as a full-time system in both visual and instrument meteorological conditions (IMC) on three different aircraft types. The operational evaluation programs continued through 1988 to validate the operational suitability of the systems.

The implementation of TCAS added a safety barrier to help prevent mid-air collisions. However, further study, refinements, training and regulatory measures were still required because the limitations and misuse of the system still resulted in other incidents and fatal accidents

A TCAS installation consists of the following components:[1][2]

TCAS computer unit

Performs airspace surveillance, intruder tracking, its own aircraft altitude tracking, threat detection, resolution advisory (RA) manoeuvre determination and selection, and generation of advisories. The TCAS Processor uses pressure altitude, radar altitude, and discrete aircraft status inputs from its own aircraft to control the collision avoidance logic parameters that determine the protection volume around the TCAS aircraft.

Antennas

The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an omnidirectional or a directional antenna mounted on the bottom of the aircraft. Most installations use the optional directional antenna on the bottom of the aircraft. In addition to the two TCAS antennas, two antennas are also required for the Mode S transponder. One antenna is mounted on the top of the aircraft while the other is mounted on the bottom. These antennas enable the Mode S transponder to receive interrogations at 1030 MHz and reply to the received interrogations at 1090 MHz.

Cockpit presentation

The TCAS interface with the pilots is provided by two displays: the traffic display and the RA display. These two displays can be implemented in a number of ways including displays that incorporate both displays into a single, physical unit. Regardless of the implementation, the information displayed is identical. The standards for both the traffic display and the RA display are defined in DO-185A

TCAS Operation

The following section describes the TCAS operation based on TCAS II, since this is the version that has been adopted as an international standard (ACAS II) by ICAO and aviation authorities worldwide.

Operation modes

TCAS II can be currently operated in the following modes:

Stand-by

Power is applied to the TCAS Processor and the mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.

Transponder

The mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in stand-by.

Traffic advisories only

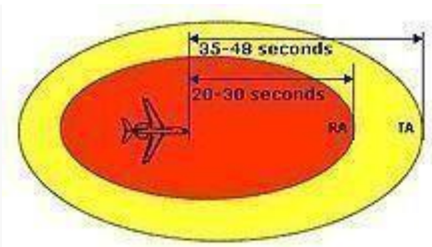
The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue traffic advisories (TA), and the resolution advisories (RA) will be inhibited.

Automatic (traffic/resolution advisories)

The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue traffic advisories (TA) and resolution advisories (RA), when appropriate.

TCAS works in a coordinated manner, so when an RA is issued to conflicting aircraft, a required action (i.e., *Climb. Climb.*) has to be immediately performed by one of the aircraft, while the other one receives a similar RA in the opposite direction (i.e., *Descend. Descend.*).

Alerts



TCAS II typical envelope

TCAS II issues the following types of aural annunciations:

- Traffic advisory (TA)
- Resolution advisory (RA)
- Clear of conflict

When a TA is issued, pilots are instructed to initiate a visual search for the traffic causing the TA. If the traffic is visually acquired, pilots are instructed to maintain visual separation from the traffic. Training programs also indicate that no horizontal maneuvers are to be made based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times have to manoeuver contrary to ATC instructions or disregard ATC instructions. In these cases, the controller is no longer responsible for separation of the aircraft involved in the RA until the conflict is terminated.

On the other hand, ATC can potentially interfere with a pilot's response to RAs. If a conflicting ATC instruction coincides with an RA, a pilot may assume that ATC is fully aware of the situation and is providing the better resolution. But in reality, ATC is not aware of the RA until the RA is reported by the pilot. Once the RA is reported by the pilot, ATC is required not to attempt to modify the flight path of the aircraft involved in the encounter. Hence, the pilot is expected to "follow the RA" but in practice this does not always happen.

Some countries have implemented "RA downlink" which provides air traffic controllers with information about RAs posted in the cockpit. Currently, there are no ICAO provisions concerning the use of RA downlink by air traffic controllers.

The following points receive emphasis during pilot training:

- Do not manoeuver in a direction opposite to that indicated by the RA because this may result in a collision.
- Inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response.
- Be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized.
- If possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA.
- When the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.

Enhanced ground proximity warning system

Enhanced Ground Proximity Warning Systems (EGPWS) are fitted to a large number of commuter and airline aircraft. These systems store flight history data in nonvolatile flash memory. The original purpose of storing this data was to help operators and the EGPWS manufacturer to isolate system or terrain/airport runway database problems. EGPWS flight history data is now becoming increasingly useful for aviation safety investigation purposes particularly when flight data recorder (FDR) or quick access recorder (QAR) data is either unavailable or consists of a limited number of parameters.

On 24 July 2004, the flight crew of a Boeing 737-838 aircraft, received a terrain proximity caution from the aircraft's enhanced ground proximity warning system (EGPWS) while descending to the south-south-east of Canberra Airport. The aircraft was being operated on a scheduled fare-paying passenger service from Perth to Canberra. Due to staff shortages on the morning of the occurrence, the approach control services normally provided by the Canberra Terminal Control Unit did not become available until approximately 40 minutes after the scheduled unit opening time. This meant that the aircraft's descent below 9,000 ft was conducted without air traffic control radar assistance. As the aircraft approached Church Creek (CCK), the copilot, under the direction of the pilot in command, entered the holding pattern details into the Flight Management Computer (FMC). In doing so, an erroneous entry was made, which resulted in the FMC computing a holding pattern with a leg length of 14 NM, instead of 1 minute or a maximum distance from Canberra of 14 NM. By entering a leg distance of 14 NM, the crew inadvertently commanded the FMC to establish the aircraft in a holding pattern that would take the aircraft about 11 NM beyond the published holding pattern limit. The crew initiated descent to 5,000 ft after passing overhead CCK. As it descended, the aircraft proceeded outside the airspace specified for holding. Consequently, the aircraft was operated closer to the surrounding terrain than would normally occur. The aircraft was fitted with an EGPWS, which detected the aircraft's proximity to the terrain and provided the crew with a 'CAUTION TERRAIN' message to which the crew responded by climbing the aircraft to 6,500 ft. Sixteen seconds before the message, the crew had commenced a right turn to intercept the inbound track to CCK. At the time of the message, the aircraft's height above terrain was 2,502 ft (radio altimeter indication). During the turn, the aircraft passed 0.6 NM (1.11 km) north abeam and 810 ft higher than the closest terrain that had a spot height of 4,920 ft above mean sea level. It also passed 2.7 NM (5 km) north abeam Tinderry Peak. The aircraft climbed to 6,500 ft and subsequently joined the runway 35 localiser.

The system monitors an aircraft's height above ground as determined by a radar altimeter. A computer then keeps track of these readings, calculates trends, and will warn the flight crew with visual and audio messages if the aircraft is in certain defined flying configurations ("modes").

The modes are:

1. Excessive descent rate ("SINK RATE" "PULL UP")
2. Excessive terrain closure rate ("TERRAIN" "PULL UP")
3. Altitude loss after takeoff or with a high power setting ("DON'T SINK")
4. Unsafe terrain clearance ("TOO LOW – TERRAIN" "TOO LOW – GEAR" "TOO LOW – FLAPS")
5. Excessive deviation below glideslope ("GLIDESLOPE")
6. Excessively steep bank angle ("BANK ANGLE")
7. Windshear protection ("WINDSHEAR")

The traditional GPWS does have a blind spot. Since it can only gather data from directly below the aircraft, it must predict future terrain features. If there is a dramatic change in terrain, such as a steep slope, GPWS will not detect the aircraft closure rate until it is too late for evasive action.

In the late 1990s, improvements were developed and the system is now named *"Enhanced Ground Proximity Warning System"* (EGPWS/TAWS). The system is combined with a worldwide digital terrain database and relies on Global Positioning System (GPS) technology. On-board computers compare current location with a database of the Earth's terrain. The Terrain Display gives pilots a visual orientation to high and low points nearby the aircraft.

EGPWS software improvements are focused on solving two common problems; no warning at all, and late or improper response.

No warning

The primary cause of CFIT occurrences with no GPWS warning is landing short. When the landing gear is down and landing flaps are deployed, the GPWS expects the airplane to land and therefore, issues no warning. However, the GPWS can also malfunction because of a short circuit. On September 26, 1997, Garuda Indonesia Flight 152 crashed into a hilly area, killing all 222 passengers and 12 crew on board. Despite the fact that the plane was nearing terrain, the GPWS did not activate, even though the leading gear and landing flaps were not deployed. EGPWS introduces the Terrain Clearance Floor (TCF) function, which provides GPWS protection even in the landing configuration.

Late warning or improper response

The occurrence of a GPWS alert typically happens at a time of high workload and nearly always surprises the flight crew. Almost certainly, the aircraft is not where the pilot thinks it should be, and the response to a GPWS warning can be late in these circumstances. Warning time can also be short if the aircraft is flying into steep terrain since the downward-looking radio altimeter is the primary sensor used for the warning calculation. The EGPWS improves terrain awareness and warning times by introducing the Terrain Display and the Terrain Data Base Look Ahead protection.

Weather radar

Airborne weather radar is a type of radar used to provide an indication to pilots of the intensity of convective weather. Modern weather radars are mostly doppler radars, capable of detecting the motion of rain droplets in addition to intensity of the precipitation.

Typically, the radar antenna is located in the nose of the aircraft. Signals from the antenna are processed by a computer and presented on a screen which may be viewed by the pilots. Droplet size is a good indicator of strong updrafts within cumulonimbus clouds, and associated turbulence, and is indicated on the screen by patterns, colour coded for intensity.

Some airborne weather radar systems may also be able to predict the presence of wind shear.

Regulation

(a) An operator shall not operate:

(1) A pressurised aeroplane; or

(2) An unpressurised aeroplane which has a maximum certificated take-off mass of more than 5 700 kg; or

(3) An unpressurised aeroplane having a maximum approved passenger seating configuration of more than 9 seats after 1 April 1999,

unless it is equipped with airborne weather radar equipment whenever such an aeroplane is being operated at night or in instrument meteorological conditions in areas where thunderstorms or other potentially hazardous weather conditions, regarded as detectable with airborne weather radar, may be expected to exist along the route.

(b) For propeller driven pressurised aeroplanes having a maximum certificated take-off mass not exceeding 5 700 kg with a maximum approved passenger seating configuration not exceeding 9 seats the airborne weather radar equipment may be replaced by other equipment capable of detecting thunderstorms and other potentially hazardous weather conditions, regarded as detectable with airborne weather radar equipment, subject to approval by the Authority.

Autopilots

The basic function of the autopilot is to control the flight of the aircraft and maintain it on a pre-determined path in space without any action being required by the pilot. (Once the pilot has selected the appropriate control mode(s) of the autopilot.) The autopilot can thus relieve the pilot from the fatigue and tedium of having to maintain continuous control of the aircraft's flight path on a long duration flight so the pilot can concentrate on other tasks and the management of the mission.

A well designed autopilot system which is properly integrated with the aircraft flight control system can achieve a faster response and maintain a more precise flight path than the pilot. Even more important, the autopilot response is always consistent whereas a pilot's response can be affected by fatigue and work load and stress. The autopilot is thus able to provide a very precise control of the aircraft's flight path for such applications as fully automatic landing in very poor, or even zero visibility conditions. In the case of a military strike aircraft, the autopilot in conjunction with a T/F guidance system can provide an all weather automatic terrain following capability. This enables the aircraft to fly at high speed (around 600 knots) at very low altitude

(200 ft or less) automatically following the terrain profile to stay below the radar horizon of enemy radars. Maximum advantage of terrain screening can be taken to minimise the risk of detection and alerting the enemy's defences.

The basic autopilot modes are covered in the next section. These include such facilities as automatic coupling to the various radio navigation systems such as VOR and the approach aids at the airport or airfield such as ILS and MLS. Flight path guidance derived from the aircraft's GPS system is also coming into increased use. The autopilot then steers the aircraft to stay on the path defined by the radio navigation aid. The autopilot can also be coupled to the flight management system which then provides the steering commands to the autopilot to fly the aircraft on the optimum flight path determined by the FMS from the flight plan input by the pilot.

The autopilot is thus an essential equipment for most military and civil aircraft, including helicopters. The advent of the micro-processor has also enabled relatively sophisticated and affordable autopilots to be installed in large numbers of general aviation type aircraft.

The prime role of the flight management system is to assist the pilot in managing the flight in an optimum manner by automating as many of the tasks as appropriate to reduce the pilot workload. The FMS thus performs a number of functions, such as:

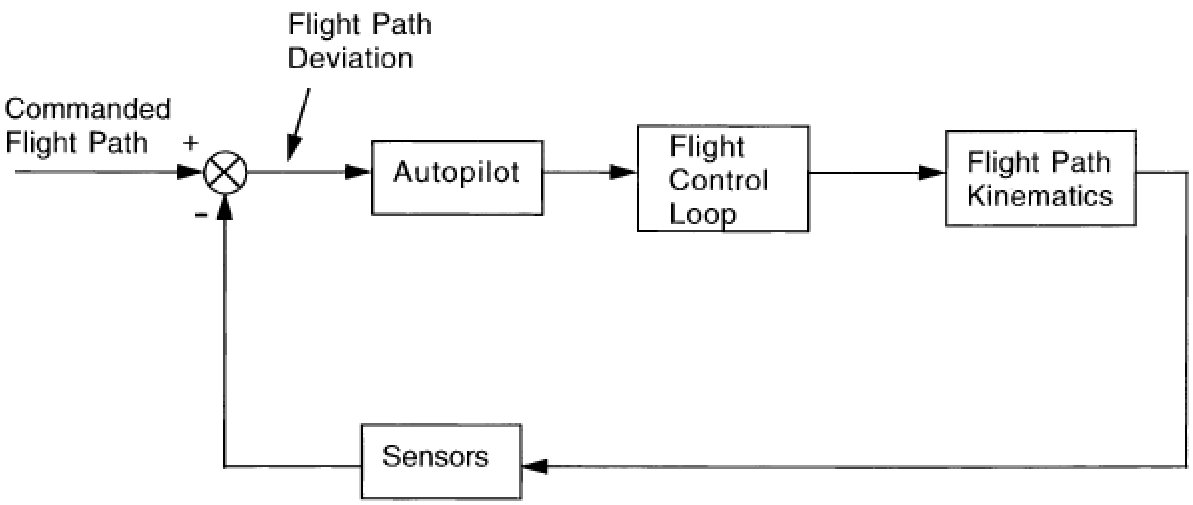
- Automatic navigation and guidance including '4D' navigation.
- Presentation of information.
- Management of aircraft systems.
- Efficient management of fuel.
- Reduction of operating costs.

It should be appreciated that the detailed implementation of an FMS is a complex subject and can involve over 100 man-years of software engineering effort and very extensive (and expensive) flight trials before certification of the system can be obtained from the regulatory authorities. It is only possible, therefore, because of space constraints to give an overview of the subject.

It should also be pointed out that an FMS has an equally important role in a military aircraft. Accurate adherence to an optimum flight path and the ability to keep a rendezvous at a particular position and time for, say, flight refueling or to join up with other co-operating aircraft are clearly very important requirements.

Basic Principles

The basic loop through which the autopilot controls the aircraft's flight path is shown in the block diagram below. The autopilot exercises a guidance function in the outer loop and generates commands to the inner flight control loop. These commands are generally attitude commands which operate the aircraft's control surfaces through a closed-loop control system so that the aircraft rotates about the pitch and roll axes until the measured pitch and bank angles are equal to the commanded angles. The changes in the aircraft's pitch and bank angles then cause the aircraft flight path to change through the flight path kinematics.



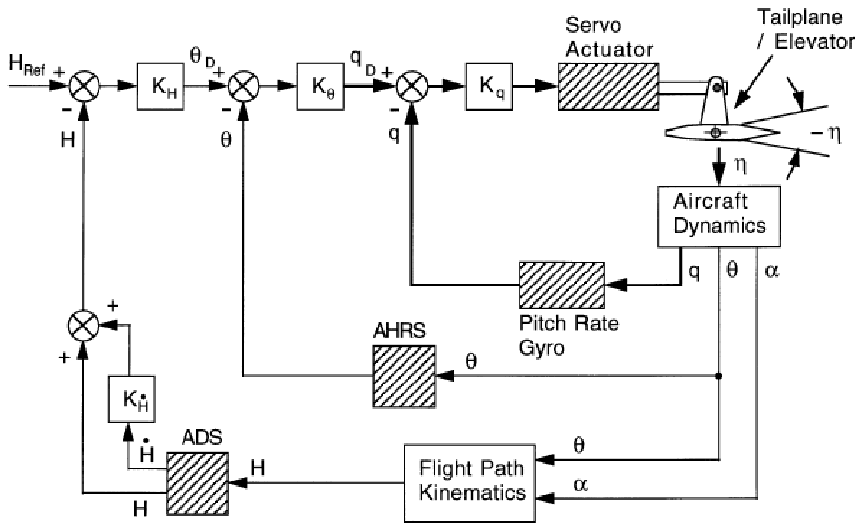
Autopilot loop.

For example, to correct a vertical deviation from the desired flight path, the aircraft's pitch attitude is controlled to increase or decrease the angular inclination of the flight path vector to the horizontal. The resulting vertical velocity component thus causes the aircraft to climb or dive so as to correct the vertical displacement from the desired flight path. To correct a lateral displacement from the desired flight path requires the aircraft to bank in order to turn and produce a controlled change in the heading so as to correct the error.

The pitch attitude control loop and the heading control loop, with its inner loop commanding the aircraft bank angle, are thus fundamental inner loops in most autopilot control modes. The outer autopilot loop is thus essentially a slower, longer period control loop compared with the inner flight control loops which are faster, shorter period loops.

Height Control

Height is controlled by altering the pitch attitude of the aircraft, as just explained. The basic height control autopilot loop is shown below.



The pitch rate command inner loop provided by the pitch rate gyro feedback enables a fast and well damped response to be achieved by the pitch attitude command autopilot loop. As mentioned earlier, a FBW pitch rate command flight control system greatly assists the autopilot integration.

The pitch attitude command loop response is much faster than the height loop response – fractions of a second compared with several seconds. The open-loop transfer function of the height loop in fact approaches that of a simple integrator at frequencies appreciably below the bandwidth of the pitch attitude command loop.

The height error gain, *KH* (or gearing) is chosen so that the frequency where the open-loop gain is equal to unity (0 dB) is well below the bandwidth of the pitch attitude loop to ensure a stable and well damped height loop response. (The design of autopilot loops is explained in more detail in the worked example in the next section.)

The pitch attitude loop bandwidth thus determines the bandwidth of the height loop so that the importance of achieving a fast pitch attitude response can be seen. The transfer function of the flight path kinematics is derived as follows. Vertical component of the aircraft's velocity vector is

$$VT \sin \theta F = \dot{H}$$

where θF is the flight path angle, that is the inclination of the velocity vector VT to the horizontal.

$$\theta F = \theta - \alpha$$

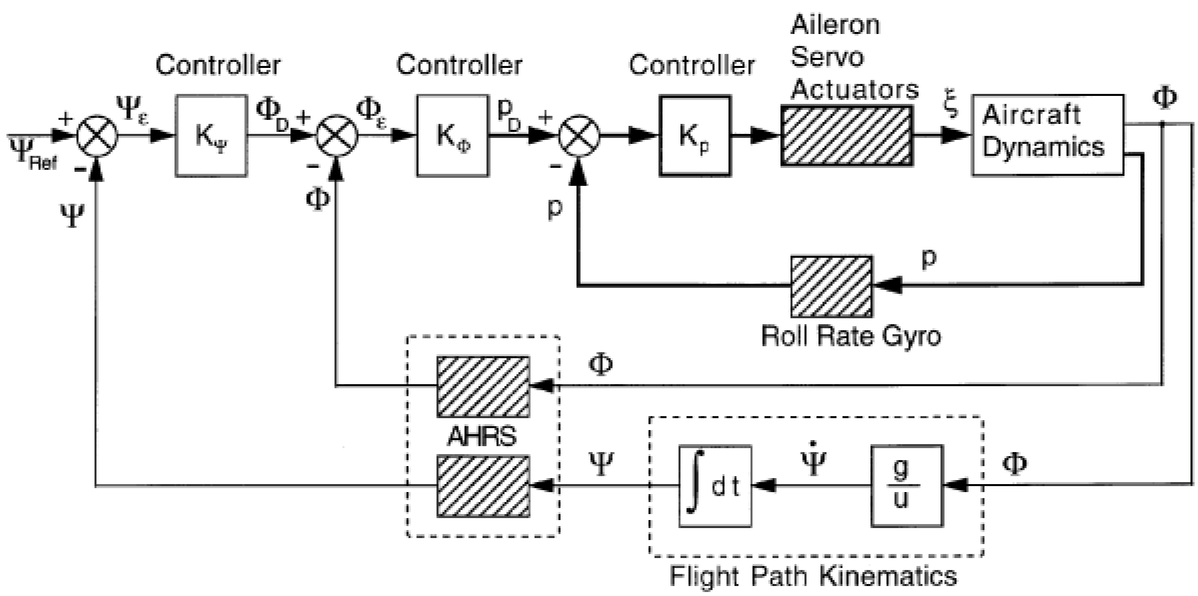
where θ is the aircraft pitch angle and α is the angle of incidence, $VT \approx U$, aircraft forward velocity and θF is assumed to be a small angle. Hence

$$\dot{H} \approx U(\theta - \alpha)$$

$$H = \int U(\theta - \alpha)dt$$

Heading Control Autopilot

The function of the heading control mode of the autopilot is to automatically steer the aircraft along a particular set direction. The heading control loop is shown in more detail in the block diagram in below Figure The inner bank angle command loop should have as high a bandwidth as practical as well as being well damped in order to achieve a 'tight' heading control with good stability margins. This will be brought out in the worked example which follows.



Roll rate command FBW enables a fast, well damped bank angle control system to be achieved. The dynamic behaviour of the lateral control system of an aircraft is complicated by the inherent cross-coupling of rolling and yawing rates and sideslip velocity on motion about the roll and yaw axes.

However, a good appreciation of the aircraft and autopilot behaviour can be obtained by assuming pure rolling motion and neglecting the effects of cross-coupling between the roll and yaw axes. This can also be justified to some extent by assuming effective auto-stabilisation loops which minimise the cross-coupling effects.

$$\frac{p}{\xi} = \frac{L_\xi}{L_p}, \cdot \frac{1}{1 + T_R D}$$

where T_R is the roll rate response time constant ($= I_x/L_p$) and L_ξ is the rolling moment derivative due to aileron angle, ξ and L_p is the rolling moment derivative due to roll rate, p and I_x is the moment of inertia of aircraft about the roll axis.

$$\dot{\Phi} = p + q \sin\Phi \tan\theta + r \cos\Phi \tan\theta$$

If Φ and θ are small angles

$$\dot{\Phi} = p$$

i.e.

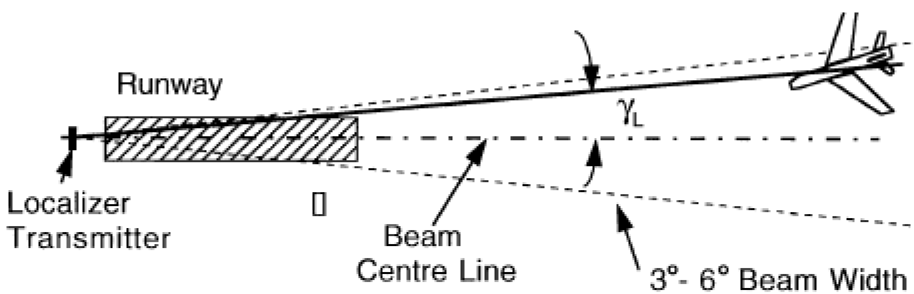
$$\Phi = \int p dt$$

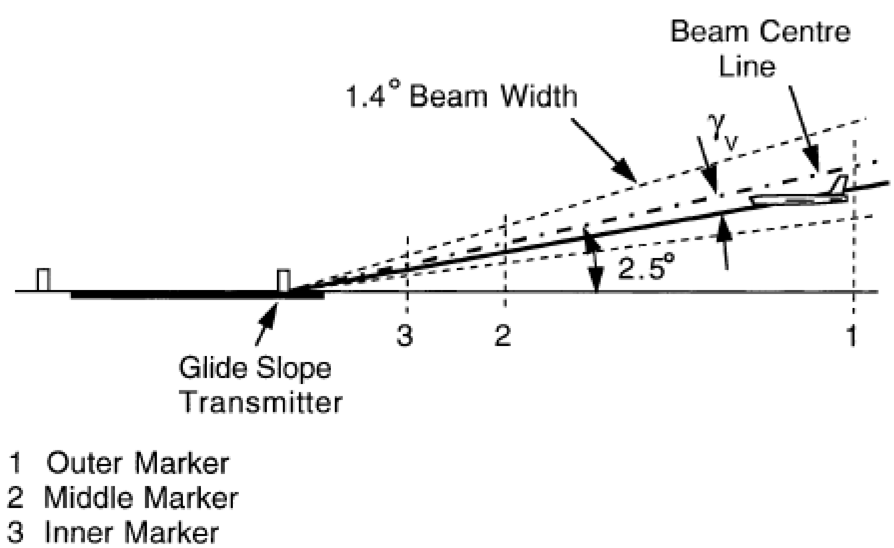
ILS/MLS Coupled Autopilot Control

ILS is a radio based approach guidance system installed at major airports and airfields where the runway length exceeds 1800 m which provides guidance in poor visibility conditions during the approach to the runway.

A small number of major airports are also now equipped with MLS – microwave landing system. MLS is a later and more accurate system which is superior in all aspects to ILS. ILS, however, is a very widely used system and it will be a long time before it is completely replaced. It will thus be supported and maintained for many years to come. The runway approach guidance signals from the ILS (or MLS) receivers in the aircraft can be coupled into the autopilot which then automatically steers the aircraft during the approach so that it is positioned along the centre line of the runway and on the descent path defined by the ILS (or MLS) beams. The autopilot control loops are basically the same for ILS orMLS coupling apart from some signal preconditioning.

Space does not permit a detailed description of either system and a very brief outline of the ILS system only is given as this is the most widely used system. The ILS system basically comprises a localiser transmitter and a glide slope transmitter located by the airport runway together with two or three radio marker beacons located at set distances along the approach to the runway. The airborne equipment in the aircraft comprises receivers and antennas for the localiser, glide slope and marker transmissions. The guidance geometry of the localiser and glide slope beams is shown below The localiser transmission, at VHF frequencies (108–122 MHz), provides information to the aircraft as to whether it is flying to the left or right of the centre line of the runway it is approaching. The localiser receiver output is proportional to the angular deviation γL, of the aircraft from the localiser beam centre line which in turn corresponds with the centre line of the runway. The glide slope (or glide path) transmission is at UHF frequencies (329.3–335 MHz) and provides information to the aircraft as to whether it is flying above or below the defined descent path of nominally 2.5°, for the airport concerned. The glide slope receiver output is proportional to the angular deviation γV, of the aircraft from the centre of the glide slope beam which in turn correspondswith the preferred descent path. (The sign of the γL and γV signals is dependent on whether the aircraft is to the left or the right of the runway centre line, or above or below the defined glide slope.)





The marker beacon transmissions are at 75 MHz. The middle marker beacon is located at a distance of between 1,000 and 2,000 m from the runway threshold and the outer marker beacon is situated at a distance of between 4,500 and 7,500 m from the middle marker. The inner marker beacon is only installed with an airport ILS system which is certified to Category III landing information standards and is located at a distance of 305 m (1,000 ft) from the runway threshold. It should be noted that ILS does not provide sufficiently accurate vertical guidance information down to touchdown.

The height limits and visibility conditions in which the autopilot can be used to carry out a glide slope coupled approach to the runway depends on the visibility category to which the autopilot system is certified for operation, the ILS ground installation standard, the runway lighting installation and the airport's runway traffic control capability.

Visibility conditions are divided into three categories, namely Category I, Category II and Category III, depending on the vertical visibility ceiling and the runway visual range (RVR). An automatic glide slope coupled approach is permitted down to a height of 30 m (100 ft) above the ground, but only if the following conditions are met:

1. There is sufficient vertical visibility at a height of 100 ft with a runway visual range of at least 400 m for the pilot to carry out a safe landing under manual control (Category II visibility conditions). This minimum permitted ceiling for vertical visibility for the landing to proceed is known as the decision height (DH).

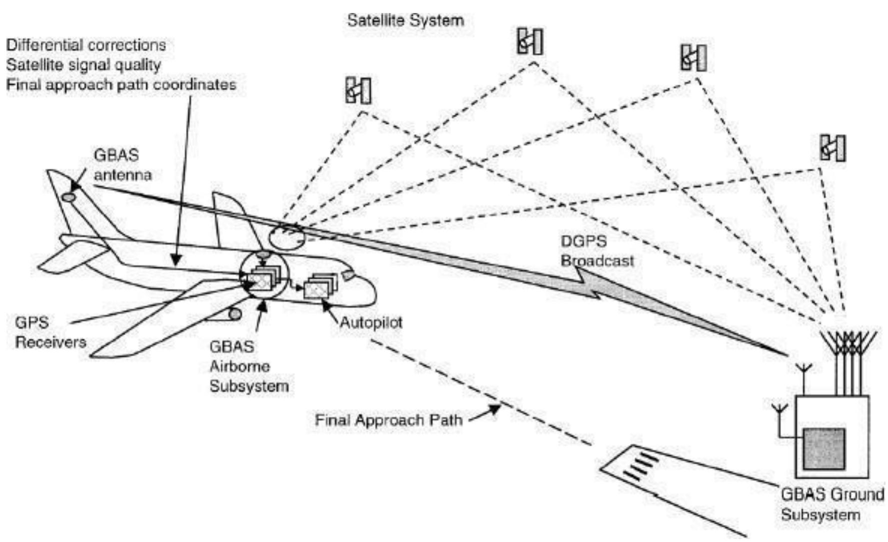
2. The autopilot system is certified for Cat. II operation. This is so that the pilot can take over smoothly in the event of a failure in the autopilot system. Hence, when the decision height is reached the pilot carries out the landing under manual or automatic control. Alternatively, the pilot may execute a go-around manoeuvre to either attempt to land a second time or divert to an alternative airport/ airfield.

Satellite Landing Guidance Systems

The navigation position accuracy of 1 m which can be achieved with the differential GPS technique is being exploited in the US for landing guidance with a system called the Ground Based Augmentation System, GBAS. The Ground Based Augmentation System, when installed at an airport, will be able to provide the high integrity and accurate guidance necessary for landing in Cat. III visibility conditions. The equipment is simpler and less expensive to install and maintain than an Instrument Landing System (ILS) or Microwave Landing System (MLS), so the

GBAS life-cycle operation costs are a fraction of the other systems. It is therefore an attractive proposition for the many smaller airports which are not equipped with ILS or MLS.

It is also a more flexible system. For example, the final approach path need not be limited to straight line approaches, but can be curved or stepped, horizontally or vertically. The Ground Based Augmentation System is shown schematically below. It consists basically of several GPS receivers connected to a base station in an equipment room. The base station processes the measurements from the GPS receivers, determines the differential corrections, estimates their quality and broadcasts this information to nearby aircraft. In addition, the co-ordinates of the final approach paths are transmitted to the aircraft. The control laws exercised by the autopilot during the automatic landing are basically similar whether the guidance is provided by an ILS or MLS, or the GBAS.

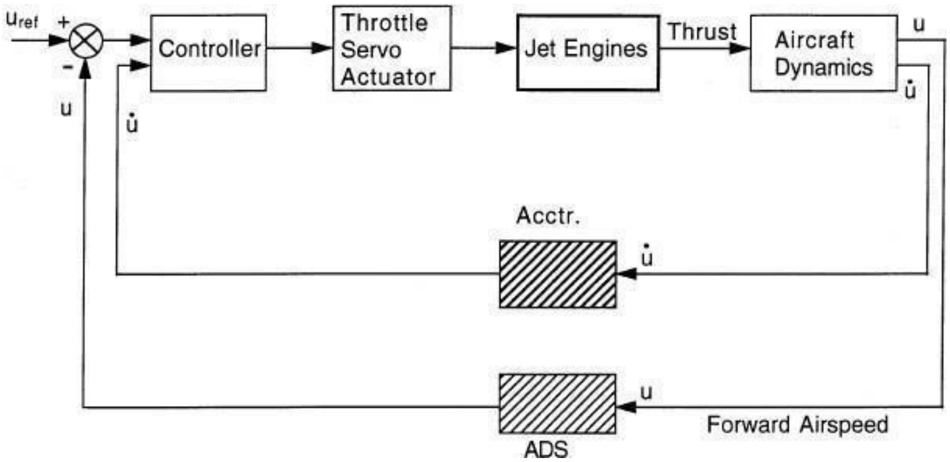


An optional provision is made in the GBAS for additional ranging signals to be provided by ground based transmitters called 'pseudolites' which can be installed to meet high availability requirements.

Speed Control and Auto-Throttle Systems

Control of the aircraft speed is essential for many tasks related to the control of the aircraft flight path, for example the position of the aircraft relative to some reference point.

The aircraft speed is controlled by changing the engine thrust by altering the quantity of fuel flowing to the engines by operating the engine throttles. Automatic control of the aircraft's airspeed can be achieved by a closed-loop control system whereby the measured airspeed error is used to control throttle servo actuators which operate the engine throttles. The engine thrust is thus automatically increased or decreased to bring the airspeed error to near zero and minimise the error excursions resulting from disturbances.



In any closed-loop system, the lags in the individual elements in the loop resulting from energy storage processes (e.g. accelerating inertias) exert a destabilizing effect and limit the loop gain and hence the performance of the automatic control system. The dynamic behaviour of the engines over the range of flight conditions, the throttle actuator response and the aircraft dynamics must thus be taken into account in the design of the speed control system. The response of the jet engine thrust to throttle angle movement is not instantaneous and approximates to that of a simple first-order filter with a time constant which is typically in the range 0.3 to 1.5 seconds, depending on the thrust setting and flight condition. Clearly, the lag in the throttle servo actuator response should be small compared with the jet engine response.

The aircraft dynamics introduces further lags as a change in thrust produces an acceleration (or deceleration) so that an integration is inherent in the process of changing the airspeed. The derivation of airspeed from the air data system can also involve a lag.

The rate of change of forward speed, $\dot{U}$, derived from a body mounted accelerometer with its input axis aligned with the aircraft's forward axis, can provide a suitable stabilising term for the control loop. (The $\dot{U}$ term could also be provided by a strap-down AHRS/INS.) A proportional plus integral of error control is usually provided to eliminate steady-state airspeed errors. A duplicate configuration is generally used so that the systems fails passive. The throttle actuator is de-clutched in the event of a failure and the pilot then assumes control of the engine throttles.

Flight Management Systems

The FMS has become one of the key avionics systems because of the major reduction in pilot work load which is achieved by its use. In the case of military aircraft, they have enabled single crew operation of advanced strike aircraft. Flight management systems started to come into use in the mid 1980s and are now in very wide scale use, ranging from relatively basic systems in commuter type aircraft to ‘all-singing, all-dancing’ systems in long range wide body jet airliners. They have enabled two crew operation of the largest civil airliners and are generally a dual FMS installation because of their importance.

Benefits are as follows:

Quantifiable economic benefits – provision of automatic navigation and flight path guidance to optimise the aircraft’s performance and hence minimise flight costs.

- Air traffic – growth of air traffic density and consequently more stringent ATC requirements, particularly the importance of 4D navigation.
- Accurate navigation sources – availability of accurate navigation sources. For example, INS /IRS, GPS, VOR, DME and ILS / MLS.
- Computing power – availability of very powerful, reliable, affordable computers.
- Data bus systems – ability to interconnect the various sub-systems.

The FMS carries out the following tasks:

1. Flight guidance and lateral and vertical control of the aircraft flight path.
2. Monitoring the aircraft flight envelope and computing the optimum speed for each phase of the flight and ensuring safe margins are maintained with respect to the minimum and maximum speeds over the flight envelope.
3. Automatic control of the engine thrust to control the aircraft speed.

In addition the FMS plays a major role in the flight planning task, provides a computerized flight planning aid to the pilot and enables major revisions to the flight plan to be made in flight, if necessary, to cope with changes in circumstances.

Two independent Flight Management Systems; FMS-1 on the Captain's side and FMS-2 on the First Officer's side carry out the flight management function.

The cockpit interfaces to the flight crew provided by each FMS comprise a Navigation Display (ND), a Primary Flight Display (PFD), a Multi-Function Display (MFD), a Keyboard and Cursor Control Unit (KCCU) and an Electronic Flight Instrument System (EFIS) Control Panel (EFIS CP).

The Multi-Function Display (MFD) displays textual data; over 50 FMS pages provide information on the flight plan, aircraft position and flight performance. The MFD is interactive; the flight crew can navigate through the pages and can consult, enter or modify the data via the Keyboard and Cursor Control Unit (KCCU).

The Keyboard and Cursor Control Unit (KCCU) enables the flight crew to navigate through the FMS pages on the MFD and enter and modify data on the MFD, as mentioned above, and can also perform some flight plan revisions on the lateral Navigation Display (ND).

The EFIS Control Panel (EFIS CP) provides the means for the flight crew to control the graphical and textual FMS data that appear on the ND and PFD.

There are three Flight Management Computers; FMC-A, FMC-B and FMC-C to carry out the functional computations, which can be reconfigured to maintain the system operation in the event of failures.

There are three different FMS operating modes;

Dual Mode,

Independent Mode

Single Mode dependant on the system status.

Dual Mode

Both flight management systems, FMS-1 and FMS-2, are healthy. In normal operation, FMC-A provides data to FMS-1, FMC-B provides data to FMC-2 and FMC-C is the standby computer. Of the two active computers, one FMC is the 'master' and the other is the 'slave', depending on which autopilot is active and the selected position of the FMS Source Select Switch.

The two active FMCs independently calculate data, and exchange, compare and synchronise these data. The standby computer does not perform any calculations, but is regularly updated by the master FMC. In the case of a single FMC failure, for example FMC-A, FMC-C provides data to FMS-1.

Independent Mode

In the Independent Mode, FMS-1 and FMS-2 are both operative, but there is no data exchange between them because they disagree on one or more items such as aircraft position, gross weight, etc.

Single Mode

The loss of two FMC's causes the loss of either FMS-1 or FMS-2. The data from the operative FMS is displayed to the flight crew by operating the Source Select Switch.

Flight Planning

As explained earlier, a major function of an FMS is to help the flight crew with flight planning and it contains a database of:

- Radio NAVAIDS – VOR, DME, VORTAC, TACAN, NDB, comprising identification,
- latitude/longitude, altitude, frequency, magnetic variation, class, airline figure of merit.
- Waypoints – usually beacons.
- Airways – identifier, sequence number, waypoints, magnetic course.
- Airports – identifier, latitude, longitude, elevation, alternative airport.
- Runways – length, heading, elevation, latitude, longitude.
- Airport procedures – ICAO code, type, SID, STAR, ILS, profile descent.
- Company routes – original airport, destination airport, route number, type, cruise altitudes, cost index.

The navigation data base is updated every 28 days, according to the ICAO AiRAC cycle, and is held in non-volatile memory. It is clearly essential to maintain the recency and quality of the data base and the operator is responsible for the detail contents of the data base which is to ARINC 424 format. The flight crew can enter the flight plan in the FMS including all the necessary data for the intended lateral and vertical trajectory. When all the necessary data is entered, the FMS computes and displays the speed, altitude, time, and fuel predictions that are associated with the flight plan. The flight crew can change the flight plan at any time; a change to the lateral plan is called a 'lateral revision' and a change to the vertical plan a 'vertical revision'. The FMS can simultaneously memorise four flight plans:

- One active flight plan for lateral and vertical long term guidance and for radio navigation auto-tuning.
- Three secondary flight plans with drafts to compare predictions, to anticipate a diversion or to store company, ATC and Onboard Information System flight plans.

The ease and visibility of the data entry process can be appreciated.

A flight plan can be created in three ways:

1. By inserting an origin/destination pair and then manually selecting the departure, waypoints, airways and arrival.
2. By inserting a company route stored in the database.
3. By sending a company request to the ground for an active Flight Plan (F-PLN) uplink.

The flight crew can perform the following lateral revisions:

- Delete and insert waypoints.
- Departure procedures: Takeoff runway, Standard Instrument Departure (SID)
- and transition.
- Arrival procedures: Runway, type of approach, Standard Terminal Arrival
- Route (STAR), via, transition.
- Airways segments.
- The flight crew can also perform the following vertical revisions:
- Time constraints.
- Speed constraints.
- Constant Mach segments.
- Altitude constraints.
- Step altitudes.
- Wind.

Performance Prediction and Flight Path Optimisation

The FMS is able to optimise specific aspects of the flight plan from a knowledge of the aircraft type, weight, engines and performance characteristics, information on the wind and air temperature and the aircraft state – airspeed,Mach number, height,etc.

The FMS continually monitors the aircraft envelope and ensures that the speed envelope restrictions are not breached. It also computes the optimum speeds for the various phases of the flight profile. This is carried out taking into account factors such as:

- Aircraft weight – computed from a knowledge of the take-off weight and the fuel consumed (measured by the engine flow meters). It should be noted that fuel can account for over 50% of the aircraft weight at take off.
- CG position – computed from known aircraft loading and fuel consumed.
- Flight level and flight plan constraints.
- Wind and temperature models.
- Company route cost index.

The recommended cruise altitude and the maximum altitude are also computed from the above information.

The flight crew enter the following data to enable the performance computations and flight plan predictions to be made.

Zero Fuel Weight (ZFW) and Zero Fuel Centre of Gravity (ZFCG).

Block fuel.

Airline Cost Index (CI).

Flight conditions (Cruise Flight Level (CRZ FL), temperature, wind).

The FMS computes the following predictions from the flight plan and the flight crew data entries:

- Wind and temperature.
- Speed changes.
- Pseudo waypoint computation: T/C, T/D, LVL OFF.

For each waypoint or pseudo waypoint:

- Distance
- Estimated Time of Arrival (ETA)
- Speed
- Altitude

- Estimated Fuel on Board (EFOB)
- Wind for each waypoint or pseudo waypoint

For primary and alternate destination

- ETA
- Distance to destination
- EFOB at destination

These predictions are continually updated depending on:

- Revisions to the lateral and vertical flight plans.
- Current winds and temperature.
- Actual position versus lateral and vertical flight plans.
- Current guidance modes.