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Automatic Dependent Surveillance Broadcast Investigating and Message Decoding

A Thesis Submitted in Partial fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Aeronautical Engineering

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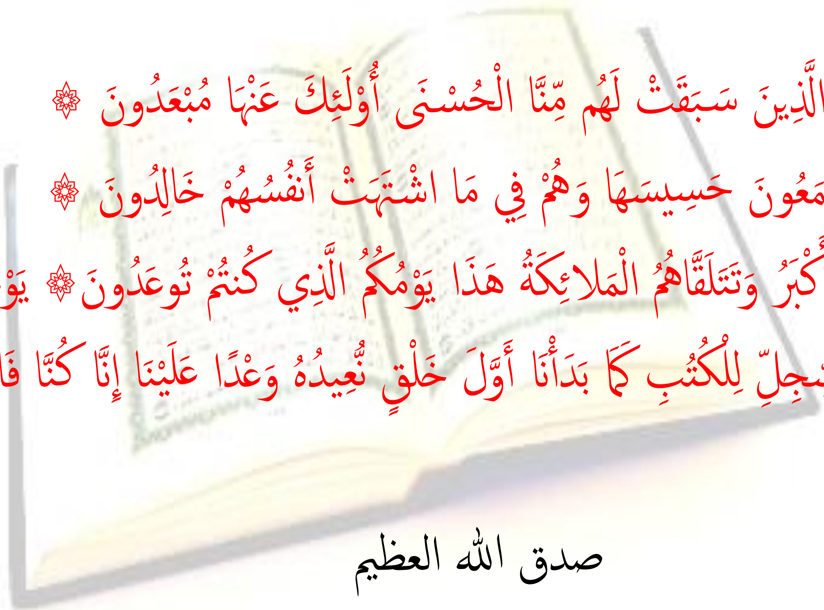
الإستهلال

قال تعالى :



{ إِنَّ الَّذِينَ سَبَقَتْ لَهُم مِّنَّا الْحُسْنَى أُوْلَئِكَ عَنْهَا مُبْعَدُونَ ۞
لا يَسْمَعُونَ حَسِيسَهَا وَهُمْ فِي مَا اشْتَهَتْ أَنفُسُهُمْ خَالِدُونَ ۞
لا يَحْزُنُهُمُ الْفَزَعُ الأَكْبَرُ وَتَتَلَقَّاهُمُ الْمَلائِكَةُ هَذَا يَوْمُكُمُ الَّذِي كُنتُمْ تُوعَدُونَ ۞ يَوْمَ نَطْوِي
السَّمَاء كَطَيِّ السِّجِلِّ لِلْكُتُبِ كَمَا بَدَأْنَا أَوَّلَ خَلْقٍ نُّعِيدُهُ وَعْدًا عَلَيْنَا إِنَّا كُنَّا فَاعِلِينَ }

صدق الله العظيم

الأنبياء (101- 104)

Dedication

Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart.

Our humble effort we dedicate to our sweet and loving

Fathers & mothers,

Whose affection, love, encouragement and prays of day and night make us able to get such success and honor,

Along with all our beloved friends, classmates and respected teachers.

Acknowledgement

Our thanks are due to Sudan University of Science and Technology and to the College of Engineering. Spatially Aeronautical department.

Our sincere gratitude to Mr. Elkatab Jadelseed who supervised this project whose advice was very helpful and important. And has made every effort in order to reach this stage. Our thanks also to the staff of Air Navigation Center who provide us with data and for their explanations.

THANKS AGAIN TO ALL WHO HELPED US.

Abstract

This research deals with the definition for a new aircraft surveillance system, Automatic Dependent Surveillance-Broadcast (ADS-B) which is being introduced by the Federal Aviation Administration (FAA) with mandated implementation in the United States by the year 2020.

ADS-B is a system used to determine the position of an aircraft and then broadcast that information, along with its altitude, call sign, heading, and aircraft type automatically (i.e., without an SSR interrogation signal) to other aircrafts and to air traffic control ground facilities. It was built using similar aspects of the current aircraft surveillance transmission mode called Mode S or mode select. There are two optional frequencies available for ADS-B, the first one is Mode S 1090ES and the second is UAT 978 MHZ, with data link length 112 bits.

The main focus of this thesis has been on ADS-B messages receiving and decoding. The MATLAB has been used to decode these messages, then the decoded messages have been displayed on Google Earth Application by using an API between it and MATLAB.A positional ADS-B message has been used in this research which is downlink format (DF) 17, subtype 5 messages.

المستخلص

سيتناول هذا البحث التعريف عن نظام ملاحة جديد أطلق بواسطة إدارة الطيران الفيدرالية الأمريكية و يطلق عليه نظام البث الإستطلاعي المستقل التلقائي يقترح أن يكون من التوصيات ضرورية التطبيق في كل أنحاء العالم بحلول عام 2020.

و هو نظام يستخدم لتحديد موقع الطائرة و من ثم بث هذه البيانات - متضمنة الإرتفاع, وجهة الطائرة و نوعها – تلقائياً (أي بدون إشارة استجواب من رادار ثانوي) إلى الطائرات الأخرى و إلى مرافق التحكم في حركة الأجواء . هذا النظام تم بناؤه على معايير مشابهة لنظام الإرسال (الوضع اس) أو وضع الاختيار.

هنالك ترددان يتم استخدامهم بواسطة نظام البث الإستطلاعي المستقل التلقائي , الأول 1090 ميقا هيرتز التردد الممتد و الثاني 978 ميقا هيرتز الخاص بترانسيفر الوصول العالمي , كلا الترددين يرسلان بيانات طولها 112 بت.

التركيز الأساسي لهذا البحث كان على إستقبال رسائل هذا النظام وفك شفرتها باستخدام برنامج الماتلاب .بعد ذلك تم عرضها على تطبيق قوقل إيرث بإستخدام كود للربط بينه وبين الماتلاب .للتذكير هذا البحث إستخدم رسائل ذات النوع الخامس (صيغة الربط 17).

Table of Contents

Chapter One:

Chapter Two:

Chapter Three:

Chapter Four:

Chapter five:

Chapter six:

Table of figures

ACRONYMS

A/C	Aircraft
ACARS	Aircraft Communication Addressing And Reporting System
ADF	Automatic Direction Finder
ADS-B	Automatic Dependence Surveillance Broadcast
ADS-R	Automatic Dependence Surveillance Rebroadcast
API	Application Programming Interface
ATC	Air Traffic Control
ATMS	Air Traffic Management System
BOC	Binary Offset Carrier
CDMA	Code Division Multiple Access
CDTI	Cockpit Display of Traffic Information
CPR	Compact Position Report
DF	Downlink Format
DGPS	Differential Global Positioning System
DH	Decision Height
DME	Distance Measurement Equipment
DNS	Doppler Navigation System
ES	Extended Squitter
FAA	Federal Aviation Administration
FAF	Final Approach Fix

FANS	Future Air Navigation System
FDMA	Frequency Division Multiple Access
FLTID	Flight Identification
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Glide Slope
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ID	Identification
IFF	Identification Friend or Foe
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ITU	International Telecommunication Units
LAT	Latitude
LON	Longitude
LORAN-C	Long Range Navigation (revision C
LSB	Least Significant Bit
MDA	Minimum Descent Altitude
MEMS	Micro Electromechanical System
MLS	Microwave Landing System

MSB	Most Significant Bit
NAS	National Airspace System
NAVIDS	Navigation Aids
NDB	Non Directional Beacon
OMEGA	Optimized Method for Estimated Guidance Accuracy
PPM	Pulse Position Modulation
PSR	Primary Surveillance Radar
QPSK	Quadrature Phase Skip Keying
RADAR	Radio Detection And Ranging
RLAT	Recovered Latitude
RLON	Recovered Longitude
RMI	Radio Magnetic Indicator
RMAV	Random or Area Navigation
RNSS	Radio Navigation Satellite Services
SAR	Service And Rescue
SPI	Special Position Identification
SSR	Secondary Surveillance Radar
TACAN	Tactical Air Navigation System
TACAS	Traffic Alert and Collision Avoidance System
TDP	Touchdown Point
TK	Track

TOA	Time Of Arrival
TOF	Time Of Flight
UAT	Universal Access Transceiver
VLF	Very Low Frequency
VOR	VHF Omni Range
VORTAC	VOR & TACAN
WAAS	Wide Area Augmentation System
WPT	Way Point

Chapter One: Introduction

1.1 Overview

Automatic Dependent Surveillance - Broadcast (ADS-B) is a surveillance technique that allows the transmission of aircraft derived parameters, such as position and identification, via a broadcast mode data link for use by any air and ground users. Each ADS-B emitter periodically broadcasts its position and other data provided by the onboard aircraft avionics systems. Any user, either airborne or ground based, within range of the emitter may choose to receive and process the information. Tow frequency options are available, The first is an extended use of the 1090 MHz Mode-S transponder protocol known as 1090 ES. The second largely being introduced as a new broadband solution for general aviation implementation of ADS-B, is at 978 MHz A 978 universal access transceiver (UAT) is used only in USA but 1090ES is global, ADS-B is a data link principle, not a technology. ADS-B allows pilots and air traffic controllers to "see" and control aircrafts with more precision, and over a far larger percentage of the earth's surface, than has ever been possible before. An ADS-B-equipped aircraft determines its own position using a global navigation satellite system (GNSS) or any navigation satellite system and periodically broadcasts this position and other relevant information to potential ground stations and other aircraft with ADS-B-in equipment without knowing what other vehicles or entities might be receiving it, and without expectation of an acknowledgment or reply.

ADSB acronym meaning:

- **A** is for **Automatic** in the sense that no pilot or controller action is required for the information to be issued. It's always ON and requires no operator intervention.
- **D** is for **Dependent** surveillance, in the sense that the surveillance-type information so obtained, depends on an accurate GNSS signal for position data and broadcast capability in the source vehicle.
- **S** is for **Surveillance**, because it provides "Radar-like" surveillance services, much like RADAR.
- **B** is for **Broadcast**, in the sense that it continuously broadcasts aircraft position and other data to any aircraft, or ground station equipped to receive ADS-B.

ADS-B is also a relatively inexpensive technology, if we consider costs respect to radar coverage range. The power requirements for ADS-B, unlike radar, are quite small, allowing an ADS-B ground station to be installed in even the most remote areas. Enhanced safety, improved surface surveillance, ADS-B has two major segments ADS-B OUT: Avionics broadcasts ADS-B Messages (e.g. Identity, Position, Velocity, etc.) This is a precondition for any ADS-B application (e.g. radar-like surveillance). ADS-B IN: Avionics receives other aircrafts' ADS-B OUT messages required for air-to-air applications and TIS-B, FIS-B and ADS-R services. (e.g. improved situation awareness, airborne separation assurance, etc.).

1.2 Aim and Objectives

Aim

The aim of this research is to investigate positional ADS-B messages. ADS-B contains multiple subtype formats for broadcasting aircraft data, this research will focus on downlink format (DF) 17. These messages contain information such as aircraft ID, altitude, latitude, and longitude, which provide the position of the target to be inserted on Google Earth application.

Objectives

- To investigate ADS-B system.
- To analyse mathematical model for ADS-B message.
- To write M file MATLAB program to decode ADS-B message.
- To plot the result on Google earth.

1.3 Problem Statement

In an effort to increase the safety, efficiency and capacity of air transport operations, the FAA proposes a comprehensive reform of the surveillance radar (NextGen). For this, the FAA deploys a relatively new technology called Automatic Dependent Surveillance-Broadcast (ADS-B). This technology allows aircraft equipped with a GPS to periodically send their position and other information to ground stations and other aircraft equipped with ADS-B that are present in the area. Although the FAA expects to keep the primary radar for defense, many of today's secondary surveillance radars will not be used in the future and ADS-B system is not familiar and it not yet investigated and tested by aeronautical engineer in Sudan University (Avionics student).

1.4 Proposed Solution

Investigate the ADS-B system. Then simulate the ADS-B receiver by using API between MATLAB and Google earth application

1.5 Motivation

The recently technical revolution which has taken place doesn't expect the aviation world especially which is related to the avionics field. If we historically look for the previous systems, we will find more weaknesses and what we are talking about is a part of avionics which involves ADS-B which improves more weaknesses of the early navigation systems .It is known that ADS-B is considered as next generation which is developed these days to cover a large area of the world.

1.6 Contribution of the Thesis

We believe that this thesis could be considered the basic to bigger projects involved of a fully monitoring and tracking system for a small surveillance aircrafts (UAVs) suggested by the aeronautical engineering department.

1.7 Methodology

In order to investigate ADS-B receiver, an important part of the investigation process is the simulation of the receiver, which has been achieved using MATLAB. The work done has been written in a report with the following description.

This research will include introduction as the first chapter which will contain: an overview of the hall thesis, the objective of the thesis, the problem statement and the proposed solution, its contribution and outlines of thesis.

The next chapter will be literature review which talk about the navigation aids, its classifications and will talk about avionics aids which will be divided into Short-Range NAVIDS, Long-Range NAVIDS, Approach-Landing NAVIDS, GPS, DGPS, WAAS and GNSS.

The following chapter talks about the early surveillance systems, illustrates subjects about primary surveillance radar (PSR), secondary surveillance radar (SSR) and ADS-B, its implementation, services and benefits.

Then after that comes a new chapter will explain the process of using the mathematical equations in signal decoding at the receiver of ADS-B.

After that the fifth chapter will illustrate simulations by using MATLAB and Google Earth Application and the method of interface used to link them.

The final chapter will include the conclusion of the thesis and the recommendations that carried out during the process of the project.

Chapter Two: Literature Review

2.1 Short range navigation aids

2.1.1 Automatic Direction Finder – ADF

- **Principle**

Provides A/C bearing w.r.t. a GND station known as Non Directional Beacon (NDB). The bearing is measured clockwise starting from the A/C longitudinal axis and stopping at the segment of the A/C – NDB. Note that the reading obtained in the Flight Compartment (F/C) indicator is a relative bearing known as the ADF bearing. The figure (2.1) below illustrates the principle.

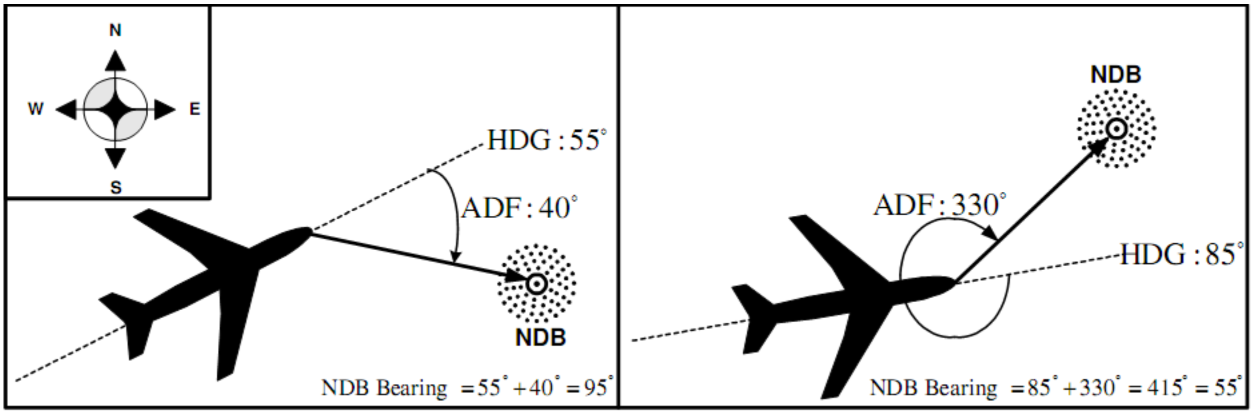


Figure 2.1 Examples illustrating the ADF principle

- **Applications**

❖ TK Intercept: To be able to get back to the TK due to crosswind.
❖ Station Homing: Travel toward or away from an NDB.
❖ Triangulation Position Fix: To know where the A/C is located.

2.1.2 VHF Omni-directional Range – VOR

- **Principle**

Provides A/C radial w.r.t. a GND station. In other words, the VOR system only informs us of the A/C location as an entity seen by a GND VOR-Tx; however, we have no knowledge whatsoever on the HDG of the A/C. The radial of the A/C is obtained by taking the phase difference of 2 signals R (Reference Phase Signal) & V (Variable Phase Signal) transmitted by the GND station.

- **Applications**

❖ V-Airway: Used to assign highways in the sky.
❖ TK Intercept.
❖ Triangulation Position Fix.[4]

2.1.3 Distance Measuring Equipment – DME

- **Principle**

Provides distance between A/C and GND station. Ideally what we want from the DME system is the separation between the A/C and the DME station measured over GND (D); however, the DME usually outputs the slant distance. The figure (2.3) below will illustrate its principle.[4]

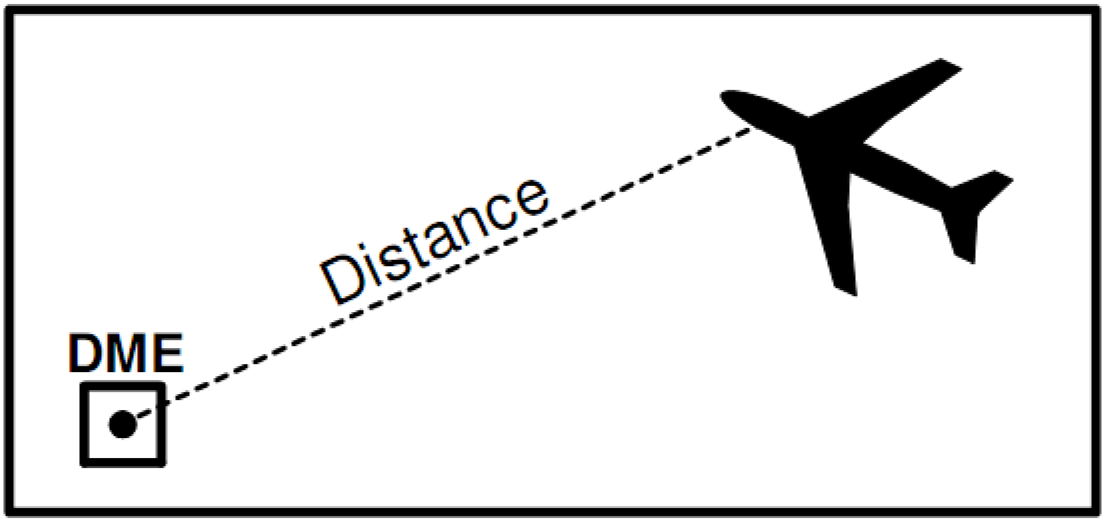


Figure 2.2 Example illustrating the DME principle

2.1.4 Tactical Air Navigation – TACAN

- **Principle**

Provides A/C bearing and distance w.r.t. a GND station for MIL purposes. The bearing part of this system is similar to VOR, but quite unique for the nature of military (MIL) operation. As for the distance measurement capability, it is in fact obtained through the integrated DME system within the TACAN GND station. The TACAN GND station is shown below in figure (2.4).[4]

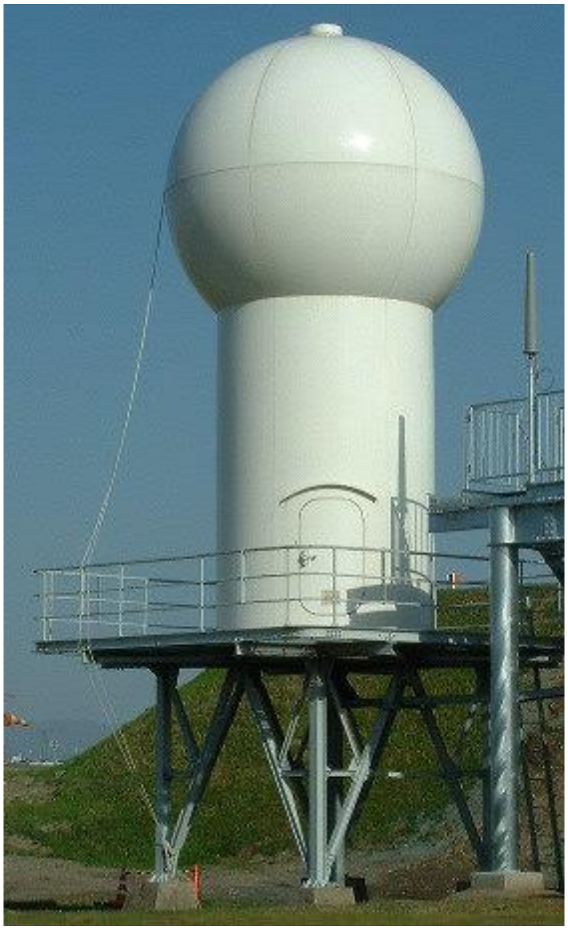


Figure 2.3 TACAN GND station

2.1.5 VOR and TACAN – VORTAC

- **Principle**

GND system with both VOR and TACAN for bearing and distance purposes. In a broader sense, instead of having VOR and TACAN GND stations separately, we could simply join them into a single GND station known as VORTAC. The figure (2.5) below show its GND station. [4]

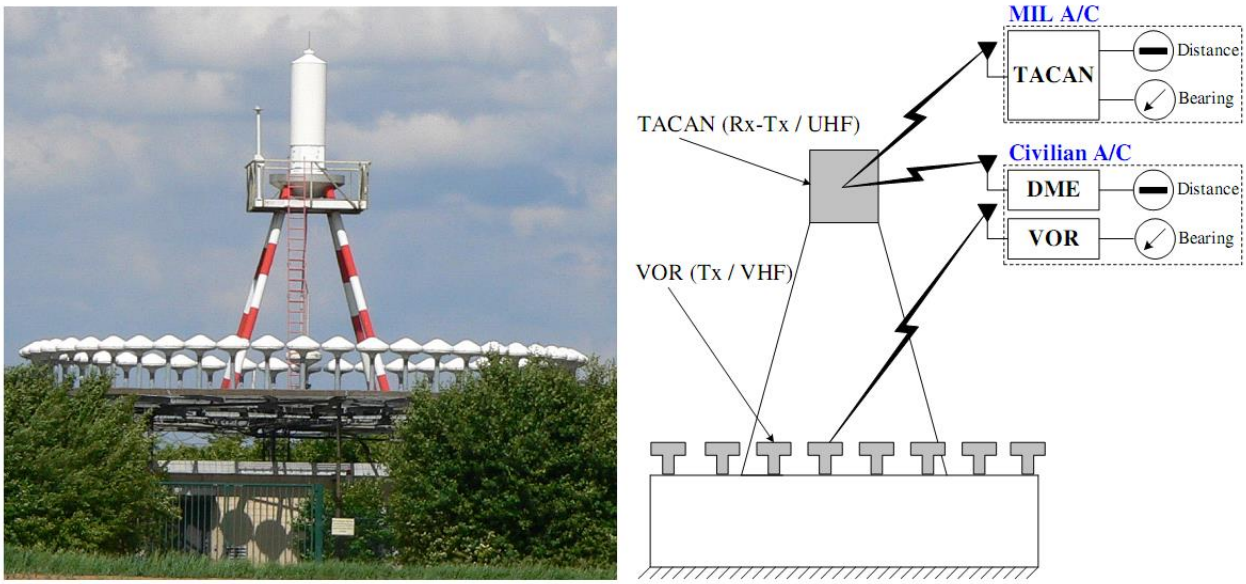


Figure 2.4 VORTAC GND station

2.1.6 Random or Area Navigation – RNAV

- **Principle**

Provides A/C bearing and distance w.r.t. a 3D artificial reference point known as Waypoint (WPT). In fact, the main motivation to navigate using computerized WPTs is to obtain optimized air routes from departure to arrival. The figure (2.6) bellows shows its principle and GND station .

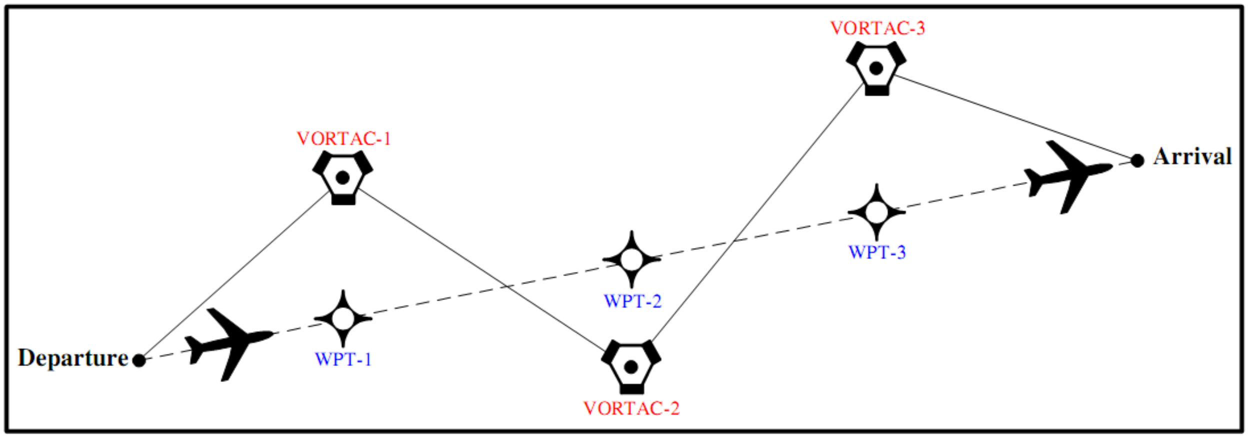


Figure 2.5 Example illustrating the RNAV principle using VORTAC GND stations

- **Position Fix**

To obtain WPTs, we need to have the present A/C 3D position fix. There are 3 general ways to do that using either:

- GND Stations and A/C Radar: GND Stations: VOR-DME or VORTAC to obtain bearing and distance; which could eventually be transformed to A/C LAT and LON. A/C Radar: Radio Altimeter (RA) to obtain the A/C ALT.
- A/C Self-Contained Systems: INS or DNS.
- Orbital SAT System: GPS.[4]

2.1.7 Radio Magnetic Indicator – RMI

- **Indicator Characteristics**

- Flux-valve compass card that indicates the A/C magnetic HDG.
- A needle driven by ADF-Rx indicating the NDB36 magnetic bearing w.r.t. A/C.
- A needle driven by VOR-Rx indicating the VOR GND station bearing (TO) w.r.t. A/C.
- If we extend the bearing lines of the 2 GND stations we obtain the position fix of the A/C.[4]

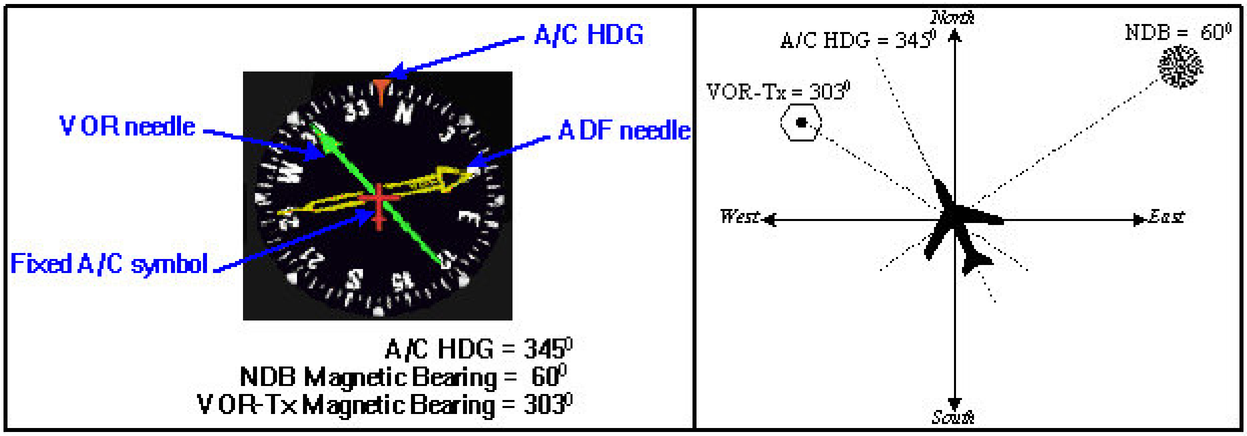


Figure 2.6 RMI

2.2 Long Range Navigation

2.2.1 Long Range Navigation (revision-C) – LORAN-C

Loran-C is a hyperbolic radio navigation system which allows a receiver to determine its position by listening to low frequency radio signals transmitted by fixed land-based radio beacons. Loran-C combined two different techniques to provide a signal that was both long-range and highly accurate, traits that had formerly been at odds. The downside was the expense of the equipment needed to interpret the signals, which meant that Loran-C was used primarily by the military after it was first introduced in 1957.By the 1970s the electronics needed to implement Loran-C had been dramatically reduced due to the introduction of solid state radio electronics, and especially the use of early microcontrollers to interpret the signal. Low-cost and easy-to-use Loran-C units became common from the late 1970s, especially in the early 1980s, leading to the earlier LORAN system being turned off in favour of installing more Loran-C stations around the world. Loran-C became one of the most common and widely used navigation systems for large areas of North America, Europe, Japan and the entire Atlantic and Pacific areas. The Soviet Union operated a nearly identical system, CHAYKA. The introduction of civilian satellite navigation in the 1990s led to a very rapid drop-off in Loran-C use. Discussions about the future of Loran-C began in the 1990s, and several turn-off dates were announced and then cancelled. In 2010 the US and Canadian systems were shut down, along with shared Loran-C/CHAYKA stations with Russia. Several other chains remain active, and some have been upgraded for continued use.

- **Principle**

Provides A/C position fix (2D) In fact, this technology is known as a hyperbolic system since it determines NAV fix using hyperboles or parabolic lines (black) generated from the intersection of signals (blue & red) radiated by GND stations. Also, notice the formation of some straight lines (green).

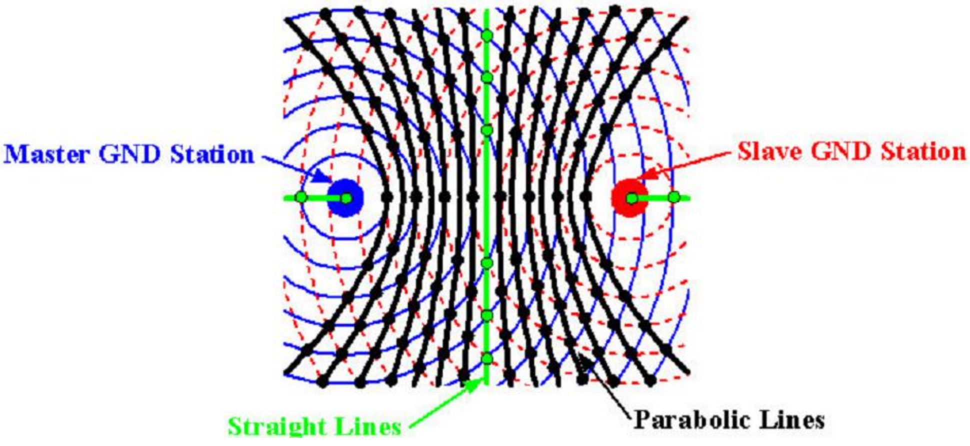


Figure 2.7 Formation of the hyperbolic grid

- **Position Fix**

To obtain the A/C position fix at least 2 hyperbolic grids are required. This means that at least 2 Line Of Position (LOP) have to be generated from a single master station, and at least 2-slave GND stations[4][6]

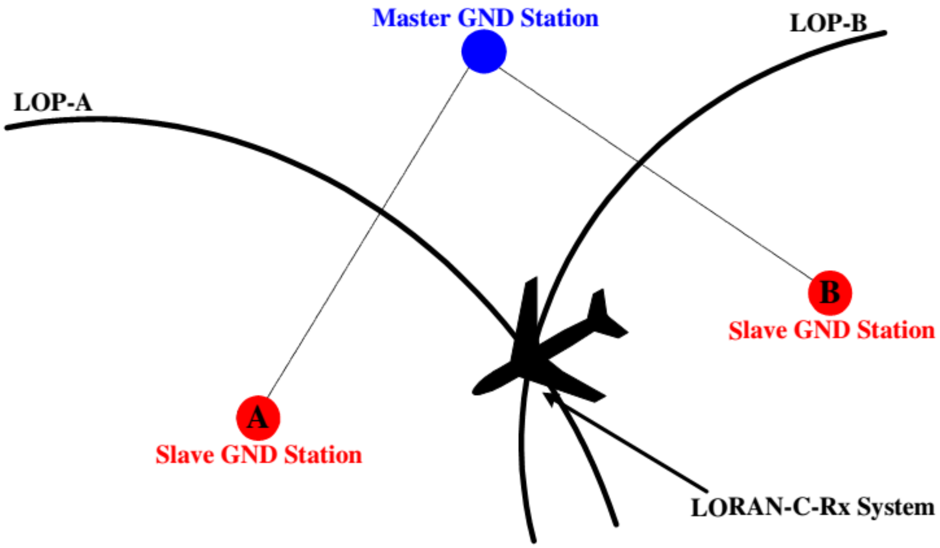


Figure 2.8 Position fix using LORAN-C system

2.2.2 OMEGA

OMEGA was the first truly global-range radio navigation system, operated by the United States in cooperation with six partner nations. It enabled ships and aircraft to determine their position by receiving very low frequency (VLF) radio signals in the range 10 to 14 kHz, transmitted by a network of fixed terrestrial radio beacons, using a receiver unit. It became operational around 1971 and was shut down in 1997 in favour of the Global Positioning Satellite system.

- **Principle**

It provides A/C position fix (2D). This technology is based on NAV using a hyperbolic grid, which is quite similar to the LORAN-C.

- **Position Fix**

To obtain the A/C position fix at least 2 LOPs are required as shown in Figure-2.8 above. The only difference is that in the OMEGA process we need 3 GND stations without tagging them as master or salve like we did using LORAN-C. [4][7]

2.2.3 Inertial Navigation System INS

An inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft. Other terms used to refer to inertial navigation systems or closely related devices include inertial guidance system, inertial reference platform, inertial instrument, inertial measurement units (IMU) and many other variations.

- **Principle**

Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation and velocity. Inertial measurement unit (IMU) typically contains three orthogonal rate-gyroscopes and three orthogonal accelerometers, measuring angular velocity and linear acceleration respectively. By processing signals from these devices it is possible to track the position and orientation of a device. Inertial navigation is used in a wide range of applications including the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines and ships.

Recent advances in the construction of micro electromechanical systems (MEMS) have made it possible to manufacture small and light inertial navigation systems. These advances have widened the range of possible applications to include areas such as human and animal motion capture. An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices. The INS is initially provided with its position and velocity from another source (a human operator, a GPS satellite receiver, etc.), and thereafter computes its own updated position and velocity by integrating information received from the motion sensors.

The advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized. An INS can detect a change in its geographic position (a move east or north, for example), a change in its velocity (speed and direction of movement), and a change in its orientation (rotation about an axis). It does this by measuring the linear acceleration and angular velocity applied to the system. Since it requires no external reference (after initialization), it is immune to jamming and deception. Inertial-navigation systems are used in many different moving objects, including vehicles—such as aircraft, submarines, spacecraft—and guided missiles. However, their cost and complexity place constraints on the environments in which they are practical for use. Gyroscopes measure the angular velocity of the system in the inertial reference frame. By using the original orientation of the system in the inertial reference frame as the initial condition and integrating the angular velocity, the system's current orientation is known at all times. This can be thought of as the ability of a blindfolded passenger in a car to feel the car turn left and right or tilt up and down as the car ascends or descends hills.

Based on this information alone, the passenger knows what direction the car is facing but not how fast or slow it is moving, or whether it is sliding sideways. Accelerometers measure the linear acceleration of the system in the inertial reference frame, but in directions that can only be measured relative to the moving system (since the accelerometers are fixed to the system and rotate with the system, but are not aware of their own orientation). This can be thought of as the ability of a blindfolded passenger in a car to feel themselves pressed back into their seat as the vehicle accelerates forward or pulled forward as it slows down; and feel themselves pressed down into their seat as the vehicle accelerates up a hill or rise up out of their seat as the car passes over the crest of a hill and begins to descend. Based on this information alone, they know how the vehicle is accelerating relative to itself, that is, whether it is accelerating forward, backward, left, right, up (toward the car's ceiling), or down (toward the car's floor) measured relative to the car, but not the direction relative to the Earth, since they did not know what direction the car was facing relative to the Earth when they felt the accelerations. However, by tracking both the current angular velocity of the system and the current linear acceleration of the system measured relative to the moving system, it is possible to determine the linear acceleration of the system in the inertial reference frame.

Performing integration on the inertial accelerations (using the original velocity as the initial conditions) using the correct kinematic equations yields the inertial velocities of the system, and integration again (using the original position as the initial condition) yields the inertial position. In our example, if the blindfolded passenger knew how the car was pointed and what its velocity was before he was blindfolded, and if they are able to keep track of both how the car has turned and how it has accelerated and decelerated since, they can accurately know the current orientation, position, and velocity of the car at any time. [4][8]

2.2.4 Doppler Navigation System – DNS

Doppler radars were used as a navigation aid for aircraft and spacecraft. By directly measuring the movement of the ground with the radar, and then comparing this to the airspeed returned from the aircraft instruments, the wind speed could be accurately determined for the first time. This value was then used for highly accurate dead reckoning. One early example of such a system was the Green Satin radar used in the English Electric Canberra. This system sent a pulsed signal at a very low repetition rate so it could use a single antenna to transmit and receive. An oscillator held the reference frequency for comparison to the received signal. In practice, the initial "fix" was taken using a radio navigation system, normally Gee, and the Green Satin then provided accurate long-distance navigation beyond Gee's 350-mile range. Similar systems were used in a number of aircraft of the area, and were combined with the main search radars of fighter designs by the 1960s.

- **Principle**

Provides A/C velocity (3D) and position fix (3D). This system is primarily used for MIL purposes requiring high-speed low-altitude flights. First, the A/C velocity is obtained using the Doppler radar, then the information is inputted (the HDG, which is provided either by a magnetic compass or a gyro, is also feed to the integrator) to a NAV computer so that the position fix can be calculated. Also, similar to INS, this technology is a self-contained DR system and therefore, does not depend on any outside source. [4][9]

2.3 Approach landing navigation aids

2.3.1 Basics of approach/landing

A\L's information's are gotten from: cockpit navigation instruments, ATC data and approach charts either as softcopy on NAV LCDs, or hardcopy on papers.

2.3.1.1 A\L phases

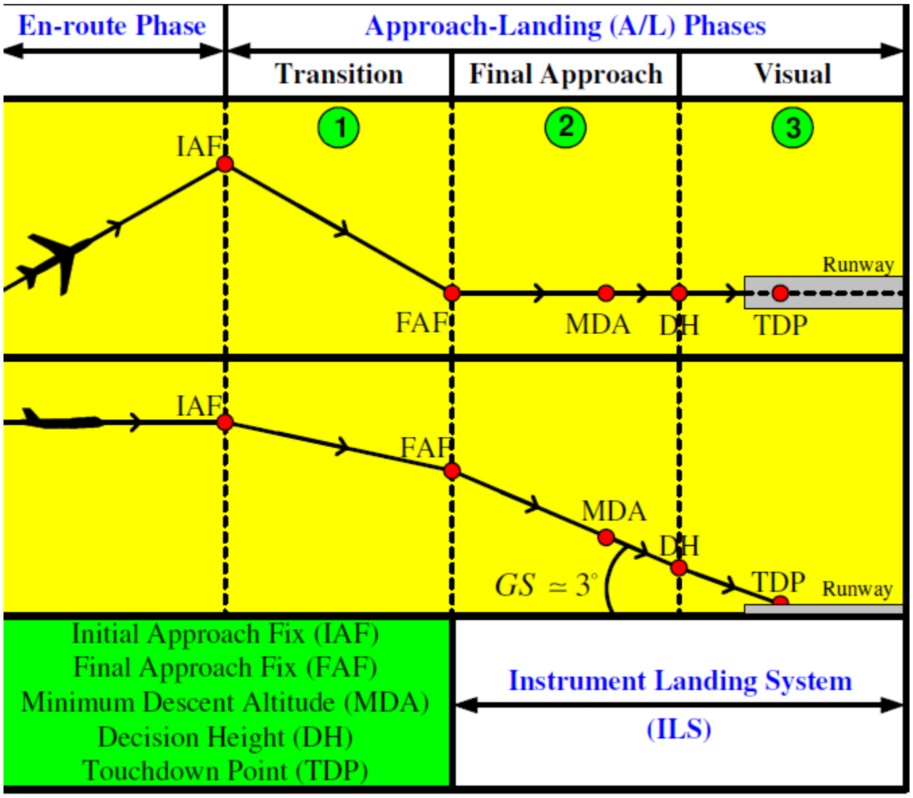


Figure 2.9 A/L phases

- Transition phase: A\C leaves the En-route and enters into A\L.
- Final approach phase : A\C enters in to the ILS Glideslope:
- IFR precision approaches: (Non precision: A\C does not support vertical NAV, and Precision: A\C does support vertical NAV).
- Depending on A\C type, decision must be taken at either MDA or DH on whether to:
  - ✓ Continue landing.

  - ✓ Declare a missed approach and then decide to either: (go around for another trial or go to another airport).
- ➢ Visual Phase: From either MDA or DH until TDP, which roughly 1 km, NAV must be performed visually.

2.3.1.2 Visual A/L Aids

Visual runway support during A/L is quite useful for both VFR and IFR A\Cs:

- ➢ Approach Lighting System – ALS
  - ✓ Supported A/C: IFR-precision
  - ✓ Phases: DH until TDP
  - ✓ Color Configurations: (DH →White, pre-threshold Area → red & white, runway Threshold → Green and centerline and edges → white
- ➢ Visual Approach Slope Indicator System – VASIS
  - ✓ Supported A/C: VFR and IFR-non-precision
  - ✓ Phases: MDA until TDP
  - ✓ Color configurations: (too-high → white & white, normal → red & white and too-low → red & red)

2.3.1.3 Runway numbering

Airport runways are numbered for identification. The method used to provide IDs are as follows:

- ➢ Obtain the runway magnetic bearing from the approaching direction.
- ➢ Rounded the bearing to the nearest 10∘
- ➢ Eliminate the last of the 3-digit bearing, the remaining 2-digits form the runway ID.
- ➢ To obtain the bearing form the other runway extremity proceed as such:

$$\{\text{Runway bearing from one extremity}\} = \{\text{runway bearing from the other extremity}\} \pm 180^{\circ}$$

- ➢ Repeat steps 2 & 3 above to obtain the ID for the other extremity.
- ➢ At large airports, there are parallel runways; hence, an extra letter is added to the ID.
- ➢ Characterize the position: Left (L), Center (C) and Right (R). These parallel runways could either be double (i.e. 2-runways “L” & “R”) or triple (i.e. 3-runways “L” “C” “R”).

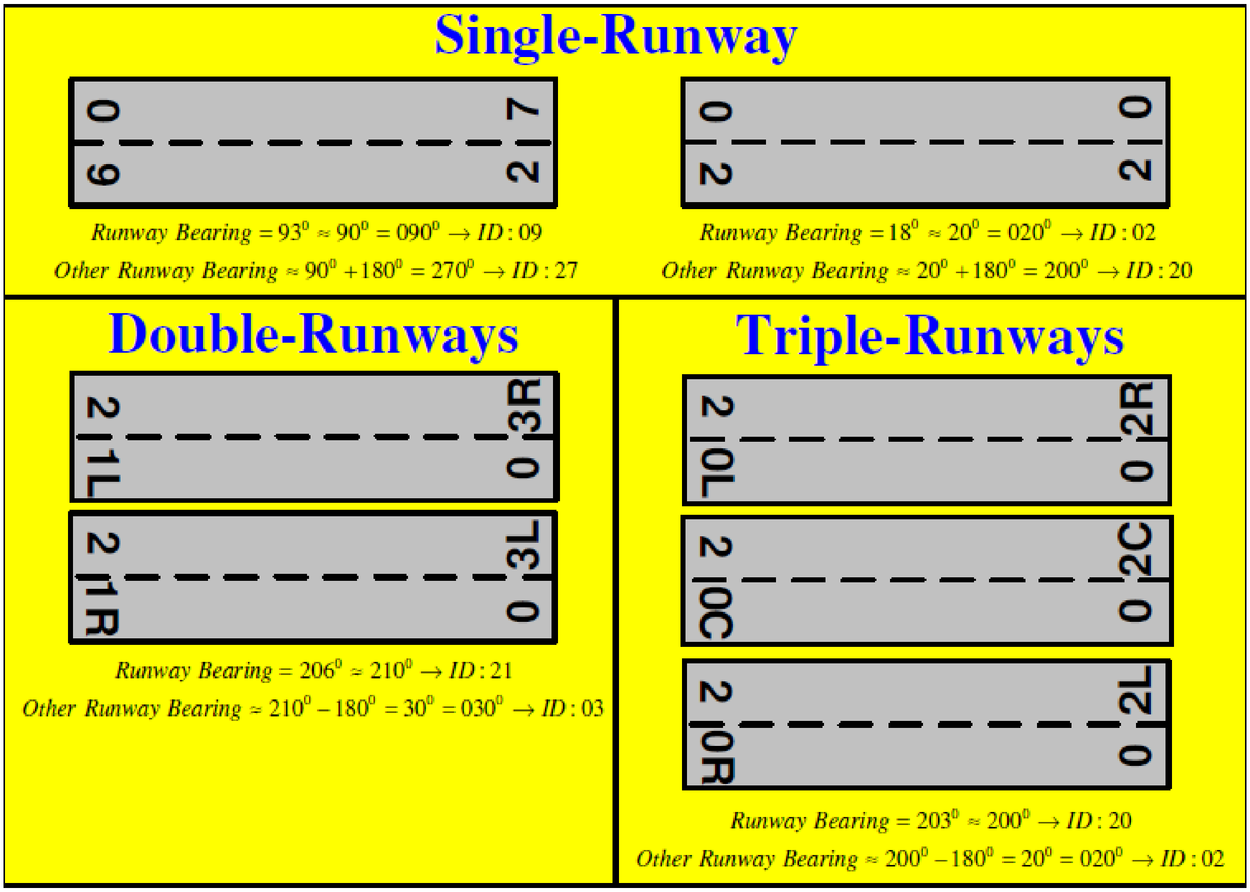


Figure 2.10 Runway Numbering

2.3.2 Instrument landing system - ILS

2.3.2.1 Principle

Provides A/C guidance for a straight flight path landing. ILS is used in IFR precision approach A/Cs from FAF until TDP. As for insuring an ideal landing, the system is based on the intersection of the runway centerline, the Localizer (LOC) beam, and the Glide slope (GS) beam.

2.3.2.2 On the ground

- **LOC-Tx**
  - ✓ Function: Provides alignment with runway centerline.
  - ✓ NAV: Horizontal Guidance.
  - ✓ Quantity per runway: 1

  - ✓ Location: At the end of the runway.
  - ✓ Frequency: VHF ≈ 108 – 112 MHz → Number of Channels: 20.
  - ✓ Horizontal Range of Operation ≈ 40 km
  - ✓ Deviation from Centerline ≈ ±2∘ [i.e. 4∘]
- ✓ **GS-Tx**
  - ✓ Function: Provides fix descent rate.
  - ✓ NAV: Vertical Guidance.
  - ✓ Quantity per runway: 1
  - ✓ Frequency: UHF ≈ 329 – 335 MHz →Number of Channels: 20
  - ✓ Vertical Range of Operation ≈ 1 km.
  - ✓ Typical GS0 Inclination ≈ 3^0
  - ✓ Deviation from GS ≈ ±0.7∘ [i.e. 1.4∘]
- ✓ **MB-Tx**
  - ✓ Function: Provides indication to crew that the A/C is in a specific location.
  - ✓ NAV: Horizontal Guidance.
  - ✓ Quantity per runway: 2 or 3.
  - ✓ Location: Prior to runway along its centerline.
  - ✓ Frequency: VHF ≈ 75 MHz
- ✓ **Transmissometer**

System used to measure the transmission of light through the atmosphere in order to determine visibility, and hence RVR.

  - ✓ Function: System used to measure the transmission of light through the atmosphere, in order to determine visibility, and hence RVR.
  - ✓ Quantity per runway: 2
  - ✓ Location: On the side of the runway.
  - ✓ Range of Operation ≈ 10 km
  - ✓ The system is able to identify 7 different types of precipitation: (Drizzle (i.e. gentle rain) || Rain, Frizzing Drizzle || Freezing Rain, Mixed Rain & Snow || Ice pellets).

2.3.2.3 In the A/C

- ✓ LOC/GS0–Rx or HSI–System
  - ✓ **Frequency: (**VHF: LOC, UHF: GS).
  - ✓ Rx compares the strength of the 90 and 150 Hz modulated signals for both LOC and GS, and outputs the actual A/C position w.r.t. ideal centered path.
- ✓ **MB–Rx**
  - ✓ Frequency: VHF
  - ✓ Rx detected the signal sent by the GND MB-Tx and alerts the A/C crew audibly and visually.
- ✓ **An advantage**
  - ✓ ILS is a powerful system available for landing guidance.
- ✓ **Disadvantages**
  - ✓ LOC and GS0 signals suffer from bending due to site and terrain effect.

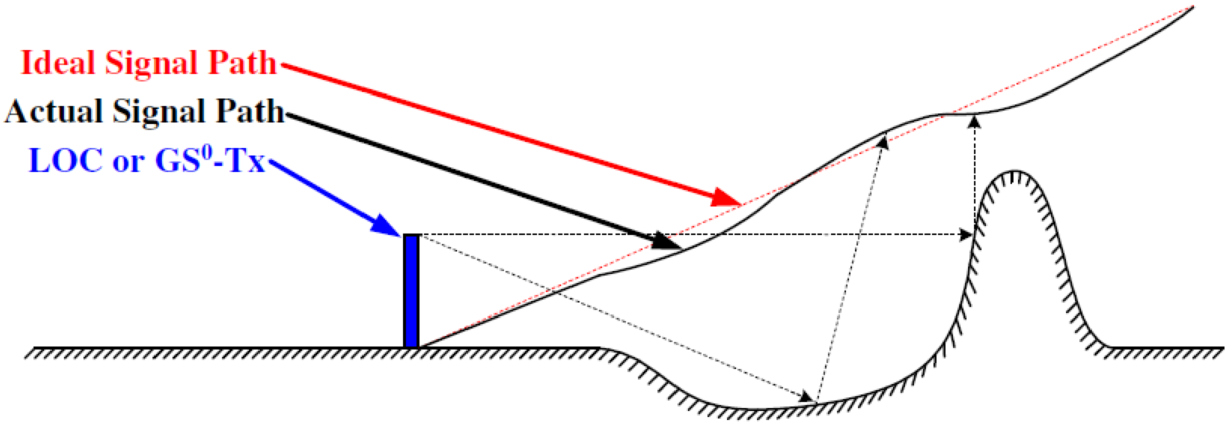


Figure 2.11 Terrain effect in ILS

- ✓ GS signals are highly sensitive w.r.t. LOC; and therefore, they are also affected by: (snow, airport GND moisture, airport GND vehicle movement
- ✓ The path used for landing in ILS cannot be flexible; it must remain straight at all times.
- ✓ Only 20 frequency channels are available for LOC and GS0 use.
- ✓ High cost of installation and maintenance.

- **Future:** ILS is expected activity until 2010 in most A/Cs and airports; following that, it will remain available as a backup system in case an unexpected malfunction occurs to GPS and/or DGPS. [4]

2.3.3 Microwave Landing System – MLS

2.3.3.1 Principle

Provides A/C guidance for curved or straight or segmented flight path land in the main outputs obtained using MLS are bearing, slant distance87, and ALT in the approach terminal area. Also it is important to mention the MLS system is exclusively used by MIL due to its flexibility in A/L as opposed to the CIV ILS.

2.3.3.2 On the GND

- **Azimuth–Tx**
  - ✓ Function: Provides bearing information.
  - ✓ NAV: Horizontal Guidance.
  - ✓ Quantity per runway: 2
  - ✓ Location: One is placed at the end of the runway, and the other one at the begging.
  - ✓ Frequency: SHF ≈ 5.031 ≈ 5.0907 GHz
  - ✓ Number of Channels: 200
  - ✓ Horizontal Range of Operation ≈ 37 km
  - ✓ Deviation from Centerline ≈ ±400 [i.e. 800]
- **Elevation–Tx**
  - ✓ Function: Provides ALT information.
  - ✓ NAV: Vertical Guidance.
  - ✓ Quantity per runway: 1
  - ✓ Location: On the side of the runway.
  - ✓ Frequency: SHF ≈ 5.031 – 5.0907 GHz
  - ✓ Number of Channels: 200
  - ✓ Vertical Range of Operation ≈ 6 km
  - ✓ Typical MLS Inclination ≈ 80

- ✓ Deviation from MLS ≈ ±70 [i.e. 140]

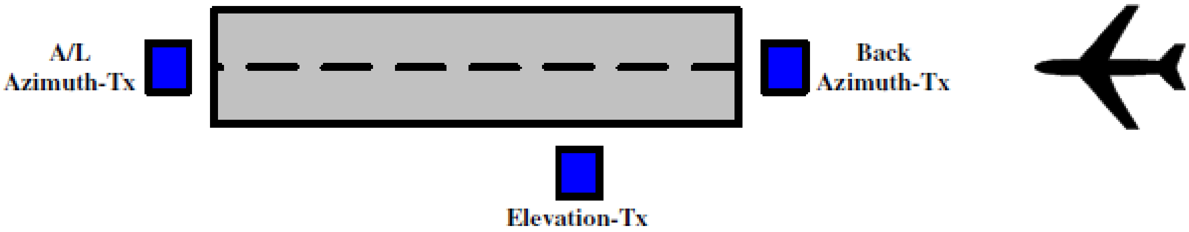


Figure 2.12 Configuration of MLS GND systems

2.3.3.3 In the A/C

- ✓ Rx: MLS-Rx system.
- ✓ Frequency: SHF
- ✓ Primary outputs from MLS: (Bearing / Slant Distance and ALT).
- ✓ Secondary outputs from MLS: (meteorological info, runway status, etc…)

2.3.3.4 Advantages

- ✓ Improved guidance accuracy with greater coverage area.
- ✓ Provide flexible landing path NAV.
- ✓ Offers guidance for missed approaches and departure NAV.
- ✓ MLS has low sensitivity from weather conditions and airport GNS traffic as oppose to ILS.
- ✓ MLS offers 200 frequency channels, 10-times more than ILS.
- ✓ Low cost of installation and maintenance**.**

2.4 Global Positioning System – GPS

2.4.1 Principle

Provides A/C position fix (3D). This technology is without any dough the most precise system used in NAV by CIV and MIL A/C. To understand why, we first need to realize that generally there exist a tradeoff between position fix accuracy and the coverage area in systems seen thus far. In other words, we cannot have the best of both worlds. However, we know for a fact that SATs operate at the UHF band (i.e. high Freq), and hence accurate position fix reading. As for ensuring a large and excellent coverage area we must place the GPS Transponder (i.e. SAT) faraway in outer space at roughly 20,000 km from the earth surface, and not on the GND.

As a result, GPS becomes an exceptional NAV tool ever invented due primarily to its accurate position fix and large coverage area.

2.4.2 More detailed description

Each GPS satellite continually broadcasts a signal (carrier frequency with modulation) that includes:

- A pseudorandom code (sequence of ones and zeros) that is known to the receiver. By time-aligning a receiver-generated version and the receiver-measured version of the code, the time of arrival (TOA) of a defined point in the code sequence, called an epoch, can be found in the receiver clock time scale.
- A message that includes the time of transmission (TOT) of the code epoch (in GPS system time scale) and the satellite position at that time. Conceptually, the receiver measures the TOAs (according to its own clock) of four satellite signals. From the TOAs and the TOTs, the receiver forms four time of flight (TOF) values, which are (given the speed of light) approximately equivalent to receiver-satellite range differences. The receiver then computes its three-dimensional position and clock deviation from the four TOFs. In practice the receiver position (in three dimensional Cartesian coordinates with origin at the earth's center) and the offset of the receiver clock relative to GPS system time are computed simultaneously, using the navigation equations to process the TOFs. The receiver's earth-centered solution location is usually converted to latitude, longitude and height relative to an ellipsoidal earth model. The height may then be further converted to height relative the geoid (e.g., EGM96) (essentially, mean sea level). These coordinates may be displayed, e.g. on a moving map display and/or recorded and/or used by other system (e.g., vehicle guidance). The figure bellow shows this system .[4]

Figure 2.13 GPS

2.5 Differential Global Positioning System - DGPS

It’s a ground station used to increase GPS accuracy, it’s found in airports in order to bring a more precise location of aircraft position fix during approach and landing phases that indicates that aircraft must contain a GPS receiver so that signals from both SATs and DGPS would be observed to correct position errors.

2.5.1 On the ground

- A DGPS system, transmitter and receiver.
- Frequency used: Rx use UHF, Tx uses LF\MF.
- Since DGPS is stationary, it’s have a well-known position (latitude, longitude, altitude).
- We use 4 SATs to obtain a 3D position fix for the DGPS.
- The DGPS then take the difference that exists between the actual known position and the calculated position obtained using GPS SATs.
- Ideally the difference should roughly be zero, but most of the time it’s not so it transmitted to the aircraft GPS Rx in the form of a correction signal.

$$\Delta = Calculated\ Position - Actual\ Position$$

$$\Delta = \overset{\text{Calculated DGPS Position}}{\begin{pmatrix} X_D \\ Y_D \\ Z_D \end{pmatrix}} - \overset{\text{Actual DGPS Position}}{\begin{pmatrix} X_{D0} \\ Y_{D0} \\ Z_{D0} \end{pmatrix}} \tag{2.1}$$

2.5.2 In the A\C

- ✓ GPS receiver.
- ✓ Frequency used: UHF used to calculate A\C position fix, and L\F M\F used to observe correction signal from DGPS.
- ✓ Its range of operation: 370 km.
- ✓ GPS Rx detects the correction sent from DGPS.

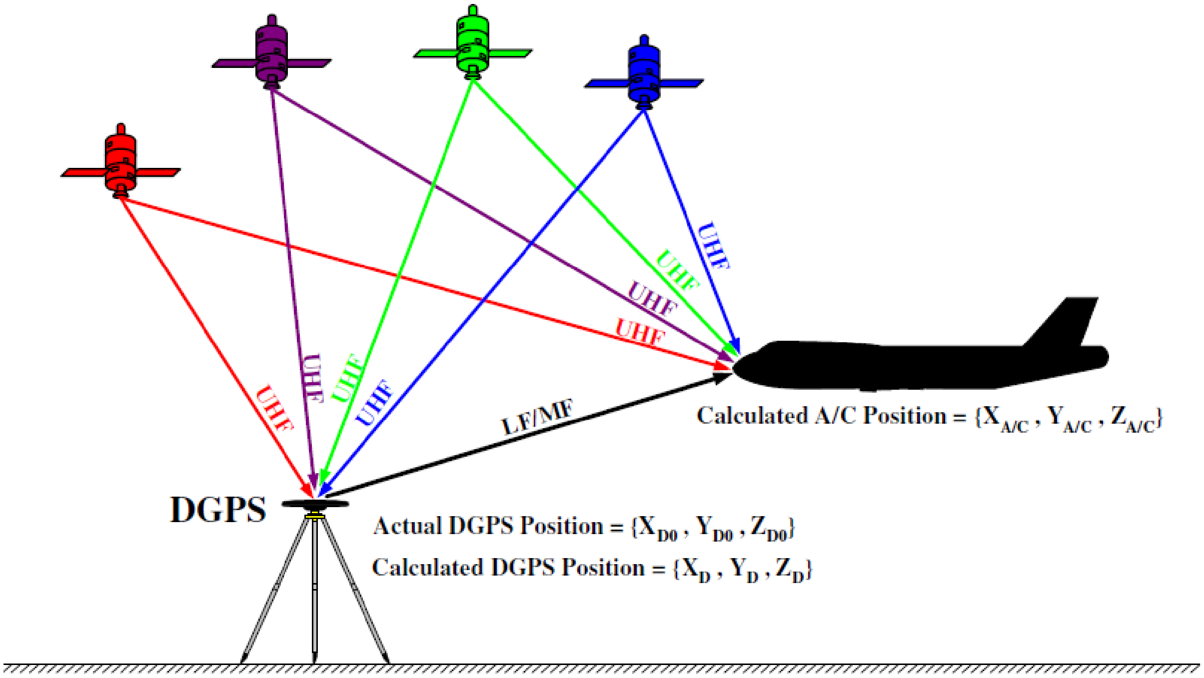


Figure 2.14 DGPS used to correct A/C position fix

2.5.3 Advantages of DGPS

- ✓ GPS is quite accurate, but using DGPS pushes its accuracy even further.
- ✓ Using GPS and DGPS makes A\L guidance very precise as appose of ILS and MLS.

2.5.4 Disadvantages

- ✓ Errors: for LON and LAT it have a typical error about 1.8m, for altitude it has 2m.
- ✓ Even using DGPS could eliminate errors but it would exist due to atmosphere and Rx noise, multipath errors and etc.
- ✓ Has a limited coverage area that leads to add more DGPS stations to ensure a greater coverage.
- ✓ The position accuracy degrades as the separation between DGPS and A\C GPS Rx increases.[4]

2.6 Wide Area Augmentation System

WAAS is an extremely accurate navigation system developed for civil aviation. Before WAAS. the National Airspace System (NAS) did not have the potential to provide horizontal and vertical navigation for approach operations for all users at all locations. With WAAS, this capability is a reality WAAS provides service for all classes of aircraft in all phases of flight including en route navigation, airport departures, and airport arrivals. This includes vertically-guided landing approaches in instrument meteorological conditions at all qualified locations throughout the NAS.

2.6.1 Principle

Unlike traditional ground-based navigation aids, the WAAS covers nearly all of the National Airspace System (NAS). The WAAS provides augmentation information to GPS receivers to enhance the accuracy and reliability of position estimates. The signals from GPS satellites are received across the NAS at many widely-spaced Wide Area Reference Stations (WRS) sites. The WRS locations are precisely surveyed so that any errors in the received GPS signals can be detected. The GPS information collected by the WRS sites is forwarded to the WAAS Master Station (WMS) via a terrestrial communications network.

At the WMS, the WAAS augmentation messages are generated. These messages contain information that allows GPS receivers to remove errors in the GPS signal, allowing for a significant increase in location accuracy and reliability. The augmentation messages are sent from the WMS to uplink stations to be transmitted to navigation payloads on geostationary communications satellites. The navigation payloads broadcast the augmentation messages on a GPS-like signal. The GPS/WAAS receiver processes the WAAS augmentation message as part of estimating position. The GPS-like signal from the navigation transponder can also be used by the receiver as an additional source for calculation of the user's position. WAAS also provides indications to GPS/WAAS receivers of where the GPS system is unusable due to system errors or other effects. Further, the WAAS system was designed to the strictest of safety standards – users are notified within six seconds of any issuance of hazardously misleading information that would cause an error in the GPS position estimate.

2.6.2 Benefits

The WAAS will allow GPS to be used as a primary means of navigation from takeoff through Category I precision approach. Other modes of transportation also benefit from the increased accuracy, availability, and integrity that WAAS delivers. The WAAS broadcast message improves GPS signal accuracy from 100 meters to approximately 7 meters.

The benefits of WAAS to civil aviation will be substantial. WAAS improves the efficiency of aviation operations due to:

- Greater runway capability
- Reduced separation standards which allow increased capacity in a given airspace without increased risk.
- More direct en-route flight paths.
- New precision approach services
- Reduced and simplified equipment on board aircraft
- Significant government cost savings due to the elimination of maintenance costs associated with older, more expensive ground-based navigation aids (to include NDBs, VORs, DMEs, ILSs).[10]

2.7 GNSS

The GNSS consist of three main satellite technologies: GPS, Glonass and Galileo. Each of them consists mainly of three segments: (a) space segment, (b) control segment and (c) user segment. These segments are almost similar in the three satellite technologies, which are all together make up the GNSS.

2.7.1 GLONASS

The GLONASS (Global Navigation Satellite System) is nearly identical to GPS. Glonass satellite-based radio-navigation system provides the positioning and timing information to users. It is operated by the Ministry of Defense of the Russian Federation (GLONASS-ICD, 2002). Glonass space segment is consist of 24 satellites, equally distributed in 3 orbit separated by 120˚ in the equatorial plane. Satellite orbital altitude is about 19,130 km above the ground surface. This results in an orbital period of 11:15:44 corresponding to 8/17 of a sidereal day. The future of GLONASS seems uncertain due to economic problems facing the Russian Federation. The number of operational satellites was steadily decreasing over the past few years. The launch of three new GLONASS satellites in December 1998 was the first launch after a lapse of 3 years. As of January 2006, a total of 10 GLONASS satellites are operational. The oldest of the still active satellites was launched in October, 2000. According to Russian officials the GLONASS system been restored the GLONASS receiver work with accuracy 5-10 meter

2.7.1.1 GLONASS Satellites signal

Glonass transmit C/A-code on L1, P-code on L1 and L2. Glonass observables (code and phase) are similar to GPS. The main difference between GPS and GLONASS is that GLONASS uses Frequency Division Multiple Access (FDMA) technology to discriminate the signals of different satellites, but GPS and Galileo use (Code Division Multiple Access, CDMA) to distinguish between the satellites. All Glonass satellites transmit the same C/A- and P-codes, but each satellite has slightly different carrier frequencies. The nominal carrier frequencies for the L1and L2 signals may be written as shown below

$$f_1^n = 1602 + 0.5625.n\text{MHZ} \tag{2.2}$$

$$f_2^n = 1246 + 0.4375.n\text{MHZ} \quad \text{with} \quad f_1^n / f_2^n = 9/7 \tag{2.3}$$

Where n is the frequency channel number $1 \leq n \leq 24$ covering a frequency range in L1 from 1602.5625MHz to 1615.5MHz. Since some of the GLONASS frequencies interfere with frequencies used for radio-astronomy, some changes in the frequency plan are expected the navigation message is contained in so-called sub frames, which have duration of 2.5 minutes. Each sub frame consists of five frames with duration of 30 seconds. The navigation message contains information, similar to GPS navigation message, about the satellite orbits, their clocks, among others. On the contrary to GPS, where the broadcast ephemerides are defined by modified Keplerian elements, the broadcast ephemerides of GLONASS satellites are defined by positions and velocities referred to an Earth-centered and Earth-fixed system. The broadcast ephemerides of the Glonass satellites are updated every 30 minutes.

2.7.2 GALILEO

GALILEO is Europe’s initiative for a state-of-the-art global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. Galileo will be not too different from the other GNSS parts modernized GPs and Glonass. It will provide autonomous navigation and positioning services, but at the same time will be interoperable with the two other global satellite navigation systems; the GPS and GLONASS. A user will be able to take a position with the same receiver from any of the satellites in any combination. By providing dual frequencies as standard, however, GALILEO will deliver real-time positioning accuracy down to the meter range. It will guarantee availability of the service under all, but the most extreme circumstances and will inform users within seconds of a failure of any satellite. This will make it appropriate for applications where safety is vital, such as running trains, guiding cars and landing aircraft. The combined use of GALILEO and other GNSS systems can offer much improved performance for all kinds of users worldwide Galileo segments are almost similar to GPS, but with some modification. The main extension of Galileo compared to GPS is the implementation of a global/ regional segment for integrity monitoring. The objective is to assist the safety critical aircraft navigation and locate and guide railway trains.

2.7.2.1 Space Segment

The space segment or the constellation features consists of 30 Medium Earth Orbiting (MEO) satellites (27 and 3 active spare satellite), distributed evenly and regularly over three orbit planes. The projected altitude is slightly larger than for GPS 23,616 km and the inclination is 56°.

2.7.2.2 Ground Segment

The Galileo ground segment is responsible for managing the constellation of navigation satellites, controlling core functions of the navigation mission such as orbit determination of satellites, and clock synchronization, and determining and disseminating (via the MEO satellites) the integrity information, such as the warning alerts within time-to-alarm requirements, at global level. The Global ground segment will also provide interfaces with service centers. The Ground Control Segment will consist of about 12-15 reference stations, 5 up-link stations and two control centers. The ground segment also will include 16-20 monitor stations, three up-link stations for integrity data and two central stations for integrity computations.

2.7.2.3 User Segment

The user segment consists of different types of user receivers, with different capabilities related to the different GALILEO signals in order to fulfill the various GALILEO services with position accuracy 1 meter**.**

2.7.2.4 Galileo signals

The GALILEO frequency should respect the radio-regulations as they are discussed and agreed on at the International Telecommunications Union (ITU) forums such as the World Radio Communication Conference (WRC). There were different studies that were conducted before the determination of the Galileo signal allocations in order to avoid interference with GPS and Glonass systems, which operate in the same portion of the RF spectrum. Galileo will provide several navigation signals in right-hand circular polarization (RHCP) in the frequency ranges of 1164–1215 MHz, 1260–1300 MHz and 1559–1592 MHz that are part of the Radio Navigation Satellite Service (RNSS) allocation All Galileo satellites will share the same nominal frequency, making use of code division multiple access (CDMA) techniques. Galileo will use a different modulation scheme for its signals, the binary offset carrier (BOC) and quadrature phase skip keying (QPSK).

2.7.3 GNSS SIGNALS

The overall mentioned signals (Modernized GPS, Galileo and Glonass signals), make up the GNSS signals. Each satellite system has specific signal characteristics, but each system attempts to be compatible with the others in order to prevent the interferences and attenuation between the signals. It is important to consider that the processing of all signals should be performed using the same receiver, thus a complex receiver design is supposed to be designed and built. As mentioned above, The GNSS frequency plan shall respect the radio-regulations as they are discussed and agreed on at ITU forums. The available spectrum which can be used for the development of Radio-Navigation Satellite Systems (RNSS). [4]

Chapter Three: Automatic Dependence Surveillance Broadcast

3.1 Primary surveillance radar

Radar is an object-detection system that uses radio waves to determine the range, altitude, direction, or speed of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. The radar dish (or antenna) transmits pulses of radio waves or microwaves that bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna that is usually located at the same site as the transmitter. Radar was secretly developed by several nations before and during World War II. The term RADAR was coined in 1940 by the United States Navy as an acronym for Radio Detection and Ranging.

- **Applications**

The information provided by radar includes the bearing and range (and therefore position) of the object from the radar scanner. It is thus used in many different fields where the need for such positioning is crucial. The first use of radar was for military purposes: to locate air, ground and sea targets. This evolved in the civilian field into applications for aircraft, ships, and roads. In aviation, aircraft are equipped with radar devices that warn of aircraft or other obstacles in or approaching their path, display weather information, and give accurate altitude readings. The first commercial device fitted to aircraft was a 1938 Bell Lab unit on some United Air Lines aircraft. Such aircraft can land in fog at airports equipped with radar-assisted ground-controlled approach systems in which the plane's flight is observed on radar screens while operators radio landing directions to the pilot.

- **Principle**

A radar system has a transmitter that emits radio waves called radar signals in predetermined directions. When these come into contact with an object they are usually reflected or scattered in many directions. Radar signals are reflected especially well by materials of considerable electrical-especially by most metals, by seawater and by wet ground. Some of these make the use of radar altimeters possible. The radar signals that are reflected back towards the transmitter are the desirable ones that make radar work. If the object is moving either toward or away from the transmitter, there is a slight equivalent change in the frequency of the radio waves, caused by the Doppler Effect.

Radar receivers are usually, but not always, in the same location as the transmitter. Although the reflected radar signals captured by the receiving antenna are usually very weak, they can be strengthened by electronic amplifiers. More sophisticated methods of signal processing are also used in order to recover useful radar signals.

The weak absorption of radio waves by the medium through which it passes is what enables radar sets to detect objects at relatively long ranges-ranges at which other electromagnetic wavelengths, such as visible light, infrared light, and ultraviolet light, are too strongly attenuated. Such weather phenomena as fog, clouds, rain, falling snow, and sleet that block visible light are usually transparent to radio waves. Certain radio frequencies that are absorbed or scattered by water vapor, raindrops, or atmospheric gases (especially oxygen) are avoided in designing radars, except when their detection is intended. The figure bellow shows the primary radar operation. [11]

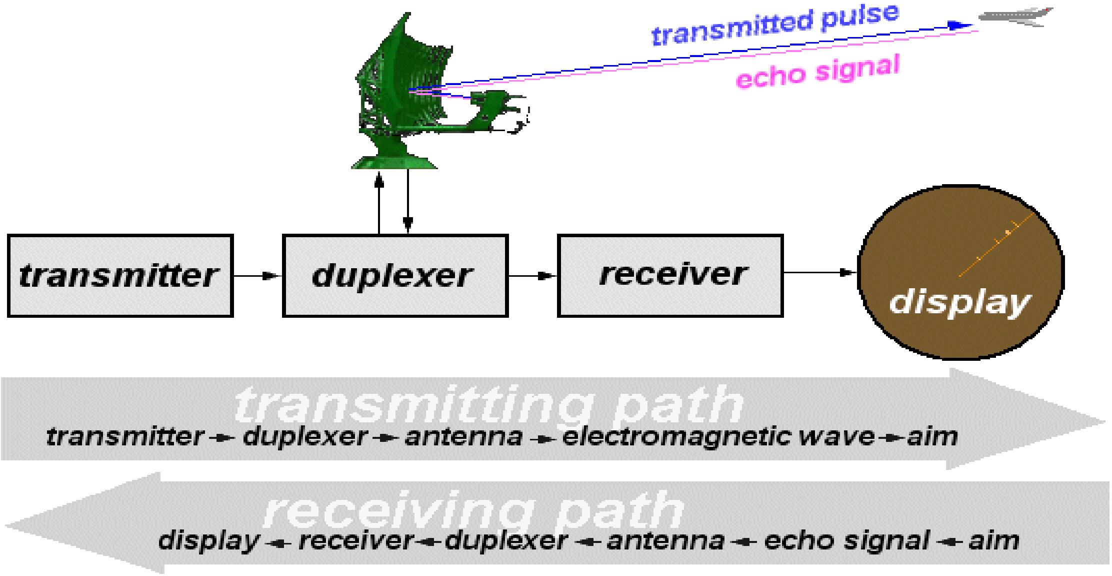


Figure 3.1 primary radar operation

3.2 Secondary Surveillance Radar System

3.2.1 System description

It consists of two main elements, a ground based interrogator/receiver and an aircraft transponder. The aircraft's transponder responds to interrogations from the ground station, enabling the aircraft's range and bearing from the ground station to be determined.

The development of SSR evolved from military Identification Friend or Foe (IFF) systems and allows the use of the Mode A/C service for civil aviation. Since then it has been significantly developed to include the Mode S service. SSR frequencies of 1030 and 1090 MHz remain shared with the military.

The system has four modes of interrogation/reply: Mode A, Mode C, Mode S and intermode. There are two classes of transponders: Mode A/C transponders, which can respond to Mode A, Mode C and intermode interrogations only, and Mode S transponders, which can respond to all modes.

The replies to all modes of interrogation can be used to determine aircraft position by measurement of the range and bearing of the reply.

In many cases SSR is co-located with a PSR, usually with the SSR mounted on the top of the PSR antenna.

3.2.2 SSR modes

- ***Mode A***

  A Mode A interrogation elicits a Mode A reply which supports the following capabilities:

  - One of 4096 codes to allow identification of individual aircraft or groups of aircraft depending upon operational requirements.
  - Identification on the display, when requested, of an individual aircraft signal by the use of the transponder special position identification (SPI) facility.
  - Immediate identification of aircraft experiencing a radio communication failure or other emergency or unlawful interference (highjack).

- ***Mode*** C

A Mode C interrogation elicits a Mode C reply. All transponders are required to reply to Mode C interrogations. The reply will contain encoded pressure-altitude information. The pressure-altitude source will be analogue or digital and the altitude information is provided uncorrected directly to the transponder from the source. Digitized altitude information is automatically derived by an analogue-digital converter connected to the altitude pressure source in the aircraft referenced to the standard pressure setting of 1013.25 hecto-pascals. If, for any reason, the transponder cannot load data for altitude report transmission, the reply will consist of framing pulses only. If suitable decoding and display facilities are available, the altitude of those aircraft transmitting altitude information can be displayed.

Note: Barometric altitude is the reference for vertical separation in ICAO airspace. There are no means to convert geometric height data to pressure-altitude.

➢ Mode S

Mode S interrogations (uplink) can be addressed to individual aircraft. This allows the transmission of coded information to the transponder fitted with data link capability. The Mode S reply (downlink) may contain the aircraft's identity, its altitude, or other data, depending on what is requested by the ground station and depending on the aircraft. The Mode S interrogations and replies are protected by a robust error detection/correction scheme which gives high reliability to the information transferred. Mode S transponders are capable of reporting pressure-altitude in either 100ft or 25ft increments. Pressure-altitude encoders will report altitude at least in 100ft increments. However, the capabilities of ground and airborne surveillance systems are significantly improved if the pressure-altitude report is transmitted with 25ft increments. Most pressure-altitude sources are capable of reporting equal to or finer than 25 increments.

Therefore, such altitude sources should be used, at least in new installations. However, using a pressure altitude source with a quantization coarser than 25ft connected to the transponder when the transponder is using the formats for 25ft increments will make the situation worse. Altitude reports must not be transmitted in 25ft increments if the pressure-altitude source is not capable of providing 25-ft or better quantization. If the pressure-altitude information is directly provided from the altitude source to the transponder then the transponder will choose the appropriate quantization for altitude report transmission. If digitized altitude information is provided via an onboard data bus the data set should also provide information on the appropriate quantization of altitude report transmission.

- **Intermode**

The Mode A or Mode C all-call intermode interrogation allows a Mode S ground station to interrogate Mode A/C transponders on Mode A or C, without Mode S transponders replying. The Mode A/C/S all-call interrogation causes Mode S transponders to reply with a Mode S reply, indicating their discrete Mode S address. Mode A/C transponders reply with a Mode A or Mode C reply according to the interrogation.[5]

3.2.3 The use of SSR

SSR alone is used for en route radar control in many States where intruder detection is not required. An SSR only installation is less expensive than a combined primary plus secondary radar, but involves a significant outlay for buildings, access roads, mains electrical power, standby generators, towers and turning gear to rotate a large elevated antenna etc. ICAO Document 4444, Procedures for Air Traffic Services – Air Traffic Management, sets out the requirements for Radar Services.

3.2.4 Combined Primary & Secondary Radar

It Makes use of the advantages of the two types of radar in one installation. Typically, the PSR antenna and the SSR antenna are mounted on the same turning gear and the associated processing performs filtering, combines the SSR and primary data and tracks the radar reports. One track message is output per aircraft each antenna rotation. The primary radar provides detection of intruder aircraft and the SSR performs detection of co-operative aircraft as well as providing altitude and identity information. Digital tracking systems gain significantly benefits from having SSR and PSR installed on the same rotating antenna. SSR can resolve tracking ambiguities that would exist in a PSR only solution and vice versa. Some States choose to mount PSR and SSR systems at separate locations thus providing separate antenna platforms. This has the advantage of a level of redundancy since one antenna stops, a level of service can be provided from the other. However, in this case, the advantages of improved tracking performance are forgone – unless the antennas are nearby and antenna rotation is synchronized. Combined PSR/SSR systems are usually provided to support approach departure ATC in terminal manoeuvring area airspace. It is in the busy terminal area airspace that the probability of general aviation aircraft straying into controlled airspace is higher and therefore some States prefer to have PSR in these environments. Often such systems are backed up by offsite SSR only systems.[3]

3.3 ADS-B

3.3.1 ADS-B Explained

ADS-B's main purpose is to determine the position of an aircraft and then broadcast that information, along with its altitude, call sign, heading, and aircraft type automatically (i.e., without an SSR interrogation signal) to other aircraft and to air traffic control ground facilities. ADS-B is automatic in that it does not require any action or input by the pilot and there is no interrogation from the ground required. It is also dependent because it relies on onboard equipment to gather the ADS-B data and broadcast it to other ADS-B users and it is a means of providing surveillance and traffic coordination.

ADS-B ground station equipment comprises a receiver unit, an antenna and a site monitor. It is a data-link system that normally utilizes the same transponder, but operates independently of the aircraft radar and traffic collision alerting and avoidance (TCAS) systems. Most modern Mode S secondary surveillance radar (SSR) transponders are capable of transmitting SSR and ADS-B (also termed extended squitter) data. The older Mode A/C transponders do not support ADS-B.

ADS-B was created with compatibility and ease of transition in mind. It was built using similar aspects of the current aircraft surveillance transmission mode called Mode S or mode select. Mode S operates by interrogating aircraft by a specific aircraft identification number. Only the aircraft possessing the correct identification number will reply to an interrogation with its flight information. Transmission types prior to Mode S include Modes A and C. Mode A provided aircraft identification and Mode C provided altitude. Mode S provides greater capabilities, primarily in the form of aircraft information to include identity, intent, capability and location.

ADS-B is similar to Mode S in that it uses the same transmission frequency of 1090 MHz. It differs in that the message is 112 bits, 120 μs long and are "squitter" messages. A squitter message is simply a transmitted message not invoked by any interrogation. In the figure bellow which shows the ADS-B transponder.

Figure 3.2 ADS-B transponder

3.3.2 Principle

An aircraft with ADS-B determines its position using GPS. The aircraft then broadcasts that position at rapid intervals, along with identity, altitude, velocity and other data. Dedicated ADS-B ground stations can receive the broadcasts and relay the information to air traffic control for precise tracking of the aircraft.

ADS-B system broadcasts data every half-second on a 1090 MHz digital data link, and like radar, is limited to "line-of-sight". The ability of a ground station to receive a signal depends on altitude, distance from the site and obstructing terrain. The maximum range of each ground station can't exceed 250 nautical miles. In airspace immediately surrounding each ground station, surveillance coverage will extend to near the surface. The figure-3.3 bellow shows the way it works.

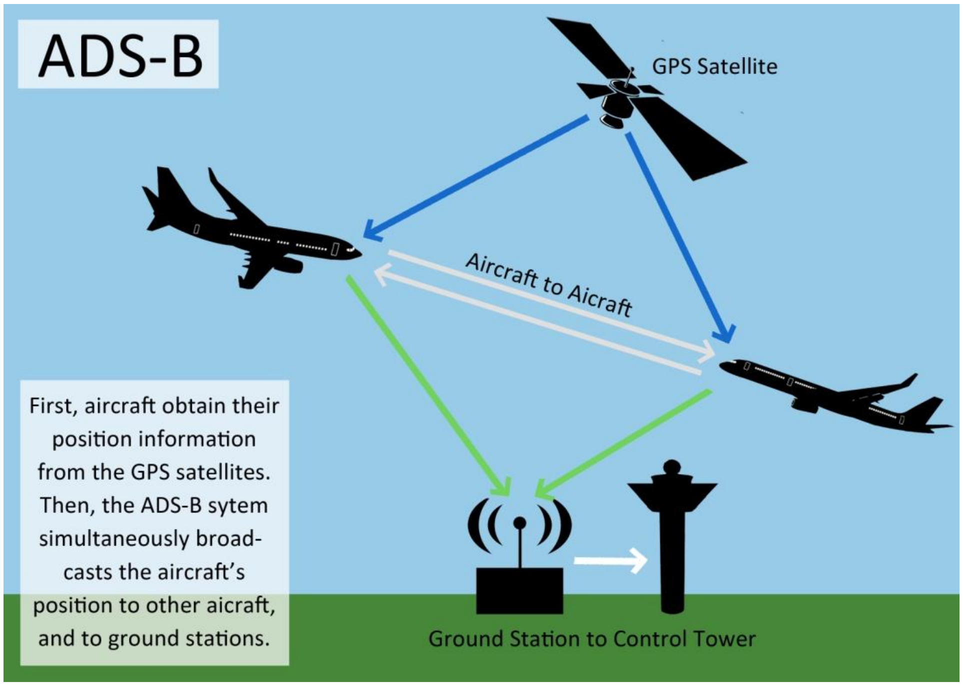


Figure 3.3 ADS-B Principle

ADS-B has two major segments ADS-B OUT: Avionics broadcasts ADS-B Messages (e.g. Identity, Position, Velocity, etc.) This is a precondition for any ADS-B application (e.g. radar-like surveillance). ADS-B IN: Avionics receives other aircrafts' ADS-B OUT messages required for air-to-air applications and TIS-B, FIS-B and ADS-R services. (e.g. improved situation awareness, airborne separation assurance, etc.).

3.3.3 ADS-B OUT

An ADS-B transmitter enables the identity, position and altitude of an aircraft to be determined and displayed to an air traffic controller. The signal is broadcast from the aircraft approximately every half second and, provided the aircraft is within the coverage volume of an ADS-B ground station, the data can be fed to the ATC facility and used to provide air traffic services.

3.3.4 ADS-B IN

Aircraft may also be equipped with a CDTI and associated receiver to display the broadcast positions of ADS-B-OUT aircraft.

Cockpit displays of traffic information may be combined with other systems, such as moving map navigation displays. The figure (3.4) shows the ADS-B IN and OUT.

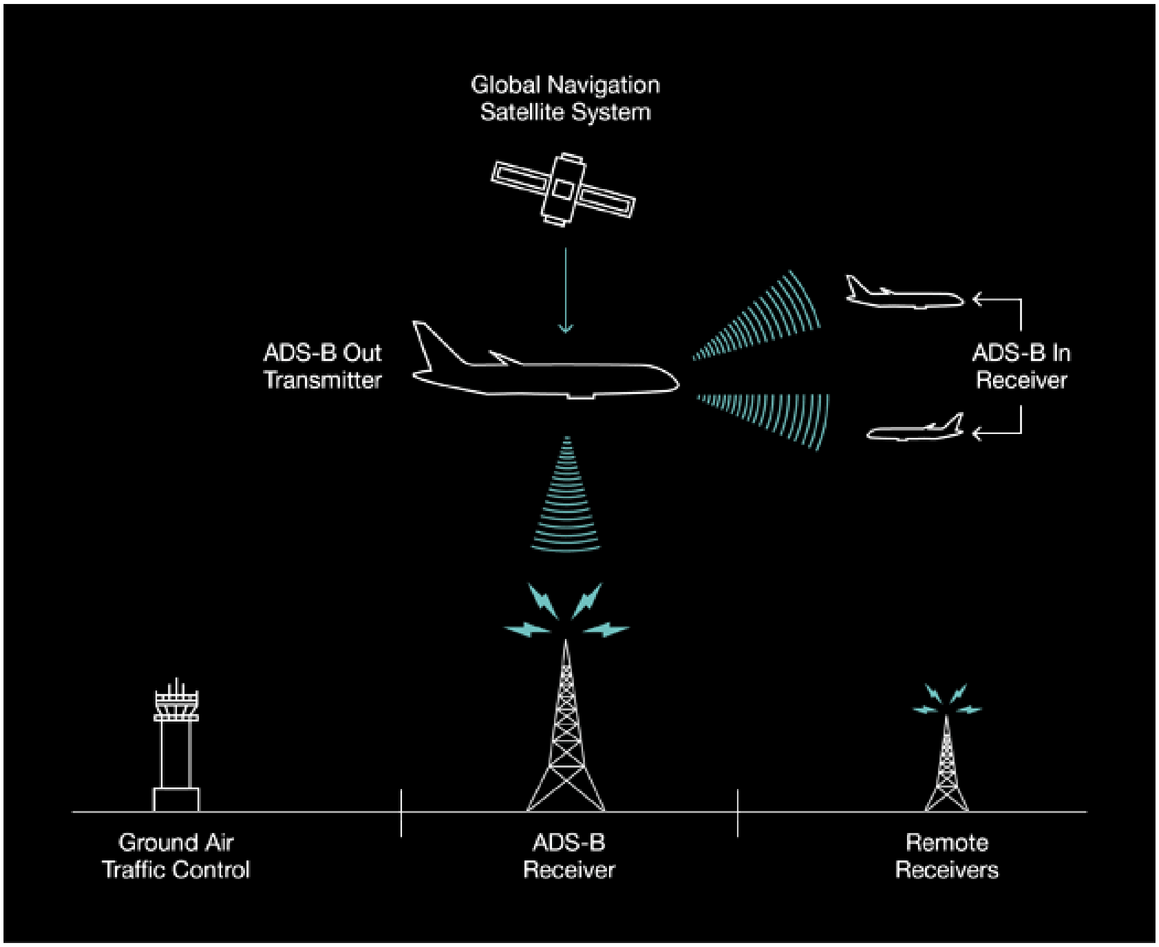


Figure 3.4 ADS-B IN-OUT

Two systems have been approved by the FAA for ADS-B:

1. A Universal Access Transceiver (UAT) operating on 978 MHz
2. A Mode S transponder operating on 1090 MHz with Extended Squitter (1090ES) that can be paired with a 1090 MHz receiver.

With these systems, three types of FAA broadcast services offer benefits to pilots of ADS-B In-equipped aircraft and are now available

3.3.5 Traffic Information Service-Broadcast (TIS-B)

This air traffic advisory service provides the altitude, ground track, speed and distance of aircraft flying in radar contact with controllers and within a 15-nautical-mile (nm) radius, up to

3,500 feet above or below the receiving aircraft's position. It can be received on both UAT and 1090 MHz. A general aviation aircraft equipped with ADS-B In can also receive position data directly from other aircraft broadcasting on the same ADS-B Out frequency. In addition, TIS-B enables pilots to see aircraft equipped with transponders flying nearby even if those aircraft are not equipped with ADS-B Out. [13]

3.3.6 Flight Information Service - Broadcast (FIS-B)

This service, available via UAT, broadcasts graphical weather to the cockpit based on what ground-based weather radar is detecting. In addition, FIS-B broadcasts text-based advisories including Notice to Airmen messages and reports on everything from significant weather to thunderstorm activity. UAT-equipped general aviation aircraft can receive this information at altitudes up to 24,000 feet. [13]

3.3.7 Automatic Dependent Surveillance–Rebroadcast (ADS-R)

ADS-R takes position information received on the ground from UAT-equipped aircraft and rebroadcasts it on the 1090 MHz frequency. Likewise, ADS-R rebroadcasts 1090 MHz data to UAT users. In concert with TIS-B, ADS-R provides all ADS-B In-equipped aircraft with a comprehensive airspace and airport surface traffic picture. ADS-R delivers traffic data within a 15-nm radius 5,000 feet above or below relative to the receiving aircraft's position.

To comply with the 2020 mandate, aircraft operating in Class A airspace "from 18,000 feet mean sea level (MSL) to and including Flight Level 600" must broadcast ADS-B Out position data using the Mode S 1090ES ADS-B link. Aircraft operating in designated airspace exclusively below 18,000 feet MSL can use either 1090ES or a UAT. [13]

3.3.8 Benefits of ADS-B

- Airservices policy is to give priority to ADS-B equipped aircraft (when doing so gives an operational advantage to air traffic control [ATC]).
- Position reports by voice no longer required for identified ADS-B aircraft.
- Ability to approve continuous rather than stepped climbs and descents to and from cruising level.

- Greater flexibility in allocating appropriate flight levels at the request of pilots. (That is, to climb to optimum flight level, as aircraft weight decreases with fuel burn).
- Airspace which previously had no radar, and only procedural separation services, can now have an ATC surveillance service.
- Greater ability for ATC to grant clearances to fly requested routes or Levels.
- Aircraft are easier to locate for search and rescue (SAR).

3.3.9 Human factors and ADS-B

ADS-B will see the introduction of new equipment and procedures, raising human factors issues including:

- Use of the equipment.
- Operation of controls and understanding the information presented e.g. a CDTI
- Display readability.
- Data entry.
- Workload.
- Human information processing and situational awareness.

CDTI and other displays

Some aircraft may be fitted with a CDTI, although many will not. This technology will add to the training needed to become proficient in using ADS-B. The lack of standardization of equipment might cause problems when pilots move between aircraft with different displays, as some CDTIs are more sophisticated than others.

For example, some allow traffic on the ground to be filtered out. Get to know the main differences between CDTIs in the aircraft you fly. The displays are simpler than some other avionics, but it is still possible to press the wrong key at the wrong time. Familiarise yourself with the technology on the ground, not in the air. Concentrating on only one thing while flying can be dangerous, leading to loss of situational awareness and control. Using interactive equipment can capture your attention for longer than you think.

The same applies to an ADS-B OUT interface in the cockpit. While it will not display traffic or terrain, it will have at least an on/off switch, and some will let you enter the FLTID as well. Understand the capabilities of each interface, especially if you fly aircraft with differing units.

- **Display readability**

The sophistication of CDTIs varies significantly. Some units display only ADS-B information of other aircraft and their position information. Most units overlay this display on a terrain display and incorporate navigational information, providing a moving map service as well as traffic information. Range settings can affect display clutter and traffic depictions. Terrain information might make the display seem cluttered and harder to interpret.

Mount the CDTI within your primary field of view in a position easily incorporated in your instrument scan. Put the unit at a viewing distance appropriate for the size of the display and the amount of information presented. LAMEs should consider location and distance when installing CDTIs, and ask a pilot to sit in the cockpit to review placement options.

- **Data entry**

Data entry applies to:

- ✓ Entering flight plans via NAIPS or other flight planning systems.
- ✓ Entering data directly into the ADS-B unit on the ground by engineers.
- ✓ Entering data into the unit in the cockpit by pilots.

To use ADS-B, ATC relies on the flight plan and FLTID matching in TAAATS. Ensure you have entered the correct call sign and FLTID into your flight plan. Errors could compromise ATC's ability to identify the aircraft. The same applies to the 24-bit code normally entered by LAMEs. This is a unique ICAO identifier, issued by CASA, and any error in entering the code will create problems for ATC identification. For example, if one digit is entered incorrectly, the ATC system could confuse your aircraft with another aircraft assigned that code. LAMEs should double check the entry. You may have an ADS-B interface that allows you to enter FLTIDs. While many FLTIDs will remain the same, some will have to be changed. This might be needed for specific activities, such as fire spotting, or be required by ATC direction. Entering an incorrect FLTID would create a mismatch of information for ATC, so you should double check your entry.

- **Workload**

Automating tasks changes workloads for pilots and controllers, reducing some tasks and increasing others. For example, use of CDTI may reduce the time spent locating particular traffic, but will increase head down time looking at the display.

ADS-B surveillance reduces the need for air-ground voice communications for position reports, cutting this part of the pilot and controller workloads. But the reduction will apply only for position reports—the ADS-B data will need to be monitored, and the mental task of tracking aircraft is still required. To maintain a listening watch, pilots with CDTIs will need to monitor both the radio and the CDTI. Balancing these tasks will create additional mental work.

➢ Human information processing and situational awareness

Humans can deal with only a certain amount of information at once. In non stressful situations, we can take in a lot about our environment. However, when the workload is heavy, as in IFR approaches, emergencies and other stressful situations, the amount of information we can process decreases.

We might exceed our capacity for information processing and start to shed seemingly trivial tasks to concentrate on what we think is the most important. That's why pilots need to be familiar with ADS-B displays and interfaces in the cockpit. If your use of them is automatic then you have a better chance of using them effectively. While the information get from ADS-B "for the air traffic controllers" is not significantly different from that obtained from radar, operational procedures change to accommodate ADS-B technology. Controllers must understand these procedures and apply them correctly to aid information processing and situational awareness. Pilots, meanwhile, will face different information processing challenges as the number of ADS-B transmitters and CDTI increases. CDTI monitoring will be an additional task to manage, but the greater accuracy of traffic information over radio position reports should improve situational awareness of ADS-B traffic and ultimately decrease workload. Pilots still need to use traditional traffic management techniques of radio communication and see and avoid. Once again, system familiarity and procedural compliance will help in managing workload and maintaining situational awareness. [1]

Chapter Four: ADS-B Message Decoding

As mentioned in the previous chapter that the ADS-B working on 1090ES frequency in this chapter we want to mention what is the difference between 1090ES and 1090 MODE S (downlink), the construction of the ADS-B frame and how we can decode the ADS-B received signal by using the mathematical equation.

4.1 The Difference between 1090ES and Current Mode S Transponders

4.1.1 Mode S 1090

Mode S reply has data rate 1Mbps and use pulse position modulation. Pulse transmitted in the 1st or 2nd half of the bit period (indicating a 1 or 0, respectively). Legacy Mode S Transponders “squitter” only the most basic aircraft ID, system status and pressure altitude information, which ground computers, must then correlate with radar tracking information to derive aircraft position, direction of flight, airborne velocity, and vertical climb/descent. The Mode S transponder outputs an unsolicited transmission once per second to enable ACAS to acquire Mode S equipped aircraft figure 4.1.

Figure 4.1 Mode S short squitter (56 BITS)

4.1.2 Mode S 1090ES

With ADS-B each aircraft’s approved GPS navigation system will generate all of this data, and then transmit it at least once per second by means of a 1090ES Mode S Transponder with “extended squitter” – hence the ES. This allows ground controllers and other aircraft in the vicinity (so equipped) to track each airplane’s flight path with much greater precision and accuracy. The ES format carries much more data than the basic “short squitter” Mode S version. In fact, some 49 individual parameters can be sent over the extended squitter, compared to three for Mode C and seven for basic non-extended Mode S. (Note: The 978 MHz UAT “Out” has the same basic data transmission elements as ES however, it uses a different frequency in the radio spectrum to broadcast the information.) The higher capacity ES Data Link will allow controllers to see not only what each aircraft is doing, but what it intends to do. The route entered into the navigation system will be broadcast on the ES so controllers and other pilots can see where you intend to fly. 1090ES includes a 56 bit data field used to carry ADS-B information, ADS-B information is derived from the onboard avionics navigation systems figure 4.2.

Figure 4.2 Extended (112 bit) squitter

4.2 Demodulating the Pulse Train

A typical ADS-B message is 120 μs long and uses PPM for transmitting the bits. PPM is a form of signal modulation where the bits are transmitted in one of two possible time slots; for ADS-B the time slot equals one microsecond [Figure 4.3]. A “1” or “0” is denoted by a pulse in the first or second half (0.5 μs) of the time slot, respectively.

4.2.1 Preamble Detection

The first step in demodulating the pulse train is to determine the presence of a signal. The first four pulses in Figure 4.3 are considered the preamble. The preamble serves as a flag and time sync, notifying a receiver that a message will begin 8μs from the first preamble pulse. The preamble does not follow conventional PPM principles (a pulse in every time slot). A method for overcoming this deviation is to represent the gaps as consecutive “0” bits.

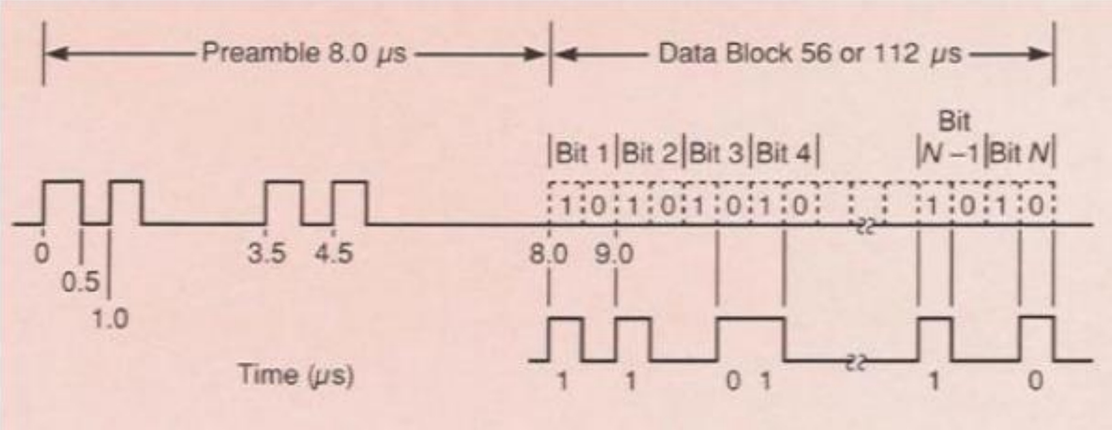


Figure 4.3 120 microsecond ADS-B message waveform

4.2.2 Message Reception

After the preamble has been detected, the individual bits need to be identified for message decoding. The bits are detected through a threshold setting based on the pulse amplitudes of the preamble. This requires the pulses to remain at relative constant amplitude throughout transmission. Pulses violating the threshold could cause bit errors and ultimately the message would be discarded. Once the bits have been received successfully, ADS-B decoder begins to decode the bits based upon the message type and the message format. DF17 messages have a particular placement for the individual components of the message. To ensure proper decoding, the format must be known to ensure the correct bits are used for altitude, aircraft ID, etc. The ADS-B message is broken into six parts including the preamble [Figure 4.4].

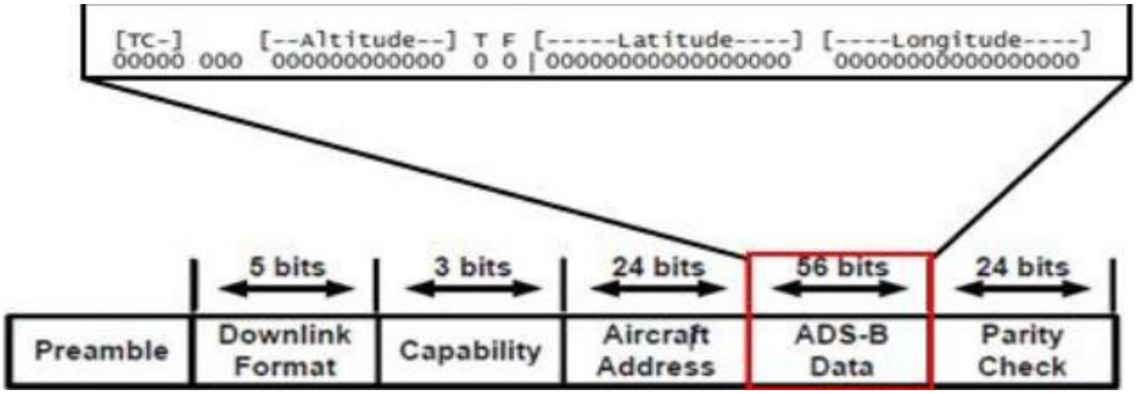


Figure 4.4 ADS-B message format.

The first field of the message is the DF type; as discussed ADS-B messages are set to 17 or 10001 binary. The next field is the capability field or subtype field. This field describes the specific data being transmitted by the ADS-B message. The subtype message focused on for this research is subtype five, positional reports. This field will be set to “101” for all tests. Following the capability field is the aircraft’s ID, which is a three byte field that contains the ICAO designation for each aircraft. The aircraft ID is assigned for the life of the aircraft but can be changed if necessary. Following the aircraft ID are the 56 bits of ADS-B data, containing (First 5 bits are the TC which is 11. A TC 11 decodes to the following fields: Bits 6 and 7 are the Surveillance Status. Bit 8 indicates the antennas used. Bits 9 (MSB) to 20 (LSB) contain the altitude. Bit 21 contains the T (Time) bit. T in this case is 0 which means we are not synchronized to UTC. Bit 22 contains the F flag which indicates which CPR format is used (odd or even). Bits 23 (MSB) to 39 (LSB) contain the encoded latitude. Bits 40 (MSB) to 56 (LSB) contain the encoded longitude. So our first frame has F flag = 0 so is even and the second frame has F flag = 1 so odd. So we finally know that we can use our information to find the position of this aircraft). Finally, the last field is the parity check, which is 24 bits. The parity bits are obtained using a cyclic redundancy check polynomial applied to the first 88 bits of the message.

4.3 ADS-B Data decoding

4.3.1 Altitude decoding

The altitude is comprised of 12 bits (bits 9-20) of ADS-B data. In order to decode the altitude, bit number eight of the 12 bits, counting from left to right, is removed. This is known as the Q bit. This bit determines whether the altitude is being reported in 25 foot increments (set to ‘1’) or 100 foot increments (set to ‘0’) [Figure 4.5]. After determining the increment value, the first seven bits are shifted to the right, essentially eliminating the Q bit. This will leave a binary number that can now be converted to decimal. Once in decimal format, the number is multiplied by the increment (25 or 100), and the final step is to add 1,000 to it.

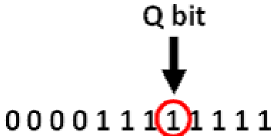


Figure 4.5 Q bit representation for altitude

For example, assume the altitude bit pattern is 000011111111. Since the Q bit is set to one, the altitude is being reported in 25 foot increments. The Q bit is then eliminated, which leaves 000001111111 or 127 decimal. Next, the decimal number is multiplied by 25 for a product of 3,175. Finally, 1,000 is subtracted to give a decoded altitude of 2,175 feet.

4.3.2 Latitude and Longitude Decoding

The next decoding to take place is the latitude and longitude. These two fields are each 17 bits. There is an additional two bits designated for Compact Position Report (CPR) format, which makes 36 bits total for this information. CPR was developed for ADS-B messages to reduce the number of bits required to transmit positional data. Accuracy for ADS-B messages is within 5.1 meters, since the Earth’s circumference is around 40,000 kilometers that would require almost 7.8 million position values (40,000km/5.1m) or 23 bits of data (2^{23} = 8,388,608). In order to fit the positional data into 17 bits, the higher order bits are eliminated. The higher order bits contain information such as the hemisphere in which the aircraft is located. Since an aircraft in most cases will remain within the same hemisphere for the lifetime of the aircraft, they can be eliminated. In order to accomplish this without causing ambiguity, the Earth is divided into odd and even latitude and longitude zones [Figure 4.6]. In order to determine the precise location, both odd and even CPR messages must be received. These two formats differ slightly in their calculations, but will be used to narrow down the location of the aircraft to an X and Y coordinate within one zone to within the 5.1 meter accuracy mentioned earlier.

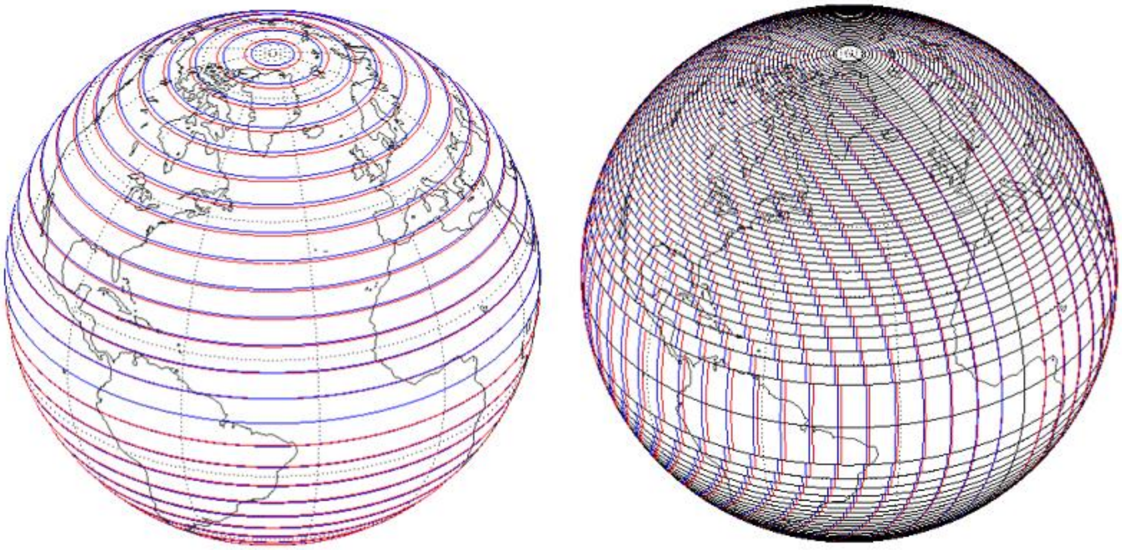


Figure 4.6 Latitude (left) and longitude (right) zone boundaries

The first step in decoding is to calculate the latitude index designated by the letter j as shown in Equation4-1. Lat (0) and Lat (1) are the odd and even format messages received.

$$j = \left(\frac{59*Lat\ (0) - 60*Lat\ (1)}{131072}\right) + \frac{1}{2} \qquad (4\text{-}1)$$

Following that the recovered latitude (Rlat) is calculated. This calculation is performed for both the odd and even messages [Equation 4-2]. For this equation, the zone size is designated by the variable Dlati. Dlat1 and Dlat0 differ slightly with an odd message equal to 360/4*(Number of

Zones-1) and an even message equal to 360/4*(Number of Zones). The number of zones equals 15 as this is the amount of zones within each quadrant of the Earth. The modulus function within this equation returns the remainder of dividing the first variable by the second variable.

$$rlati = Dlat_i * (modulus(j, 60) + \frac{Lat(i)}{131072}) \tag{4-2}$$

The next variable to determine is the number of longitude zones (NL). This is determined by using the rlat value from the previous equation. A lookup table [Appendix A] is used to determine the NL (rlat) value. Next is the width of the longitude zone (ni) which is calculated by dividing 360 by NL–i. Further decoding leads us to the longitude index [Equation 4-3]. [2]

$$Longitude\ index = \frac{\big(Lon(0)*(NL(i)-1)\big)-(Lon(0)*NL(i))}{131072} \tag{4-3}$$

Finally, the longitude of the second message received (the odd message) is found using [Equation 4-4].

$$Longitude = Dlon(i) * (\frac{(modulus(longitude\ index, ni)}{131072}) \tag{4-4}$$

(The latitude of the odd and even message approximately equally and the NL value for both of them are the same for this we can take any value of latitude to calculate the longitude index).

Chapter five: Simulation and Results

5.1 Chapter overview

As stated in the previous chapter that the ADS-B has a preamble known as downlink format (DF) DF=17 which mean that the message is extended squitter, the DF=17 mean the message is a TIS-B, our focus in this research is DF=17 and specifically only at the data block of the DF=17 message. The decoding process has been shown by using the MATLAB script and the Google earth as monitor for the decoded message, a toolbox has been installed in MATLAB to create an API between the MATLAB and the Google earth application, this toolbox creates a KML file format.

5.2 Keyhole Markup Language

Keyhole Markup Language (KML) is an XML notation for expressing geographic annotation and visualization within Internet-based, two-dimensional maps and three-dimensional Earth browsers. KML was developed to be used with Google Earth which was originally named Keyhole Earth Viewer. It was created by Keyhole, Inc. which was acquired by Google in 2004. KML became an international standard of the Open Geospatial Consortium in 2008. Google Earth was the first program that is able to view and graphically edit KML files**.** The KML file specifies a set of features (place marks, images, polygons, 3D models, textual descriptions, etc.) for display in Here Maps, Google Earth, Maps and Mobile, or any other geospatial software implementing the KML encoding. Each place always has a longitude and latitude. Other data can make the view more specific, such as tilt, heading, altitude, which together define a "camera view" along with a time stamp or time span.[11]

5.2.1 KML File setup

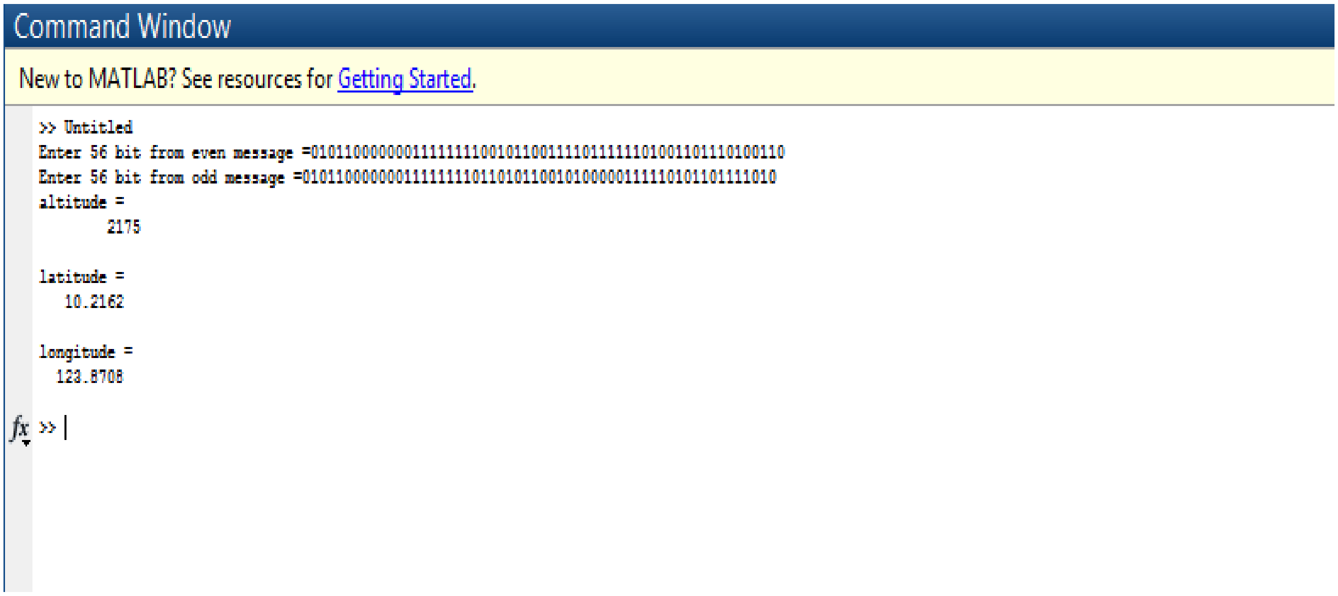
In order to perform this setup we use MATLAB R2014B script look at appendix B. The lines from 1 to 207 in appendix B is related to decoding process of the message in its three parameters (altitude, latitude, longitude), and lines from 208 to 214 describe the method of creating the KML file.

5.3 Validation of ADS-B script

It is reasonable to question the validity of ADS-B decoder, ADS-B depends on the code developed in Appendix B and here are some examples for messages and results in both MATLAB program and Google earth application.

5.4 Decoding and Simulation results

Here are the results of both decoding and simulation of three messages showed side by side:



```
>> Untitled
Enter 56 bit from even message =01011000000011111111001011001111011111101001101110100110
Enter 56 bit from odd message =01011000000011111111011010110010100000111110101101111010
altitude =
        2175

latitude =
   10.2162

longitude =
  123.8708

>> |
```

Figure 5.1 message 1 decoding result

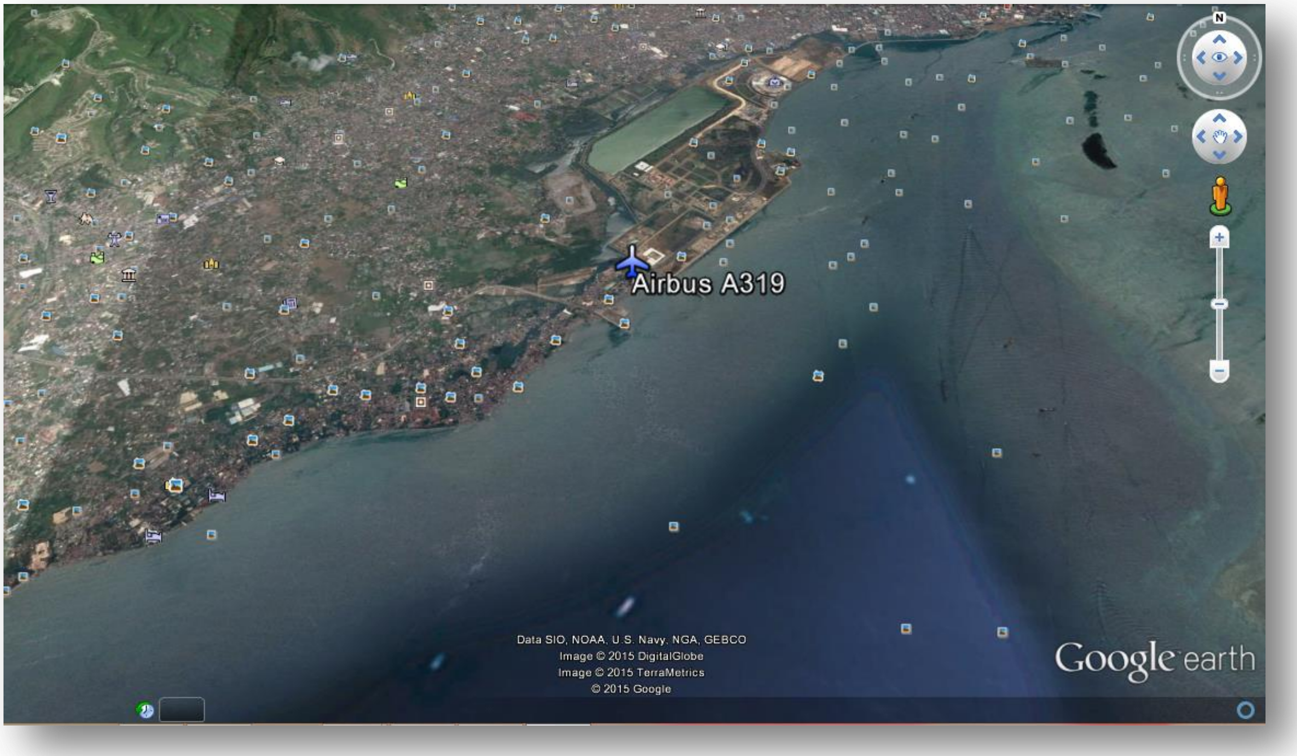
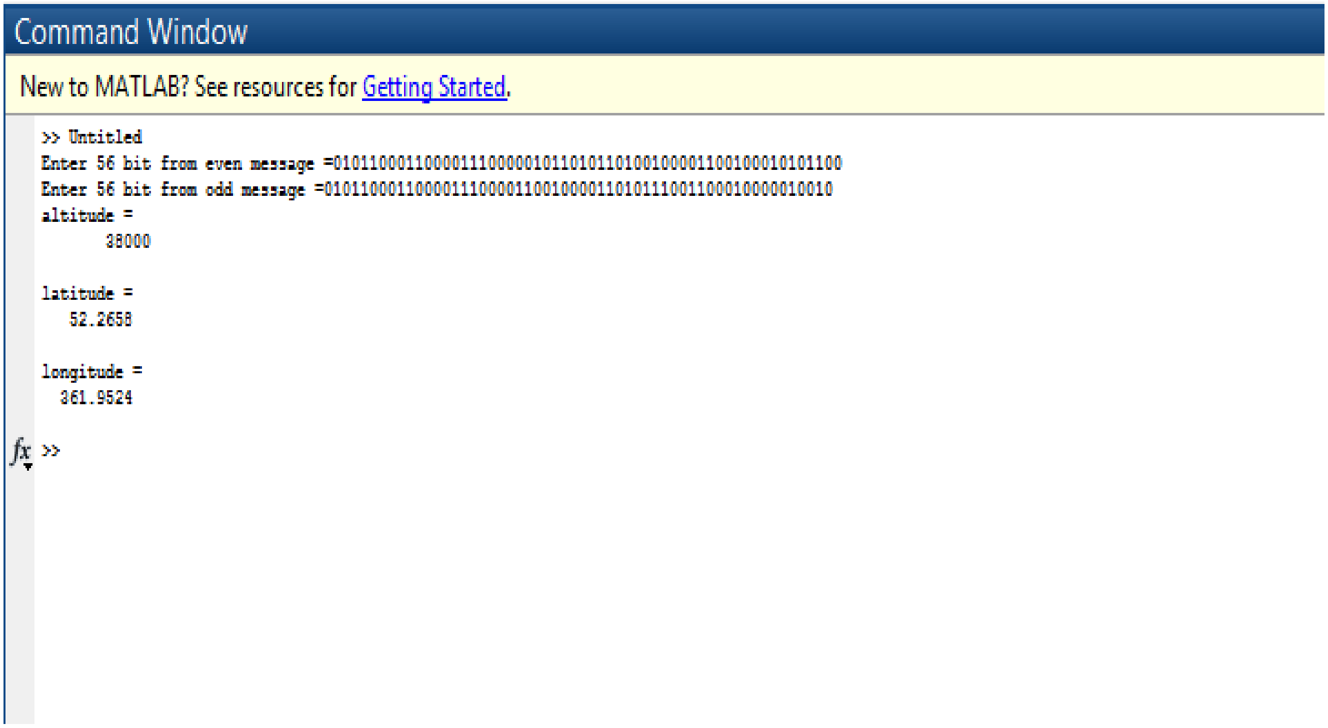


Figure 5.2 Airbus A319 simulation snapshot



```
>> Untitled
Enter 56 bit from even message =01011000110000111000001011010110100100001100100010101100
Enter 56 bit from odd message =01011000110000111000011001000011010111001100010000010010
altitude =
       38000

latitude =
   52.2658

longitude =
  361.9524

>>
```

Figure 5.3 message 2 decoding result

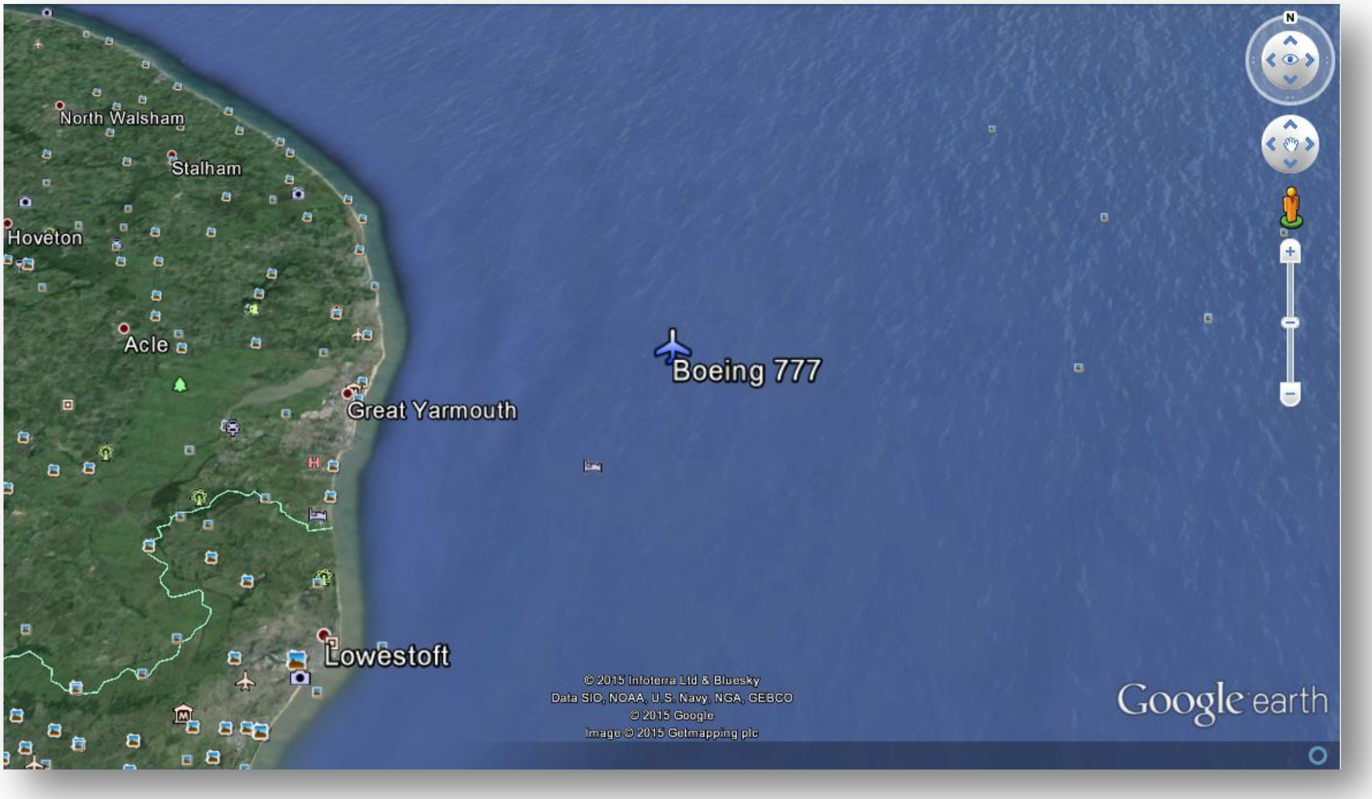
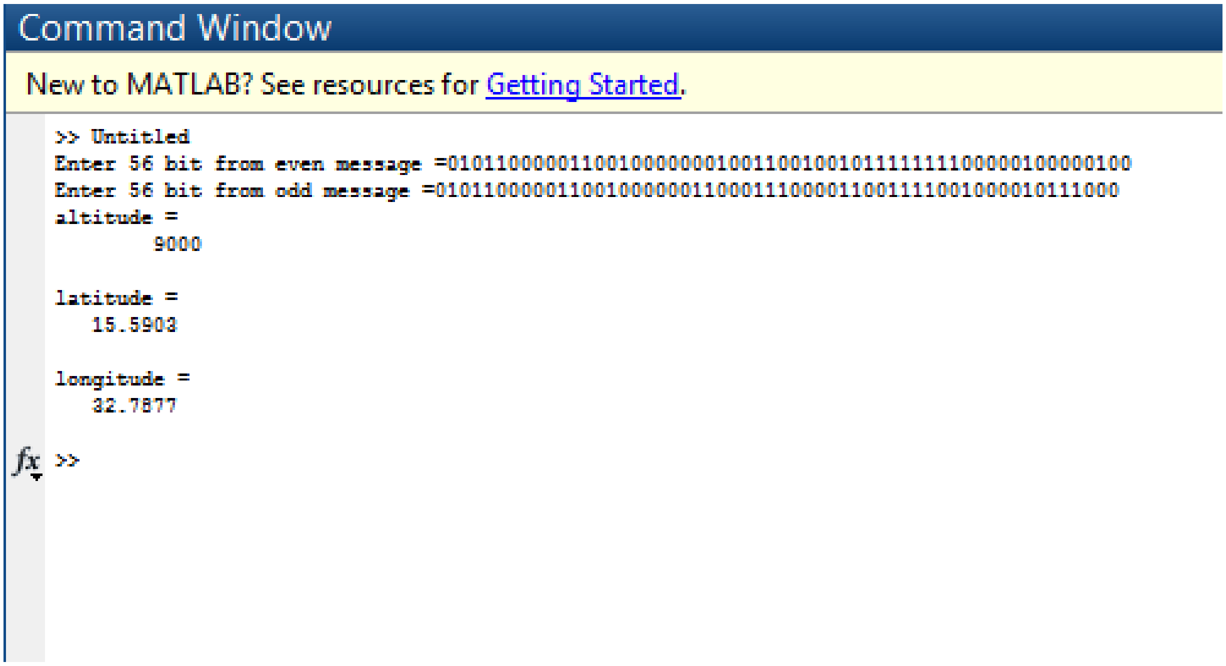


Figure 5.4 Boeing 777 simulation snapshot



```
>> Untitled
Enter 56 bit from even message =01011000001100100000001001100100101111111100000100000100
Enter 56 bit from odd message =01011000001100100000011000111000011001111001000010111000
altitude =
        9000

latitude =
   15.5903

longitude =
   32.7877

>>
```

Figure 5.5 message 3 decoding result

Figure 5.6 Boeing 737-8KN simulation snapshot

Chapter Six: Conclusion and Recommendations

6.1 Conclusion

This research presented an overview of past, present, and future Air Traffic Control (ATC) systems in order to provide background necessary to understand how the current system came into use, why this system needs to be replaced, and an introduction into future generation ATC systems. With regard to the future ATC systems, the focus of this review would be on the main area of this research, Automatic Dependent Surveillance-Broadcast (ADS-B).

In an effort to save fuel and money while enhancing aircraft safety, the FAA has begun actions to overhaul their traditional radar based surveillance system with a next generation (NextGen) solution based on ADS-B technology. Rather than relying on ground based radar to determine an aircraft's position, a unit onboard the aircraft determines the exact coordinates of the aircraft using the Global Positioning System (GPS) satellite constellation. In addition the ability of ADS-B to provide coverage where radar could not reach there before. For these reasons, ADS-B has the superiority to be used among the other navigation aids.

The focus of this research was on positional ADS-B messages. ADS-B contains multiple subtype formats for broadcasting aircraft data, this research focused on downlink format (DF) 17, subtype 5 messages. These messages contain information such as aircraft ID, altitude, latitude, and longitude, which provide the potential for false targets to be inserted on a radar display. The purpose of this research was to investigate the Automatic Dependent Surveillance – Broadcast system to include the ability of receiving ADS-B messages and decoding them MATLAB script has been written to accept ADS-B message (DF 17) in binary format and the code generate kml file which include aircraft ICAO 24 bit address, longitude, latitude, and altitude. To validate the messages google earth toolbox has been installed in MATLAB to create API between it and google earth application, then the output has been showed in google earth.

6.2 Recommendations

Although the software system (MATLAB Script) developed in this thesis has the ability to decode ADS-B messages, it currently can only accept one message at a time. Future researches should include generating and receiving multiple messages in dynamic manner work could also include the development of separate functions to perform certain tasks such as generating a complete track with only a starting (both latitude and longitude) and end point.

Other researches could be performed in the use of ADS-B messages subtype 9, this provides aircraft speed and track information. Having the ability to add this information to the current system would increase the appearance of an authentic aircraft broadcasting ADS-B data.

Because of the high cost which has been faced when wanted to provide hardware in this research, software has only been used. So future researches should include hardware in the research which can be achieved by encouraging and developing the relations with the Air Navigation Center (ANC).

Since this research focused on the ADS-B message decoding, additional researches should include ADS-B message encoding, in order to design a complete system which can be used to test and calibrate ADS-B systems on both ground and aircraft.

Although this research used an API between Google Earth Application and MATLAB, a previous knowledge of interfacing techniques should be provided for students.

References

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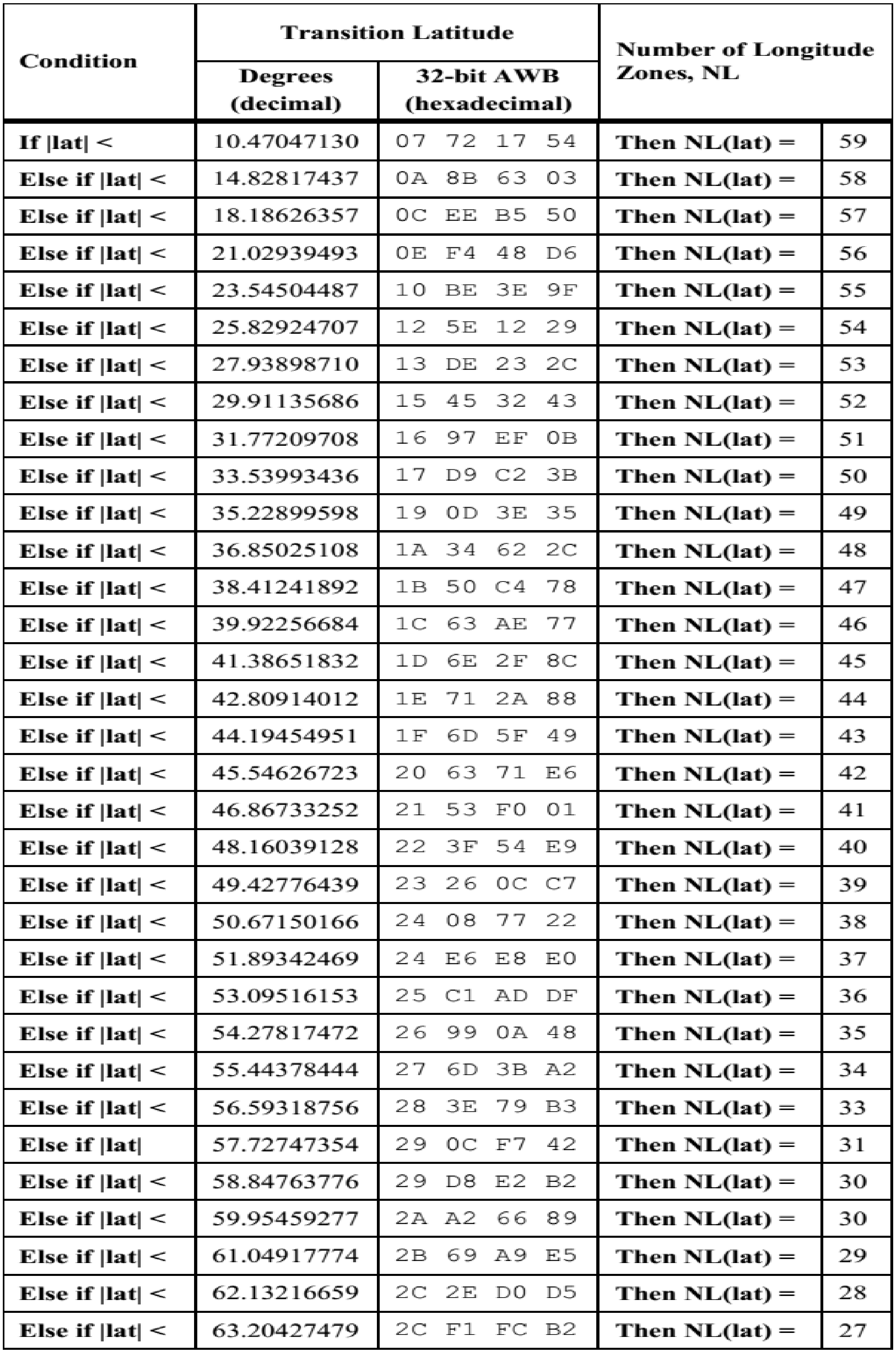
Appendix A



Condition	Transition Latitude		Number of Longitude Zones, NL	
	Degrees (decimal)	32-bit AWB (hexadecimal)		
If |lat| <	10.47047130	07 72 17 54	**Then NL(lat) =**	59
Else if |lat| <	14.82817437	0A 8B 63 03	**Then NL(lat) =**	58
Else if |lat| <	18.18626357	0C EE B5 50	**Then NL(lat) =**	57
Else if |lat| <	21.02939493	0E F4 48 D6	**Then NL(lat) =**	56
Else if |lat| <	23.54504487	10 BE 3E 9F	**Then NL(lat) =**	55
Else if |lat| <	25.82924707	12 5E 12 29	**Then NL(lat) =**	54
Else if |lat| <	27.93898710	13 DE 23 2C	**Then NL(lat) =**	53
Else if |lat| <	29.91135686	15 45 32 43	**Then NL(lat) =**	52
Else if |lat| <	31.77209708	16 97 EF 0B	**Then NL(lat) =**	51
Else if |lat| <	33.53993436	17 D9 C2 3B	**Then NL(lat) =**	50
Else if |lat| <	35.22899598	19 0D 3E 35	**Then NL(lat) =**	49
Else if |lat| <	36.85025108	1A 34 62 2C	**Then NL(lat) =**	48
Else if |lat| <	38.41241892	1B 50 C4 78	**Then NL(lat) =**	47
Else if |lat| <	39.92256684	1C 63 AE 77	**Then NL(lat) =**	46
Else if |lat| <	41.38651832	1D 6E 2F 8C	**Then NL(lat) =**	45
Else if |lat| <	42.80914012	1E 71 2A 88	**Then NL(lat) =**	44
Else if |lat| <	44.19454951	1F 6D 5F 49	**Then NL(lat) =**	43
Else if |lat| <	45.54626723	20 63 71 E6	**Then NL(lat) =**	42
Else if |lat| <	46.86733252	21 53 F0 01	**Then NL(lat) =**	41
Else if |lat| <	48.16039128	22 3F 54 E9	**Then NL(lat) =**	40
Else if |lat| <	49.42776439	23 26 0C C7	**Then NL(lat) =**	39
Else if |lat| <	50.67150166	24 08 77 22	**Then NL(lat) =**	38
Else if |lat| <	51.89342469	24 E6 E8 E0	**Then NL(lat) =**	37
Else if |lat| <	53.09516153	25 C1 AD DF	**Then NL(lat) =**	36
Else if |lat| <	54.27817472	26 99 0A 48	**Then NL(lat) =**	35
Else if |lat| <	55.44378444	27 6D 3B A2	**Then NL(lat) =**	34
Else if |lat| <	56.59318756	28 3E 79 B3	**Then NL(lat) =**	33
Else if |lat|	57.72747354	29 0C F7 42	**Then NL(lat) =**	31
Else if |lat| <	58.84763776	29 D8 E2 B2	**Then NL(lat) =**	30
Else if |lat| <	59.95459277	2A A2 66 89	**Then NL(lat) =**	30
Else if |lat| <	61.04917774	2B 69 A9 E5	**Then NL(lat) =**	29
Else if |lat| <	62.13216659	2C 2E D0 D5	**Then NL(lat) =**	28
Else if |lat| <	63.20427479	2C F1 FC B2	**Then NL(lat) =**	27

Condition	**Transition Latitude**		**Number of Longitude Zones, NL**	
	Degrees (decimal)	**32-bit AWB (hexadecimal)**		
Else if |lat| <	64.26616523	`2D B3 4C 60`	**Then NL(lat) =**	26
Else if |lat| <	65.31845310	`2E 72 DC 8C`	**Then NL(lat) =**	25
Else if |lat| <	66.36171008	`2F 30 C7 D8`	**Then NL(lat) =**	24
Else if |lat| <	67.39646774	`2F ED 27 0C`	**Then NL(lat) =**	23
Else if |lat| <	68.42322022	`30 A8 11 2E`	**Then NL(lat) =**	22
Else if |lat| <	69.44242631	`31 61 9B A1`	**Then NL(lat) =**	21
Else if |lat| <	70.45451075	`32 19 DA 2E`	**Then NL(lat) =**	20
Else if |lat| <	71.45986473	`32 D0 DF 12`	**Then NL(lat) =**	19
Else if |lat| <	72.45884545	`33 86 BA F3`	**Then NL(lat) =**	18
Else if |lat| <	73.45177442	`34 3B 7C CB`	**Then NL(lat) =**	17
Else if |lat| <	74.43893416	`34 EF 31 C5`	**Then NL(lat) =**	16
Else if |lat| <	75.42056257	`35 A1 E4 F8`	**Then NL(lat) =**	15
Else if |lat| <	76.39684391	`36 53 9E FA`	**Then NL(lat) =**	14
Else if |lat| <	77.36789461	`37 04 65 38`	**Then NL(lat) =**	13
Else if |lat| <	78.33374083	`37 B4 38 EB`	**Then NL(lat) =**	12
Else if |lat| <	79.29428225	`38 63 15 64`	**Then NL(lat) =**	11
Else if |lat| <	80.24923213	`39 10 ED 48`	**Then NL(lat) =**	10
Else if |lat| <	81.19801349	`39 BD A5 B3`	**Then NL(lat) =**	9
Else if |lat| <	82.13956981	`3A 69 0D 67`	**Then NL(lat) =**	8
Else if |lat| <	83.07199445	`3B 12 CB 8A`	**Then NL(lat) =**	7
Else if |lat| <	83.99173563	`3B BA 3A 96`	**Then NL(lat) =**	6
Else if |lat| <	84.89166191	`3C 5E 0E 31`	**Then NL(lat) =**	5
Else if |lat| <	85.75541621	`3C FB 4C 0F`	**Then NL(lat) =**	4
Else if |lat| <	86.53536998	`3D 89 48 8A`	**Then NL(lat) =**	3
Else if |lat| <	87.00000000	`3D DD DD DE`	**Then NL(lat) =**	2
`Else`			**NL(lat) =**	1

Appendix B

```
a=input('Enter 56 bit from even message =','s');
b=input('Enter 56 bit from odd message =','s');
c=a(23:39);                                % extract the 17 bit of the lat(0) from message a
lat0=bin2dec(c);                           % lat (0) in decimal
d=b(23:39);                                % extract the 17 bit of the lat(1) from message b
lat1=bin2dec(d) ;                          % lat(1) in decimal
e=a(40:56);                                % extract the 17 bit of the lon(0) from message a
lon0=bin2dec(e);                           % Lon(0) in decimal
f=b(40:56);                                % extract the 17 bit of the lon(1) from message b
lon1=bin2dec(f);                           % Lon(1) in decimal.
dlat1=360/59;                              % calculate Dlat.
j=floor(((59*lat0-60*lat1)/131072)+0.5);   % calculate latitude index.
latitude=dlat1*(mod(j,59)+lat1/131072);    % calculate the latitude.
if abs(latitude)<10.47047130
   NL=59;
elseif abs(latitude)<14.82817437
   NL=58;
elseif abs(latitude)<18.18626357
   NL=57;                               % all if condition in order to choose the value of NL.
elseif abs(latitude)<21.02939493
   NL=56;
elseif abs(latitude)<23.54504487
   NL=55;
elseif abs(latitude)<25.82924707
   NL=54;
elseif abs(latitude)<27.93898710
   NL=53;
elseif abs(latitude)<29.91135686
   NL=52;
elseif abs(latitude)<31.77209708
```

```
    NL=51;
elseif abs(latitude)<33.53993436
    NL=50;
elseif abs(latitude)<35.22899598
    NL=49;
elseif abs(latitude)<36.85025108
    NL=48;
elseif abs(latitude)<38.41241892
    NL=47;
elseif abs(latitude)<39.92256684
    NL=46;
elseif abs(latitude)<41.38651832
    NL=45;
elseif abs(latitude)<42.80914012
    NL=44;
elseif abs(latitude)<44.19454951
    NL=43;
elseif abs(latitude)<45.54626723
    NL=42;
elseif abs(latitude)<46.86733252
    NL=41;
elseif abs(latitude)<48.16039128
    NL=40;
elseif abs(latitude)<49.42776439
    NL=39;
elseif abs(latitude)<50.67150166
    NL=38;
elseif abs(latitude)<51.89342469
    NL=37;
elseif abs(latitude)<53.09516153
    NL=36;
```

```
elseif abs(latitude)<54.27817472
   NL=35;
elseif abs(latitude)<55.44378444
   NL=34;
elseif abs(latitude)<56.59318756
   NL=33;
elseif abs(latitude)<57.72727354
   NL=31;
elseif abs(latitude)<58.84763776
   NL=30;
elseif abs(latitude)<59.95459277
   NL=30;
elseif abs(latitude)<61.04917774
   NL=29;
elseif abs(latitude)<62.13216659
   NL=28;
elseif abs(latitude)<63.20427479
   NL=27;
elseif abs(latitude)<64.26616523
   NL=26;
elseif abs(latitude)<65.31845310
   NL=25;
elseif abs(latitude)<66.36171008
   NL=24;
elseif abs(latitude)<67.39646774
   NL=23;
elseif abs(latitude)<68.42322022
   NL=22;
elseif abs(latitude)<69.44242631
   NL=21;
elseif abs(latitude)<70.45451075
```

```
    NL=20;
elseif abs(latitude)<71.45986473
    NL=19;
elseif abs(latitude)<72.45884545
    NL=18;
elseif abs(latitude)<73.45177442
    NL=17;
elseif abs(latitude)<74.43893416
    NL=16;
elseif abs(latitude)<75.42056257
    NL=15;
elseif abs(latitude)<76.39684391
    NL=14;
elseif abs(latitude)<77.36789461
    NL=13;
elseif abs(latitude)<78.33374083
    NL=12;
elseif abs(latitude)<79.29428225
    NL=11;
elseif abs(latitude)<80.24923213
    NL=10;
elseif abs(latitude)<81.19801349
    NL=9;
elseif abs(latitude)<82.13956981
    NL=8;
elseif abs(latitude)<83.07199445
    NL=7;
elseif abs(latitude)<83.99173563
    NL=6;
elseif abs(latitude)<84.89166191
    NL=5;
```

```
elseif abs(latitude)<85.75541621
   NL=4;
elseif abs(latitude)<86.53536998
   NL=3;
elseif abs(latitude)<87
   NL=2;
else NL=1;
end
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end
end
end
   dlon1=360/(NL-1);                                       % calculate longitude zone.
   i=(lon0*(NL-1)-(lon1*NL))/131072;                % calculate longitude index.
longitude=dlon1*(mod(i,58)+lon1/131072);        % calculate the longitude.
   c=b(9:20);                                             % extract the altitude from  message.
c(8)=[];                                                   % check the Q bit.
if c(:,1)==0;
      g=bin2dec(c);
alt=g*25;
else c(:,1)==1;
      g=bin2dec(c);
alt=g*25;
end
Altitude=alt-1000;
meteraltitude=altitude*.3048;                      % convert altitude from ft to m.
disp('altitude =')
disp(altitude)
disp('latitude =')
disp(latitude)
disp('longitude =')
disp(longitude)
  if altitude==2175;
description=sprintf('%s<br>%s</br><br;>%s</br>', ...
         'CEB [5J] Cebu Pacific Air',' Registration RP-C3191',...
         'Airbus A319');                      % the if condition to represent the name and description
 name='Airbus A319';                                           inside the kml file.
  else if altitude==38000;
description=sprintf('%s<br>%s</br><br;>%s</br>', ...
            'BAW [BA] British Airways','Registration G-STBC',...
         'Boeing 777');
 name='Boeing 777';
   else altitude==9000
 description=sprintf('%s<br>%s</br><br;>%s</br>', ...
```

```
                'UAE [EK] Emirates' ,'Registration A6-END',...
'Boeing 737-8KN');

 name='Boeing 737-8KN';
        end
        end
 iconDir = fullfile(matlabroot,'toolbox','matlab','icons');  % to show figure of A/C inside kml file
iconFilename = fullfile(iconDir, 'airports.png');
filename='ads-b.kml';                                          %to name kml file
kmlwritepoint(filename,latitude,longitude,altitude,'Description', description,'Name',
name,'Icon',iconFilename);                             %to load the description,name,icon within kml
                                                                    file,
   winopen(filename)                                   %to open the google earth program which have
                                                                 kml file data.
```