Integrations of Airborne Satellite Communication Systems into Global Aeronautical Distress and Safety System (GADSS) Network

Dimov Stojce Ilcev – Spice Science Centre (SSC), Durban University of Technology (DUT),
Tel: +27 82 7650817 & E-mail: ilcev@dut.ac.za

Abstract: This paper describes the integrations of current and new airborne satellite communication systems and networks as a subsegment of the Global Aeronautical Distress and Safety System (GADSS). The traditional aircraft satellite communications are based on analog and new digital transmission systems. However, in the mid 1990s the use of satellite digital communications became a reality. In such a way, the airspace management system is transferring into the computer and information technology with new requirements to expand satellite Communication, Navigation and Surveillance (CNS) systems for enhanced Air Traffic Control (ATC), safety and security, and as well as collision avoidance. Namely, to improve aeronautical VHF/HF radio communication systems aircraft are currently using and improving satellite communications for Voice, Data and Video (VDV) transmission solutions between aircraft and ground infrastructures. A range of aeronautical modern satellite communication, such Inmarsat Geostationary Earth Orbit (GEO with airborne Inmarsat SwiftBroadband-Safety (SB-S) system; airborne Inmarsat Global Xpress (GX) System; Aeronautical Weather and S-ADS Solutions via Inmarsat; Hybrid GEO and HEO Satellite Constellations, Twins HEO Satellite Constellations, Aeronautical Iridium Low Earth Orbit (LEO) Communication and Surveillance Networks; and Aeronautical Iridium Communication System are introduced in this paper.

Keywords: GADSS, CNS, ATC, VDV, GEO, SB-S, GX, LEO, MSC, MES, SATC

1. Introduction

The first successful experiments in Mobile Satellite Communication (MSC) systems for aeronautical applications were carried out by the Pan Am airlines and NASA program in 1964 for achieving aeronautical satellite links using the Syncom-3 GEO spacecraft. The frequencies used for experiments were the VHF band (117.9 to 136 MHz), which had been allocated for Aeronautical MSC (AMSC).

However, the US Comsat General began with development of the first global MSC system for maritime applications with the launch of the three Marisat satellites in 1976, at first for US Navy and soon after for merchant ships. Thus, Marisat spacecraft had a hybrid payload wit one transponder for US Navy ship's operating on an UHF-band and with another for commercial merchant fleets utilizing newly allocated frequency bands for Maritime MSC (MMSC). The first official mobile satellite telephone call in the world was established between vessel-oil platform Deep Sea Explorer operating close to the coast of Madagascar and the Phillips Petroleum Company in Bartlesville, Oklahoma, USA on 9 July 1976, using AOR CES and GEO of the Marisat system. The MSS communication systems for maritime, land and aeronautical satellite applications are designed to address their special service for enhanced commercial, distress and safety networks at sea, on the ground and in the air. Namely, all these applications have certain common characteristics and the similar purposes, especially maritime and aeronautical MSC systems. Likewise, the satellites employed in these MSS systems can be found in constellations using the GEO, MEO, LEO or Highly Elliptical Orbits (HEO) with widely differing perigees and apogees.

The GEO satellite configuration is undoubtedly the simplest and least expensive type of system to deploy, since from the geostationary altitude (height above the Earth's surface) of approximately 36,000 km, so satellite can see about one third of the Earth's surface and is visible from about 80° North to 80° South latitude. Therefore, with 3 or 4 satellites can be provided global coverage, with the exception of both poles, which minimizes launch costs and the number of feeder link or gateway stations is held to a minimum. In addition, gateway and semi-fixed Mobile Earth Station (MES) terminals have simplified tracking, because a satellite in GEO (24 h orbital period plus in the equatorial plane) will appear at a stationary point in the sky, as viewed from any point of Earth. The disadvantages of the GSO orbit are lack of coverage at high latitudes near the poles and a fairly long propagation delay time of about 240 ms minimum. This delay is depending on the slant range to the satellite for a round trip at uplink and downlink. On the plus side, no hand-over of feeder links is required, since a given gateway station will generally be tracking the same satellite in the particular regions of the world it is serving. The GEO satellite that can be implemented for aeronautical MSS service is Inmarsat MSC system.

All Non-GEO satellites, such as LEO, appear to move with time relative to the location of any MES terminal or feeder link/GES terminal. Thus, LEO satellites are placed in circular, inclined orbits at altitudes below 2,000 km and the Van Allen belts of Earth-trapped intense radiation run from 3 200 to 7 600 km. In fact, LEO orbits are located below the lowest Van Allen belts and the exact altitude depends upon a trade-off between the desired coverage and other factors needed to provide this coverage generally the orbit selected provides an overlap between cones of visibility as seen from the Earth of a given satellite at the desired altitude.

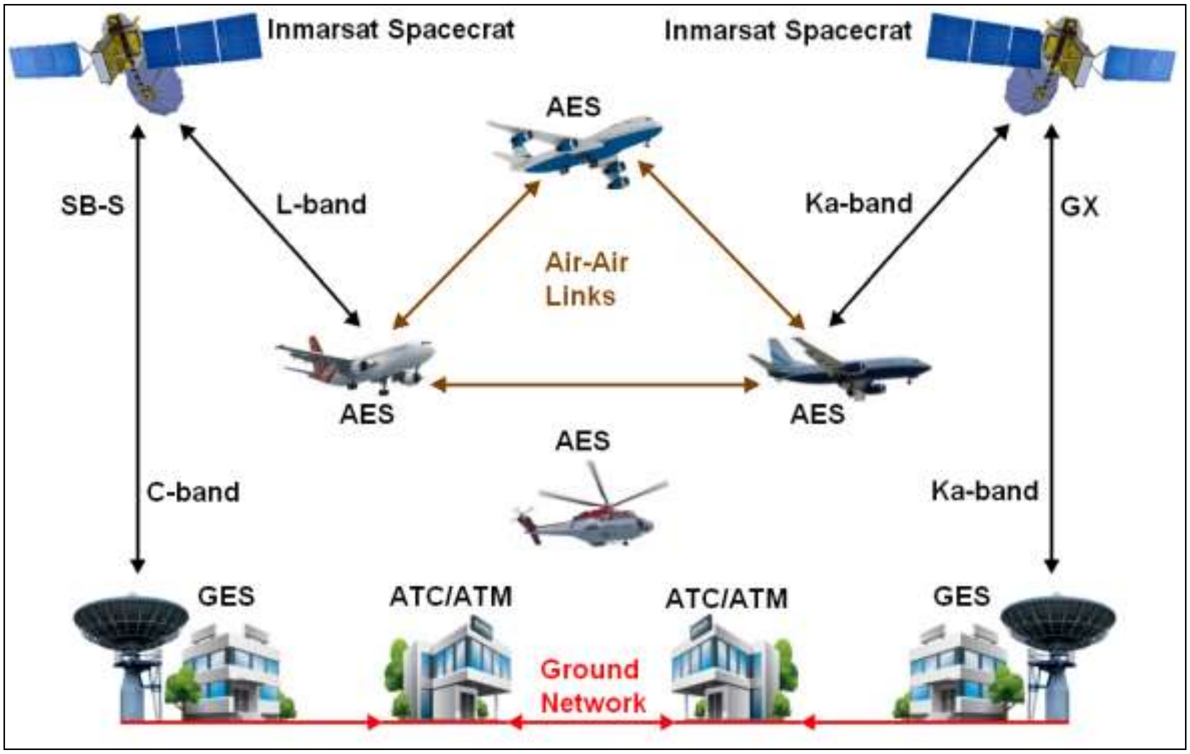

Figure 1. Aeronautical Inmarsat Communication Network – Courtesy of Manual: by Ilcev

The LEO satellites have an advantage over GEO system in their ability to provide coverage at higher latitudes right up/down to the poles, such as Iridium LEO system. There is a trade-off in complexity versus altitude, so at the lower LEO altitudes more satellites are required for the real global coverage than at the higher LEO altitudes.

2. Inmarsat GEO Satellite Communication System

The GEO Inmarsat satellite subsystem can bi involved in significant service for the future GADSS aeronautical emergency system including for commercial communications in all 3 flights ocean areas, except both poles. In **Figure 1** is illustrated scenario of aeronautical Inmarsat communication network with two current services at L/C-band and Ka-band. Both Inmarsat satellite bands are providing A/G (Air-Ground) commercial, routine and distress communications with ATC/ATM via Inmarsat satellites and Ground Earth Station (GES) terminals including A/A (Air-Air) links.

The Inmarsat network was initially targeted to providing a maritime communication service to the community for safety of life related issues. However, Inmarsat soon began to provide service to other communities such as aircraft and other land mobile users. The Inmarsat space segment is a constellation composed of 3 or 4 GEO satellites, which number depend on the service as not all of them support all the services, that cover the entire Earth with the exception of the poles. Aeronautical services supported by the system are currently ATS and AOC services. These can either be used through the legacy Classic Aero service or the recently introduced SwiftBroadband-S (SB-S) service, based on the BGAN technology adapted to the aeronautical context, and newest Global Xpress (GX).

The Inmarsat satellite constellations use three different types of spot beams, one is global spot beam for initial signalling and specific services, a since Inmarsat 3rd generation set of regional spot beams and very small spot beams in radius in the order of hundreds of kilometers used for the BGAN service and allowing for smaller antennas to be used on the handheld terminals. In terms of frequencies, the Inmarsat-4 satellite system operates the feeder link in C-bands and the service (user) link in AMS(R)S reserved portions of the L-band. The Classic Aero service is mainly used for establishing circuit oriented connections for low and medium quality voice, data and fax. In addition to these services, packet data services such as ACARS and ADS can also be used.

The last generation of Inmarsat satellites is providing faster throughout links between AES terminals and ATC/ATM station via Inmarsat-5 satellite constellation and GES terminals for GX aeronautical terminals known as Jet Connex. The new Inmarsat-5 satellite system operates the feeder link in Ka-bands and the service link in AMS(R)S reserved portions of the Ka-band as well.

Figure 2. Airborne Inmarsat SwiftBroadband-Safety (SB-S) System – Courtesy of Manual: by Cobham

2.1. Inmarsat SwiftBroadband-Safety (SB-S) Communication System

The SwiftBroadband-Safety (SB-S) service SB-S is the first and only global, secure, IP connection for operations and safety communications, delivering incomparable amounts of protected data everywhere airlines fly. The SB-S standard is a strategic asset that unlocks a new world of digital transformation, making airline operations more efficient and helping to assure safety, delivering game-changing visibility into global airline operations. The SB-S service offers much higher data rates than Classic Aero and takes advantage of the spot beams of the fourth generation Inmarsat satellites to provide users with these data rates. This service is based on the use of the IP protocol at network layer and is mainly used to provide passengers with Internet access. Thus, the Inmarsat Classic Aero protocol is also used by the Multifunctional Transport Satellite (MTSAT) system operated for the Japanese Civil Aviation Bureau (JCAB). The MTSAT system as described in offers ATS and AOC services to airlines in the Asia/Pacific area and provides increased availability by using two specifically located geostationary satellites (MTSAT-1R and MTSAT-2).
On of the best product representing SB-S equipment is AVIATOR 350D business jet for commercial aviation designed by Cobham, which configuration is depicted in **Figure 2.**
The main components of AVIATOR 350D are SwiftBroadband Unit (SBU); High Power Amplifier, Low Noise Amplifier and Diplexer (HLD); High Gain Antenna (HGA-6000) 3rd party Aircraft Interface Device (AID), which is required for secure segregation between cockpit and cabin; and A429 to RS 422 Converter. The HLD unit is connecting Transmitter and Receiver (Tx/Rx) in SBU, from where is connected Communication Management Unit (CMU), 2-Wire, Voice Priority Discrete and NAV Input.
The main features and capabilities of SB-S transceiver are as follows: it is weighing just 8.2 kg including the antenna; AVIATOR 350D provides connectivity speed at up to 432 Kb/s SwiftBroadband data; simultaneous FANS, voice and cabin data; built-in 6 port router and WLAN; Integral SB-Safety service; DO178B Level D software and DO254 Level D hardware; and supports ICAO voice via external dialer (such as Cobham PTA12. The cockpit board interfaces 2 x 2-Wire Voice; wired Ethernet (LAN); 1 x CMU; and 1 x Air Traffic Services Unit (ATSU).
On the other hand, cockpit interfaces built in Session Initiation Protocol (SIP) server for Voice over IP (VoIP) calls, 2 x 10/100 Mb Ethernet ports, and 802.11a/b/g/n access point, as stated this interfaces are requiring the use of a 3rd party AID for secure segregation between cockpit and cabin.
The HGA-6000 is the smallest and lightest mechanically steered SB antenna, specifically designed for mounting under the tail radome of an aircraft. Antenna options also include HGA-6000 slim, the ruggedized fuselage mounts HGA-6500 or the fuselage mount, phased array, electronically steered, HGA-7001. The SB-S unit is the first near global, secure and IP connection for operations and safety communications, delivering incomparable amounts of protected data everywhere airlines fly. This unit is a strategic asset that unlocks a new world of digital transformation, making airline operations more efficient and helping to assure safety, delivering game-changing visibility into global airline operations. It builds on the capabilities of the earlier cockpit satellite technologies combined with secure IP broadband connectivity. The result is vastly improved operational efficiency, enhanced safety and delivering much faster transmission along with a host of new solutions.
The FB-S unit provides operational advantages for airlines, flight route optimization and trajectory-based operations save time and fuel. With Electronic Flight Bag (EFB) apps such as chart updates and real-time graphical weather assist efficient flight paths. Parts can be pre-positioned for better asset utilization and improved turnaround through air to ground tech log notifications.

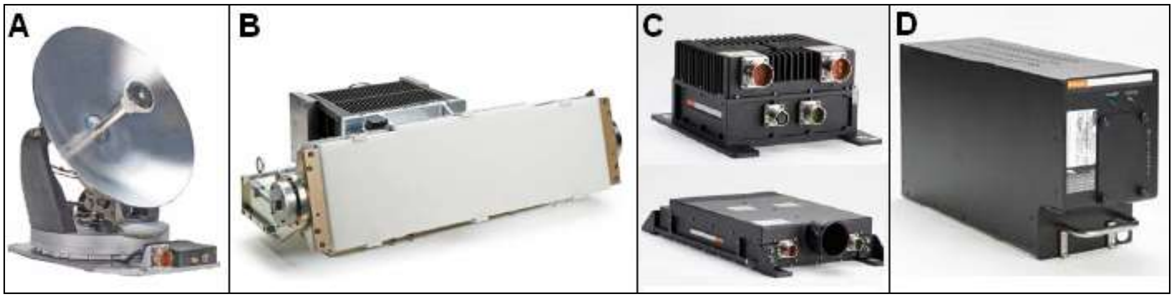

Figure 3. Airborne Inmarsat Global Xpress (GX) System – Courtesy of Manual: by Honeywell

Medical diversions can be reduced with the capability for real-time video for telemedicine. High-frequency positional reporting enables reduced separation minima, whilst VoIP and ACARS over IP bypass VHF congestion to improve ATC and ATM communications. Safety is enhanced over an encrypted, segregated network. Better than 99.9% L-band availability gate-to-gate worldwide coverage meets ICAO Global Operational Data Link Document (GOLD) standard. It also does aircraft position reporting service, which regularly reports latitude, longitude, altitude, speed and true heading.

Using global L-band of Inmarsat-4 satellites network, SB-S delivers faster communications for airlines worldwide fit for the digital age. The SB-S unit uses spot beam technology over Inmarsat's I-4 constellation to dynamically allocate resources to the areas where it is most needed. Thus, this helps ensure that safety-critical information is available on-demand for the pilot, the airline and air traffic controllers.

2.2. Inmarsat Global Xpress (GX) Communication System

The Jet ConneX Inmarsat GX system is the first worldwide Ka-band network from a single operator. In **Figure 3** are depicted main elements of the Jet ConneX transceiver, such as: Tail-mount antenna (MCS-8000) for business jet aircraft (A), Fuselage-mount antenna (MCS-8100) for air transport category aircraft (B), Ka-Band Aircraft Networking Data Unit (C-above), Ka-Band Radio Frequency Unit (C-below) and Modem Manager (D).

The Honeywell producer designed the JetWave satellite communications system providing a critical Jet ConneX link for commercial and emergency inflight connectivity globally except both poles. Thus, Honeywell's JetWave antennas and hardware enable Inmarsat's high-speed Jet ConneX service, video streaming and VoIP (phone calls), music and movie downloads, access to private company networks, online shopping, and much more through one global network, even over oceans.

A foundation layer of global coverage is capable of providing up to 50 Mb/s to fuselage mounted, and 33 Mb/s to tail mounted, antennas. Capacity can be supplemented by each satellite's unique steerable beams, which direct additional capacity three times as powerful as the spot beams to busy airspace during high traffic periods.

Therefore, each of the network's current Inmarsat-5 (I-5) satellites in global spot coverage operates with 89 highly efficient Ka-band spot beams. The next three satellites (GX-5, I-6 F1 and I-6 F2) will all deliver further Ka-band bandwidth, providing additional capacity in regions of highest demand. The first of these, GX-5, is scheduled to launch in 2019.

2.3. Inmarsat Avionic Safety Services

Inmarsat has a long-standing commitment to aviation safety services, secure and reliable global connectivity solutions that set the standard for flight deck communications. More than 90% of the world's oceanic fleet and over 12,000 aircraft use Inmarsat safety and operational services for communication and surveillance today. In fact, Inmarsat provided 35 million aircraft position reports in 2018, roughly 100,000 per day, thanks to its satellite network. With own global satellite constellation Inmarsat is working with international aviation organizations to make flying safer, faster and more predictable.

The Inmarsat AMSC system can also play a major role in improvement of ATC and ATM systems to ensure that a plane gets to its destination both safely and efficiently, to establish new Global Aeronautical Safety Satellite Communications (GASSC) and to improve SAR facilities, alerting and location services for aircraft involved in accidents. In respect of the ATC/ATM function, both must perform three basic tasks of satellite CNS as follows:

1. Satellite Communications – The AMSC is the exchange of voice, data and even video in routine traffic or instructions between the aircraft pilots and ATC in airports.

2. Satellite Navigation – The GPS, GLONASS or new enhanced Inmarsat GNSS satellite positioning is a process providing pilots with information on the position of the aircraft.
3. Satellite Surveillance – The new aeronautical satellite surveillance solution, known as an Automatic Dependent Surveillance-Broadcast (ADS-B) via Radio or Satellite media is the process of detecting the position of the aircraft by ATC.
Until recently, the only means of communication between pilots and ATC was by voice VHF and HF radio equipment. The HF radio is used for long-distance communications in ocean or remote continental airspace areas, while the VHF radio is used for LOS or short distance direct-line communications in regional or domestic airspaces. To overcome the disadvantage associated with HF/VHF radio, the ICAO encouraged the development of AMSC and airborne AES located onboard aircraft. A most important application within AMSC is for route communications, which are in relation to safety and regularity of flights primarily along national or international civil air routes.
To negate the effects of current unreliable HF/VHF radio communications or unavailability of radar coverage, the ATM system maintained safety by keeping aircraft separated from one another by large distances in air spaces. Unfortunately, this method of aircraft operation was relatively inflexible. Pilots often could not reliably contact ATC to deviate around adverse weather systems or take advantage of any new information on weather conditions.
The procedure of the current ATM system thereby resulted in aircraft delays, inefficient operation and high fuel costs, all of which were further compounded by a growing air traffic demand along heavily traveled routes. The new safety/security application, requiring an integrated AMSC system with GNSS capability, for aeronautical services is a part of the ICAO’s CNS/ATM system. Many AES terminals will support ATC, ADS-B and ATM, which allow air traffic controllers to poll the aircraft for positioning, weather, safety and other information.

2.3.1. Satellite Air Traffic Control (SATC)

Inmarsat AMSC application plays a major role in the implementation of the ICAO CNS/ATM concept for a new SATC in oceanic and remote airspace. The Inmarsat Aero network will support direct pilot-to-controller voice and data communications and ADSS. Improved routing and enhanced SATC are expected to yield millions of dollars in fuel, safety and other operational cost savings to airline operators, while reduced separations will increase the capacity of oceanic and remote airlines.
With new, enhanced SATC monitoring and control of all movement of airplanes and vehicles traffic on the airport surface can be improved. The new Inmarsat aeronautical data link will be used for routine pilot-to-controller kinds of communications and requirements. Voice communications can be used for non-routine and emergency transmissions. Use of the AMSC data link to integrate aircraft fleets in flight into airline formation systems can yield significant increases in operational and administrative efficiency for the airlines.
There are a variety of AMSC applications that have been developed to support the CNS of ATM system. The applications necessitate high levels of availability, performance and integrity, as defined internationally in the new ICAO SARP and regionally, by standards such as the Radio Telecommunication Association and Minimum Operational Performance Standards (RTCA-MOPS). The main types of AMSC applications are related either to the SATC and airline administrative communications or to passenger services.
These are summarized as follows:
1. Air Traffic Control (ATC) – For ATC, AMSC solutions are used by pilots to keep in contact with ground staff in airports and other offices for routine communications such as sending Estimated Time of Arrival (ETA), routine air traffic, request for clearances and advisories and other corporate and safety transmissions. The ground controllers use AMSC to monitor and direct the position of aircraft, even when outside normal radar range.
According to the ICAO declaration, the data communications will be primary means of pilot-controller information exchange, so NOTAM and voice will be used in emergencies and other non-routine situations.
2. Air Passenger Services (APS) – For APS, AMSC non-corporate communications are used by customers to make phone calls, send data or facsimiles whilst in flight.

2.3.2. Aeronautical GNSS Augmentation System via Inmarsat

The aeronautical Inmarsat GNSS Augmentation System (ISAS) is an integral part of the Global Satellite Augmentation System (GSAS) for enhanced satellite CNS to provide flight control in the air (domestic and international flying corridors) and control of all movements on the ground (airports). All aircraft flying in certain ocean areas can be controlled with enhanced safety, security and efficiency getting augmented and not-augmented GNSS data.

In such a way, airborne AES terminal can receive both not-augmented positioning data from GNSS (GPS or GLONASS) satellites and augmented positioning data.
The GNSS data received by Ground Monitoring Station (GMS) are sent to Master control Station (MCS), which is processing this data and sending via GES and Inmarsat satellite to the shipborne GNSSS receiver as augmented PVT data. The GSAS configuration requirement will be a combination of existing Inmarsat GEO satellite systems for communications and navigation data with GNSS networks (GPS and GLONASS), which can include other developed Regional Satellite Augmentation Systems (RSAS) as well. The aeronautical GNSS augmentation via Inmarsat network can provide the following features: 1. Enhanced Positioning; 2) Reduction of Separate Minima (RSM); 3) Flexible Flight Profile Planning (FFPP); 4) Surface Movement Guidance and Control (SMGC); and Oceanic Flight Guidance and Control (OFGC).

2.4. Aeronautical Navigation Report Services (ANRS)

The basic principles of air navigation are identical to ship navigation, which includes the process of planning, recording, and controlling the movement of a craft from one place to another. Every pilot is planning a flight usually using aeronautical chart of the certain area published for airmen and updated by “Notice To Airmen" (NOTAM). A NOTAM is created and filed with an aviation authority to alert aircraft pilots of any hazards en route or at a specific location, and are transmitted directly in cockpit by government agencies and airport operators under guidelines specified by Annex 15 of the Aeronautical Information Services (AIS) of the Convention on International Civil Aviation (CICA).
The information is always updated in the notices to airmen or NOTAM sent via radio or satellite data links to pilots or reported for reasons such as different hazards, flights by important people, closed runways, inoperable radio navigational aids, military exercises with resulting airspace restrictions. The Inmarsat system can provide enhanced Navigation (NX) service via satellites to aircraft and vice versa direction.

2.5. Aeronautical Weather Report Services (AWRS)

The ARINC Global Link Value Added Service (VAS) provides a text and graphics and text Weather (WX) service receiving weather products from specialized aviation weather service providers, it adds the information to its database and transmits it to requesting aircraft as text or compressed graphic weather images directly to the cockpit via AES terminal. Therefore, weather products can include radar precipitation images, winds aloft, icing, turbulence, precipitation, upper air meteorological situation (wind speed, direction and temperature), significant WX and lightings. In addition, Meteorological Aviation Reports (METAR) and Terminal Area Forecasts (TAF) can be requested in either standard text format or as enhanced plain language transmissions.
The SITA Gateway service for Digital Automatic Terminal Information Service (D-ATIS) with established data link via Radio VHF or Inmarsat satellite system is another means for ATS providers to deliver current information on weather and airport conditions to pilots as a NOTAM. In this sense, the ideal means of WX data and other NX transmissions will be on a global basis from one service provider to all airline companies with compliance only to ICAO communication standards and regulations.
The important WX services for aircraft provided by operators are as follows:
1. Aeronautical Weather Reports – Two types of weather reports are METAR and the aviation Selected Special Weather Report (SPECI). The METAR is observed hourly between 45 minutes after the hour till the hour and transmitted between 50 minutes after the hour till the hour. It can be encoded as a METAR even if it meets SPECI criteria.
2. ARINC Value Added Service (VAS) – Except other corporate and safety contribution the VAS system provides similar media as SITA to transfer all meteorological parameters and information to civil aircraft including METAR and Terminal Area Forecast (TAF). Aeronautical weather products include radar precipitation images, lighting, temperatures, icing, turbulence and accurate forecast of wind aloft are used to define areas of severe WX and contribute to flight planning efficiencies and aviation safety. On the other hand, Terminal Weather Information for Pilots (TWIP) provides valuable situational awareness of weather conditions within 15 Nm of the airport. On the other hand, the TWIP service collects information from airport sensors and transmits severe WX warnings such as wind shear microbursts, gust fronts, heavy-to-moderate precipitation to aircraft and ground operations computers.
3. SITA Aircom Weather System – This WX system offer several alternatives via Radio, Inmarsat Aero terminals, Internet, On-site or Hosted solutions such as: Graphical WX charts created with country boundaries, airports and various other aeronautical features, thus providing maximum information within one viewable image; and Graphical representation of WX data, mapped over airline routes, facilitates alternative route selection based on wind patterns and other critical WX information.

Figure 4. Aeronautical Weather and S-ADS Solutions via Inmarsat – Courtesy of Reference Manual: by Ilcev

In addition, each instance of wind within user's environment can be programmed to receive a unique set of charts; Aircom surface WX with all meteorological parameters and NOTAM information important for safety flight; and Different WX charts adapted to pilot needs like Surface WX, Visibility, Satellite Imaginary, Radar Imaginary and Lighting. The Aircom WX charts service includes, but is not limited, the following types of weather information: significant weather, upper air weather (wind speed and direction), temperatures, icing, turbulence and precipitation. The Inmarsat satellite system can provide enhanced weather reports and forecasting services that is broadcasting from ground weather centres via satellites to aircraft and OBS messages in the opposite direction, as is depicted in **Figure 4 (Left)**.

The Weather Centres receive many WX and meteorological data directly from meteorological satellites, Ground Observation Centres, WX data known as OBS messages from ships and aircraft and other information resource centres, processing these WX data and information and afterwards sending via landline telecommunications to an Airline Information Centre, which retransmits these messages in IFP form to AES, via Inmarsat satellites.

The best solution for the transfer of WX messages, charts and NOTAM to aircraft is by using Flight Internet access via the Inmarsat Mobile ISDN Swift64 and FleetBroadband service. However, a decade ago author of this book nominated SwiftBroadband as a Broadband Aeronautical Communications Service (BACS). Thus, both Swift Services including Classic Aero Standards and especially Inmarsat-C can be very suitable for transfer of all data and information for corporate, commercial, distress and safety purposes.

2.6. Satellite Automatic Dependent Surveillance - Broadcast (SADS-B)

Whilst Primary and Secondary Surveillance Radars (SSR) have been the core aeronautical systems providing ATM Surveillance for over 30 years, the continuous growth in ATC has led to enhance these surveillance systems and help support increased airspace capacity. Moreover, it has long been recognized that there are parts of airspace where rotating SSR systems are not feasible or are too costly. On the other hand, there is an emerging new technology Satellite Automatic Dependent Surveillance-Broadcast (SADS-B) that may resolve the above issues. Namely, this solution represents a surveillance technique in which an aircraft transmits onboard data from avionics systems to ground-based and/or airborne receivers. The data may include: aircraft identity, position, altitude, velocity and intent.

The SADS-B application is the reporting via Inmarsat network of position and intention information derived from an aircraft's aboard navigation system. Presented on the radar screen like displays at ocean control centres, it will give controllers a real-time knowledge about the air traffic situation, permitting more fuel-efficient routing and reduced separation standards as shown in **Figure 4 (Right)**. Namely, GNSS airborne receivers are receiving from GPS or GLONASS satellites aircraft PVT data, which after deriving is automatically transmitted to the ground using AES data link. Finally, all received SADS-B information in the Data Centre will be forwarded via landline to ATC site and displayed to the air traffic manager on radar-like displays. This solution will also be convenient for military applications and it will enable new airborne and ground ATM functions, with the potential to bring extra capacity and increased safety in air corridors. In addition, using satellite SADS-B via Inmarsat will improve the availability of the real-time flight navigation data from aircraft, support airport ground surveillance, provide surveillance services in areas with none or only locally limited radar coverage and contribute to the compatibility of air and ground systems.

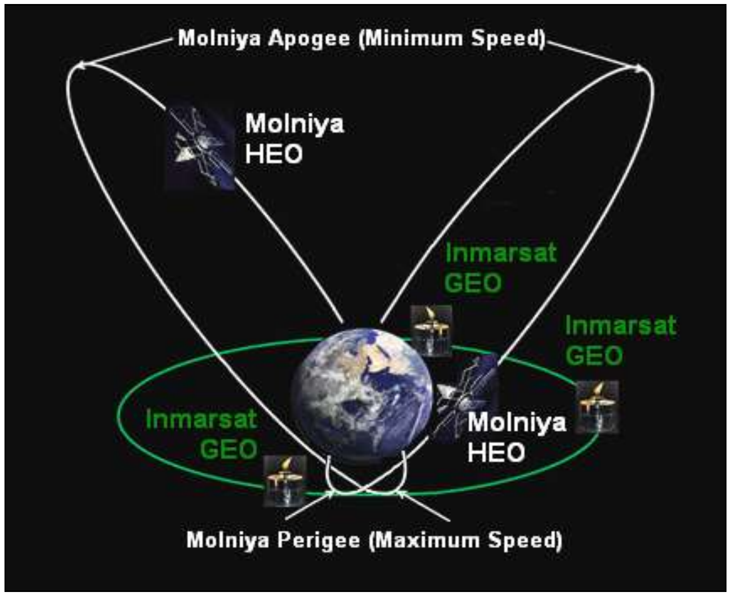

Figure 5. Hybrid GEO and HEO Satellite Constellations – Courtesy of Book: by Ilcev

2.7. Inmarsat Integrated Aeronautical Satellite Subsystem

For several decades HF radio has provided reliable communication services throughout the world and in particular for aeronautical radiocommunications. Today, it may be regarded as outdated due to the development and deployment of modern communication means such as VHF/UHF, microwave, satellites and optical fibers, but it will still be used in particular situations for a long time. In fact, fixed and mobile HF radiocommunication systems may provide back up in case of critical problems with satellite communications, especially during possible world war situations. As with other technologies, there are disadvantages and advantages with the use of HF SSB radiocommunication. Thus, the most obvious disadvantages are associated with interference due to the congested spectrum and the effects of atmospheric noise and fluctuations of propagation effects, which normally affect the quality and reliability of the HF radiocommunications.

Besides, the Inmarsat GEO mobile satellite system will be the one of the major integrator of GADSS Network. The main advantage of Inmarsat and other GEO satellites is that are always in same position relative to Earth, because the satellite appears to be stationary or fixed when viewed from the Earth and no tracking required for Earth station antennas.

In addition, about 40% of the Earths surface is in view from one GEO satellite and so this type of orbit is more reliable than LEO and MEO constellations. The main disadvantages of Inmarsat GEO satellite systems are larger propagation delay of 238 to 284 ms in satellite communication than in terrestrial communication, high attenuation level of power loss at 200dB on the path and what is critical GEO satellites can only be above the equator and therefore Polar Regions cannot be covered beyond 80^{o} latitudes. The lack of Polar coverage is not a problem for most users, while for aeronautical is important because of flights over North Pole. In the similar way, new Arctic shipping routes as the maritime paths used by vessels to navigate through parts or the entirety of the Canadian and Russian coastal Arctic Ocean will need more reliable satellite communications system than MF/HF radio. Thus, to solve this problem GADSS infrastructure will need some sort of Hybrid Satellite Orbits (HSO), such as combination of GEO and HEO (Molniya) satellite constellations, or simply to integrate existing Big LEO Iridium satellite constellation.

The overall objective of the HEO integrated with GEO constellation in HSO system is for enhancement of satellite communications system options focused on the provisioning of GMDSS, Ship Traffic Control (STC) and Air Traffic Control (ATC) dedicated mainly to ships sailing in Arctic costal waters, helicopter and small aircraft traffic on the North and Polar routes. This study aims at defining a reference system architecture and preliminary system design, such as HSO constellation between Inmarsat GEO and Twins (two) HEO Molniya satellites for entire Arctic coverage, which scenario is shown in **Figure 5.**

The HEO constellation system of Molniya satellites is already designed by former-USSR, today Russia, for civilian and military communications satellite service coverage at high latitudes of vast Russian land and sub polar regions.

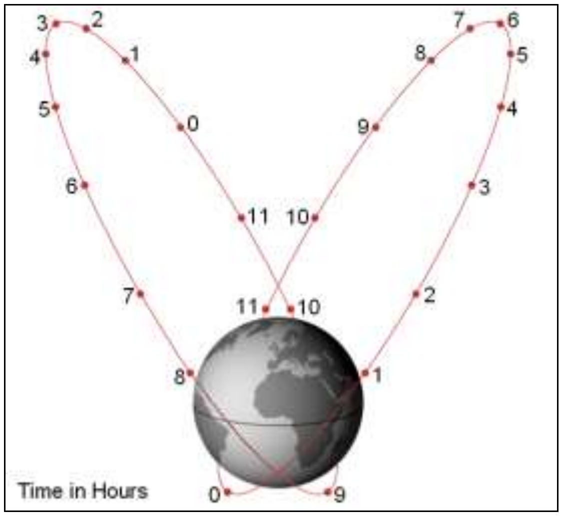

Figure 6. Twins HEO Satellite Constellations – Courtesy of Book: by Ilcev

In fact, Molniya satellite has an orbital period of slightly less than 12 hours (semisynchronous orbit), inclination of 63.4° and high eccentricity of 0.722. In the apogee, where the Molniya satellite lingers over the service coverage area at 25,000 miles (40,000 kilometers), the satellite in perigee at only 300 miles (500 kilometers) is not visible. Therefore, this type of HEO satellites was pioneered by the USSR and is particularly suited to high latitude regions, which are difficult or impossible to service with GEO satellites such as Inmarsat system. By carefully spacing 2 to 3 Molniya spacecraft, continuous communications can be maintained.

Another aspect of HSO theory is that Molniya orbits are unique because they maintain a fixed argument of perigee. The orbit has a period of one half of a sidereal day, giving two fixed geographic longitudes for alternate apogees. Namely, because of the Earth's size, Inmarsat or any GEO satellites are not visible in arrears of North Pole that includes much of Russian territory. Therefore, as is illustrated in **Figure 5,** Molniya orbits fill the gap with the twins (two) Molniya spacecraft provide approximately nadir pointing surfaces that the Molniya onboard instruments sit on. Such an arrangement is ideal for establishment HSO integration of 3 GEO and 2 HEO spacecraft of real global and very reliable satellite system for distress and commercial communications. Since the two spacecraft have a significant offset in their orbital phases (apogees at different 12 hours times), the pair can provide continuous coverage with a dual platform viewing for a main portion of Earth surface.

Soviet satellite scientists were very clever when first started using the HEO and somehow figured out that a HEO satellite with a 12 hour orbital period using a specific inclination of 63.4° nearly nullified the Earth perturbation, which means the Molniya satellite orbits the Earth twice a day. The best thing about the Molniya is when a satellite in that orbit is near and at the apogee hovering over the Earth. In such a way, of a 12 hour period, there's nearly 8 - 9 hours of time when the satellite can "see" most of a particular part of the Northern hemisphere and maintaining communication and contacts with an GES terminals, broadcasting messages to all receivers within that satellite footprint.

There's one obvious problem for users wanting to broadcast 24 hours a day. With only one Molniya satellite communications lasts just about 8 to 9 hours from a Molniya satellite's rise to its set on the opposite side of the Earth when there is not broadcast service area for nearly 15 to16 hours each day. However, there is an answer to this problem, namely, if 1 or 2 more satellites are put into different Molniya orbits separate for about 270°, then the broadcast coverage provides 24 hours service for entire Arctic Ocean area, which initiate rotation for both satellites at 0 hours is illustrated in **Figure 6.**

The Antarctic continent with southern oceans is the last great-uninhabited wilderness on Earth, which needs to be connected with reliable communication means. A continuous coverage by GEO satellites such as those used by communications and TV satellites isn't an ideal solution at the South Pole. Some Antarctic stations can access GEO satellites, but the quality and capacity of the service is challenging. To get around this, the Antarctic communication satellites would be also placed in a Molniya highly elliptical orbit with the apogee over the Southern Pole.

At present, the GADSS network infrastructure doesn't need complete coverage of Southern Pole for aircraft communications. However, if in the near future some necessity arise the question, in the same way as Northern coverage, can be established similar HSO of 3 GEO and 2 Molniya orbits to cover South Pole with opposite apogee and perigee distances from the Earth.

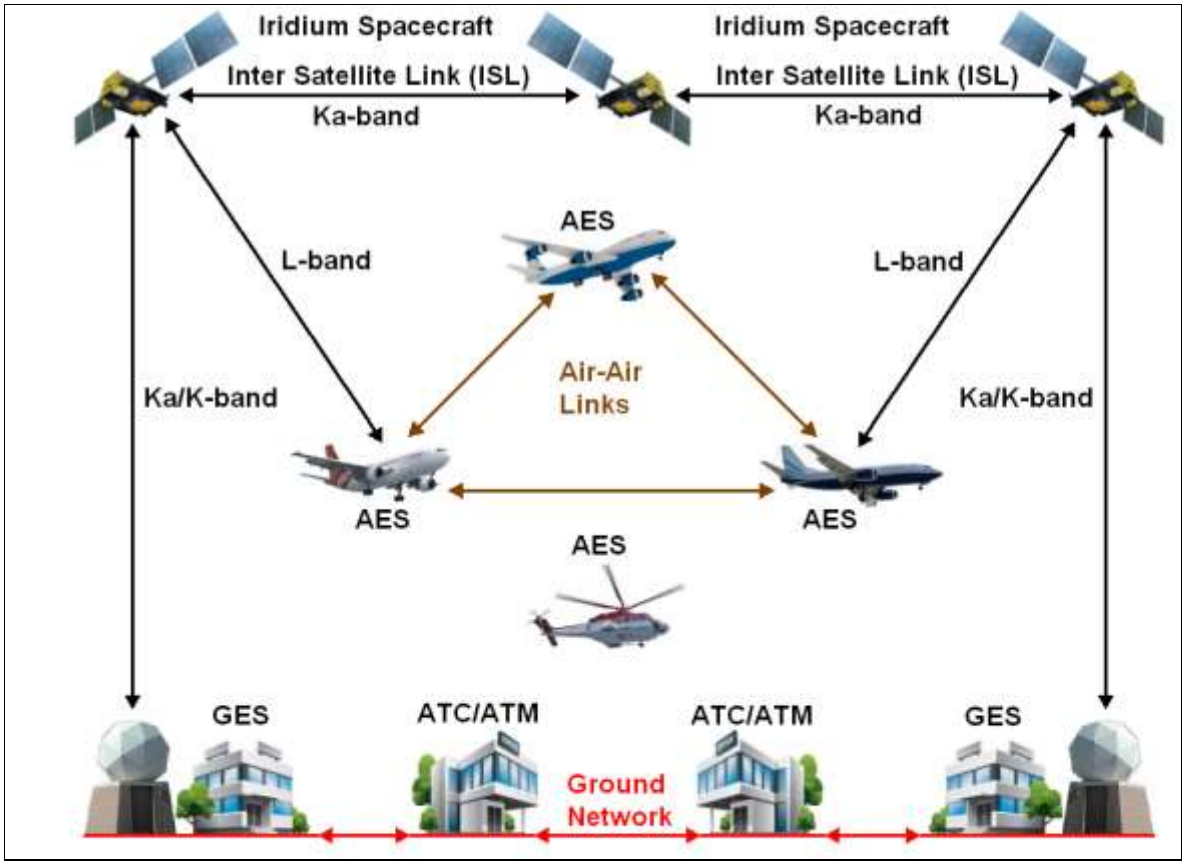

Figure 7. Aeronautical Iridium Communication Network – Courtesy of Manual: by Ilcev

To keep size and weight down and communications capacity Molniya satellite network can use Ka-band (26.5-40 GHz) satellite communication and highly directional transmitting and receiving antennae on the spacecraft. In such a way, this would necessitate a complex attitude control system on board each spacecraft in order to keep the antennae pointed at any Polar circle and Internet Gateways back on the other continents as the satellite sweeps across the sky. The other negative challenge a HEO satellite constellation faces, which a GEO satellite normally doesn't, is that the HEO satellite's orbit transits the Earth's Van Allen belts four times a day.

3. Iridium LEO Satellite Communication System

The LEO Iridium satellite subsystem will be the ideal component of future GADSS space segment as well. In **Figure 7** is illustrated scenario of aeronautical Iridium satellite communication network with current services at Ka/K-band between satellites and Ground Earth Stations (GES) or Gateways terminals and at L-band frequencies between aircraft and satellites. The Iridium network is providing A/G (Air-Ground) commercial, routine and distress communications with ATC/ATM via Inmarsat satellites and GES terminals including A/A (Air-Air) links.

The main advantage of Iridium satellite network over Inmarsat is not only that Iridium provides a real global coverage, but also that has Inter Satellite Links (ISL). While Inmarsat needs many GES terminals to support 3 or 4 GEO satellites, with ILS network Iridium can use just 1 or 2 GES terminals and to cover entire globe. The Iridium network provides A/G commercial, routine and distress links with ATC/ATM via Inmarsat satellites and GES terminals including A/A links.

Therefore, the Big LEO Iridium constellation of 66 satellites interfaced with Inter Satellite Links (ISL) will be ideal to provide a real global coverage including both poles and to improve GADSS functions in this region. Although the satellites in the Iridium network are primarily designed to support the Iridium mission of all mobile communications, they have been adapted to accommodate hosted payload missions. Mission data and sensor telemetry and command data for these missions can be transported in near real-time utilizing the K-band network of crosslinks between satellites, feeder links to the ground and teleports connecting the satellites through Gateway stations to a MPLS (Multi Protocol Label Switching) cloud called the Teleport Network.

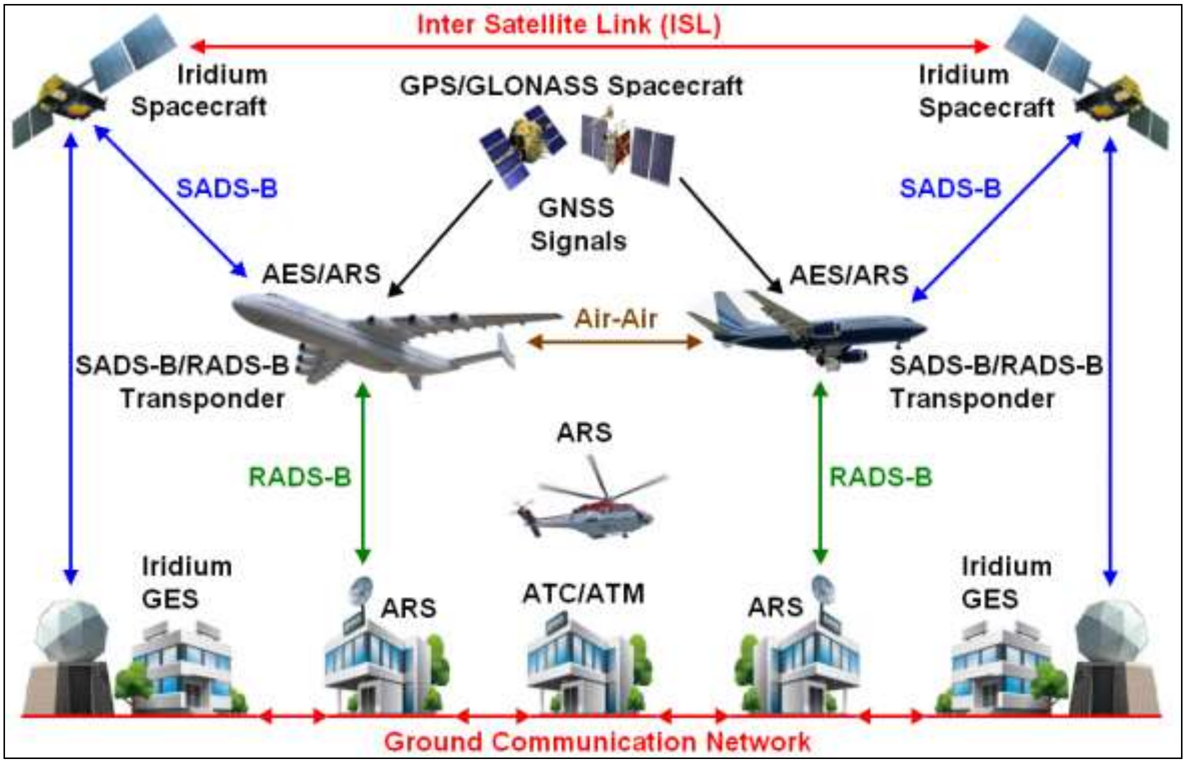

Figure 8. Aeronautical Iridium Surveillance Network – Courtesy of Manual: by Ilcev

2.1. Iridium Surveillance System

The ADS-B system is a surveillance technique that relies on aircraft or airport ground vehicles broadcasting their identity, position and other information derived from onboard systems of GPS/GLONASS receivers. These signals (ADS-B Out) can be captured for surveillance purposes on the ground (ADS-B Out) or onboard other aircraft in order to facilitate airborne traffic situational awareness, spacing, separation and self-separation (ADS-B In).

The ADS-B system is automatic because no external stimulus is required; it is dependent because it relies on on-board systems to provide surveillance information to other parties. Finally, the data is broadcast, the originating source has no knowledge of who receives the data and there is no interrogation or two-way contract.

There are four the following subsystems of ADS-B shown in **Figure 8**:

1. GPS/GLONASS Subsegment – This satellite subsegment is providing GNSS signals (highlighted in black) to the onboard aircraft of ground vehicles GPS/GLONASS receivers These GNSS receivers are providing PVT, ID and other aircraft data to ADS-B onboard transmitter. The ADS-B transmitter can have own integrated GPS/GLONASS receiver or can use data from the independent airborne GNSS receiver.

2. Satellite ADS-B (SADS-B) Transponder – This transponder is sending PVT, ID and other data of aircraft via Iridium spacecraft (highlighted in blue) to the Iridium GES as A/G link and then from there are forwarded via Ground Communication Network (GCN) to the nearest ATC/ATM stations. In the other words, through the satellite system, SADS-B messages are broadcast by the aircraft can be received directly by a constellation of satellites at low altitude, processed in a data center and then be channeled through telecommunications networks and delivered to the end user. In case that certain Iridium satellite is not in LOS with GES, the signals are flowing through channel between satellites (highlighted in red) as Inter Satellite Links (ISL).

3. Radio ADS-B (RADS-B) Transponder – This transponder is sending PVT, ID and other data of aircraft or ground airport vehicles (highlighted in green) directly to the ARS terminals and from there are forwarded via GCN lines to the nearest ATC/ATM stations. In the same way, under the traditional system, the RADS-B PVT message broadcast by the aircraft can be received directly by the receiving equipment on the ground, within the previously established technical scope. This equipment is located in a strategic site, to obtain the maximum possible coverage by a line of sight, and then the RADS-B message will be channeled through telecommunications networks and delivered to the ATC/ATM and other end users. In addition, the onboard aircraft RADS-B transponders can provide A/A transmission between aircraft flying nearby.

In a further context will be introduced the following type of ADS-B equipment and data:

1. Aircraft Equipment – The ADS-B Out capability on board is enabled by transponders interfaced with the relevant avionics systems, such as GNSS, pressure altimeters etc. Many aircraft have ADS-B Extended Squitter capability already available packaged with the Mode S Enhanced Surveillance installations already mandated for core-European airspace. The ADS-B In capability requires a receiver, a processing system (traffic computer) and an HMI unit often called Cockpit Display of Traffic Information (CDTI). Thus, the ADS-B in system could be integrated in the forward field of view or be in the form of the so-called Electronic Flight Bag (EFB). The operational use of ADS-B requires certification and operational approval by the regulatory authorities. The relevant certification documents are EASA AMC 20-24 for ADS-B in Non-Radar Airspace or CS-ACNS for ADS-B Out.

2. Ground Equipment – The ADS-B data transmitted by the aircraft or airport vehicles are received by the ADS-B AGS terminals. In most of the cases, the output of the ADS-B AGS terminals will be sent to Surveillance Data Processing and Distribution systems (SDDPDS) where they are fused with inputs from other possible surveillance sensors, such as radars, Multilateration, to create a traffic situation picture for the users.

3. ADS-B Data – The ADS-B data transmitted are defined in the relevant standards and certification documents, such as European Union Aviation Safety Agency (EASA) and Acceptable Means of Compliance (AMC) 20-24 for ADS-B in Non-Radar Airspace (NRA) or Certification Specifications - Airborne CNS (CS-ACNS) for ADS-B out. Thus, amongst others they include the following: aircraft horizontal position (latitude/longitude); aircraft barometric altitude; quality indicators; aircraft identification; emergency status; and special Position Indicator (SPI) when selected. The aircraft identification can be: unique 24-bit aircraft address, aircraft identification and Mode A code (in the case of CS ACNS for ADS-B Out).

The following context describes the details of the most significant ADS-B advantages over sensors such as secondary radar:

(1) Acquisition, installation and operation costs of an ADS-B onboard aircraft station are the lowest compared to other surveillance systems;

(2) High position accuracy given by the US GPS and Russian GLONASS or similar;

(3) There are minimum infrastructure requirements, because the equipment can be installed in a very simple infrastructure; and

(4) High update rate (sent every 1 second) and the report of each position is transmitted with an indication of the integrity associated with the data, so different users can determine with which applications the data can be compatible.

(5) Immune to multi-path; low latency; and in general, very low cost in its life cycle.

(6) It is feasible to use it for surveillance of aircraft and land vehicles;

(7) It is possible to have a data link, air to ground;

(8) Intent available (level altitude, next waypoint, etc.); and

(9) If the advantages mention more precision and more

precise traffic control, the advantages of operational safety and efficiency in the operation increase and generate greater fuel savings and less environmental impact.

In addition, the context presents some more visible disadvantages of ADS-B:

(1) Within the airspace defined by the air navigation service provider, it requires that the aircraft have to be equipped with a transponder that has the ability to broadcast an extended Squitter in S mode;

(2) To determine the position and speed of the aircraft, it is based exclusively on the GNSS network of GPS or GLONASS systems. The position of the aircraft is determined onboard aircraft and does not have a validation with ground-based systems;

(3) The ionospheric effects around the line of ground-based equator that could affect the GNSS signals;

(4) The fleet of aircraft operating in the South American (SAM) Region does not have a homogeneous avionics, so some flights with Extended Squitter (ES) capacity to transmit messages in version 0 and others in 1 or 2;

However, the installation of ADS-B sensors in existing onboard aircraft infrastructures does not give the necessary redundancy in case of problems of electrical power supply and/or security that compromises the aforementioned site. In this case, seamen have emergency radio equipment onboard oceangoing ships that have to use alternate power supply via batteries, so in any situation of main power supply failure can be used batteries.

The ADS-B transponder also needs own integrated in GPS or GLONASS receivers, so in case that onboard GNSS receivers have some problem ADS-B transponder could not work. The biggest problem is that in case of hijacking of aircraft or if captain has some psychological problem ADS-B can be switched off and transmission will stop. Therefore, all emergency equipment should be installed outside the cockpit and cannot be controlled by pilot.

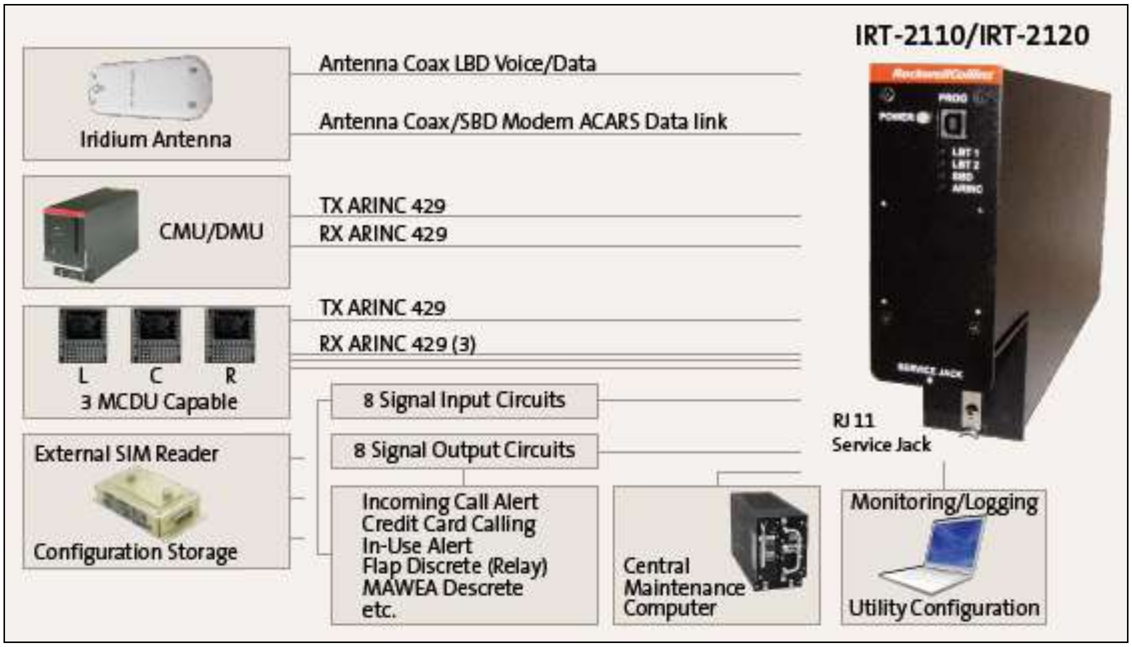

Figure 9. Aeronautical Iridium Communication System – Courtesy of Manual: by Rockwell Collins

2.2. Iridium Communication System

The Iridium satellite communication system and electronic devices provide aircraft flight crews with reliable, long-range voice and data-link communications facilities for both AOC and ATS messaging. These devices offer voice links through either standard 2-wire Tip and Ring circuits or 4-wire audio connections. The voice features include intercom calling, call transfer, conferencing and follow-on dialing. It meets all of the standards and compliances to support installations and certification on any aircraft model.
The Iridium L-band transceivers (LBT) offer two channels of communications in a small 2 Modular Concept Unit (2 MCU) line replaceable unit. The Iridium transceivers provide reliable and global voice, while some of Iridium transceivers include a special Short Burst Data (SBD) modem with communications channel for flight deck data-link services. Flight crews can access contemporary and mandated communications services, including ATS voice, FANS-1/A, ADS-C, CPDLC and standard ACARS operations.
The Iridium transceivers of producer Rockwell Collins operate with the Rockwell Collins Iridium Configuration Module (ICM-2100), a separate device that holds the Iridium SIM cards and the system configuration information, which configuration is shown in **Figure 9.** This unit utilizing the Iridium network is designed specifically to provide flight crews with reliable voice and data communications over the global Iridium satellite network. The IRT-2110 is a dual- channel device that incorporates a single Iridium transceiver (LBT) for global voice and data communications and an SBD modem dedicated to data link services. The IRT-2120 is a three-channel device that combines dual LBT modules providing two channels of global voice and data communications with the SBD modem. The IRT-2110 and IRT-2120 provide connections to customary and standard flight deck voice and data systems. Both systems support FANS and ACARS requirements. This device offers satellite communication flexibility via conventional telephony devices, which features include intercom calling, call transfer, conferencing and follow-on dialing. It meets all of the standards and compliances to support installations and certification on any aircraft model. This Iridium transceiver operates with a separate device that holds the Iridium SIM cards and the system configuration information and offers wireless credit card telephones. This transceiver optionally also offers cabin crew deck cordless phone sets and jet-phone flight deck multi-feature telephone.

3. Conclusion

The Global Aeronautical Distress and Safety System (GADSS) was proposed by author of this paper in 1999 and since than ICAO is still in the development phase of this very important future avionic infrastructure. The GADSS network has to integrate radio and satellite subsystems, which both have to be implemented under an GADSS umbrella. In GADSS network has to integrate radio and satellite elements capable of being operated by and an individual onboard aircraft with minimum communication knowledge, even they are crew staff, and yet enable alerting with Search and Rescue (SAR) services to be reliably coordinated.

The GADSS has to be an international system that uses radio and satellite technology to ensure rapid, automated alerting of ground-based communication and rescue authorities, in addition to ships in the immediate vicinity of aircraft in distress at sea, and in the event of an aircraft distress on the ground. The basic concept is that search and rescue authorities ashore, as well as shipping in the immediate vicinity of the aircraft in distress at sea, will be rapidly alerted through radio and satellite communication techniques so that they can assist in a co-ordinated search and rescue operation with the minimum of delay.

4. References

[01] Ilcev D.S., “Implementation of the Global Aeronautical Distress and Safety system (GADSS)”, Aviation Journal, Elsevier, Vilnius, Lithuania, 2018.
[02] Ilcev D. S., “Global Aeronautical Communications, Navigation and Surveillance (CNS)”, Volume 1 - Theory, AIAA, Reston, 2013.
[03] Ilcev D. S., “Global Aeronautical Communications, Navigation and Surveillance (CNS)”, Volume 2 - Applications, AIAA, Reston, 2013.
[04] Cobham, “Inmarsat SwiftBroadband Diplexer and Low Noise Amplifier (DLNA)”, Lyngby, Denmark, 2014.
[05] Cobham, “SwiftBroadband Hardware”, Lyngby, Denmark, 2014.
[06] Ilcev D.S., “Global Radio and Satellite CNS”, Manual, DUT, Durban, 2014.
[07] Inmarsat, “GX Aviation”, London 2016
[08] Honeywell, “Global Xpress Jet ConneX AES”, Morristown, NJ, 2010.
[09] Stacey D., “Aeronautical Radio Communication Systems and Networks”, John Wiley, Chichester, 2008.
[10] Guilbaudeau A., The Challenges for GADSS”, ENAC, Toulouse, France, 2014.
[11] Thales Alenia, “ADS-B Overview”, Paris, 2019.
[12] Gilbert J. & Trieu F., “ICAO-GADSS Concept of Global Flight Tracking”, Blue Sky Network, La Jolla, CA.
[13] Hof H., “GADSS – Concept of Operations”, Adhoc Working Group on Aircraft Tracking**,** ICAO, Vancouver, 2015.
[14] Ilcev D. S., “Global Mobile Satellite Communications for Maritime, Land and Aeronautical Applications”, Volume 1 - Theory, Springer, Boston, 2016.
[15] Ilcev D. S., “Global Mobile Satellite Communications for Maritime, Land and Aeronautical Applications”, Volume 2 - Applications Springer, Boston, 2017.
[16] Rockwell Collins, “Iridium Communications Systems - IRT-2110/IRT-2120”, Cedar Rapids, Iowa, 2015.
[17] Freeman R.L., “Radio Systems Design for Telecommunications (1-100 GHz)”, Wiley, Chichester, 1987.
[18] Ostroumov I., “Avionics”, National Aviation University, Kiev, Ukraine, 2019.

BIOGRAPHIES OF AUTHORS

Prof. Dimov Stojce Ilcev is a research leader and founder of the Space Science Centre (SSC) for research and postgraduate studies at Durban University of Technology (DUT). He has three BSc degrees in Radio, Nautical Science and Maritime Electronics and Communications. He got MSc and PhD in Mobile Satellite Communications and Navigation as well. Prof. Ilcev also holds the certificates for Radio operator 1st class (Morse), for GMDSS 1st class Radio Electronic Operator and Maintainer and for Master Mariner without Limitations. He is author of several books in mobile Radio and Satellite CNS, Space DVB-RCS, Satellite Asset Tracking (SAT), Stratospheric Platform Systems (SCP) for maritime, land (road and railways) and aeronautical applications.