Currently Developing and Future Communications and Technology Impact on AMDAR

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FOREWORD

The WMO Aircraft Meteorological Data Relay (AMDAR) observing system is a sub-system of the WMO Global Observing System (GOS), which is defined and maintained under the WMO World Weather Watch Program. AMDAR now provides around 700,000 meteorological observations per day on the WMO Global Telecommunications System and comprises over 4000 commercial jet aircraft that collect and report high quality wind, temperature and other data according to WMO specification, utilizing predominantly onboard sensors and computing and avionics systems. The observations from this system, which currently provide only partial potential global coverage, have been demonstrated to have a significant postitive impact on global meteorological numerical weather prediction systems, generally resulting in a contribution of around ten to fifteen percent of all observing system forecast error reduction.

Given the importance of the AMDAR observing system to the meteorological community, it was deemed important to undertake a study that assesses the current and likely future technological developments in aviation communications and avionics technology that might impact upon its operation. This document is the result of such a study that was commissioned by WMO under the leadership and direction of the Commission for Instruments and Methods of Observations (CIMO), Expert Team on Aircraft-based Observations.

In broad summary, it is clear that the AMDAR system will continue to be a critical and integral component of the GOS in the future, while there also exists the possibility to obtain greater efficiencies in its operation and improve the spatial and temporal coverage of aircraft-based observations through the collection of high resolution aircraft reports derived from other developing and expanding aviation systems.

I wish to thank the consulting author of this study, Mr Jean-Marc Gaubert and also the CIMO Expert Team on Aircraft-based Observations for their work done in commissioning the study and assisting in revising and editing the document for publication.

(Prof. B. Calpini)

President

Commission for Instruments and Methods of Observation

Contents

1 Introduction

1.1 Document object

This document has been prepared in the frame of WMO study SSA-2604-14/REM/PEX, for which the objective is to assess currently developing and future communications and technology impacts on AMDAR.

AMDAR is a recognised asset resulting from a fruitful collaboration between aviation and meteorological communities. Nowadays, AMDAR data is routinely assimilated by Numerical Weather Prediction models and is a key contributor to forecast performance. To maintain current functional capability and possibly improve the impact of the AMDAR concept, the system has also to evolve to take into account new capabilities in particular in the area of avionics and aviation communication as specified in [AD-1].

- .Changing, alternative and emerging aviation communications solutions, technologies and protocols;
- Changing, alternative and emerging avionics systems and capabilities;
- Changes to aircraft design (including the suite of sensors relevant to AMDAR) and construction; and,
- The work of groups and bodies that are undertaking studies on future requirements for Air Traffic Management and aviation operations, e.g. NextGen, SESAR, RTCA, ARINC.

The report reviews current and foreseeable future technical evolutions potentially impacting AMDAR, and provides recommendations to be further considered by the programme.

1.2 Structure of the document

The document is structured as follows:

Section 1 and 2 provide general documentation introduction, references and acronyms,

Section 3 reviews impact of Aircraft Communications evolutions,

Section 4 reviews impact of Avionics Systems evolutions,

Section 5 assess potential deployment of AMDAR on Regional and Business Aircraft,

Section 6 reviews activities linked to AMDAR in on-going R&D programmes,

Section 7 provides a summary of study findings and recommendations to the programme.

1.3 Applicable Document

[AD-1]	WMO Description of Work Study and Document on : Currently Developing and Future Communications and Technology Impact on AMDAR (WMO Secretariat – 17/07/2014)

1.4 Reference documents and web links

[RD-1]	A380 Aircraft Chararcteristics Airport and Maintenance Planning Document Issue 30.05.2005 http://www.airbus.com/fileadmin/media_gallery/files/tech_data/AC/Airbus-AC-A380-20131201.pdf
[RD-2]	Handbook on Radio Frequency Spectrum Requirements for Civil Aviation, ICAO Doc 9718-AN/957 (Issue 2013)
[RD-3]	Presentation : Inmarsat Investor Day Aviation September 2014, Leo Mondale http://www.inmarsat.com/wp-content/uploads/2014/09/Inmarsat_Investor_Day_Aviation_September_2014_EN.pdf
[RD-4]	Technical issues in the implementation of Regulation (EC)No 29/2009 (Data Link). Version 1.1 , European Aviation Safety Agency http://ec.europa.eu/transport/modes/air/single_european_sky/doc/implementing_rules/2014-04-23-easa-datalink-report.pdf
[RD-5]	Minimum Operational Performance Specification for SSR Mode-S Transponders. (Adopts EUROCAE ED-73A).
[RD-6]	Technical Provisions for Mode S Services and Extended Squitter, ICAO Doc 9871-AN/464, 2008
[RD-7]	MOPS for 1090MHz Extended Squitter ADS-B and TIS-B, RTCA DO-260B December 2011
[RD-8]	Global Operational Data Link Document (GOLD), 2nd edition, ICAO, 26 April 2013;
[RD-9]	The use of a commercial ADS-B receiver to derive upper air wind and temperature observations from Mode-S EHS information in The Netherlands, Haan, S. de, M. de Haij and J. Sondij, KNMI publication: TR-336, 2013 http://www.knmi.nl/bibliotheek/knmipubTR/TR336.pdf
[RD-10]	Availability and quality of Mode-S MRAR (BDS4.4) in the MUAC area: a first study, S. de Haan, KNMI Internal Report: IR-1, 2014, KNMI, 2014 http://mode-s.knmi.nl/documents/IR-2014-01.pdf
[RD-11]	Suggested Standards Development Activities to Move Forward with Aircraft-Derived Data for Wake Vortex, Air Traffic Management, and Meteorological Applications, WVTT, March 2015
[RD-12]	PROBA-V Tracking Aircraft In Flight From Orbit, European Space Agency website, 13 June 2013 http://www.esa.int/Our_Activities/Space_Engineering_Technology/Proba_Missions/Proba-V_tracking_aircraft_in_flight_from_orbit
[RD-13]	Multi-function air data sensing probe having an angle of attack vane, Patent n°US6941805 B2 , 13/09/2005, http://www.google.com/patents/US6941805
[RD-14]	Aircraft Description Document – Navigation, Airbus, 09/04/2010
[RD-15]	Boeing 737 NG Systems Summary, SMARTCOCKPIT http://www.smartcockpit.com/aircraft-ressources/b737ng-flight-instruments.html
[RD-16]	Airlines AMDAR Compatible Systems Survey, World Meteorological Organization, Aircraft-based Observations, 30 January 2014 http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/AMDAR_Programme_Development.html

[RD-17]	A380 TECHNICAL TRAINING MANUAL MAINTENANCE COURSE - T1 & T2 (RR / Metric) LEVEL I - ATA 46 Network Server System & Onboard Information System, 2006 http://www.scribd.com/doc/226100920/A380-LEVEL-I-ATA-46-Network-Server-System-Onboard-Information#scribd
[RD-18]	Wind Information Requirements for NextGen Applications Phase 1: 4D-Trajectory Based Operations (4D-TBO), 20 February 2013, T.G. Reynolds, Y. Glina, S.W. Troxel, M.D. McPartland, 20 February 2013, Massachusetts Institute of Technology
[RD-19]	The Water Vapor Sensing Program: Present and Future, WMO AMDAR Panel Newsletter, WMO October 2012 https://sites.google.com/a/wmo.int/amdar-news-and-events/newsletters/volume-4-october-2012
[RD-20]	CDA experiments (SESAR MINT project - http://www.sesarju.eu/tags/mint) have been using AMDAR to provide accurate wind information in TMA.
[RD-21]	Meteorology in Continuous Descent Operations, Rosalind Lapsley, EUMETNET EIG, SESAR WP11.2 Leader, 19 March 2013 http://www.eurocontrol.int/sites/default/files/field_tabs/content/documents/events/Presentations/130318-third-cdo-workshop-lapsley.pdf
[RD-22]	WAFTAGE Wind Nowcast to support continuous descent opertions, UK MET OFFICE, Philip Gill, UK Met Office, Exeter, Devon, United Kingdom; and D. Turp and M. Madgin https://ams.confex.com/ams/pdfpapers/131776.pdf
[RD-23]	Colaborative Meteorological Concept Validation, COMET, (Cleansky RfP Study 2010), Atmosphere http://cordis.europa.eu/project/rcn/101039_fr.html
[RD-24]	Cleansky 2 work plan 2014-2015, version 3, Cleansky JU, Novembre 2014 http://ec.europa.eu/research/participants/portal/doc/call/h2020/h2020-cs2-cpw01-2014-01/1615103-clean_sky_2_joint_undertaking_work_plan_2014_-_2015_en.pdf

1.5 List of acronyms

ABOP	Aircraft Based Observations Programme
ACARS	Aircraft Communications and Reporting System
ACMS	Aircraft Conditioning and Management System
ADF/NDB	Automatic Direction Finder / Non Directional Beacon
ADS-B	Automatic Dependant Surveillance Broacast
AMDAR	Aircraft Meteorological Data Relay
ATA	Air Transport Association of America
ATN/IPS	Aeronautical Telecommunications Network (ATN) using the Internet Protocol Suite (IPS)
ATSU	Air Traffic Services Unit
BDS	Binary Data Store
CBS	Commission for Basic Systems
CIMO	Commission for Instruments and Methods of Observations
CMU	Communications Management Unit
CPDLC	Controller–pilot data link communication
DFDAU	Digital Flight Data Acquisition Unit
DME	Distance Measuring Equipment
DMU	Data Management Unit
EGOS-IP	Implementation Plan for the Evolution of the Global Observing System
EUROCAE	European Organisation for Civil Aviation Equipment
FANS	Future Air Navigation System
GA	General Aviation
GOS	Global Observing System
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
LDACS	L-band Digital Aeronautical Communication System
MIAM	Media Independent Aircraft Messaging
MLS	Microwave Landing System
MU	Management Unit
NMHS	National Meteorological and Hydrological Service
NWP	Numerical Weather Prediction
PLMN	Public Land Mobile Network
RA	Regional Aviation (designed to fly up to 100 passengers on short-haul flights)
RTCA	Radio Technical Commission for Aeronautics
RRR	Rolling Review of Requirements
Rx	Receive or Receiver
TCAS	Traffic alert and Collision Avoidance System
ET-AO	Expert Team on Aircraft-based Observations
Tx	Transmit or Transmitter
VDL	VHF Data Link
VHF	Very High Frequency (30 MHz to 300 MHz)
VOR/LOC	VHF Omnidirectional Range Localizer
WIS	WMO Information System
WMO	World Meteorological Organization

2 Review of Future Airlines Communications

2.1 Air to Ground Data Communications

Background : Aeronautical Safety Communication Systems and Spectrum

Aircraft are using a wide range of systems for navigation and communication purposes. The following figures show the baseline equipment of a modern aircraft in terms of antennae and probes (figure 1). All the equipment, that are contributing to the safety of flights, are using sections of the radiofrequency spectrum exclusively allocated to aviation (see figure 2).

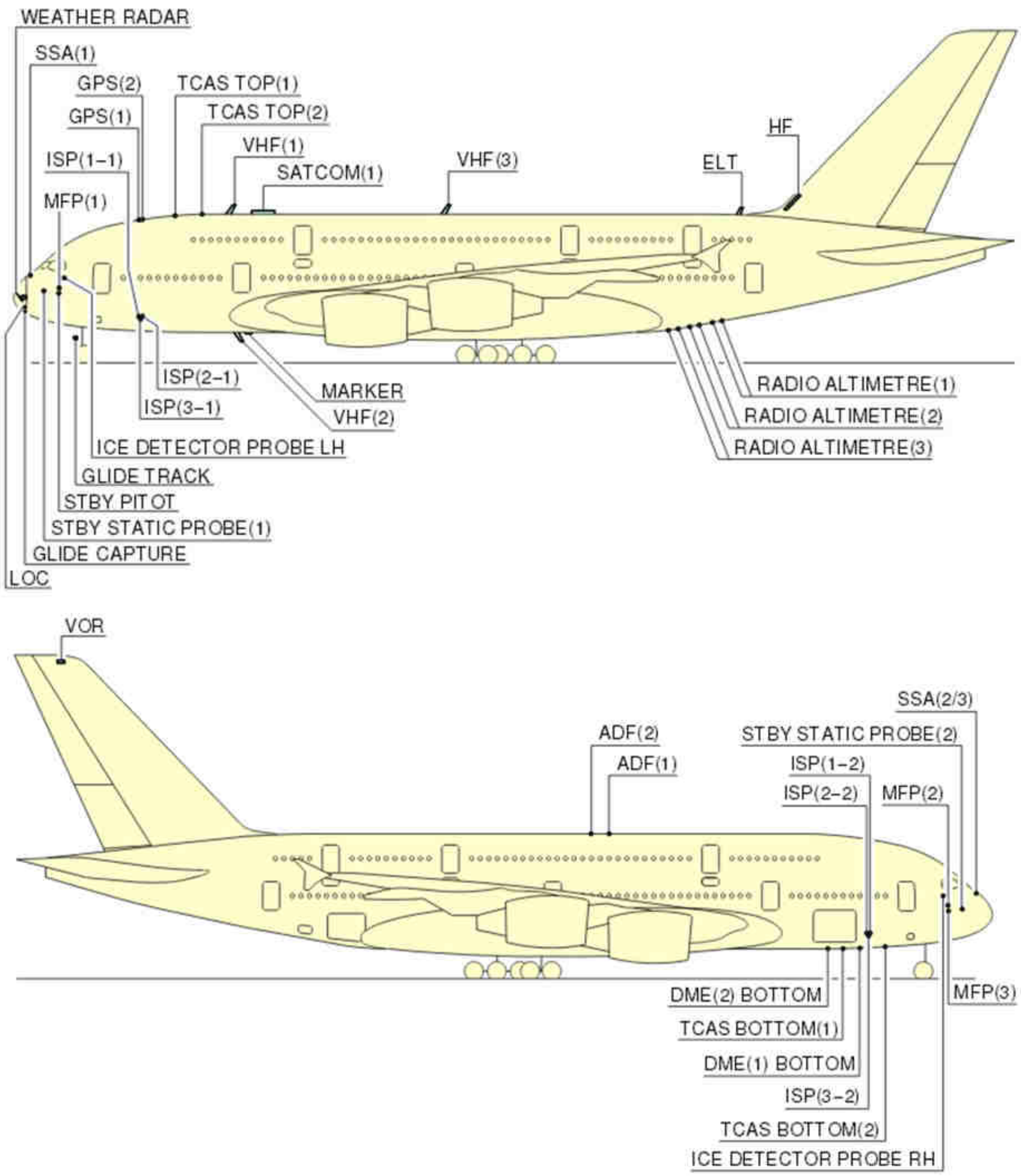


Figure 1 : Antennas and Probes Locations

Source Airbus : A380 Aircraft Chararcteristics Airport and Maintenace Planning Document [RD-1]

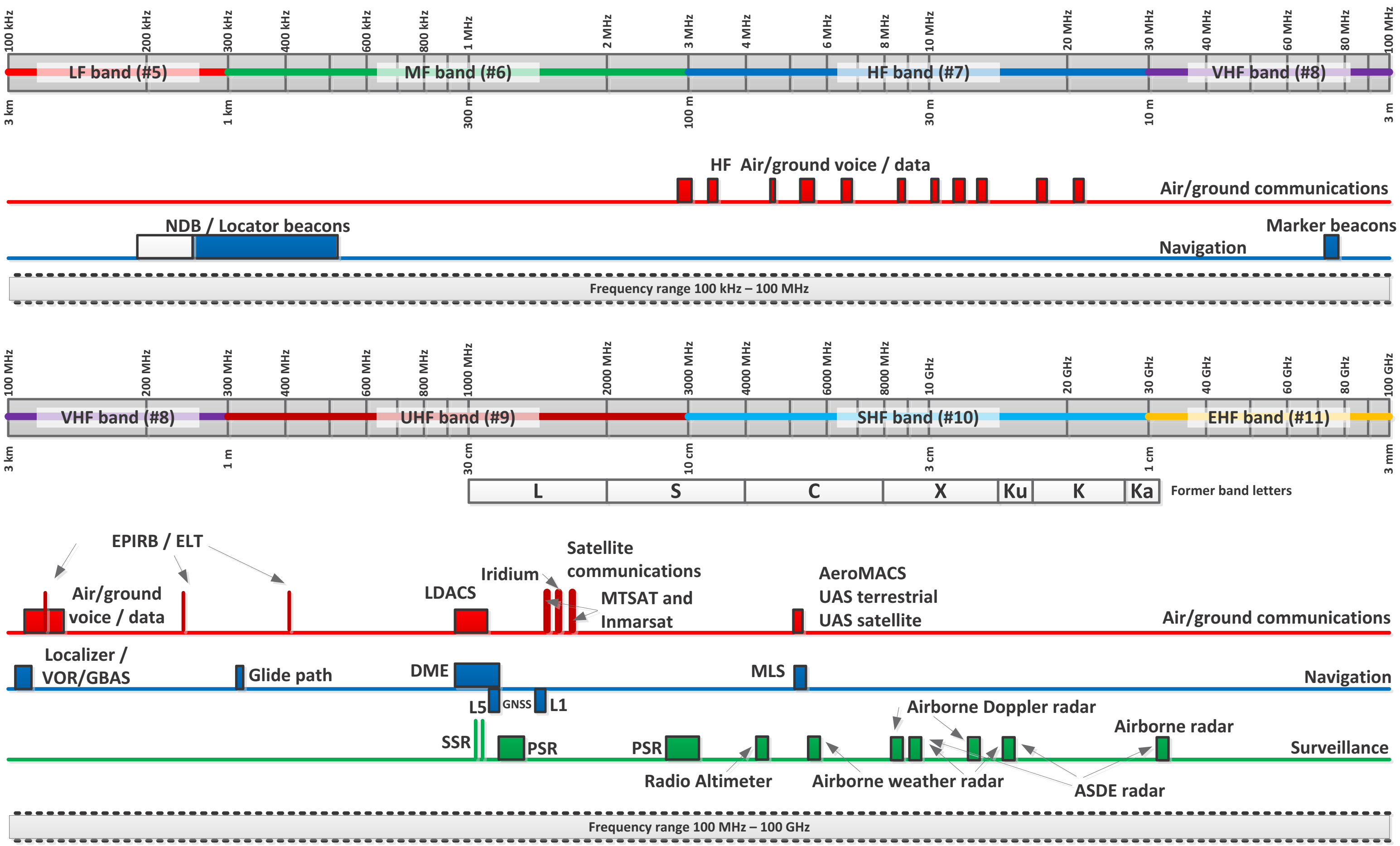
The following table lists the main functional components with their operating frequencies. A figure representing the aeronautical allocations is given on the next page.

Function	Frequency	Comment
Radionavigation ADF/NDB	190-1750 kHz	
Communication HF	3.4 à 23.5 MHz	Includes voice and digital communications (very few)
Communication VHF	118.0-137 MHz	Includes voice and digital communications (ACARS network)
Radionavigation Marker Beacon Glide	 75 MHz 329-335 MHz	
Radionavigation VOR/LOC/ILS	108-118 MHz	
Emergency Locator ELT	406MHz	
Radionavigation DME	Tx 1025-1150 MHz Rx 962-1213 MHz	
Surveillance Transponder	1090 MHz	
Anticollision TCAS	1030 MHz	Receives at 1090MHz
Radionavigation Altimeter	4200 - 4400 MHz	
Satellite Navigation	1559 – 1610 MHz	
Satellite Communication	1.5 - 1.6 GHz	Oceanic FANS support ADS-C and CPDLC (Inmarsat and Iridium) on ACARS network
Radionavigation MLS	5030 – 5091 MHz	
Weather Radar	C (4/8GHz) or X (8/12GHz) bands	

Figure 2 : Antennae and Probes Locations

Today, AMDAR uses the ACARS system operated by Aviation Data Service Providers such as SITA and ARINC. ACARS relies on VHF datalink in continental airspace, and L band Satcom (Inmarsat, Iridium) or HF datalinks in Oceanic airspaces.

In response to the objective to migrate Air Traffic Management from voice paradigm to data centric operations, safety datalink improvements are currently being developed. Initiatives include development of VDL mode 2 in VHF spectrum, study of LDACS in L-band spectrum, and other network level improvement such as MIAM, or ATN/IPS.



Notes:
Drawing not to scale
Not all Regional or sub-Regional allocations are shown
Band identification (e.g. VHF) and band # per Radio Regulations
The satellite communication bands used by MTSAT and Inmarsat are not allocated the the Aeronautical Mobile Satellte (R) Service

Figure 3 : Overview of spectrum allocation to aeronautical services

Source ICAO Doc 9718-AN/957 [RD-2]

Non safety communications

Provision of non-safety communications for passenger and cabin applications started to emerge in the 90's. Initial initiatives have faced serious business and regulatory challenges (Connexion by Boeing for instance), and only few of the pioneers are still alive today. The first Satcom system available (Inmarsat, and later on Iridium) have supported oceanic safety traffic, and non-safety passenger and company correspondance. Yet the motivation for Satcom was primary for passenger use, safety usage coming as a by-product as no reliable communication is available in oceanic airspace. Technology and evolution of its use has moved in two directions. Small aircraft and cargo are installing more and more Satcom just for cockpit use (this results mainly from cheaper/lighter Satcom solutions being available : Iridium, Inmarsat SB200). While for large aircraft new high capacity Satcoms (K_u and K_a bands) are being fitted to meet cabin capacity demand for passenger services. The last decade has shown a strong revival of the aircraft passenger connectivity market, sustained by new user demand linked to mobile internet boom. In-flight passenger connectivity solutions operate in non-safety spectrum allocations, and are implemented using either Direct Air to Ground Systems in UHF or S-band, or Satellite Systems opertating in L, K_u or K_a band[1]. The following table provides an overview of current and in-development cabin connectivity solutions.

System	Characteristics	Status
Inmarsat Classic Aero	Satellite - Global coverage L band spectrum	Operational Support FANS in Oceanic
Inmarsat Swift64/Swiftbroadband	Satellite - Global coverage L band spectrum	Operational
Iridium	Satellite - Global coverage L band spectrum	Operational Support FANS in Oceanic
Panasonic	Satellite - Regional (main traffic areas) - K_u band spectrum	Operational
Row 44	Satellite - Regional (main traffic areas) - K_u band spectrum	Operational
Viasat Yonder	Satellite - Regional (main traffic areas) - K_u band spectrum	Operational
Viasat Exede	Satellite - Regional (main traffic areas) - K_a band	Operational on Viasat-1 and Eutelsat K_a Viasat-2 satellite 2016
Gogo	Direct Air to Ground – North America only - UHF band	Operational
Inmarsat Global Express	Satellite – Global coverage K_a band	Planned 2016
Iridium NEXT	Satellite – Global coverage L band	Planned 2017
Inmarsat S	Satellite with Complementary Ground Component – Regional (Europe) in S band	Planned 2017

Figure 4 : In-Flight Connectivity Systems

As a result of the recent developments, about 60 airlines / 3000 aircraft were providing in-

[1] L-band: 1-2 GHz, S-band: 2-4 GHz, K_a band (K-above): 26.5-40 GHz, K-band: 18-27 GHz, K_u-band (K-under): 12-18 GHz

flight passenger connectivity in 2014. It is expected that about half of the wordwide commercial aircraft will be connected within the next 20 years (source Inmarsat [RD-3]).

Cabin connectivity solutions clearly provide a quantum leap in throughput performance and price per Megabyte compared to safety communication systems. Typically throughput lies in the range of several Mbytes per second, while the price per Megabyte is in the order of US$1 or less. It is to be noted however that those systems may have operational limitations in terms of coverage, reliability and usability (sometimes limited to cruise phase).

For more information: the appendix I provides a short summary of a representive set of current and emerging commercial aeronautical communication systems.

Introduction on Aircraft Communication Networks Architectures

ARINC-664 has defined a formalized organization of aircraft systems and airborne networks into so-called “aircraft domains”. The following domains are defined:

- the Aircraft Control Domain (ACD),
- the Airline Information Services Domain (AISD),
- the Passenger Information and Entertainment Services Domain (PIESD),
- and the Passenger Owned Devices Domain (PODD).

The Aircraft Control Domain comprises the avionics systems which control the aircraft from the flight deck and the systems for environmental control, smoke detection and slides and doors management.

The Airline Information Services Domain provides operational and airline administrative information to the flight deck and the cabin and maintenance services and to support the passengers (such as passenger listings, transfer gate information).

The Passenger Information and Entertainment Services Domain provides the in-flight entertainment (i.e., video, audio, gaming), passenger flight information, and access to the Intranet and Internet using built-in terminals including related services like Voice over IP, Short Message Service (SMS), and Email.

The Passenger Owned Devices Domain is a network of those devices that passengers may bring on board to connect to the Passenger Information and Entertainment Services or to each other.

To ensure the appropriate level of safety and security, these domains are physically separated by appropriate means. Notably, aircraft control systems are separated from other domains. This strong partitioning results in the introduction of constraints and restrictions for the use of the communication systems by the different airborne data link applications. Typically:

- Radio communication equipment attached to the ACD are today only accessible to data link applications (typically ATC/AOC) located in the ACD.
- Radio communication equipment attached to the other domains are mainly for applications (typically AAC/APC) located in these domains. ACD applications have very limited access to these communication means (they can be used in the Air-to-Ground direction only by ACD applications),

The figure on the next page, presents a global overview of the communications systems implemented in commercial aircraft. As shown in the figure, Safety Communication uses specific aeronautical systems, in a close and controlled environment, while Non-Safety Communications uses "open world" technologies. The L-band Satcom is currently an exception to the above typical repartition. It is shared between and simultaneously attached to the Aircrat Control Domain and the other domains.

The non-Safety Communications include Aeronautical Passenger Communications (APC) and Airline Administrative Communication (AAC), presented respectively in green and in orange. Distinct on-board networks are implemented on large commercial aircraft.

The APC communication network supports the In-Flight-Entertainment system (IFE), providing in-seats internet and voice communications applications. It also supports wireless connectivity directly available to passengers' equipment.

The on-board systems are designed so that AAC/APC networks should not interfere with the ATS/AAC infrastructure, as shown by the "diode" symbol. This concept also shows that cockpit data could get out via the AAC/APC networks, depending on applications and operational conditions.

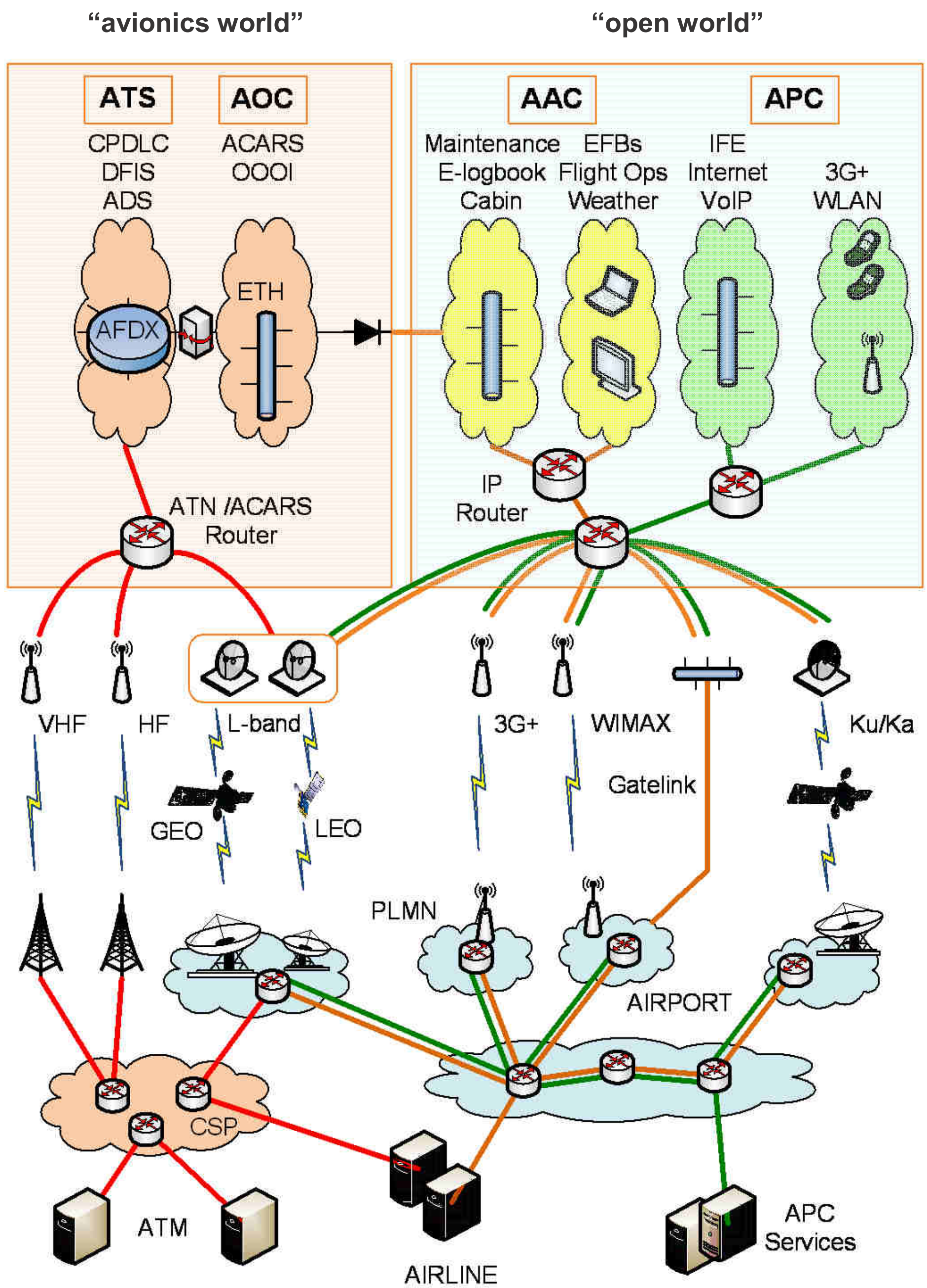


Figure 5 : Aircraft Communications Overview

Summary of Current Situation, Issues and Perspectives

At present , Aircraft Control Domain datalink is essentially supported by VHF ACARS, complemented in oceanic airspace by L-band Satcom ACARS. Improvement of VHF systems to offer more capacity and performance has been implemented under VDL mode 2 programme in Europe. This programme is currently facing significant technical and operational challenges, which have been extensively documented in an EASA report published in 2014 [RD-4]. The network in Europe is currently operating a mix of VHF data link systems including Plain Old ACARS (POA), ACARS over AVLC (AOA), and ATN. Performance issues on the ATN network have led to the postponement till 2020 of the mandate for VDL mode 2 equipage in Europe, while corrective actions to overcome technical and operational limitations are under way within the SESAR programme. However, such a new safety system cannot be envisaged before 2030 at best. Nevertheless, as AMDAR reports have less stringent latency requirements than many airline ACARS applications, no shortcoming is identified to transport AMDAR data over POA or AOA modes. In other parts of the world, legacy VHF ACARS is planned to be used with no change until at least 2025.

While ACARS is de-facto the universal messaging system available throughout commercial air transport, and migration to a completely new system is a major challenge, as shown by VDL mode 2 programme issues. Industry has taken a pragmatic route to overcome the current situation with the development of the Media Independent Aircraft Messaging system (MIAM). MIAM, standardised as ARINC841, creates an additional networking layer on top of existing networks. It enables on one hand to route messaging traffic to different media (ACARS AOA, POA, Satcom, or Gatelink), and on the other hand to optimise datalink capabilities when operating over legacy ACARS. On legacy ACARS, MIAM enables transmission of longer messages and the compression of data to save network capacity. A typical text message of 1000 characters can be transmitted with a gain of about 50% with MIAM.

MIAM is a pragmatic solution to overcome the limitations of current aircraft datalink infrastructure. However, while it provides some operational improvement that may have positive impact on overall datalink communication costs, it is a solution confined within the realm of the closed Aircraft Control Domain.

A potential paradigm shift for AMDAR would be to benefit from the so called “open world” avionics systems and communication links. Hosting AMDAR in the “open world” avionics would bring less stringent implementation and certification requirements, and would enable the use of cabin connectivity systems offering a quantum leap improvement in terms of operational cost. This option is further described in the Avionics Systems Evolution section.

2.2 Automatic Dependent Surveillance

Background

Automatic Dependent Surveillance systems based on Mode-S (selected) technology are progressively evolving to the ADS-B standard[2]. Both system uses 1090 MHz channel communication to send position data to the ground using the on-board transponder. This section recalls some basics about current and future surveillance systems (mode-S, ADS-C, ADS-B).

Mode-S : The mode S is a Secondary Surveillance Radar (SSR) technique that permits selective interrogation of aircraft by means of a unique 24-bit aircraft address. This collaborative system, standardized by ICAO [RD-7], includes an on-board transponder able to answer specific interrogations from ground based SSR. The Mode-S messages sent to the ground are defined by Binary Data Store (BDS) registers (see definition below). Only 3 BDS registers are currently mandatory and implemented in every transponder (BDS 4.0, 5.0 and 6.0).

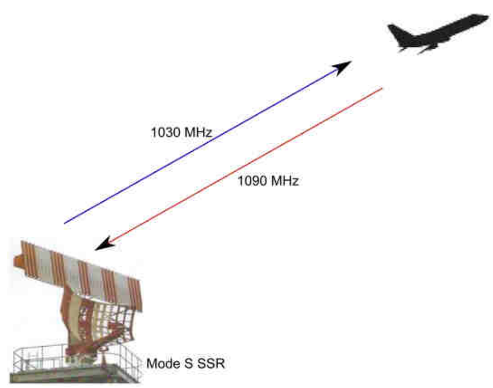


Figure 6 : Radar Mode S operation

In Europe, SSR mode S is being implemented in two stages[3]:

- Mode S Elementary Surveillance (ELS) provides ‘basic functionality’ such as automatic reporting of aircraft identity, altitude reporting, and flight status or transponder capability.
- Mode S Enhanced Surveillance (EHS) provide the basic functionality but is also able to request and receive information about the selected altitude, the roll angle, the ground speed, the magnetic heading, the indicated airspeed etc.

BDS : This register code corresponds to a specific transponder answer that can be implemented in the on-board system (only some BDS are mandatory). Table 1 lists all BDS defined by ICAO [RD-6].

Table 1: list of BDS registers

Type Number	Description	Rate
0,5	Extended squitter airborne position	0.2s
0,6	Extended squitter surface position	0.2s
0,7	Extended squitter status	1.0s
0,8	Extended squitter aircraft identification and category	15.0s

[2] http://www.skybrary.aero/index.php/Automatic_Dependent_Surveillance_Broadcast_%28ADS-B%29

[3] https://www.eurocontrol.int/articles/mode-s-operational-overview

Type Number	Description	Rate
0,9	Extended squitter airborne velocity	1.3s
0,A	Extended squitter event-driven information	Variable
0,B	Air/air state information 1 (aircraft state)	1.3s
0,C	Air/air state information 2 (aircraft intent)	1.3s
1,0	Data link capability report	< 4.0s
1,7	Common usage GICB capability	5.0s
1,8 to 1,C	Mode S specific services GICB capability reports	5.0s
1,D to 1,F	Mode S specific services MSP capability reports	5.0s
2,0	Aircraft identification	5.0s
2,1	Aircraft and airline registration markings	15.0s
2,2	Antenna positions	15.0s
2,5	Aircraft type	15.0s
3,0	ACAS active resolution advisory	Variable
4,0	Selected vertical intention	1.0s
4,1	Next waypoint details	1.0s
4,2	Next waypoint details	1.0s
4,3	Next waypoint details	0.5s
4,4	Meteorological routine air report	1.0s
4,5	Meteorological hazard report	1.0s
4,8	VHF channel report	5.0s
5,0	Track and turn report	1.3s
5,1	Position report coarse	1.3s
5,2	Position report fine	1.3s
5,3	Air-referenced state vector	1.3s
5,4 to 5,6	Waypoints 1, 2 and 3	5.0s
5,F	Quasi-static parameter monitoring	0.5s
6,0	Heading and speed report	1.3s
6,1	Extended squitter emergency/priority status	1.0s
6,5	Extended squitter aircraft operational status	1.7s
E,3	Transponder type/part number	15.0s
E,4	Transponder software revision number	15.0s
E,5	ACAS unit part number	15.0s
E,6	ACAS unit software revision	15.0s
F,1	Military applications	15.0s
F,2	Military applications	15.0s

ADS-B The Automatic Dependent Surveillance-Broadcast is a surveillance technique that relies on aircraft broadcasting their position, identity, speed and other information derived from on-board systems. This signal is captured by ground surveillance systems (mode-S radar, ADS-B antennas) for surveillance purposes but also by other aircraft (via the Traffic Collision Avoidance System, TCAS) for situation awareness. The minimum operational requirements are defined in the DO 260 [RD-7].

ADS-C: Automatic Dependent Surveillance - Contract is a datalink application that enables one or more ground systems (supporting ATS or AOC) to establish an ADS contract with an aircraft. The ADS contract instructs the aircraft system to automatically provide ADS-C reports that contain certain parameters (position, altitude, and speed) and intent information for surveillance and route conformance monitoring [RD-8].

Surveillance and Meteorology

Using surveillance communications channels to collect meteorological observations has been considered by the weather community, and early applications have been demonstrated in recent years.

KNMI innovative method to derive upper air wind and temperature from ADS-B data

KNMI has proposed an innovative method to derive upper air wind and temperature from classic ADS-B data (2011 [RD-9]). The algorithm calculates wind speed and direction, and temperature, based on BDS mandatory registers 4.0, 5.0 and 6.0 data sent by two different receivers (an ADS-B antenna operated by the KNMI and a classic mode-S radar operated by the ATC).

The benefit of the proposed technique is that it can collect a large number of observations while relying only on existing on-board equipment. Compared to AMDAR direct parameter measurements, both ADS-B and Mode-S derived measurements satisfy data quality requirements. However, parameters used to derive air temperature are not precise enough to provide data to the same level of quality as AMDAR data.

Mode-S MRAR Data Collection

Mode-S defines a large panel of registers (BDS). While some of them are mandatory (BDS 4.0, 5.0, 6.0), the Mode-S Meteorological Routine Air Report (MRAR or BDS 4.4) remains optional. The MRAR provides direct wind and temperature observations sensed by the aircraft. The MRAR can be acquired by interrogating the airplane with a classic Mode-S surveillance radar. Since this BDS is not mandatory, the availability of MRAR cannot be guaranteed.

The KNMI has also studied MRAR data received through Maastricht Upper Area Control Center (MUAC) ([RD-10]). In this case, about 16% of interrogated aircraft answer to BDS 4.4 and provide acceptable data for both temperature and wind parameters. Better results in term of quantity of data is directly linked with the type of aircraft interrogated by the radar. While the majority of regional jets, built by Canadair, Bombardier, ATR, Dassault, etc. implement the MRAR, neither Airbus nor Boeing commercial airplanes provides MRAR reports.

Compared with the indirect method, collecting MRAR provides better results in terms of validity and accuracy. While performance of both methods are suitable in terms of quality for the wind parameter, only MRAR can provide an adequate quality temperature measurement, potentially providing valuable and high volume temperature data in the lower troposphere (altitude lower than 500hPa). However, a radar modification is required to retrieve MRAR (BDS4.4 interrogation implementation) while the indirect method is based on mandatory information. Moreover, MRAR is not commonly implemented in Aircraft Mode-S transponders. This last issue limits the scope of the method since its performance will directly be linked to the number of equipped aircraft.

Compared with the AMDAR solution, MRAR potentially offers a larger impact for very little cost, since the method does not imply aircraft modification (if we consider only MRAR compatible aircraft) but would require only ground system implementation (implementing BDS 4.4 interrogation in mode-S radar). This latter point remains significant as the European sky coverage is enabled by several hundred mode-S radars managed by national ANSP. According to studies, data quality for both wind and temperature is sufficiently accurate to allow direct assimilation into NWP systems. Additionally, the method is not based on a communication channel managed by a private operator (such as ARINC or SITA for

ACARS). Thus, operational costs of a system based on this method would be reduced.

Wake Vortex Application and link to weather data collection

Several projects are analyzing the use of Aircraft Derived Data delivered by Surveillance systems for various ATM and Safety applications. The most active field is related to wake vortex applications. A "Tiger Team" implemented under the auspices of RTCA SC-206 has been tasked to develop a white paper on the subject [RD-11]. The produced paper reviews all possible applications including wake vortex, ATM applications and weather applications.

The paper suggests evolution of the ADS-B standard towards provision of weather parameters. However, it recommends leaving implementers the option to deliver this feature. The strategy is to rely on an incentive policy, rather than a mandate, to promote this capability.

It must be noted that the [RD-12] paper also mentions alternative means to collect data using aircraft connectivity systems as an interim or complementary solution.

Satellite Automatic Dependent Surveillance (Satellite ADS-B)

ADS-B is effective for tracking aircraft over continents via antennas on ground but there is no coverage at sea. As a result the idea of satellite ADS-B has emerged which could potentially provide global coverage for aircraft tracking application via ADS-B. In 2013, the ESA experiment Proba-V, for which the main objective was to take pictures of the Earth vegetation, was also equipped with an ADS-B payload [RD-12]. The objective was to perform a proof of concept for ADS-B reception in-orbit. On its first use (23rd of May, 2013), it received over 12000 ADS-B reports within two hours at an altitude of 820 km. The satellite ADS-B system requires no modification of the current avionics hardware.

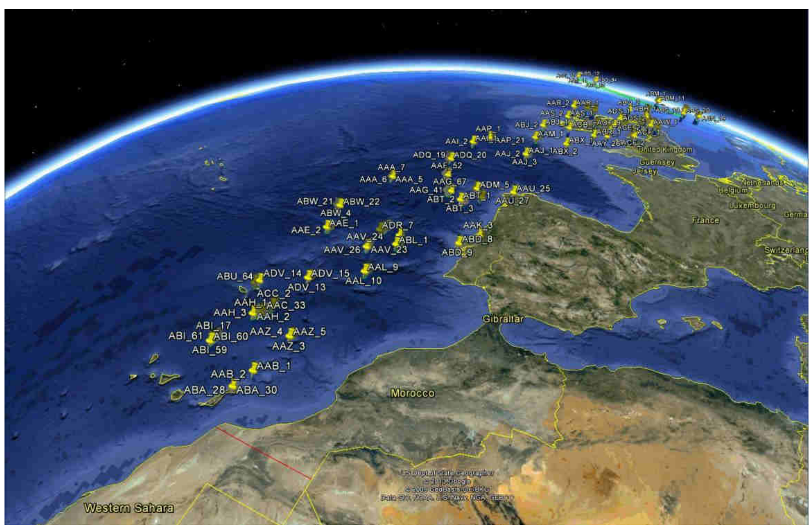


Figure 7 : Proba-V ADS-B aircraft detection Europe (Source ESA)

The concept is currently being implemented on the Iridium Next constellation, and will be operated by an independent private venture (Aireon). The constellation will be launched over the period June 2015 to 2017. It is composed of 66 Low Earth Orbit (altitude 780 km) satellites, 6 in-orbit spares and 9 ground spares as backup support. Iridium Next will provide a global coverage for ADS-B messages. It is designed to maximize investments that were already made in aircraft hardware, giving the possibility to collect positional data over the oceans. This solution eliminates the need to install, maintain and protect infrastructure in desert or mountainous areas.

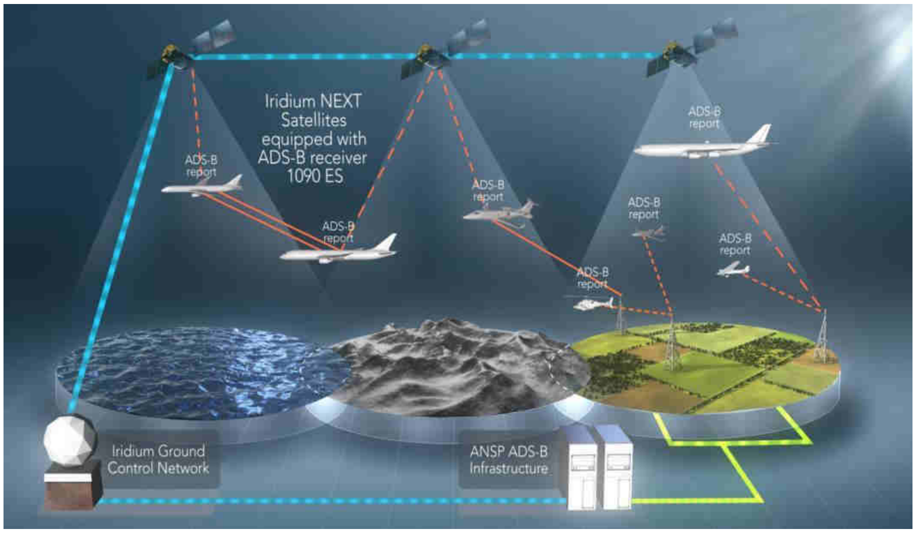


Figure 8 : Iridium Next ADS-B infrastructure (source Aireon)

It is designed to provide better service for aircraft over ocean, remote or polar regions.

In the current state of aircraft equipment and satellite payloads, using the system also for the collection of meteorological data would be limited to the techniques deriving such data from the mandatory registers (such as those described in [RD-9]). The system could collect valuable weather data if such data were to become systematically included as a component of the broadcast message protocol. The possibility to have satellite interogating aircraft is not available in the current system design, but could be seen as an option for future ADS-B payloads.

ADS-C:

ADS-C is an application that enables one or more ground systems to establish an ADS contract with an aircraft. The ADS contract instructs the aircraft system to automatically provide ADS-C reports that contain certain parameters (e.g. position, altitude, and speed) and intent information for surveillance and route conformance monitoring. Some of these parameters are mandatory, while others are optional and are defined in the ADS contract uplinked by the ground system [RD-8].

Although the terms are similar, ADS-C and ADS-B are two different applications. ADS-C permits ground systems to establish a contract with an aircraft through datalink (usually VHF or Satcom ACARS). The ground system specifies to the aircraft system the information to be included in a report and the conditions on when to send it. The aircraft sends the report only to the ground system(s) that have established the contract.

After receiving a login demand from the aircraft (AFN logon), the Air Traffic Service Unit (ATSU) will need to establish ADS contract(s) with the aircraft before it can receive any ADS-C reports. There are three types of ADS contracts:

- Periodic contracts allow ATSU to specify the time interval between ADS-C reports. The ATSU also specifies the ADS-C groups that the aircraft have to provide.
- Demand contracts allow the ATSU to request a single ADS-C report.
- Event Contracts allows the ATSU to send an ADS-C report whenever a specific event occurs.

The aircraft system sends specific aircraft data in different groups of an ADS-C report. Each group contains different types of data. An ADS-C event report contains only some of the groups, which are fixed. The ADS-C periodic report can contain any of the ADS-C groups, which the ATSU specifies in the contract request. The ADS-C group include:

- Basic group (position, altitude, date, TCAS status, navigation system redundancy);
- Flight identification group (aircraft identification);
- Earth reference group (True track and ground speed, vertical rate);
- Air reference group (Mach number, true heading and vertical rate);
- Airframe identification group (aircraft address);
- Meteorological group (wind speed and direction, temperature);
- Predicted route group (two next waypoint position and altitude);
- Fixed projected intent group (position, altitude and date of arrival); and
- Intermediate projected intent group (position, altitude and date of arrival of the next waypoints)

The ATSU may use an ADS-C report for a variety of purposes. These include:

- Establishing and monitoring of traditional time-based separation minima;
- Establishing and monitoring of distance-based separation standards;
- Flagging waypoints as 'overflown';
- Updating estimates for downstream waypoints;
- Route and level conformance monitoring;
- Updating the display of the ADS-C position symbol, and the associated extrapolation;
- Generating (and clearing) alerts;
- Generating (and clearing) ADS-C emergencies;
- Updating meteorological information; and
- Updating other information in the flight plan held by the ATSU.

ADS-C equipped aircraft are able to use VHF and Satcom communication channels to establish ADS-C contracts. The system main interest is during transatlantic flights, where the aircraft flight is outside radar coverage area.

Nowadays, almost all aircraft flying into oceanic airspace are ADS-C capable (at least below 80° of latitude as per Inmarsat coverage). According to [RD-8], about 50 ATC centers worldwide are able to receive ADS-C data. However the situation is not uniform over the globe as Pacific Region has 25 centres equipped, while South America only two according to [RD-8]. To assess the existing improvement potential it requires to compare the list indicated in [RD.8] and the list of ATC centers already providing data to the WMO. Then further actions could be taken to collect available and yet unused data through ICAO or individual states. It should be noted however that ADS-C provides only en-route upper air data (no profiles).

3 Avionics systems evolution

3.1 Aircraft Design and Sensors

This part focuses on sensors and the air data monitoring chain (described by ATA 34 “Navigation”) and their evolution from the older generation of commercial planes (A330/B737) to the newest aircraft (A350/B777).

3.1.1 Air Data and Inertial Reference System (ADIRS) evolution in Airbus

3.1.1.1Legacy Aircraft example: the A330

Based on three separate sets of probes and avionics systems, the A330 Air Data and Inertial Reference System (ADIRS) supplies temperature, anemometric, barometric and inertial parameters to a large panel of avionic systems (EFIS, FADEC, FMGC, SEC, etc).

Each of those units is composed by an Air Data and Inertial Reference Unit (ADIRU), connected to the following probes:

- an angle-of attack (AoA) sensor
- a total air temperature probe (TAT probe)
- a total air pressure probe (pitot probe)
- two static air pressure probes

Moreover, specific Air Data Modules (ADM) convert pneumatic data from pitot and static air pressure probes into numerical data for the ADIRU. The probe’s architecture is detailed in the following figure.

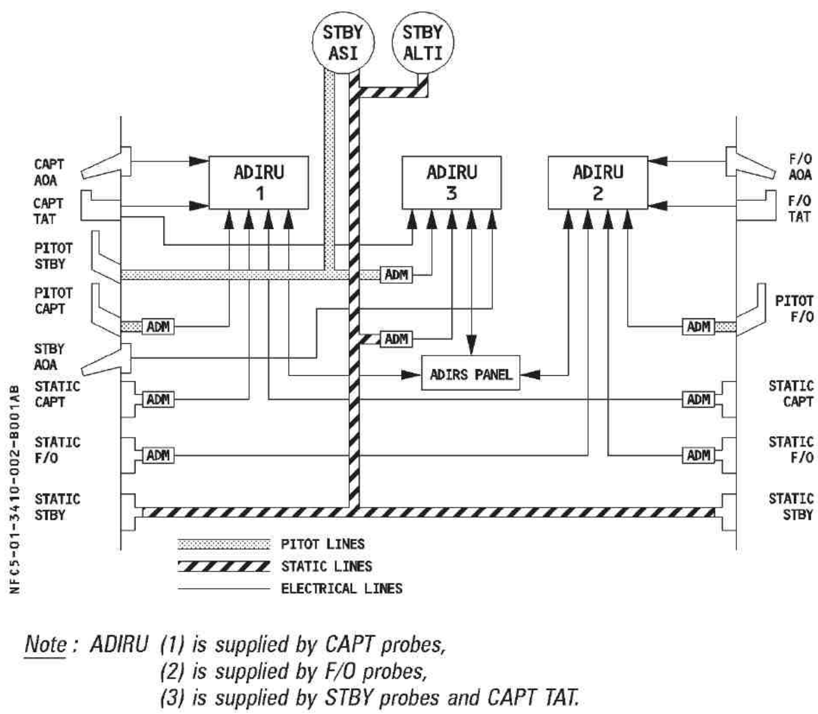


Figure 9 : A330 ADIRS probes architecture

Source www.smartcockpit.com

The ADIRU is also supplied by a GPS system (through Multi Mode Receiver - MMR) and combines satellite measure with internal inertial sensors (gyro) to evaluate the aircraft position (Inertial Reference part of the ADIRS).

Using those two sources of information (Air Data and Inertial Data), each ADIRU computes environment and inertial data. The ADIRS provides the other system with about 90 flight parameters (about 60 flight data parameters from the inertial system and 30 from the air data system).

Parameter	**Output frequency (times per second)**
Air data parameter	
Standard altitude	16
Altitude rate	16
Computed airspeed	8
True airspeed	8
Mach	8
Corrected AoA	16
Indicated AoA	16
Static air temperature	2
Total air temperature	2
Total air pressure	8
Inertial reference parameter	
Pitch altitude (angle)	50
Pitch rate	50
Pitch acceleration	50
Roll altitude (angle)	50
Roll rate	50
Roll acceleration	50
Flight path angle	25
Flight path acceleration	50
Groundspeed	25
Magnetic heading	25
Wind speed	10
Wind direction	10
Inertial latitude	5
Inertial longitude	5

Table 2 : Example of ADIRU flight data parameters

3.1.1.1New generation aircraft example : the A350

Compared to the A330 example, the A350 integrates some evolutions in term of sensor design and architecture modularity. The fundamental behavior of the ADIRS system has not changed, but technological improvements in terms of avionic systems lead to more integrated and intelligent sensors.

The three main evolutions in architecture are:

- Integration of Multi Function Probes, able to provide 3 environment parameters, such as Total Air Pressure, Total Air Temperature and Angle of Attack.
- Integration of the Air Data Module directly on the sensor.
- Addition of Side Slip Angle probes, used to measure aircraft sideslip.

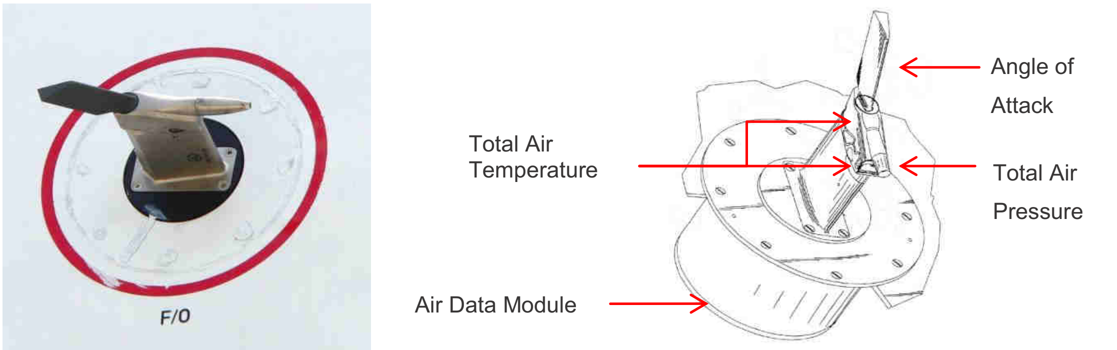


Figure 10 : Multi Function Probe

Source [RD-13]

The Multi Functional Probe evolution implies connection and architecture changes. The Air Data Module directly integrated to the probe manages data computation and sends all parameters sensed by the probes to the ADIRU through the ARINC 429 bus. The ADIRU also integrates a new parameter sent by the sideslip angle sensor, and is used to correct the static pressure information or the angle of attack. The following figure provides a general overview of the ADIRS architecture in an A350.

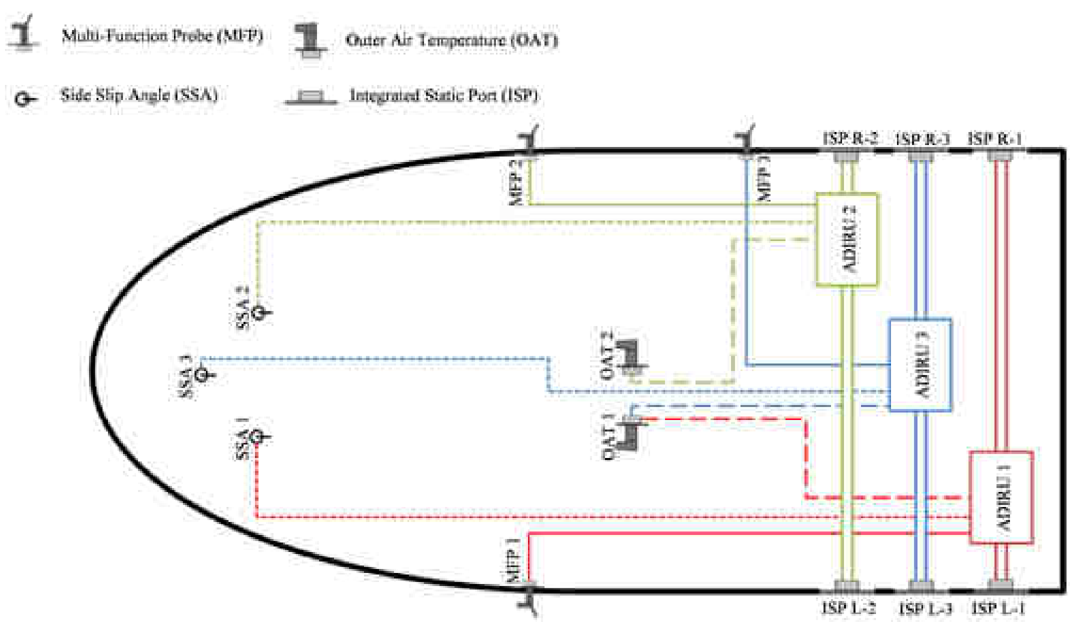


Figure 11 : A350 ADIRS architecture overview

Source Airbus [RD-14]

The evolutions implemented in the last generation of aircraft do not change the general behaviour of the Air Data and Inertial Reference System. Each ADIRU still centralizes both air and inertial data, from its own probe and inertial network, in order to compute and supply the other avionic systems with every flight data parameter. Airbus ADIRS integrates three independent sub-systems to prevent any failure. This choice, mainly made for safety reasons, allows to detect ADIRU failures thanks to a “voting” process (compare the three ADIRU outputs to detect if one is aberrant.

Other manufacturers, such as Boeing, have chosen an alternative Air Data system design as described below.

3.1.2 Boeing Air Data and Inertial Reference System

3.1.2.1 Legacy aircraft example : the B737-NG

Boeing Air Data and Inertial Reference System integrated on the legacy aircraft generation have major differences compared to the Airbus design, even though the system provides the same resulting data to the recipient avionic systems.

The B737-NG ADIRS produces flight data such as position, speed, altitude and air data such as temperature, pressure and wind. The complete system includes twelve probes, two ADIRUs and four ADMs. The probes network is composed of:

- Six static ports (static air pressure)
- Three pitot probes (total air pressure)
- Two alpha vanes (angle of attack sensors)
- One Total Air Temperature probe.

Figure 12 :details the ADIRS overview for a B737-NG. Additional to the data in the probes network, the ADIRUs also compute inertial position and track data thanks to internal gyro, accelerometers and the GPS signal.

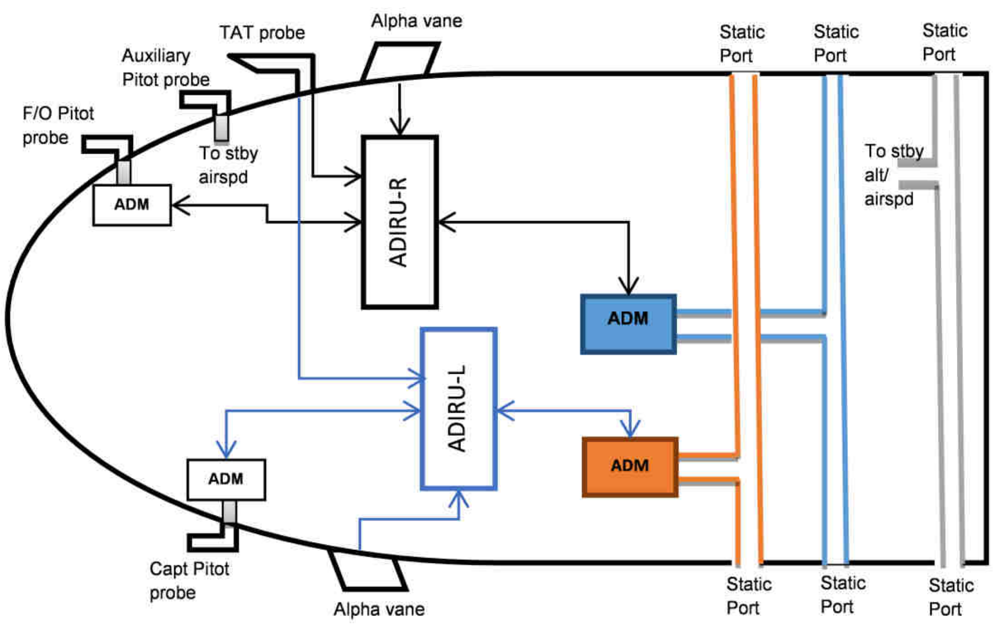


Figure 12 : B737-NG ADIRS architecture overview

Source [RD-15]

Compared to Airbus, Boeing designs a two ADIRU system that only shares the total air temperature probe between these two avionics systems. Despite this difference in architecture, the overall system objective is quite similar in the provision of the same parameters as the Airbus system.

Since the ADIRS provides only two sources of information, automatic error detection is not possible and the fault arbitration can only be done by the crew.

3.1.2.2 New Generation aircraft example : the B777

Integrating an automatic failure detection system in the ADIRS architecture leads to important changes in the overall system. The number of probes has been increased to enable the "voting" concept and the ADIRU logic has been redesigned. First integrated in the B777, the new ADIRS system designed by Boeing is composed of the following elements:

- 3 pitot probes (total air pressure)
- 6 static air pressure sensors
- 2 angle of attack vanes
- 1 single total air temperature (TAT) sensor
- 8 Air Data Modules
- 1 Air Data Inertial Reference Unit (ADIRU)
- 1 Secondary Attitude Air Data Reference Unit (SAARU)

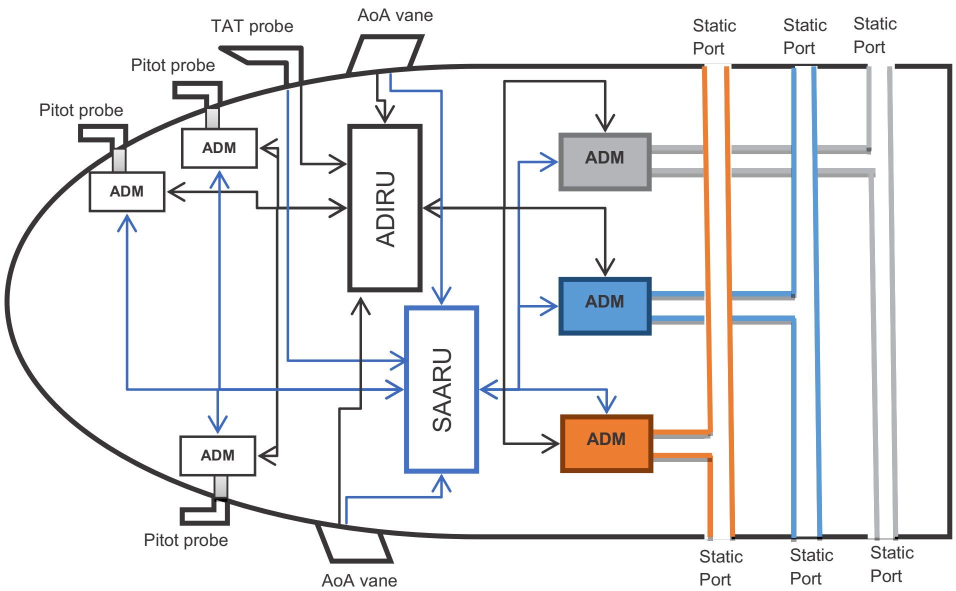


Figure 13 : B777 ADIRS system overview

Source www.smartcockpit.com

Compared to the older aircraft types, the B777 integrates priority between the two Air Data Reference Units (respectively ADIRU and SAARU). The ADIRU is the primary source of information. This unit provides the other avionic systems with primary flight data, inertial reference and air data. The SAARU is a secondary source of critical flight data for display, flight control and other systems. If ADIRU fails, the SAARU automatically supplies attitude, heading and air data.

Connecting the three primary sources of pressure measurements to both ADIRU and SAARU enables automatic fault detection and thus reduces probe failure risks.

3.1.3 Summary on Aircraft Sensors

Being essential for safe operation of the aircraft, aircraft sensors and the associated data processing chain are designed with great care. There is no big revolution in this area, but sensor systems are delivered with improved levels of performance and reliability from one aircraft generation to the next. For the purpose of AMDAR, aircraft sensors continue to provide a high quality data source. This is enhanced due to the integration of multiple sensors that provide redundancy, allowing fault detection and determination of the best quality data source.

3.2 AMDAR system hosting

3.2.1 AMDAR in legacy aircraft

The AMDAR system has two main dependencies: access to aircraft sensor data, and access to air-ground communication. In legacy aircraft, the AMDAR system is thus “ACARS” centric as it is the sole quasi-universal data communication means available. The software is either hosted in an avionics system that handles ACARS communication (such as ACARS MU, ATSU, or CMU), or a peripheral acquisition system that has the capability to send ACARS messages (such as DFDAU or ACMS). The variety of implementations is documented in the WMO survey [RD-9]. On the software side, the ACARS application may be installed as a stand-alone application, or as an AOC application within ATSU or CMU.

In typical legacy Airbus architecture (A330 example), the ACARS communication is managed by the Air Traffic Service Unit (ATSU), see figure 14. AMDAR software may be hosted in the ATSU (as an AOC application) and it may also be hosted in the ACMS (using the ACARS peripheral capability for message transmission).

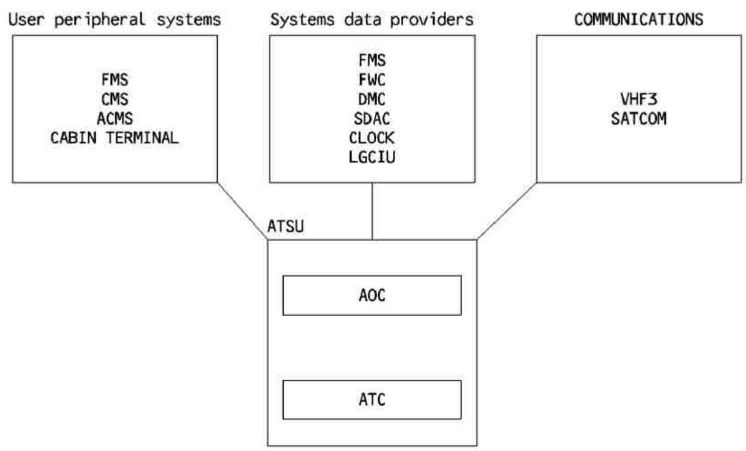


Figure 14 : ATSU connections in Airbus legacy architecture

Source www.smartcockpit.com

3.2.2 Open-World concept in new generation of aircraft

The open world concept is based on a separation of airborne devices between an “Avionics World” and an “Open World”:

- The Avionics World contains all critical avionic systems (FMS, ADIRS, FADEC etc). This world remains closed and highly secured.
- The Open World contains the rest of non critical systems such a cabin entertainment systems or compagnies applications.

The concept has been first developed by Airbus for its latest generation of aircraft. The A380 is the first airplane being integrated with a functional Open World network.

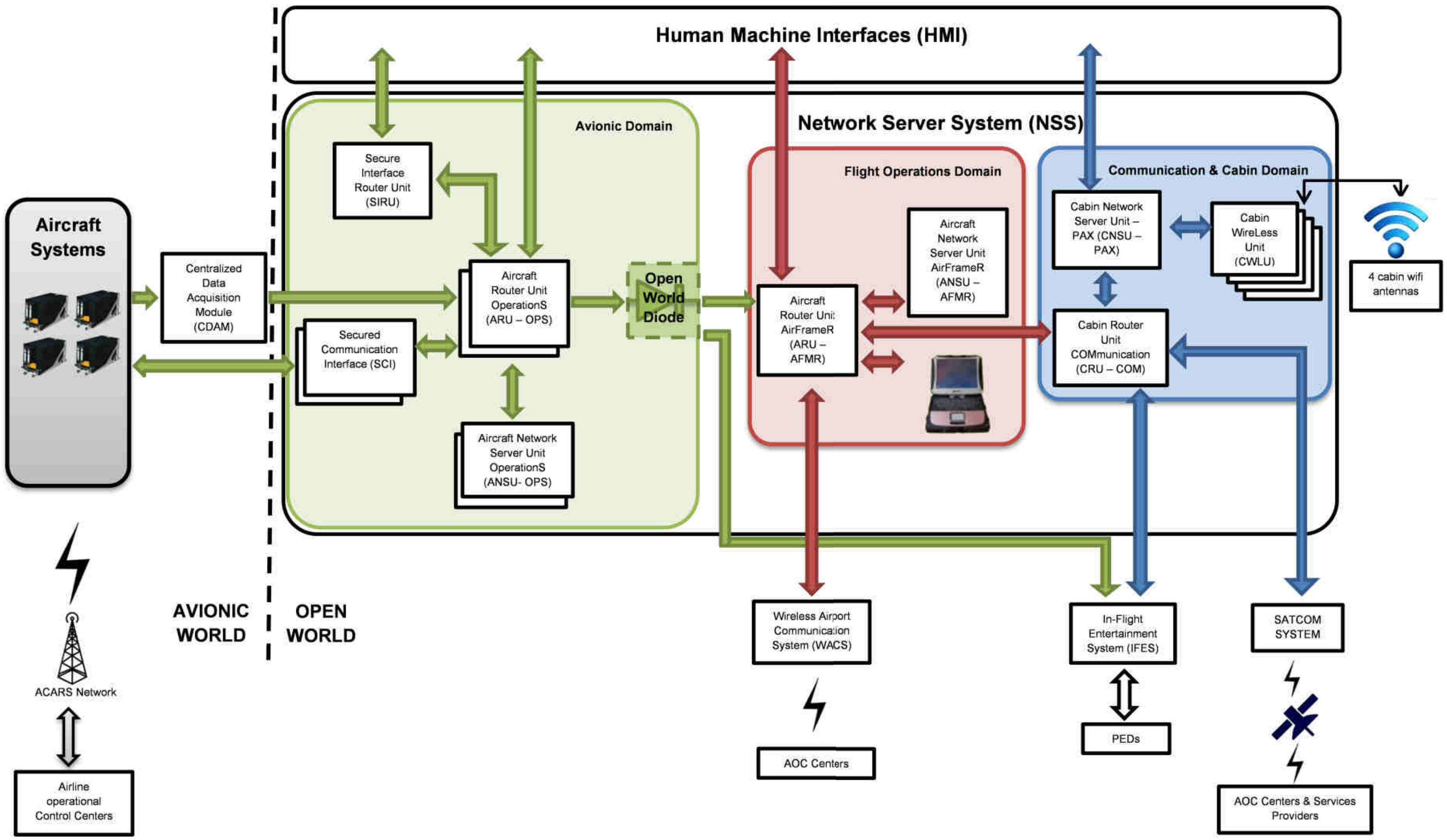


Figure 15 : Secured connection between avionic and open world throught the NSS in an A380

Source Airbus [RD-17]

The “Open World” systems may retrieve a large set of non critical avionic data, such as weather data and offers different communication means, such as a cabin connectivity system (when it exists) and classical L-band Satcom means. The main interest in such media is the cost of data communications, compared to the use of ACARS channels.

Open World also differs from the avionics world on the certification level. Since this part doesn’t host any critical application and cannot proactively interact with the avionics part, the Open World is subject to less stringent software certification requirements. Thus the Open World application development and integration is cheaper and easier.

The above figure provides an architecture overview of the A380 data network. The NSS (Network Server System) guarantees a secure connection at three levels:

- The Secured Communication Interface (SCI) manages secured data sharing between the NSS and the aircraft systems.
- The Open World Diode (OWD) provides a one way direction communication between the avionic domain and the flight operations and cabin domains.
- The Centralized Data Acquisition Module (CDAM) ensures the avionics data acquisition and transfer to the NSS for information, operation and maintenance purposes.

Thus, as long as it remains impossible (for Open World applications) to interact with the avionics domain from the cabin area, accessing weather data (those data are transferred) and interacting with cabin connectivity systems or the L-Band Satcom system is possible.

This type of architecture is also used in the A350. The AFSC (Avionics Function Server Cabinet) is able to interact with the avionic equipment and transfers data to the OFSC (Open World Function Server Cabinet), located in the Open World.

3.2.3 Summary on AMDAR hosting in Open World

The main rationale for hosting AMDAR within the closed avionics domain was its reliance on the ACARS system. The progress of Open World systems in modern aircraft offers new opportunities to host AMDAR in a cabin cabinet so as to benefit from a less stringent implementation environment on one hand, and also to get access to cheaper networking and communicatons capabilities on the other (i.e. IP datalinks and internet connection).

Modern aircraft, such as A350, already provide the necessary environment for such implementation. In legacy aircraft, access to aircraft avionics data may still be performed through Aircraft Interface Devices (AID) usually installed together with cabin connectivity systems.

Such a system would require the development of two components :

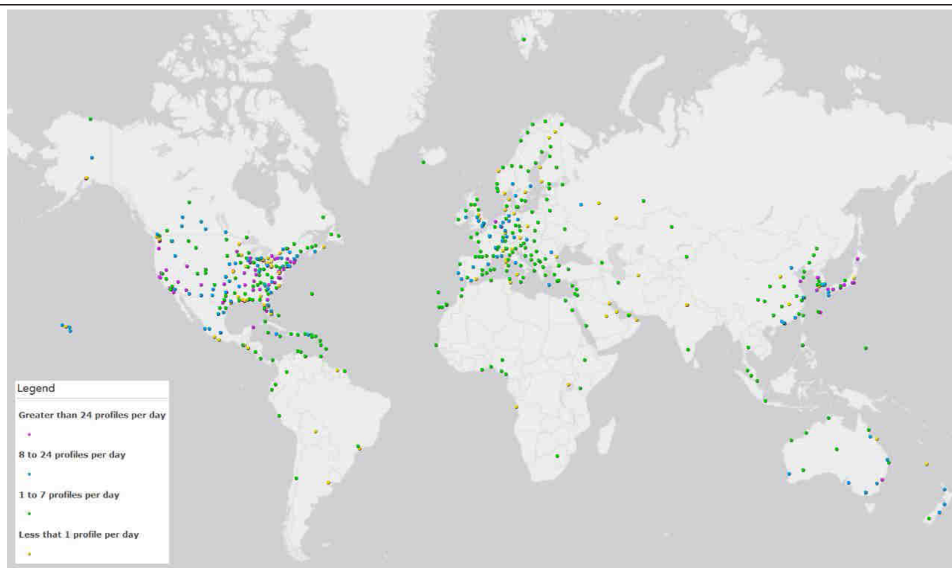
- AMDAR on-board software, to be hosted in a generic open world computer,
- AMDAR ground server software, directly hosted by the AMDAR operator.

Connectivity between on-board software and ground server can be performed through public internet (IP routing), avoiding the need to have airline or data link service provider hosts involved.

4 Regional Aircraft and Business Aviation

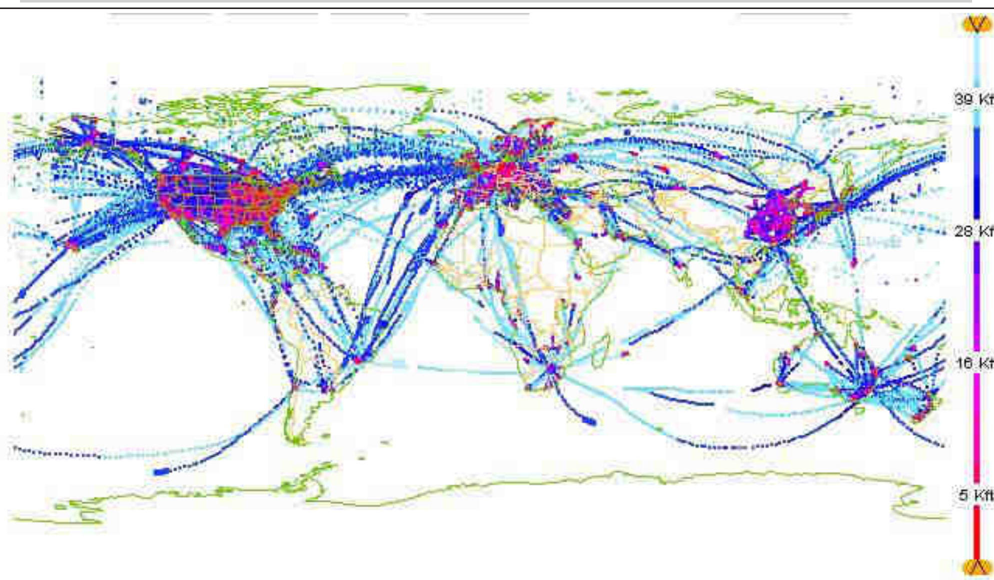
AMDAR is currently deployed mainly on commercial air transport jets. This segment of aviation represents by far the largest amount of flight hours. Nevertheless, the data collection network solely based on this segment of aviation has some limitations (cf. figure 17) :

- Commercial jets connect major airports only. Descent/Ascent profiles from small airports, such as the ones used by Regional or Business aircraft, are thus not collected.
- Commercial jet traffic is essentially concentrated in the most developed regions of the world and the routes that interconnect those regions. As a consequence, little measurement is available for large continental and oceanic areas.



Vertical Profiles Coverage

17 May 2015 - 79231 soundings at 542 airports for the period



Two Dimensional Coverage

30/9/2015 (24h)

Figure 16 : Worldwide AMDAR reports snapshot (source WMO/ABO)

Regional and Business aircraft can offer a very valuable complement to commercial jet aircraft to achieve a more uniform in-situ data collection, with profiles at small airports and observations over inter-regional routes, as well as lower (Regional) and higher (Business) altitude en-route measurements.

Some simulation exercises have been implemented, in the frame of the study, to obtain a preliminary assessment of the potential for Regional aircraft to complement the current AMDAR system. The simulations are based on a database of scheduled flights for the year 2014. The database includes around 850 airlines worldwide. The route plots are based on departure and arrival airports, and flight plans when known (otherwise direct routes are taken into account in the simulations).

The figures presented over the following pages show the flight routes with all traffic and with only the Regional traffic (range<1500NM) for specific regions of the world currently lacking in-situ profiles measurements, as identified above.

Within the limits of the present exercise, the snapshots presented highlight opportunities for Regional AMDAR in South America, India and South East/Indonesia regions. While African Regional traffic seems to remain scarce apart from around South Africa.

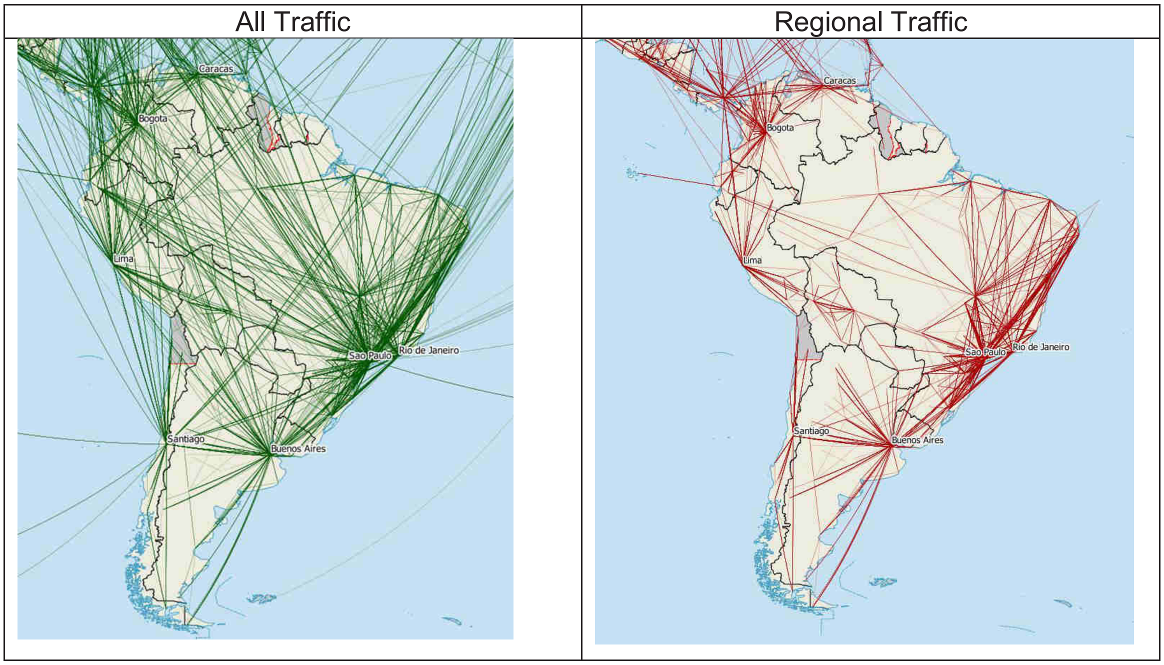


Figure 17 : South America

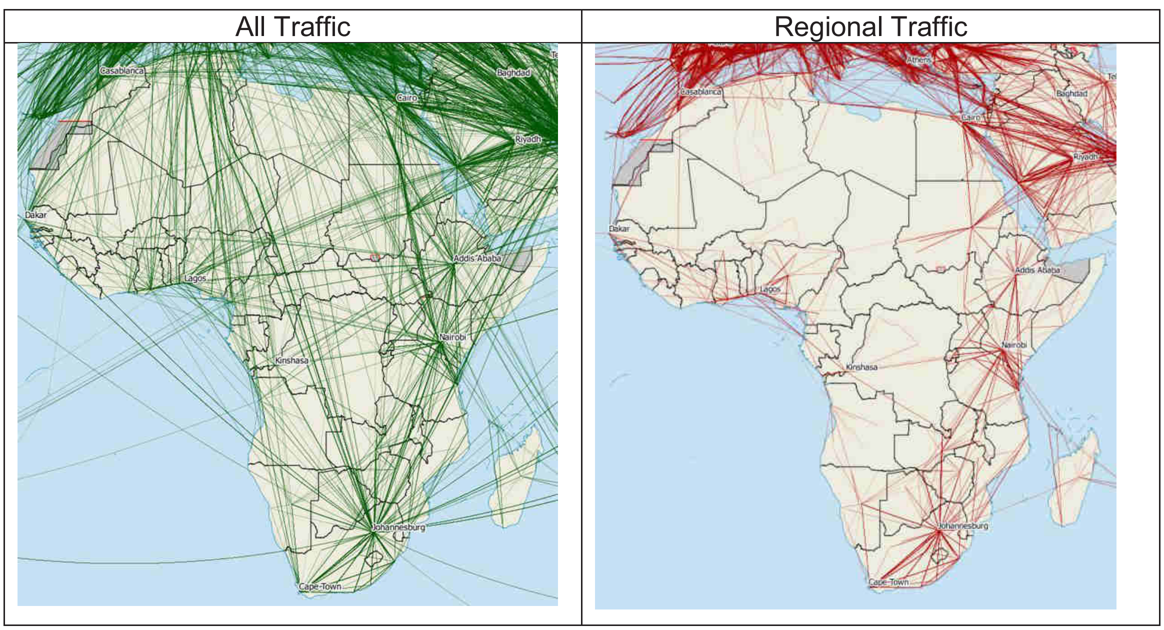


Figure 18 : Africa

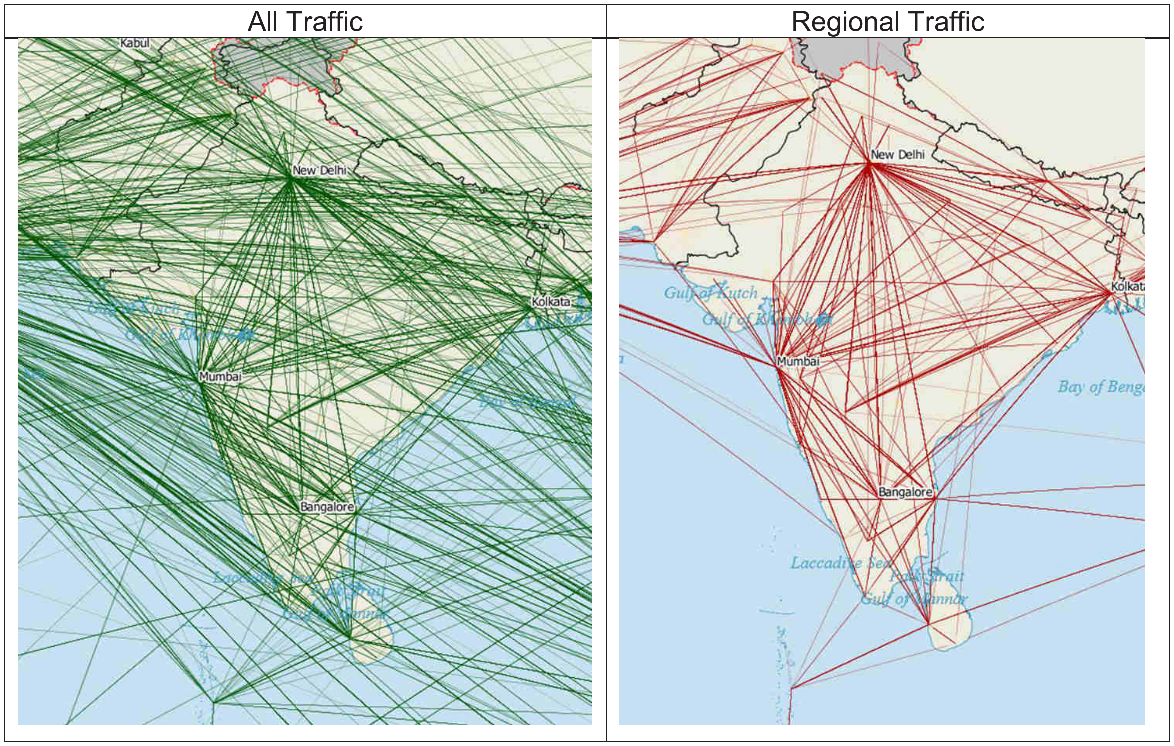


Figure 19 : **India**

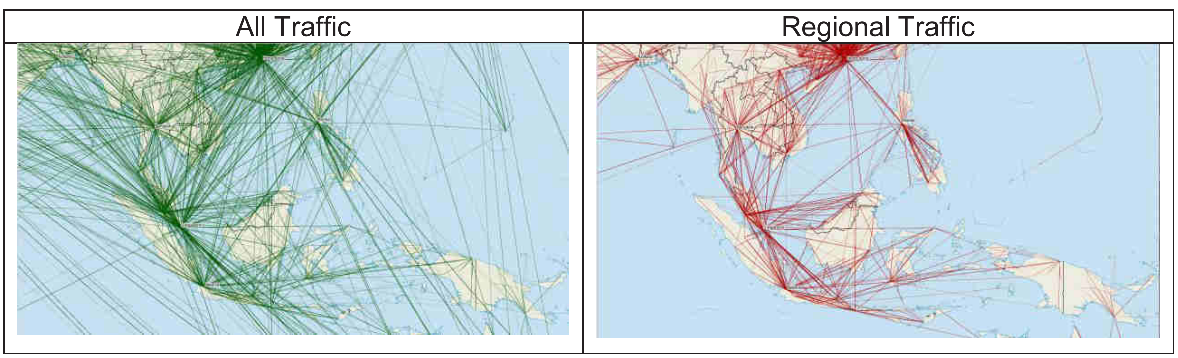


Figure 20 : **South East Asia / Indonesia**

This initial assessment shows that Regional and Business aircraft may represent a real opportunity to extend the AMDAR network to regions of the world that are currently poorly covered. On the technological side, several avenues to collect data from Regional and Business aircraft can be envisaged.

A first option could be to rely on ADS-B. Direct access to MRAR reports would be required. This would be the simplest option as it would require minimal effort from the NMHS community to collect this data. However, as MRAR reports are not yet in baseline ADS-B registers, availability of such data will not be widespread.

A second option is to use mode S interrogation for collecting meteorological reports, but this does not seem to be realistic for the considered regions. The reasons for this is that, firstly, the target regions are largely without radar coverage, and secondly, such a solution requires specific configuration of radar systems to interrogate the proper registers, and then to collect the data. As an example, in Australia, this equipment is only installed on the east Coast (Cairns to Adelaide) and then in important locations (Perth & Darwin) which enables about 50% landmass coverage.

Finally, the third option would be to implement classical AMDAR on-board software on the target fleets.

Availability of communication means on high end Business jets is clearly not an issue, as these aircraft are generally fitted with latest connectivity solutions. In addition, this aircraft category brings the additional advantage of providing in-situ measurement at higher altitudes than commercial jets. For low end Business aircraft (piston or turbine engine), both communication means and access to aircraft sensors can be an issue.

Regional aircraft are usually low cost platforms, performing relatively short flights, and are thus not systematically fitted with data link capabilities. The ACARS system is often considered too expensive for Regional operators, and is not used, even if the aircraft is fitted with this capability. However, as technology evolves, and new connectivity offers are brought to market, the situation is likely to change in the coming decades. Regional aircraft are unlikely to host a broadband cabin Satcom, but might adopt an Iridium or Inmarsat omnidirectional transceiver, or a Direct Air to Ground connectivity solution.

5 Impact of Research and Development Activities

This section briefly reviews the potential links between the AMDAR programme and on-going research in the fields of Air Traffic Control and aviation. The exercise is by nature non-exhaustive as it is practically impossible to identify all initiatives. Various sources have been reviewed including activity reports and planned work programmes of NEXTGEN, SESAR or CLEANSKY.

NEXTGEN is essentially focusing on Air Traffic Management applications. Its main objective is to develop the capability to handle more traffic, while maintaining or improving safety levels. ADS-B deployment is one of the main objectives of the programme. In [RD-18] AMDAR is quoted as a key contributor to meet wind forecast requirements for Trajectory Based Operations. In addition, NEXTGEN is promoting the reporting of turbulence and icing information. Integration of humidity sensors is being implemented , chiefly in the US, with already around 130 aircraft reporting routinely [RD-19]. There is also a smaller humidity sensor network being implemented in Europe.

The Wake Vortex Tiger Team has also published a report that includes a survey of past and on-going research activities with a focus on Aircraft Derived Data applications.

SESAR objectives are consistent with NEXTGEN. On weather aspects, the current focus is on the set-up of a single European-wide Meteorological Information Service for aviation. It can be noted that the AMDAR system has been successfully trialed in wind nowcast applications to demonstrate the benefits of Continuous Descent Approach (SESAR MINT [RD-20, 21, 22]).

While NEXTGEN and SESAR focus on Air Traffic Management, CLEANSKY (http://www.cleansky.eu) aims to provide a more efficient and environment-friendly aviation industry. With this objective, CLEANSKY has already fostered research on AMDAR fleet-level standardisation as a means to achieve overall optimisation of operations [RD-23]. One of the topics also addressed was avoidance of Contrail Formation. For the medium term perspective CLEANSKY is promoting further research on weather information fusion [RD-24] within system activities of the work programme. The use of AMDAR as a key source of information within an overall weather fusion system is foreseen.

6 Summary and Recommendations

This section summarises the main study findings and provides recommendations for future aircraft-based observations and AMDAR system development.

As a first general study outcome, it can be stated that the concept of “aircraft as a sensor” which underpins AMDAR, is extremely sound and future proof. Despite progress in ground and satellite observation systems, the “in-situ” measurement and sampling capabilities of the atmosphere provided by aircraft traffic are unique. AMDAR has a proven positive impact on weather forecasting, together with a reasonable operational cost. High quality data are delivered by aircraft for essential parameters such as temperature, pressure and wind. In addition, AMDAR provides the capability to collect other highly valuable data such as humidity when sensors are available. On a more long term perspective additional atmosphere components derived from other on-board sensors can be expected.

On avionics aspects, aircraft development is essentially characterised by its conservative nature, linked both to safety culture and long airframe lifetime. Still avionics architectures are evolving from one aircraft generation to the next, with more integrated sensors and processing architectures. As a result of the latest evolution, multi-functional probes are now state of the art in current commercial aircraft. It is to be noted that new generation on-board weather radar can already deliver detailed information on hail, snow, windshear, ice crystals - all phenomena of potential interest for weather forecasting, and candidate for medium-term AMDAR extension. Beyond radar, other types of sensors, such as lidar, new multifunctional probes, or estimates derived from radio-navigation signals might also be of interest.

On air-ground communication aspects which are essential to AMDAR, new avenues are clearly emerging. While aircraft connectivity in the aeronautical safety spectrum is facing transitional challenges, “connected aircraft” are currently becoming a reality through advances in cabin connectivity. In the US, cabin connectivity is already mature. Europe and Asia are currently active in setting up satellite and ground-based systems to offer passenger connectivty over continental areas. Cabin connectivity comes with a quantum leap in performance in bandwidth and cost per bit. In addition cabin services are backed by powerful generic computing resources. This combination of cheap connectivity and flexible processing has clear implications and potential to optimise the operational cost of AMDAR. Still, legacy air-ground communication systems will maintain a central role in AMDAR in the coming years, and significant efforts are engaged to improve safety-dedicated communication systems, including the possibility to route non critical traffic to non-safety systems. However, a paradigm shift from voice to data coupled with aeronautical safety spectrum scarcity will limit operational cost optimisation possibilites.

In this context and in the medium to long term, ADS-B can be seen as a natural complement to “traditional” AMDAR. ADS-B systems are being mandated by civil aviation and will thus become standard aircraft equipment in the coming years. ADS-B has the capability to deliver through broadcast, essential weather parameters with much greater volume and frequency and with gloal coverage. However, based on the current ADS-B standard, aircraft must be interrogated and “requested” to deliver weather data. This limits the applicability of this technique to radar-covered areas. However, it would be feasible to update the standard specifications to include weather fields as mandatory broadcast elements, although this type of change is likely to be slow in being realised and made operatonal. In addition, new possiblities to collect ADS-B data using satellite constellations would offer worldwide collection capabiltiy of essential airborne weather measurements.

In terms of coverage, AMDAR is currently deployed on commercial jet aircraft. This concentrates the location of the collected profiles to developed countries, while large areas are left uncovered. Promoting AMDAR to Regional aircraft is a means to improve this situation. Regional aircraft are used in many areas of the world where upper air observations are currently sparse or nonexistent. Observations from Regional aircraft, utilising either AMDAR or ADS-B, would likely have a significant impact on weather forecast skill in areas such as Africa, South and Central America, South East Asia, or Oceania.

The following summary comment and recommdendations are made:

1. The AMDAR system is making a highly valued contribution to weather forecasting improvement through the provision of meteorological upper air observations. No major immediate alternative to the current operational AMDAR system is foreseen for the next one to two decades. Therefore, its long term viability should be secured and strengthened through continuous efforts towards technical and operational maintenance and through continued programme promotion and expansion.

2. Opportunities exist to optimise operational cost of AMDAR, in particular through the use of cabin systems and connectivity. Aircraft passenger connectivity is now a reality. To exploit this new innovation, further study work is recommended, including on the possibilitiesfor the development of generic AMDAR software packages for deployment in the airborne cabin infrastructure. As “Open World” solutions are less standardised than those for avionics, direct collaborations with airlines is seen as the best approach to explore this new avenue. Another possibility would be to initiate links with cabin connectivity providers and satellite operators.

3. As remarkably highlighted by RTCA SC-206 Wake Vortex Tiger Team [RD-11], ADS-B promises to deliver high quality in-situ measurements with little extra effort or cost for the weather community. The key enabler to achieve such a goal is to obtain a change in the ADS-B standard so that weather data becomes a commonly broadcast data element in ADS-B systems. Joint efforts with other interested parties, such as satellite ADS-B operators and other Air Traffic Management stakeholders should be undertaken to push this position and obtain industrial support, through interaction and promotion within the appropriate bodies and forums (ICAO, RTCA, EUROCAE and national CAAs). However it was noted that the current approach being used by ATC bodies for the provision of ATM information such as meteorological data, is to adopt incentive schemes rather than issue mandates. Without a mandate, there is no guarantee on the actual implementation of this feature. And the time for change could be in the order of the life-time of a commercial aircraft.

4. AMDAR has the unique capability to deliver specific parameters such as humidity, icing and turbulence. In the future, AMDAR could deliver new valuable in-situ measurements as on-board sensor technologies progress. In the short term, efforts should be devoted to increasing the number of aircraft that deliver humidity data, as well as standardised turbulence information. Some private operators have already pushed initiatives in this direction. Data sharing schemes between commercial and public institutions remains however an open challenge. For the long term, possibilities to integrate new in-situ measurement data should be left open in AMDAR infrastructure, and monitoring activities on new airborne weather sensing technologies implemented accordingly.

5. Implementation of AMDAR on Regional Aircraft would significantly improve observations coverage in several areas of the world. Efforts should be devoted to the promotion of AMDAR for Regional Aircraft, possibly through operational show-casing and pilot projects in candidate areas. Based on past experience within the AMDAR programme, it seems that the best approach remains bottom-up through direct interaction with airlines and operators, but WMO can certainly act as facilitator for integration of new contributors within AMDAR community.

APPENDIX I

OVERVIEW OF CURRENT AND FUTURE AERONAUTICAL (IP) COMMUNICATION SYSTEMS

- ## Inmarsat

Classic Aero (Aero-L, Aero-I, Aero-H/H+)

Inmarsat Classic Aero (Aero-L, Aero-I, Aero-H/H+)– Overview								
Consortium/ Company Roles	Inmarsat (Satellite System Operator)							
Main Market	☒	**Business/VIP**	☒	**Commercial aviation**		☒	**Other**	
Status, Installations	~10000 installations (Classic Aero and S64)							
Services	☒	**Telephony**	☒	**Data/IP**	☐	**Broadcast**	☐	**Other**
Applications	(multichannel) high-quality voice		low speed data fax					
Com. Technology	☒	**Sat., L-band**	☐	**Sat., K_u-band**		☐	**Air-to-Ground, Other**	
Coverage	global (except poles)							
Bit rates Ground-to-AC AC-to-Ground	600 bps – 10.5 kbps (depending on service) 600 bps – 10.5 kbps (depending on service)							
QoS	circuit-switched							
Notes, References								

Swift 64

Inmarsat Swift64 – Overview								
Main Market	☒	**Business/VIP**	☒	**Commercial aviation**		☒	**Other**	
Status, Installations	~10000 installations (Classic Aero **and** S64)							
Services	☒	**Telephony**	☒	**Data/IP**	☐	**Broadcast**	☐	**Other**
Applications	voice		IP connectivity					
Com. Technology	☒	**Sat., L-band**	☐	**Sat., K_u-band**		☐	**Air-to-Ground, Other**	
Coverage	global (except poles)							
Bit rates Ground-to-AC	64 kbps (up to 256 kbps with channel bonding)							

Inmarsat Swift64 – Overview			
AC-to-Ground	64 kbps (up to 256 kbps with channel bonding)		
QoS	circuit-switched ("mobile ISDN") best effort (MPDS)		
Notes, References			

SwiftBroadband

SwiftBroadband – Overview								
Main Market	☒	**Business/VIP**	☒	**Commercial aviation**	☒	**Other**		
Status, Installations			~400 channels (i.e. 200-400 installations)[3]					
Services	☒	**Telephony**	☒	**Data/IP**	☐	**Broadcast**	☐	**Other**
Applications	voice		IP connectivity					
Com. Technology	☒	**Sat., L-band**	☐	**Sat., K_u-band**	☐	**Air-to-Ground, Other**		
Coverage	global (except poles)							
Bit rates **Ground-to-AC** **AC-to-Ground**	432 kbps/per channel 432 kbps/per channel							
QoS	circuit-switched ("streaming class") best effort ("background class")							
Notes, References	http://www.inmarsat.com/Downloads/English/Aero/SwiftBroadband_fact_sheet_EN.pdf?language=EN&textonly=False http://www.bjtonline.com/print-article/article/cabin-tech-a09-2069.html http://www.inmarsat.com/about/Newsroom/00026067.aspx							

- **Iridium**

Technologies & System Architecture

System overview:[4]

- Space Segment
  - 66 LEO satellites (orbit height is approximately 780 km) in 6 orbital planes.
  - Inter-Satellite Links (ISL) in K_a-band (23.18-23.38 GHz)
- User Segment
  - L band (1616-1626.5 MHz)
  - Circular polarization
  - Aeronautical terminals
    - small and light weight antennas (e.g. 20 cm x 8 cm x 2.5 cm, 500 g)
    - low weight, low cost aircraft equipment (~5000 US$, equipment only)
- Gateways
  - Satellite-gateway links in K_a-band (down: 19.4-19.6 GHz, up: 29.1-29.3 GHz).
  - Little ground infrastructure is required for global coverage due to the ISL technology; a commercial gateway (in Arizona, USA), several military gateways around the world[5], Network Operations Center (in Virginia, USA), four telemetry tracking and control sites at strategic locations around the world.

Services & Applications

Iridium's has adopted a wholesale distribution model, i.e. it is not a direct service provider for passenger communications.

Data rates for both voice and data services are 2.4 kbps inbound and outbound.[6]

Besides voice services, Iridium offers several data services that differ in several aspects, e.g. in the way how the connection between the Iridium mobile and ground networks is established and, related to, connection set-up times[7]:

- **Dial-up Data Service**
  suitable for applications that require direct computer-to-computer or device-to-device connections; sample applications comprise:
  - Connecting Remote Terminal Units (RTUs) to central control and monitoring systems,
  - Connecting monitoring equipment to central data collection systems.
  - Continuous real time transfer of data.
  - Dialing into an Internet Service Provider.
  - Dialing into a LAN (Local Area Network.)
- **Direct Internet Service**

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[4]http://www.wcclp.com/index.asp?pgid=11, http://www.iridium.com/about/press/pdf/Iridium_system.pdf

[5] https://www.disadirect.disa.mil/products/asp/news/gateway_closures.asp

[6] http://iridium.com/support/data/data.php

[7] http://www.stratosglobal.com/documents/factsheets/irid_whitePaper_satelliteDataServices.pdf

typical applications comprise:

  - Email,
  - FTP,
  - Web browsing (primarily on text based sites).
  - Telnet sessions

- **PPP service**
  this service is designed to serve two types of applications:
  - Direct connection to the Internet for non-Windows based computing platforms.
  - Application specific data communications for telemetry, remote monitoring or tracking of field based assets.

- **Router based Unrestricted Digital Interworking Connectivity Solution (RUDICS)**
  Typical applications include (note that RUDICS is typically best suited for applications that deploy more than 500 units, which report to a central host application):
  - Email,
  - FTP,
  - Periodic data reporting by remote sensors,
  - Polling of remote units to collect data,
  - Control of remote equipment,

- **Short Burst Data (SBD) service**

  Message size is 1 and 1960 Byte for mobile originated messages and 1 and 1890 Byte for mobile terminated messages. Below are a number of sample applications listed, which require data messages of typically less than 300 Byte:
  - Flight following for aircraft and helicopters
  - Tracking and messaging for maritime vessels
  - Tracking of mobile land based assets such as trucks and heavy equipment
  - Monitoring of equipment on oil and gas pipelines
  - Monitoring of equipment of water, gas and electric utility distribution networks

- **Short Message Service (SMS)**
  160 characters per message,
  sample applications comprise
  - Weather information & alerts
  - Schedule information
  - News & Sports information
  - Personal messaging
  - Basic email messaging
  - Monitoring of remote applications

- **Panasonic eXConnect, eXPhone**

eXConnect, eXPhone – Overview								
Consortium	Panasonic (service provider, with emphasis on equipment provision), partner Aeromobile (for GSM telephony)							
Commercial Service Start	2010							
Main Market	☐	**Business/VIP**	☒	**Commercial aviation**	☐	**Other**		
Status, Installations			n/a					
Services	☒	**Telephon y**	☒	**IP**	☒	**Broadcast**	☐	**AAC, Other**
Applications	GSM (provided by Aeromobile)		web		Live TV			
Com. Technology	☐	**Sat., L-band**	☒	**Sat., K_u-band**	☐	**Air-to-Ground, Other**		
Com. Systems			iDirect modem					
Coverage								
Bit rates Ground-to-AC AC-to-Ground								
QoS								
Notes, References								

Status Summary

Panasonic Avionics, based in Lake Forest, California, is a division of Panasonic Corporation (formerly Matsushita Electric Industrial Co), Japan's largest electronics manufacturer and ranked 59th largest company in the world in 2007. Risk-sharing with partners, which include VT iDirect (satellite modem and other network technology and services) and wireless network aggregator Boingo (service operation).

Related to eXconnect, Panasonic acts as the service provider, with emphasis on equipment provision. Panasonic is also the world's leading provider of audio/video-on-demand (AVOD) inflight entertainment, though now being pressed ever harder by Thales.

The eXconnect offering is still in development. First announced three years ago and delayed by a protracted antenna selection, it is due to be rolled out initially on the North Atlantic, with Asia and South America, the South Pacific and Africa following a few months later.

Service is expected to be first provided on launch customer Lufthansa mid 2010.[8]

Getting the equipment into aircraft fast will be vital. The business case for K_u-band is initially fragile until installations reach circa 500 aircraft.

Coverage and Markets

Panasonic claims more than 100 national licences currently and expects to have about 180

[8] http://iagblog.blogspot.com/2009/10/panasonic-announces-lufthansa-as-gcs.html

at launch out of a required total of 207 and is still working on several major nations, including the USA, Canada, China, Russia and Australia. Roll-out to Asia (Russia, China, South-east Asia) and South America/South Pacific/Africa a few months after launch on USA-to-Europe. The primary market Panasonic is aiming at is long-haul air transport worldwide.

- **Row 44**

<table>
<tr><th colspan="13">Row 44 – Overview</th></tr>
<tr><td>Consortium</td><td colspan="12">Row 44 (service provider, using leased satellite capacity)</td></tr>
<tr><td>Commercial Service Start</td><td colspan="12">limited commercial operations in 2009 (commercial trials on 5 A/C from Alaska and Southwest Airlines)
large roll-out announced for 2010</td></tr>
<tr><td>Main Market</td><td colspan="4">☒ Business/VIP</td><td colspan="4">☒ Commercial aviation</td><td colspan="4">☐ Other</td></tr>
<tr><td>Status, Installations</td><td colspan="4">n/a</td><td colspan="4">commercial trials on 5 aircraft of 2 US airlines
>700 installations announced for 2010[1]</td><td colspan="4"></td></tr>
<tr><td>Services</td><td colspan="3">☒ Telephony</td><td colspan="3">☒ Data, IP</td><td colspan="3">☒ Broadcast</td><td colspan="3">☐ Other</td></tr>
<tr><td>Applications</td><td colspan="3">GSM (voice, SMS)
VoIP</td><td colspan="3">web</td><td colspan="3">IPTV</td><td colspan="3"></td></tr>
<tr><td>Com. Technology</td><td colspan="4">☐ Sat., L-band</td><td colspan="4">☒ Sat., K_u-band</td><td colspan="4">☐ Air-to-Ground, Other</td></tr>
<tr><td>Com. Systems</td><td colspan="4"></td><td colspan="4">Row 44 (AeroSat antenna, Hughes modem)</td><td colspan="4"></td></tr>
<tr><td>Coverage</td><td colspan="4"></td><td colspan="4">North America initially followed by North Atlantic, Europe, and eventually global</td><td colspan="4"></td></tr>
<tr><td>Bit rates
Ground-to-AC
AC-to-Ground</td><td colspan="4"></td><td colspan="4">
30 Mbps[2]
620 kbps</td><td colspan="4"></td></tr>
<tr><td>QoS</td><td colspan="4"></td><td colspan="4">n/a</td><td colspan="4"></td></tr>
<tr><td>Notes, References</td><td colspan="12">http://en.wikipedia.org/wiki/Row_44
http://row44.com/faqProduct.php</td></tr>
</table>

- **Viasat Yonder**

Yonder – Overview								
Consortium	ViaSat (satellite network provider, equipment provider), Satcom Direct (value-added reseller and customer support), KVH (satellite network provider, for coverage extension)							
Main Market	☒	**Business/VIP**	☐	**Commercial aviation**	☒	**Other**		
Status, Installations	Few (one?) installations announced so far[4]				military government no customers announced so far			
Services	☒	**Telephony**	☒	**Data, IP**	☒	**Broadcast**	☐	**Other**
Applications			all standard applications		Live TV (YonderTV)			
Com. Technology	☐	**Sat., L-band**	☒	**Sat., K_u-band**	☐	**Air-to-Ground, Other**		
Com. Systems			ViaSat ArcLight					
Coverage			Initially North, Middle America, Europe, Near&Middle East, North Atlantic, North Pacific, East Asia, Australia later quasi-global on main air routes[2,3]					
Bit rates **Ground-to-AC** **AC-to-Ground**			depends on antenna type/size[1] 500 kbps-30 Mbps 32 kbps – 1 Mbps					
QoS								
Notes, References	http://www.viasat.com/files/assets/web/datasheets/Mobile_Broadband_Yonder_Brochure_017_lores.pdf http://www.viasat.com/broadband-satellite-networks/mobile-broadband http://www.satcomdirect.com/main/docs/Coverage_Plan_Brochure.pdf http://www.viasat.com/news/viasat-and-innotech-aviation-complete-first-ku-band-high-speed-broadband-service-installation-global							

Status Summary

Corporate/VIP initially, followed by military/government and air transport. No customers for the Yonder offering have been announced so far.

Coverage and Markets

Roll-out of the Yonder service takes place in several phases, initially covering North and Middle America, Europe, Near&Middle East, North Atlantic, North Pacific, East Asia, and Australia. Later, coverage is extended to include South America and largest part of Africa, Indian Ocean, and Soute-East Asia (cf. Figure 6-1). Global coverage is announced for mid

2011.[9]

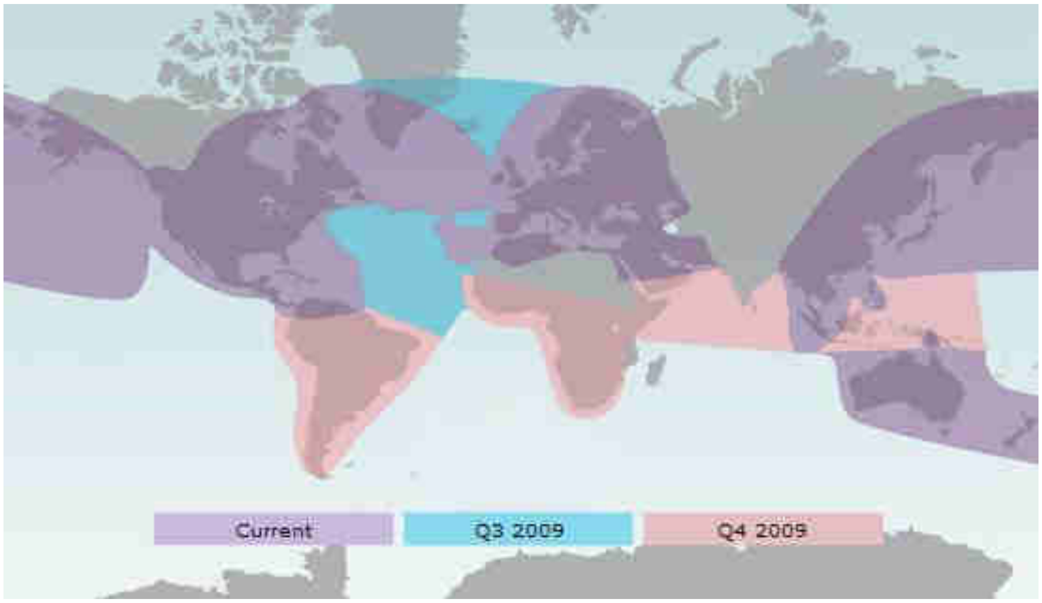

Figure 21 : Figure 6-1: Viasat Coverage

http://www.viasat.com/broadband-satellite-networks/mobile-broadband], also cf. http://www.satcomdirect.com/main/docs/Coverage_Plan_Brochure.pdf

Yonder aims at corporate/VIP market initially, followed by military/government and also air transport.

Technologies & System Architecture

The Yonder service is based on leased K_u-band satellite capacity combined with ViaSat's ArcLight technology. Coverage is extended with capacity provided from partner KVH.

ViaSat offers three aero equipment packages sized for medium and large business jets and VIP aircraft in the Airbus ACJ/Boeing BBJ class and above:

- For large cabin aircraft, the VMT-1500 includes a tail-mounted mechanically steered antenna capable of supporting up to 10 Mbps to the aircraft and 1 Mbps in the other direction.
- For mid-size aircraft, the VMT-1520 features a fuselage-mounted phased-array antenna and offers 5 Mbps to the aircraft and 256 kbps from.
- For VIP aircraft, the VMT-1560 includes the HR-6400 top-mounted phased-array antenna, rated at 30 Mbps/1 Mbps, supplied by Row 44 vendor AeroSat.

  In aircraft equipped with Lufthansa Technik's NICE network the link with the satellite network will be provided by VMT-1560, designed for the Airbus and Boeing families of VIP aircraft, which range from the narrowbody ACJs and BBJs up to conversions of the A350, A380, B747-8 and B787.

  ViaSat says VMT-1560 will offer data throughput in the 768 kbps-2 Mbps range to support email, VoIP, Web and VPN access, and the new television service. The system comprises the antenna, radome, attachment ring, antenna control unit, high-power transceiver and integrated modem/router.

- **Viasat Exede**

[9] http://www.viasat.com/news/viasat-and-innotech-aviation-complete-first-ku-band-high-speed-broadband-service-installation-global

Viasat Exede exploits new Viasat satellite capacity in the K_a-band. Exede portable satellite terminals offer flexible options to meet the needs of multiple requirements from a deployable hand-carried system to auto-point terminals ideal for command vehicles and communications trailers. These terminals are ideally suited for high bandwidth applications including video, voice, and data. 75 cm and 1.2 m antennas can easily be integrated on vehicles. The main point of this service is to provide instant IP access to the client. The throughput is up to 18 Mbps in download and 5 Mbps in upload over all the United States. This service uses Viasat-1 and it will use Viasat-2 when it is available mid-2016.

- Gogo

Gogo created a proprietary network with more than 200 cellular (800 MHz) towers in North America. It provides Air-To-Ground (ATG) connectivity to aircraft over the United States. The next generation of ATG, ATG4, uses dual modems to triple the data speed of the basic ATG. The first ATG system provides data speed of 3.1 Mbps to 1500 aircraft while ATG4 provides 9.8 Mbps to 500 Mbps. Gogo also sale different existing services like Inmarsat Swift BroadBand or Global Express. They have a partnership with Intelsat and SES to provide K_u band connectivity to aircraft.

Emerging Systems

- ## Iridium NEXT

There is still relatively little secured information on Iridium NEXT and the details presented below (mainly regarding bit rates) may be subject to change in the future.

Status Summary

Planning for Iridium's next-generation satellite network, Iridium NEXT, is on track, and the company plans to begin deployment of the new constellation in 2014. Iridium NEXT will be designed to seamlessly replace the current constellation with new satellites, providing enhanced capabilities, higher data speeds and greater bandwidth while maintaining Iridium's unique attributes of low-latency, global coverage. It also will offer the potential for new data services and applications and the opportunity to host secondary payloads on Iridium's global constellation.[10]

Coverage and Markets

Being based on 66 LEO satellites, coverage will be global incl. poles.

There is no detailed information available on coverage, however, as the transition from the existing Iridium to Iridium NEXT is intended to be seamlessly, no significant change is expected w.r.t. to the served markets.

Technologies & System Architecture

Iridium NEXT will be based on 66 LEO satellites; initial launch was planned for 2014.[11]

The NEXT generation Iridium constellation will be backwards-compatible, but also offer data transfer speeds of up to 1.5 Mbps (mobile) and maybe even up to 10 Mbps (portable) to 30 Mbps (fixed?) ;whether 10 or even 30 Mbps will be available seems yet not clear, however, even if, it is very unlikely that it will be available to mobile terminals. It will have an IP-based architecture, which means it will interface easily with all manner of ground and air-based systems.[12]

It is stated that Iridium NEXT will eventually cut its cost per bit at least 90%, allegedly making brief connections to the Internet affordable to vast new market segments.[13]

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[10] http://iridium.mediaroom.com/index.php?s=43&item=905

[11] http://www.iridium.com/files/next/Iridium_NEXT_april09.pdf

[12] http://www.flightglobal.com/articles/2008/10/07/317142/nbaa-2008-iridium-cash-will-launch-next-satellites.html, http://www.forbes.com/forbes/2009/0413/036-wireless-satellites-iridium-rising.html

[13] http://www.forbes.com/forbes/2009/0413/036-wireless-satellites-iridium-rising.html

NEXT Communications Services 12

Core Voice and Data Services	High Speed Data Services	Private Network Gateways	Wide Area Broadcast Services
▪ Flexible delivery of bandwidth ▪ From existing 2.4 kbps to 1.5 Mbps ▪ Voice and data ▪ L-Band service ▪ Backward compatibility	▪ Up to 10 Mbps to a portable terminal ▪ Up to 30 Mbps to a transportable terminal ▪ Ka-Band service	▪ Dedicated gateway ▪ Private Network on Iridium system ▪ Subscriber group "homed" to private Gateway	▪ Two broadcast channels ▪ Dedicated continuous global broadcast channel ▪ Demand assigned channels for location specific data broadcast

NEXT offers new high performance global services, enabling cost effective and flexible allocation of bandwidth to the user

Figure 22 : Iridium NEXT key figures,

http://acast.grc.nasa.gov/wp-content/uploads/icns/2007/Session_G/06-Thoma.pdf

- ## Inmarsat Global Express (K_a-band)

Global Express aeronautical Satcom terminal is developed by Honeywell. Modem is provided by iDirect. Inmarsat Global Express satellites are scheduled to be launched in 2015-2016. This version of K_a uses steerable spot beams to deliver consistent, global high-speed broadband connectivity, and to provide capacity where and when it's needed. Its flexible bandwidth is ideal for in-flight entertainment and meets the needs of passengers and crew.

The Inmarsat-5 satellites operate with a combination of fixed narrow spot beams that enable Inmarsat to deliver higher speeds through more compact terminals. Operating in the resilient K_a-band, while integrating seamlessly with their proven L-band network, Global Xpress allows customers across aviation, maritime, enterprise and government sectors to have reliable and assured access to high-throughput communications.

- ## Inmarsat S-Band

Inmarsat has invested half a billion dollars in an S-Band satellite. This satellite will be geostationary above Europe and will provide the fastest mobile service to aircraft with an announced throughput of 75 Mbps. The satellite is built by Thales Alenia Space and the ground infrastructure is built in a joint effort by Inmarsat and Alcatel-Lucent. This network aims to provide a high throughput broadband to busy regional traffic routes and complementing Inmarsat satellite services.

The users would just need to log in to have an internet access. Reading mails, accessing social media or watching live TV on their laptop or smartphone will be possible while in the sky. This service should be available by 2016-2017.

The mobile satellite services from the S-band satellite will be supported by a Complementary Ground Component. This infrastructure, deployed across Europe, will use the same S-band allocation. This will provide customers an enhanced experience and integrated set of services.

The S-Band architecture is composed of four elements:

- Feeder links route traffic from the S-Band satellite to the Satellite Access Stations. Those feeder links will most likely operate in K_a-band. Inmarsat already manages and operates K_a-band ground station facilities in Italy and Greece.
- A private terrestrial network, called Inmarsat Data Communications Network, will interconnect the Satellite Access Stations and the Network Operation Center. This network transports traffic data and supports signaling between ground stations of network management information.
- The satellite will provide multi-beam coverage over Europe. The service should be able to match user needs by allocating resources with flexibility.
- Inmarsat plans to use existing BGAN terminals or broadband/broadcast terminals using DVB-SH/DVD-S2 standards.