ELEVENTH AIR NAVIGATION CONFERENCE

Montreal, 22 September to 3 October 2003

Agenda Item 7: Aeronautical air-ground and air-to-air communications

AERONAUTICAL MOBILE COMMUNICATION SYSTEMS DEVELOPMENT

(Presented by the Secretariat)

SUMMARY

This paper is based on material developed by the Aeronautical Mobile Communications Panel (AMCP). It contains background information on current and future aeronautical mobile communications systems development, including but not limited to ICAO activities. The information is intended to complement the material presented in AN-Conf/11-WP/11 and AN-Conf/11-WP/12.

1. INTRODUCTION

1.1 This paper contains background information intended to complement the material presented in AN-Conf/11-WP/11 and AN-Conf/11-WP/12. It includes historical background information on developments since the Tenth Air Navigation Conference (section 2), an overview of current communication technologies as a basis for the assessment of future implementation scenarios (section 3), a brief survey of future trends relevant to the evolution of aeronautical mobile communication systems (section 4) and a review of potential candidate frequency bands for their implementation (section 5).

1.2 The scope of the paper encompasses all the communication services that support air traffic management (ATM), including air traffic services (ATS) and aeronautical operational control (AOC) communications. Surveillance functions are discussed only to the extent that they are supported by a data link system. Navigation functions are not addressed.

1.3 Supplementary material in the appendices includes an overview of trials, validation and pre-operational activities and information on early implementation of data link services using ACARS.

2. HISTORICAL BACKGROUND

2.1 Tenth Air Navigation Conference (1991)

2.1.1 The Tenth Air Navigation Conference, held in September 1991, endorsed the concept of a future air navigation system as developed by the Future Air Navigation Systems (FANS) Committees to meet the needs of the civil aviation community well into the twenty-first century. The FANS concept is now known as the communications, navigation, surveillance/air traffic management (CNS/ATM) systems.

2.1.2 The results of the conference were summarized in a set of recommendations covering the full spectrum of CNS/ATM activities which over the last decade have continued to offer guidance and direction to the international civil aviation community as it plans and implements the CNS/ATM systems.

2.1.3 In particular, the conference presented Recommendation 3/2 for the development of SARPs for aeronautical data links, recommending that "ICAO ensure that SARPs for all forms of air-ground data links, whether terrestrial- or satellite-based, are completed in a timely manner to enable States to implement the appropriate systems for use in airspace of their responsibility."

2.2 Special Communications/Operational Divisional Meeting (1995) (SP COM/OPS/95)

2.2.1 Subsequent to the Tenth Air Navigation Conference, the Special Communications/Operations Divisional Meeting (1995) (SP COM/OPS/95) addressed, among other issues, the congestion in the VHF frequency band and on possible solutions to relieve the congestion.

2.2.2 The meeting agreed on a number of improvements in the use of the VHF spectrum. In particular, the meeting agreed on some near-term improvements to increase voice capacity in areas with severe frequency congestion and presented Recommendation 6/1, requesting ICAO to amend Annex 10 to include the SARPs for 8.33 kHz channel spacing for DSB-AM voice that had been drafted by the AMCP. It also agreed that the future VHF system should be the integrated voice and data link system that had been in development in the AMCP, and presented Recommendation 6/2 requesting that ICAO expedite work on the system. The meeting further recognized that additional services were needed to support navigation and surveillance elements of the CNS/ATM system and presented Recommendation 6/3 requesting that ICAO expedite the development of operational requirements and appropriate SARPs for data links to support these applications.

2.2.3 The meeting also recognized that any impact from the proposed new systems in geographic areas not affected by VHF frequency congestion must be minimized, and that ICAO should take the necessary actions to ensure that harmonized planning and implementation of new VHF ground and airborne sub-systems would be developed at the regional level.

2.3 Amendments to Annex 10

2.3.1 On the basis of the recommendations developed by the Tenth Air Navigation Conference and the SP COM/OPS/95, ICAO undertook an extensive plan to develop SARPs for air-ground data links, which led to the introduction of a number of new systems in Annex 10. The corresponding amendments to Annex 10 are listed in AN-Conf/11-WP/12.

2.4 Global and regional planning

2.4.1 ICAO has published Doc 9750, 2nd Edition, *Global Air Navigation Plan for CNS/ATM systems*, which describes the transition to the CNS/ATM System. Beyond its technical scope, it also includes relevant economic, organizational, environmental, legal and technical cooperation issues as well as a global planning methodology expected to guide regional planning groups in their planning and implementation work.

3. CURRENT AERONAUTICAL MOBILE COMMUNICATIONS TECHNOLOGIES

3.1 Introduction

3.1.1 This section provides an overview of the present aeronautical mobile communication infrastructure, covering both voice and data services.

3.2 High frequency band

3.2.1 Within the high frequency (HF) band, both analog voice and digital data services are available. Services are operated on 3 kHz wide channels in the frequency bands between 2.85 MHz and 22 MHz that are allocated to the aeronautical mobile (R) service.[1]

HF single side band voice

3.2.2 HF single side band (SSB) voice is among the oldest forms of aeronautical mobile radio communications. It supports ATS voice communication exchanges in oceanic and remote regions between aircraft and air traffic control centres or flight service stations. In addition it is used for aeronautical operational control (AOC) between aircraft and airline operations centres. HF SSB voice enables very long-range communications extending up to several thousand kilometres, but it is affected by solar activity and other natural phenomena. Range and intelligibility may vary, and at times some frequencies are unusable. In general, specially trained radio operators and experienced pilots are needed to make effective use of this system. Service providers in the various regions typically share families of frequencies distributed among sub-bands to provide frequency and range diversity, and to vary capacity and provide redundant communications paths. HF SSB voice remains the primary communications link for long-range procedural air traffic control.

HF data link

3.2.3 In the 1990s, the airline industry sought ways to improve HF communications. A successor to a military design, the HF data link (HFDL) was developed for use in the aeronautical HF band and thus makes use of the same frequencies and equipment as HF voice. It operates in the same 3 kHz channels with a single side band digital modulation scheme, providing up to 2.4 kilobits per second data throughput. HFDL is less sensitive to varying propagation conditions than is HF voice because it is automatically adaptive both in radio frequency and data rate and it includes extensive error detection and correction algorithms in the protocol. This system uses a bit-oriented data protocol designed to function as a sub-network of the ATN. In order to be compatible with present airline data communications infrastructures, it also supports character oriented ACARS messages. HFDL provides an average transfer delay of 75 seconds and a 95th percentile delay of 200 seconds. It is presently used for AOC applications globally. It is also being used in pre-operational trials for ATS

[1] International Telecommunication Union (ITU) Radio Regulations, Appendix 27 describes the Aeronautical Mobile (R) Service in the HF band.

applications in the North Pacific and North Atlantic. Several studies indicate that HFDL can also be a backup to satellite communications, notably in polar regions where geostationary satellites have reduced or no coverage.

3.2.4 Standards and recommended practices for HFDL were developed by the AMCP and became applicable in 1999. A global commercial service is presently operating.

3.3 Very high frequency band

VHF DSB-AM voice

3.3.1 Double side band — amplitude modulation (DSB-AM) analog voice is the primary line of sight service for ATS and AOC. Channel spacing has been reduced over time, down from the initial 100 kHz to the present values, to accommodate growing requirements for voice communication channels.

3.3.2 It was recognized by SP COM/OPS/95 that a further reduction in channel spacing to 8.33 kHz was the near term solution to alleviate the congestion in the VHF communication band in Europe. This spacing was developed by the AMCP and became applicable in 1996. It was first implemented starting 7 October 1999 within the FIR/UIR of the core area of Europe (Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland), where the carriage of 8.33 kHz channel voice radio equipment is currently mandatory for all aircraft when operating or capable of operating above FL 245. The 8.33 kHz spacing has been expanded horizontally to nineteen additional States, which removed exemptions and commenced 8.33 kHz operations as of 31 October 2002 above FL 245. Mandatory carriage of 8.33 kHz equipment has been extended to additional airspace above FL 245 in additional European States since October 2002. At the ICAO EANPG/44 Meeting (December 2002), a decision was taken to proceed with 8.33 kHz vertical expansion. The decision foresees a phased implementation starting at FL 195 in the ICAO EUR Region in 2006, and covering as required selected TMAs and CTRS based upon individual State decision considering VHF congestion. The decision foresees too the extension to designated controlled airspace in the ICAO EUR Region from 2009 onwards.

VHF data

3.3.3 During the 1980s the airline industry saw the need for a data communications system to supplement AOC voice services. Originally intended as a management tool, the VHF aircraft communication, addressing and reporting system (ACARS) was developed by the Airlines Electronic Engineering Committee (AEEC) to transmit automatically messages between aircraft and ground stations to indicate when an aircraft departed and arrived at its assigned gate. The industry standard is known as the *ARINC Specification 618-5 Air-Ground Character-Oriented Protocol Specification*. As the use of AOC data communications grew it became apparent that ATS benefits could also be realised through the use of VHF data communications.

ACARS and VDL Mode 1

3.3.4 The ACARS data link provides character oriented data services at 2.4 kilobits per second rate on shared 25 kHz wide channels. The channels may be assigned in AOC sub-bands or on specific frequencies in the VHF band as determined by local administrations. The ACARS radio signal uses a minimum shift keying (MSK) modulation scheme that allowed for early use in the band in compliance with the Radio Regulations. Channel access is shared on a contention basis known as carrier sense multiple access (CSMA) and there are limits to the efficiency of spectrum use. These limits are offset to a great degree by the efficiency of the information exchanges, which greatly exceeds that of voice. The ACARS protocol is not compliant with ICAO standards, but it does support a number of ATS applications (Appendix B refers) in addition to many AOC applications. Communications services are offered by commercial operators around the world and several million messages are handled by ACARS each month. Approximately ten thousand airline transport and business aircraft are equipped with VHF ACARS.

3.3.5 ICAO saw the need to adopt a data link system in the VHF band that would be bit oriented, would offer greater message integrity, and would be suitable for ATS. The AMCP developed the VHF digital link (VDL) Mode 1 based on the ACARS physical layer (modulation scheme, data rate and channel access protocol) to enable the early introduction of VHF data services into Annex 10. These standards became applicable in 1996 but were later withdrawn from Annex 10, as no plans for implementation of VDL Mode 1 existed, whereas implementation of VDL Mode 2, with a higher level of performance, was already underway.

VDL Mode 2

3.3.6 The VDL Mode 2 digital link is an evolution from Mode 1 that uses a digital, 8-phase shift keying (D8PSK) modulation scheme at a data rate of 31.5 kilobits per second. It is ATN compliant, providing a bit oriented protocol that may also handle character oriented messages that are compatible with non-ATN infrastructures. It has limitations in its support of time critical applications in high air traffic density areas because of its CSMA channel access protocol that exhibits a non-deterministic behaviour. It does not support message priorities and it cannot guarantee the message transfer time. VDL Mode 2 employs a globally dedicated common signalling channel at 136.975 MHz.

3.3.7 ICAO SARPs for this air ground data link became applicable in 1997. Guidance material is provided in ICAO Doc 9776, *Manual on VHF Digital Link (VDL) Mode 2*. VDL Mode 2 commercial services are being gradually put into operation.

VDL Mode 3

3.3.8 At the SP COM/OPS/95 meeting, this system was recognized in Recommendation 6/2 as the future ICAO integrated voice and data link VHF communications system that would replace the VHF DSB-AM systems in the long term. The VDL Mode 3 uses the same physical layer as Mode 2 with a time division multiple access (TDMA) technique. This enables up to four 4.8 kilobit per second circuits for voice or data on each 25 kHz channel that may be assigned anywhere in the band. The data capability provides a mobile subnetwork that is compliant with the ATN.

3.3.9 ICAO SARPs became applicable in November 2001. Guidance material is provided in ICAO Doc 9805, *Manual on VHF Digital Link (VDL) Mode 3*. Frequency assignment planning criteria are still under development by the Aeronautical Communications Panel (ACP) (former AMCP). There is currently no operational use of VDL Mode 3. Implementation plans in the United States (NEXCOM programme) are presented in Appendix B.

VDL Mode 4

3.3.10 SP COM/OPS/95 requested in Recommendation 6/3 the development of SARPs for data links to support navigation and surveillance elements of CNS/ATM applications. One of the data links that was considered by ICAO for surveillance at that time was VDL Mode 4. This is based on a self-organizing time division multiple access (STDMA) scheme, using 19.2 kilobit per second Gaussian frequency shift keying (GFSK) modulation. Broadcast surveillance data applications are supported by non-ATN compliant specific services, and point-to-point data surveillance[2] applications are supported both on ATN and non-ATN compliant basis. VDL Mode 4 requires the assignment of two global signalling channels and additional regional and local channels to support service requirements.

3.3.11 ICAO SARPs for the VDL Mode 4 became applicable in November 2001. Guidance material will be provided in an ICAO *Manual on VHF Digital Link (VDL) Mode 4*. Frequency planning criteria are under development by the ACP (former AMCP).

3.3.12 Operation of VDL Mode 4 in the band 108 - 117.975 MHz is also proposed. Radio regulatory aspects of such operation will be reviewed at the ITU World Radiocommunication Conference in 2003 (WRC-2003).

3.4 **UHF band - terrestrial systems**

3.4.1 Terrestrial systems that are within the scope of this paper and operate in the UHF band include the secondary surveillance radar (SSR) Mode S extended squitter and the universal access transceiver (UAT).

SSR Mode S data link and extended squitter

3.4.2 The SSR Mode S is the latest generation ground-based secondary radar surveillance system. In addition to SSR Mode A/C and Mode S surveillance capability, Mode S supports data link transactions and is defined as an ATN-compliant sub-network. The operating frequencies are 1 030 MHz from ground to air and 1 090 MHz from air to ground. Extended squitter is an addition to the Mode S system designed to support automatic dependent surveillance broadcast (ADS-B), which will also allow enhancements to the airborne collision avoidance system (ACAS). The extended squitter consists of a set of broadcast messages that provide information regarding, inter alia, the aircraft position, velocity, and identification. It uses the same format as the current Mode S data link and operates on the Mode S downlink frequency of 1 090 MHz.

3.4.3 ICAO SARPs for SSR Mode S became applicable in 1996. Guidance material is provided in ICAO Doc 9688, *Manual on Mode S Specific Services* and in ICAO Doc 9684, *Manual of the Secondary Surveillance Radar (SSR) Systems*.

Universal access transceiver

3.4.4 The universal access transceiver (UAT) is designed to support ADS-B, and also offers a ground to air data broadcast capability. The UAT operates in the 960 - 1 215 MHz band (the frequency 978 MHz has been proposed). The ACP (former AMCP) has begun the work on SARPs development.

3.5 **UHF band — Satellite-based systems**

Aeronautical mobile satellite service

3.5.1 The aeronautical mobile satellite service (AMSS) provides digital voice and data services using geostationary satellites and operates in the mobile satellite service bands 1 545 MHz - 1 555 MHz and 1 646.5 - 1 656.5 MHz. To ensure adequate protection for safety and regularity of flight messages, provisions are included in the SARPs to ensure that these messages have priority and pre-emption over other non-safety

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[2] AMCP/8 (February 2003) agreed to the future use of VDL Mode 4 for communication applications, on the understanding that certain concerns shall be addressed satisfactorily within ACP (former AMCP), and recommended that the Annex 10 Note restricting the use of VDL Mode 4 to surveillance applications be removed.

aeronautical users. While AMSS has priority access to the spectrum for safety and regularity through provisions in the Radio Regulations, practical implementation of the provisions in situations where the spectrum is already in use by non-aeronautical service providers is a concern for the aviation community and needs to be closely monitored.

3.5.2 The AMSS is designed to be a sub-network of the ATN, and it can also support ACARS messages. In the South Pacific area, where AMSS is used to support ATS through FANS-1/A systems, the requirements are for a mean transfer delay for data messages of typically less than 30 seconds while 95 per cent of all messages are delivered within 60 seconds. Trials using prototype ATN-compliant systems have shown considerable improvement on these times. In the North Atlantic, AMSS is used to support FANS-1/A service with about 30 per cent of flights using ADS-C waypoint reporting. The digital voice component of the AMSS is designed to interface with terrestrial public switched telephone networks (PSTN) and with dedicated ATS voice networks, and to provide high quality telephone service both for aeronautical passenger correspondence (APC) and for ATS and AOC. Several ATS communication service providers have published telephone numbers that may be accessed using the AMSS for emergency and non-routine communications. Approximately 3 000 aircraft have been equipped with satellite communications systems. The majority is configured for APC, but a large number is also capable of ATS and AOC satellite voice communications.

3.5.3 ICAO SARPs and guidance material for the aeronautical mobile satellite service became applicable in 1995. Subsequent evolutionary updates became applicable in 2000.

3.5.4 The Inmarsat commercial global satellite system supports AMSS and provides geostationary satellite coverage of most of the world (except for the polar regions). Another system, the multifunctional transport satellite (MTSAT) is planned to be launched by Japan in 2003 to operate in the Pacific region.

3.6 Current system comparison

3.6.1 The table below contains a technical comparison of the systems presented in this section.

3.7 Trials, validation, implementation and research activities

3.7.1 Since the Tenth Air Navigation Conference, various programmes have been undertaken leading to trials, validation, implementation and research activities. Examples of various recent activities are provided in Appendix A.

Table 1. Comparison of current aeronautical mobile communications systems

Characteristic	VHF 25 kHz and 8.33 kHz DSB-AM	HF SSB	HFDL	AMSS	VHF ACARS	VDL Mode 2	VDL Mode 3	VDL Mode 4	UAT	Mode S D/L & Extended Squitter
Service types	Voice	Voice	Data	Voice / Data	Data	Data	Voice / Data	Data	Data	Data
Standardisation status	SARPs complete	SARPs complete	SARPs complete	SARPs complete	No SARPs, AEEC industry standards	SARPs complete	SARPs complete	SARPs complete for surveillance	SARPs under development	SARPs complete
Connection topology	A/G and A/A Broadcast	Broadcast (note: G to A selective addressing)	A/G Point-to-point	A/G Point-to-point	A/G Point-to-point	A/G Point-to-point	Voice: broadcast Data: A/G Point-to-point, Ground broadcast	Point-to-point, Broadcast	Broadcast	Point-to-point, Broadcast
Operating band	117.975 – 137 MHz	2.85-22 MHz	2.85-22 MHz	1545 - 1555 MHz uplink, 1646.5-1656.5 MHz downlink	117.975 – 137 MHz	117.975 – 137 MHz	117.975 - 137 MHz	108 -137MHz[1]	960-1215 MHz.	1030 MHz uplink, 1090 MHz downlink
Current spectrum utilisation	Congested in US and Core Europe	Heavily utilised[2]	Heavily utilised	Utilised[3] (priority to AMS(R)S)	Congested in US and Core Europe	Congested in US and Core Europe	Congested in US and Core Europe	Congested in US and Core Europe	Lightly used for DME	Shared with SSR Mode A/C
Geographical coverage	Continental land-based A/A Global	Global	Global	Global (except polar regions)	Continental land-based	Continental land-based	A/G Continental land-based A/A Voice Global	A/G continental land-based A/A Global	A/G continental land-based A/A global	A/G continental land-based A/A Global
Range	Line of sight	6500 NM	6500 NM	Satellite footprint	Line of sight	Line of sight	Line of sight	Line of sight	Line of sight	Line of sight
ATN compliance (data only)	Not applicable	Not applicable	Yes	Yes	No	Yes	Yes	Yes	No	Yes

Note 1.— Use of 108-117.975 MHz for surveillance being considered at WRC 2003.

Note 2.— Only part of this band allotted for ATC purpose (ITU Appendix 27).

Note 3.— Band shared with non-safety services.

4. FUTURE TRENDS

4.1 This section presents background information on various topics relevant to the evolution of future communications.

4.2 Evolution of voice communications capacity requirements

4.2.1 Figure 1 below (based on European data) shows trends of voice communications capacity requirements, as they are expected to develop over the next two decades in a high density area. It indicates the relative scale of exchanges that are expected between pilots and controller. Within the time frame being considered, a radical evolution of the voice operating concept is not expected. A controller will still rely on a dedicated communication channel to communicate with the aircraft under control. While the figure indicates that the number of exchanges will stabilize and even later decrease, the expected growth in air traffic will cause the introduction of additional sectors and services, an increase in the number of radio channels, and therefore an increased need for spectrum. In addition, the introduction of data link services will require additional spectrum.

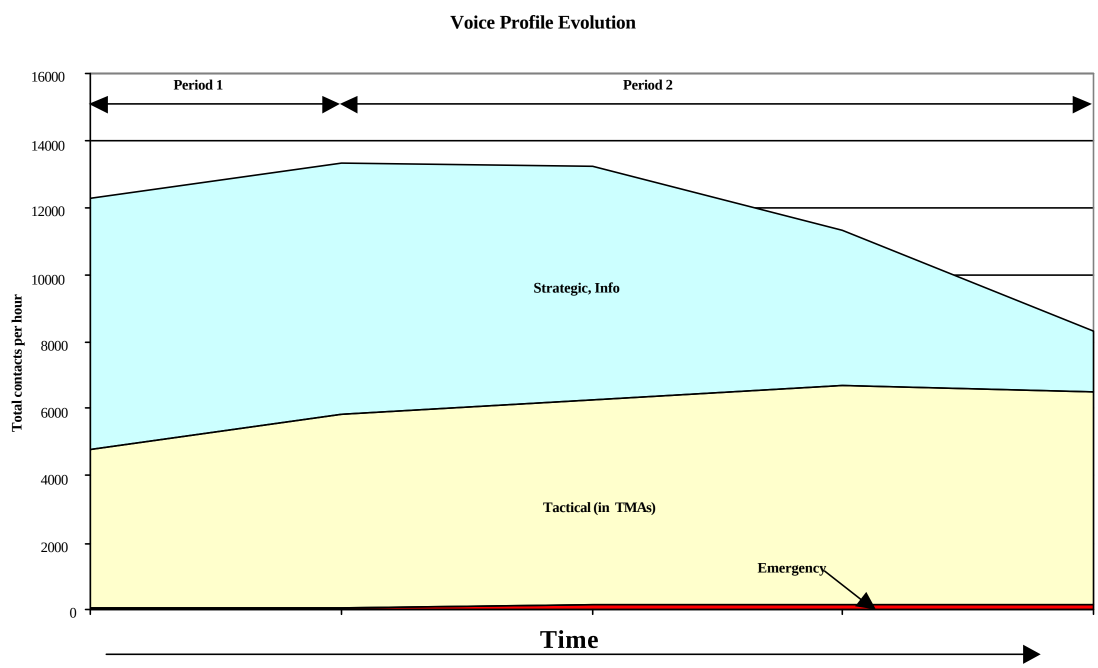

Figure 1. Tactical and strategic voice profile evolution

4.2.2 The figure shows a continuous increase in tactical message exchanges in the TMA that will still be supported by voice. Tactical en-route exchanges will be transferred over data link systems. Note that the increase in tactical exchange in TMAs illustrates the increase of air traffic and therefore the need to increase capacity.

4.2.3 The evolution of the strategic control and aeronautical information voice exchanges illustrates their transfer over data link services. During the initial period when data link is introduced the number of exchanges will stabilize. In a second time period there will be a decrease in the total number of exchanges.

4.2.4 Forecasts show also show that the European communication infrastructure around 2015 will need to cope with a significant (~40%) increase in voice exchanges in the TMAs and a similarly significant

(~75%) decrease in exchanges with en-route aircraft. The feasibility to reorganize the available resources to cope with such a traffic loading increase in TMAs must be assessed.

4.3 Voice versus data link considerations

4.3.1 One transition path towards increased use of data link which takes due account of human factors considerations is the one whereby use of datalink is introduced first for non-time critical routine communication applications such as ATIS, departure clearance and initial taxi clearance.

4.3.2 As equipage and confidence in the system increase, more routine applications can be transferred from a voice to a data link medium such as en-route frequency changes, route changes and re-routing and standard instrument arrival (STAR) clearance.

4.3.3 The ultimate goal is to reserve the voice communication environment for time critical safety applications. Transferring all other applications to data link will create the spare capacity necessary for transitioning to the future systems and for increasing air traffic capacity. A reorganization of ATS services and of their corresponding frequency assignments will be necessary in order to release voice channels for data link use.

4.4 Demands on communications capacity

4.4.1 Communication capacity is influenced by two key characteristics.

4.4.2 The first characteristic is the total amount of information that must be exchanged and the efficiency with which it is exchanged. Analysis of communication capacity using this characteristic involves considering the number and complexity of message elements and the amount of time a communication channel must be occupied in order to send the message at a given information rate. While other factors must also be considered, it is generally acknowledged that most information is more efficiently sent using data link than using voice because of the relatively inefficient way in which voice is used to convey pieces of information. Having identified the channel loading per aircraft, the total communications system loading may then be computed by analysis factors such as peak instantaneous aircraft count.

4.4.3 The second characteristic to be considered is the number of discrete channels required by the communications concept. This characteristic assumes that each air traffic control sector both in en route and terminal airspace and at the airport must be assigned a dedicated voice channel. Therefore, a lightly loaded sector consumes as much spectrum as one that is more heavily loaded. Since one of the constraints with the current communications concept is the lack of available channels to meet all requirements, this characteristic is complementary to information rate in communication system design. Data link design typically decouples the data rate and channel count characteristics since data packets from multiple users can be multiplexed over a common channel and, occasionally, increased bandwidth requirements have been met by distributing the load over multiple paths. Although not currently employed for aeronautical use, voice can be multiplexed similarly using concepts such as “trunked radio” to better decouple the message efficiency and channel count characteristics.

4.4.4 Where possible, communication systems can make optimum use of available spectrum if the two key characteristics of capacity can be optimised independently. Research into such techniques is needed. The above considerations are important in determining whether a given RCP level can be achieved as a function of available spectrum and operational environment characteristics.

4.5 Future aeronautical mobile communications technologies

4.5.1 In addition to the aeronautical mobile communications technologies listed in section 3, two new technology areas are under consideration for future aeronautical mobile communications systems.

4.5.2 Next-generation satellite systems

4.5.2.1 These AMSS systems may complement the current ground based systems in congested regions. They are also able to provide communication services in regions where it is difficult to install ground based equipment, and will provide wide area coverage to facilitate seamless communications during flight. They could be designed to meet the performance requirements and levels of service expected from future ATM applications, and, depending on benefit-cost assessments, could replace some of the ground-based systems. Draft SARPs for next-generation satellite systems were developed by AMCP/7 (March 2000) but were not included in Annex 10 due to lack of viable prospects of implementation at the time. AMCP/8 (February 2003) identified as an area for further work the investigation of the feasibility to introduce new AMSS technologies, such as those currently under investigation in Europe by the European Space Agency.

4.5.3 Next-generation terrestrial systems

4.5.3.1 One approach to developing next-generation terrestrial systems is to derive them from existing mobile communication technologies, such as 3G, which are presently available for public telephony. Such systems are able to provide large communications capacities for a great variety of applications including voice, data and video. Their constituents could be derived from the telecommunication industry as commercial off-the-shelf (COTS) products. An alternative/complementary approach is to draw as much as possible on existing ICAO material. AMCP is currently evaluating the potential of alternative terrestrial technologies, based where possible on existing ICAO material.

4.5.4 Future system comparisons

4.5.4.1 The table below contains a technical comparison of the systems presented in this section.

Table 2. Comparison of potential future aeronautical mobile communications systems

Characteristic	Next-generation satellite	Next-generation terrestrial
Service types	Voice and data	Voice and data
Standardization status	High level SARPs drafted	Not started
Connection topology	Voice: A/G point-to-point and ground-to-aircraft broadcast Data: A/G point-to-point, ground-to-air broadcast	Point-to-point
Operating band	1 545 - 1 555 MHz aircraft to satellite uplink 1 646.5 - 1 656.5 MHz satellite to aircraft downlink	5 091 – 5 250 MHz
Geographical coverage	Global (except polar regions)	Continental land based
Range	Satellite footprint(s)	[TBD]
ATN data compliance	Yes	Expected

5. CANDIDATE BANDS FOR FUTURE AIR/GROUND COMMUNICATION SYSTEMS

5.1 Introduction

5.1.1 This section reviews a number of aeronautical and non-aeronautical bands that are considered to be potential candidates for use by future air/ground communication systems.

5.1.2 The introduction of communication systems supporting wide-band data transmissions may provide aviation the opportunity to introduce new applications to improve security, safety and efficiency. In this case, the frequency bands required for such systems would be of the order of 30 to 60 MHz may be necessary.

5.2 Potential candidate aeronautical bands

74.8 - 75.2 MHz

5.2.1 This band might become available for future systems only if marker beacons were to be phased out. Due to its limited bandwidth, this band is not considered useful for the development of a global communications system.

108 - 117.975 MHz

5.2.2 This band is being proposed for an additional allocation to support GBAS and VDL Mode 4.

117.975 - 137 MHz

5.2.3 The introduction of new air/ground communication systems in this band can only take place if sufficient spectrum capacity is released in the band while still meeting existing frequency assignment planning constraints.

138 - 144 MHz

5.2.4 This band is allocated to military aeronautical mobile communications (AM(OR)S) in Europe and might be used to accommodate military aircraft flying under civil control. The lack of an operational “party line” with civil aircraft would require study.

328.6 - 335.4 MHz

5.2.5 The global use of glide path equipment is expected to continue for the foreseeable future, particularly for higher category ILS (CAT III). The bandwidth is limited. Should a significant reduction in ILS requirements be achieved in the future, for example due to an increased use of MLS or GNSS for final approach and landing, this band could be considered for AM(R)S use to accommodate air-ground data communications capacity requirements that cannot be met in the VHF band.

960 - 1 215 MHz

5.2.6 The 960 to 977 MHz portion of this band is currently reserved for national allotments and further work is necessary to determine its suitability to meet future communications requirements. The frequency 978 MHz is little used worldwide and is currently under consideration for the introduction of the UAT. Systems such as DME and SSR that are currently operated in the remainder of this band are expected to continue for the foreseeable future. Furthermore, the RNSS allocation introduced by WRC-2000 contributes to make this band an unlikely candidate despite its favourable propagation characteristics. As a result, only portions of the band could be considered to accommodate capacity requirements that cannot be met in the VHF band.

1 545 - 1 555 MHz and 1 646.5 - 1 656.5 MHz

5.2.7 These bands, previously allocated exclusively to the AMS(R)S, were reallocated to generic MSS use by the ITU WRC-97 with provisions for priority use by safety-related aeronautical communications. Systems that comply with the AMSS SARPs operate in these bands, which are also the most likely candidate bands for next-generation satellite systems.

1 670 - 1 675 MHz and 1 800 - 1 805 MHz

5.2.8 These bands are presently allocated to the aeronautical mobile service for non-safety communications such as aeronautical passenger correspondence (APC) using systems such as the terrestrial flight telephone system (TFTS). The TFTS has ceased operation and the band is under consideration to be reallocated.

2 700 - 2 900 MHz

5.2.9 Not to be considered due to ground based radar systems operating worldwide.

4 200 - 4 400 MHz

5.2.10 Not to be considered due to radio altimeter operations worldwide.

5 091 - 5 250 MHz

5.2.11 This band is viewed to have the best potential for a future aeronautical mobile communications service. However, due to relatively high propagation losses, it is less suitable for conventional line of sight services using the nominal powers available on aircraft. Alternative short-range uses include terminal area applications or data-only communications. Appropriate regulatory provisions would be required to enable the use of this band for aeronautical communications. The two main sub-bands of this band are:

5 091 – 5 150 MHz sub-band (“MLS extension” band)

Subject to the requirement to maintain its availability for extended MLS use, which will be reviewed at the ITU WRC-2003, this band could be used for air/ground digital communication systems. Introduction of AM(R)S in this sub-band would need to include the protection of the current use by the fixed-satellite service (FSS).

5 150 – 5 250 MHz sub-band

Originally allocated for ARNS use, this is now used by the fixed-satellite service and by the mobile service (MS) for a variety of licensed and non-licensed applications. This band will also be reviewed at the WRC-2003 to introduce regulatory measures to protect the FSS from the MS. Only non-safety-related aeronautical use of this band should be considered.

Above 10 GHz

5.2.12 Bands around 13 GHz, 15 GHz and 30 GHz are used for aeronautical radionavigation (radar) services.

5.3 Potential non-aeronautical candidate bands

Below 10 GHz

5.3.1 The introduction of aeronautical systems with exclusive or priority use of bands below 10 GHz that are not currently allocated to aeronautical services is unlikely due to the heavy use of these bands by a variety of radio services.

Above 10 GHz

5.3.2 The 14 GHz band is a candidate for non-safety aeronautical mobile satellite systems. The use of spectrum above 10 GHz by aeronautical communication systems is constrained by propagation conditions including distance and precipitation. An inventory of the uses of these bands, with a view to assessing availability under acceptable sharing conditions, is required.

5.3.3 Some bands above 10 GHz are allocate to generic radionavigation or mobile services. These bands are therefore potentially available for use by aeronautical systems, terrestrial or satellite-based as applicable.

5.4 Conclusions on candidate bands

5.4.1 The 1.5 and 1.6 GHz bands are the most suitable for next-generation satellite systems.

5.4.2 The 5 GHz band is currently considered the most likely candidate to support next-generation terrestrial systems.

5.4.3 Other bands (e.g. the band 960 - 977 MHz and bands above 10 GHz) are candidates for further study to assess their reliability for aeronautical communications.

5.4.4 Outside the bands allocated to aeronautical services, the basic aviation requirements for safety services and global allocation might be difficult to meet.

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APPENDIX A

TRIALS, VALIDATION, IMPLEMENTATION AND RESEARCH ACTIVITIES

1. 8.33 kHz DSB-AM

1.1 See section 3.3.2 in the body of the paper.

2. HFDL

2.1 HFDL is in commercial operation worldwide. Operated by ARINC, this service provides AOC and some pre-operational trials of ATS message services.

3. VDL MODE 2

3.1 A two step implementation plan is being pursued for VDL Mode 2 services. The first step,termed AOA (ACARS over Aviation VHF Link Control (AVLC)), includes VDL Mode 2 features and foresees the deployment of an air-ground segment limited to the functions required for delivering higher performance to the current ACARS applications. Service providers have started AOA operation in Europe, the United States and Japan. As the second step, full VDL Mode 2 services will be implemented.

3.2 Furthermore, both EUROCONTROL and the FAA have set up projects, Link2000+, and Build 1/1A respectively, to coordinate the deployment of ATS data link services based on VDL Mode 2.

3.3 In the framework of the United States NEXCOM Programme, a number of alternatives, including VDL Mode 2 and Mode 3 or analog voice are being assessed. According to the current NEXCOM implementation path, it is not anticipated that VDL Mode 2 will be decommissioned.

3.4 According to the EUROCONTROL communication systems roadmap data services will be supported by VDL Mode 2. As a first phase, ATIS and departure clearance applications will be based on AOA. It is expected that VDL Mode 2 will be in full operation around 2007.

3.5 The ENRI (Electronic Navigation Research Institute) of Japan developed VDL Mode 2 test equipment by 1999. Using this test equipment, ENRI has conducted in-flight tests and evaluations to validate the operational performance of VDL Mode 2. EUROCONTROL is also developing similar tools and has carried out similar tests.

3.6 At EUROCONTROL, the PETAL II (Preliminary Eurocontrol Test of Air/ground data Link/II) project has developed an operational environment for CPDLC, including the human-machine interface (HMI) for both pilots and controllers.

3.7 By conducting multiple aircraft air/ground data-link operational trials during routine ATC operations, PETAL II had the following objectives:

a) to validate operational concepts, requirements and procedures for air/ground data-link; and

b) to obtain data on the operational benefits, requirements, human factors, procedures and problems associated with using air/ground data-link in busy continental European airspace.

3.8 The EUROCONTROL Petal II Extension project has operated four aircraft equipped with ATN and VDL Mode 2 from May 2001, in order to evaluate potential operational issues. PETAL is now included within the Eurocontrol Link2000+ programme.

3.9 At the United States FAA the operational verification of an initial set of message elements of CPDLC is currently in process in United States CPDLC build 1 and 1A programme.

3.10 The European Aircraft in the Future ATM System (AFAS) programme is the first step in achieving the airborne components of the functionality set out in the ECAC ATM 2000+ baseline. It defines three new operational services: pre-flight trajectory coordination, 4D flight trajectory, and re-planning of 4D trajectory.

3.11 The AFAS concept includes data link communications using VDL Mode 2, ATN, CPDLC, ADS and FIS applications, and surveillance using air/ground data link communications.

3.12 Through coordination with MITRE, services to be provided as part of AFAS will be distributed by phase (pre-flight, flight). Validation will be performed through fast-time simulations. The programme is expected to last until 2003.

4. VDL MODE 3

4.1 The implementation of VDL Mode 3 in the United States will be accomplished through the Next Generation Communications Programme (NEXCOM). The FAA established the NEXCOM Programme in 1998 to address NAS future domestic air/ground communications for voice and data.

4.2 Initial implementation will occur in two phases.

4.3 Phase I, the design, demonstration, and validation phase will include the development of a preliminary design of the ground system. The Engineering Development Model (EDM) will be demonstrated and validated to show compliance with a group of minimum threshold requirements that are a subset of the system requirements.

4.4 Additionally, the FAA will demonstrate a "certifiable" VDL-3 avionics voice system and an "interoperable" data system by 2004.

4.5 The objectives of this rapid preliminary development effort (RPDE) phase are:

a) development of ground prototype system (radio interface unit, ground network interface unit);

b) development of certifiable avionics;

c) demonstration of an engineering development model (EDM) of the system;

d) development and updates of a “strawman” AEEC Characteristic;

e) development of commercial avionics radios; and

f) flight demonstrations of certified radios in operational National Airspace System (NAS) by 2004.

4.6 Phase II of the NEXCOM programme is the Full Scale Development of the system. The final NEXCOM system production design will be completed, the operational system will be developed, tested, and produced, and will be fully deployed. Plans anticipate operational digital voice beginning in 2009. Data capabilities are expected to be enabled after operational digital voice service is in place.

4.7 The objectives of this full-scale development programme (FSDP) phase are:

a) ground system production design and development;

b) operational system testing, and deployment throughout the enroute domain of the NAS;

c) initial deployment and key site operational testing and evaluation (OT&E) in 2007; and

d) initial deployment of operational voice service in 2009.

4.8 Implementation Constraints:

4.9 Recently, the NEXCOM Aviation Rulemaking Committee (NARC) recommended an investigation of the following options:

a) use VDL Mode 3 for voice and data;

b) continue to support VDL Mode 2 for data link communications and support its continued evolution to meet the needs of future ATS data link requirements; and

c) use VHF 8.33 kHz DSB-AM for voice and VDL Mode 2 for data if VDL Mode 3 proves untimely.

4.10 In Europe, there are some concerns about the feasibility of transitioning to a VDL Mode 3 environment, especially for voice, due to the heavy congestion of the VHF COM band and the benefit of implementing 8.33 kHz. The potential use of VDL Mode 3 in Europe needs further investigation.

4.11 **United States FAA rule making**

4.11.1 An effective employment of NEXCOM necessitates the formal requirement for equipage of aircraft in specified airspace. The FAA Notice of Proposed of Proposed Rule Making (NPRM) is projected for publication in 2004, with the final rule completed by June 2005. The objectives of the NPRM effort are:

a) gather comments from the aviation community on the proposed rule; and

b) establish a rule that mandates aircraft equipage with NEXCOM in specified NAS airspace.

4.12 ENRI Japan

4.12.1 The development of the test equipment and the protocol simulation model on VDL Mode 3 is in progress at the ENRI in Japan. The validation on operational performance of VDL Mode 3 will start in early 2003 through flight tests utilising test equipment and simulation.

5. VDL MODE 4

5.1 NEAN Update Programme (NUP)

5.1.1 The North European automatic dependent surveillance — broadcast network (NEAN) update programme (NUP) Phase II is a European ADS-B programme based on VDL Mode 4. Begun in mid 2001 with a four year life cycle, this programme addresses the transformation of research activities into commercial products, bringing the work to a pre-operational status. Supported by the European Commission, airlines, ATS providers and manufacturers, the project shall establish an European ADS-B network based on global standards supporting certified applications and equipment in synergy with the European ATM concepts providing benefits to ATM stakeholders.

5.1.2 The work has been divided into five major areas: surveillance in non radar environments, off shore operations, surface movement operations, air to air applications and ATC integration.

5.2 More autonomous aircraft in the future ATM system (MA-AFAS)

5.2.1 The European MA-AFAS programme addresses areas such as:

a) evaluation of airborne 4D flight path generation for integration with ground based flight path planning;

b) integration of airborne taxiway map and data linked clearances; and

c) validation of ADS-B with airborne cockpit display of traffic (CDTI) and airborne separation assurance algorithms (ASAS).

5.2.2 The MA-AFAS avionics package will be validated using both light simulators and trials on experimental aircraft, with simulated and operational ATC centres in shadow mode. This validation will use real data link communication, representative navigation facilities and surveillance functions including ADS-B (using VDL Mode 4) to provide traffic information. Final results are expected by 2007.

5.3 Mediterranean Upgrade Programme (MEDUP) and Mediterranean Free Flight (MFF)

5.3.1 The ongoing ADS Mediterranean Upgrade Programme (MEDUP) and Mediterranean Free Flight (MFF) programmes evaluate the feasibility of applying ADS-B services in the Mediterranean area. MEDUP is focussing on establishing an extensive VHF digital link (VDL) Mode 4 infrastructure while MFF is focussing on operational aspects when taking advantage of ADS-B based services.

5.3.2 The ADS MEDUP includes the following functions: GNSS augmentation; ADS-B using VDL Mode 4; TIS-B using VDL Mode 4; airborne 4D flight path handling; and, CPDLC for ATC communications. The programme is planned to be completed by mid 2004.

5.3.3 The MFF programme includes the following objectives: to evaluate CNS/ATM technologies and applications for a future Mediterranean ATM scenario; to verify new procedures for free routing and free flight; to address system standards; and, to define guidelines for free flight. The MFF is also expected to be completed in 2004.

5.4 Implementation of ADS-B services using VDL Mode 4 in Sweden

5.4.1 Under the ADS2005 programme, twenty-three ground stations will be installed in Sweden to provide national coverage for VDL Mode 4 to support ATM applications covering all phases of flight. The first station at Kiruna in northern Sweden will provide air traffic surveillance in this non-radar airspace. Testing is underway and operational service is expected in 2003.

5.4.2 In the south, VDL Mode 4 is being implemented at Stockholm — Arlanda to enable enhanced surface movement surveillance and to provide operational data. When fully operational by the end of 2003, services will include global navigation satellite system (GNSS) augmentation, ADS-B reporting, FIS-B, INFO-B which is AOC data, TIS-B, departure clearances, and CPDLC.

6. AMSS

6.1 Since October 1997, FAA and the Japan Civil Aviation Bureau (JCAB) have been conducting CPDLC/ADS data link operation in North Pacific, and the *Datalink Operation Review Group* has been responsible to monitor the data link operations by reviewing problem reports and assessing the system performance. Results developed by the group are made available to the North and Central Pacific FANS Interoperability Team (FIT). The FIT was formed under an agreement of the thirteenth meeting of the Informal Pacific ATC Coordinating Group (IPACG) in January 2001 to implement FANS benefits by monitoring data link system performance to identify and resolve any associated problems. The FIT consists of two functions. One of them is the FIT Meeting where operational procedures, system performance and other issues are reviewed, and the other is the Central Reporting Agency (CRA), which performs day-to-day tasks of FIT activities.

6.2 The Japan Civil Aviation Bureau (JCAB) is developing the multifunctional transport satellite (MTSAT) which will consist of two geostationary earth orbit (GEO) satellites (MTSAT-1R and -2). MTSAT-1R is scheduled for launch in 2003 and MTSAT-2 in 2004. Each of the two satellites will be operated as a “hot stand-by” for the other, and both will be interoperable with present AMSS avionics.

6.3 AMSS is also used extensively in other regions of the world for operational and pre-operational ATS services.

7. STATUS SUMMARY

7.1 Table A1 shows the present status of these systems.

Table A1. Status summary of aeronautical mobile communications systems

Systems/status	Operational	Pre-operational	Validation	Trials	Research
VHF 25 kHz DSB-AM	world-wide				
8.33 kHz DSB-AM	core Europe				

Systems/status	**Operational**	**Pre-operational**	**Validation**	**Trials**	**Research**
HF SSB	world-wide				
HF data link	AOC only	Ongoing for ATS in North Atlantic	Ongoing for ATS in North Atlantic		
ACARS	world-wide (AOC, some ATS)				
AMSS[1]	South Pacific North Atlantic	North Pacific			Next generation satellite systems
VDL Mode 2	No[2]	Ongoing in Europe and United States	Ongoing in Europe, United States, and Japan		
VDL Mode 3	No	No	Ongoing in the United States and Japan	Ongoing in the United States	
VDL Mode 4	No	Ongoing in some parts of Europe	Ongoing in Europe	Ongoing in Europe	

Note 1.— AMSS can support both ACARS-based FANS-1/A services and CNS/ATM (ATN-based) services using Data-3.

Note 2.— Operational systems are being purchased for installation by 2002 and onwards.

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APPENDIX B

EARLY IMPLEMENTATION OF DATA LINK SERVICES USING ACARS

1. The aircraft communications addressing and reporting system (ACARS) (see section 3.3.4 to 3.3.5 in the body of the paper) was originally designed for AOC applications and it is not an ICAO standard system. Currently, however, in addition to AOC, ACARS is also used for ATS applications.

2. Among the early ATS applications of ACARS, the most common have been pre-departure clearance (PDC/DCL), digital ATIS, and waypoint position reports. The specifications for these messages have been evolving, resulting in some incompatibility between aircraft implementations and ATS implementations. The most current specifications for ATS messages over ACARS are found in *ARINC Specification 623-2 Character-Oriented Air Traffic Service (ATS) Applications* (ARINC 623) as well as standards material produced by EUROCAE. ARINC 623 defines the application text formats for character oriented ATS messages that can be transmitted over the ACARS data link. The messages defined in ARINC 623 are not specific to any data link and they are limited in scope to character oriented applications.

3. With the introduction of *ARINC Specification 622-4 ATS Data Link Applications Over ACARS Air-Ground Network* (ARINC 622) the ACARS message format has been used increasingly in most regions, making use of VHF, HF, and AMSS data links. This specification defines ATS applications that enhance the usability of the ACARS system and it provides design guidance to developers to ensure interoperability among the implementations of these applications. Some ATC applications such as departure clearance and ATIS are in use extensively in North America and Europe and are being implemented in other regions.

4. ARINC 622 provides addressing functions, a cyclic redundancy check (CRC) for error detection, and a bit-to-character conversion to transfer data generated by bit-oriented applications over the character oriented ACARS communication network (ACARS convergence function (ACF)). ARINC 622 was developed to support FANS-1/A (avionics and applications suites provided by Boeing and Airbus) over AMSS for ATC services in oceanic areas. Using ARINC 622 as a base, bit-oriented FANS-1/A applications data are routed between aircraft and air traffic control centres through the communication service providers' central processing facilities.

5. A second convergence function called ACARS over AVLC (aviation VHF link control), or AOA, has been developed to enable character oriented ACARS message transfers using the higher data rate of the VDL Mode 2.

6. These initial implementations, although not fully ATN compliant, have facilitated the early introduction of CNS/ATM system services.

— END —