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Project EMERTA
Final Report

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Prepared by:

Title:

Signature: ______________________________

Date:

Reviewed by:

Title:

Signature: ______________________________

Date:

Approved by:

Title:

Signature: ______________________________

Date:

Authorised by:

Title:

Signature: ______________________________

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Abstract

This report is the Final Report of Project EMERTA which was conducted by DERA, SOFREAVIA, NLR NATS, AIRSYS ATM and AEROSPATIALE MATRA AIRBUS on behalf of DG:TREN of the European Commission.

The work of Project EMERTA was centred on the implications of two emerging technologies and associated concepts for aeronautical use, Next Generation Satellite Systems (NGSS) and Automatic Dependent Surveillance-Broadcast / Airborne Separation Assurance System (ADS-B/ASAS).

During Project EMERTA the following volumes have been produced:

- ‘Volume 1 – Final Report’.
- ‘Volume 2.1 – NGSS Study Summary Report’
- ‘Volume 2.2 - Safety/separation modelling of a particular AMSS application’
- ‘Volume 3.1 – ASAS feasibility study and transition issues’
- ‘Volume 3.2 – Safety/separation modelling of a particular ASAS application’
- ‘Volume 4 – The EMERTA seminar’

Executive summary

The European Commission Fourth Framework programme covers all the Research and Technical Development (RTD) activities carried out by the European Union during the period 1994-1999. Nineteen specific programmes are part of the Fourth Framework programme. Project EMERTA (EMERging Technologies, opportunities and impact on ATM) is part of the Transport programme.

Project EMERTA was initiated in response to the Air Transport Research Task 4.1.2/19 in the fourth call for proposals by the European Commission (EC) Fourth Framework programme.

The work of Project EMERTA is centred on the implications of two emerging technologies and associated concepts for aeronautical use, Next Generation Satellite Systems (NGSS) and Automatic Dependent Surveillance-Broadcast / Airborne Separation Assurance System (ADS-B/ASAS).

Next Generation Satellite Systems Study

The EMERTA's NGSS study-programme contained four main work packages:

- WP2.1 – Emerging NGSS
- WP2.2 – Safety Assessment
- WP2.3 – Costs and Institutional Issues
- WP2.4 – Long Term Benefits

The first three work packages are concerned with the application of NGSS technologies in the near term (2000 to 2005 timeframe). At the onset of the EMERTA work-study, the NGSS operational scenario dealt primarily with Europe's peripheral areas, where NGSS can provide a service where traditional ground infrastructure is not available.

WP2.1 was conducted in four parts:

- WP2.1.1 identified ATM and AOC application requirements.
- WP2.1.2 identified the expected capabilities of emerging NGSS.
- WP2.1.3 investigated considerations relating to the avionics required for emerging NGSS.
- WP2.1.4 matched the perceived capabilities with the identified requirements.

In WP2.2 a safety assessment was conducted of a particular scenario involving NGSS mediated communications. The selected scenario involved sequences of aircraft on two opposite direction parallel lanes on the same route and same flight level separated via ADS monitoring outside radar control, in the Southern Mediterranean airspace. The scenario has the benefit of increasing that route's ATM capacity. The TOPAZ safety assessment conducted in WP2.2 includes the selection of an ATC operational situation

Work package 2.3 included investigations of both costs related to the introduction of NGSS and Institutional aspects including a brief account of events which have affected the NGSS industries over the last 5 years or so since the inception of NGSS work by the ICAO AMCP panel.

Work package 2.4 considered the long term (beyond 2005) and investigated future ATM concepts which may enabled by new communication services supported by advanced communications systems such as the emerging NGSS. A first cut at defining requirements for both voice and data transmission in a top-down "clean-sheet approach" is also presented.

The key findings of the EMERTA NGSS study can be summed up as follows:

- NGSS are being assessed in the current SATCOM context under which the INMARSAT AMSS is used on a daily basis on about 2000 aircraft. So far, the use of this SATCOM technology has been restricted to oceanic/remote areas, on account of both high airborne equipment costs and communication charges. This may explain why AMSS has so far experienced a rather slow uptake of its safety-related service - AMS[R]S.
- NGSS, since their inception in the mid 1990s, have given rise to expectations of bringing a better and cheaper AMSS service to the aviation community. These expectations have not materialised at the time of writing of this report.
- In 1999, ICAO, at the 6th AMCP meeting, formally endorsed the conceptual feasibility of the use of commercial NGSS for the provision of AMS[R]S and subsequently, in year 2000 decided to develop appropriate SARPs needed for deployment world-wide. These SARPs are two-tier, comprising (a) a **generic** set of high-level regulatory and **service** definition standards applicable to all systems and (b), **system-specific detailed specifications** of performance and interface characteristics with airborne avionics and ground ATM/AOC infrastructure.
- However with the recent demise of IRIDIUM, the NGSS Industry effort needed to develop the second level has stopped until such a time another system's promoter, formally offers AMS[R]S and is willing to contribute the significant level of effort within ICAO's panels required for such a development. They will also need to assist RTCA/EUROCAE in generating the usual aviation industry standards - MASPS and MOPS.
- There are serious doubts about the long-term availability of the AMS[R]S service of satellite systems mainly developed to serve a bigger evolving mobile communication market, beyond the specific needs of civil aviation - which is a small but difficult market in comparison.
- With the demise of IRIDIUM, there is only a single LEO/MEO NGSS project planning to offer AMSS/AMS[R]S; namely New-ICO. It is worth noting that this New-ICO offer is based upon granting access to its new packet data transmission service, making use of the TCP/IP protocols suite starting with the AOC provision. If such an offer succeeds, there will be pressure on ATS authorities to move towards, or be compatible with, the TCP/IP protocols for ATS communications in addition to AOC, instead of deploying the ICAO-standardised ATN which is based on the OSI protocols.
- The ESA/SDLS concept based on the use of geostationary satellites and dedicated to the provision of AMS[R]S is now proposed as the next generation AMSS with the capabilities to serve high-density airspace in addition to oceanic/remote areas. A technical demonstrator is currently under industrial development, as a first step to establish this new concept credibility.
- The AMS[R]S data market, over Europe by year 2008 is estimated to be in the range of 20 to 60 millions EURO, at a the charging rate of 0.1 EURO per kilobit and under avionics equipage varying from 30 to 90 % of the commercial aircraft fleet.
- The feasibility and options for cost-sharing should be investigated (a) with other satellite systems and (b) between aviation users and industry suppliers, including by setting-up PPP (public private partnership)
- Financial and institutional arrangements. Specifically ways of sharing costs with other satellite systems such as GALILEO should be looked into.

The following short term programmes are considered to be of value to the future of ATM:

- Aeronautical Frequency Review: Development of a consensus of the frequency requirements for ATM into the future and adoption of strategy, co-ordinated at European level to ensure continuous access to RF spectrum for both AMSS and terrestrial systems.

- Develop a back-up RT Strategy using SATCOM Voice: Trials of existing SATCOM voice services as a backup voice system.
- Experimentation and use on pre-operational basis of NGSS demonstrators, i.e. of the New-ICO and ESA/SDLS types in order to both assess technical performance and the impact on operational personnel's (ATC and pilots) acceptability and work-procedures.
- Looking into the feasibility, both technical and economic, of a combined safety-related communication and satellite navigation mission, specifically on the European GALILEO GNSS

ASAS Feasibility and Transition Issues

Work package 3.1 considered the feasibility of the early introduction of ASAS applications in European Airspace and the associated transition issues. The work was conducted as three separate but related tasks:

- WP3.1.1 considered the ASAS applications in terms of technical feasibility and transition issues including benefits, costs, standardisation and institutional issues. The selected scenarios are analysed in terms of the supporting technology, data availability and operational implementation. The immediate benefits of the introduction of these applications are identified, and an initial assessment of costs is made.
- WP3.1.2 considered the availability of the data required for the ASAS applications in terms of the avionics fitted on the commercial fleet.
- WP3.1.3 considered the requirement for, and use of, a traffic information service as a means of supporting ASAS applications in a mixed equipage environment.

The report concludes that the early adoption of ASAS applications for enhanced situational awareness and pair-wise tactical co-operative applications is not only possible but indeed could be beneficial within the next few years – assuming that the remaining technical and institutional issues are resolved.

In terms of the initial implementation of ASAS the 'transition' is key since this is not only the environment in which the initial use of the first ASAS applications will be introduced but, as discussed, is likely to be of indefinite duration and therefore the environment in which ASAS will continue to exist.

The fundamental reason why a ground based traffic information service (TIS(-B)) will be needed is to support a partial ADS-B equipage environment which is unavoidable in the transition period. The 'gap filler' role can also provide some backup in the event of ADS-B equipment failure. As well as this there is the issue of the integrity of ADS-B surveillance information and whether this is sufficient for it to be solely relied on in ASAS applications, this implies an ongoing role for TIS-B in the ASAS environment.

The data available on board the majority of aircraft is sufficient to support the requirements of the chosen initial ASAS applications. In particular the use of TIS(-B) to support a partial equipage environment means that those aircraft which have the data available, primarily the modern jet aircraft, will be able to take part in ASAS without the need for older aircraft to equip. There are a number of non-aircraft state parameters such as call sign, aircraft type and emergency status which need to be made available either through the FMS or via the airborne equipment which will support ASAS on the aircraft. This is discussed further below.

The introduction in the relatively near term of some initial ASAS applications is feasible given that a number of prerequisites are satisfied, these can be split into technical and institutional issues:

Institutional Issues:

- The initial applications must be chosen carefully.
- The relevant procedures must be developed.
- Issue of separation responsibility must be resolved.
- The benefits must be demonstrable and sufficient to justify the required investment.

Technical Issues:

- A specification for TIS(-B) must be finalised.
- For the chosen data-link medium the technical issues must be closed.
- Suitable airborne equipment must be developed, certified and available.
- The aircraft which are to be involved must be suitably equipped.
- Appropriate supporting ground systems must be implemented.
- CDTI functionality and related HMI issues must be addressed.

As has been discussed earlier the choice of initial ASAS applications is crucial to the feasibility to the introduction of the ASAS concept. The two applications chosen for analysis in EMERTA both have key features which allow them to be candidates for early implementation.

The Enhanced Visual Acquisition (EVA) application is one where ASAS is used essentially without consequence, it is a VFR tool on which there is no reliance other than being used to improve the see and avoid principle. While this means that this application is easily certifiable, and therefore a good candidate for early implementation, it also has the problem that because it is only a VFR application the benefits to be gained are unlikely to drive equipage in the air transport community. GA pilots may find the potential safety enhancement to their normal VFR operations a benefit which will inspire investment by the individual, but for an airline operating almost exclusively IFR it will not.

The Station Keeping on Approach (SKA) application is by its nature a local application and does not require full equipage in the environment, any suitable equipped aircraft can take part in this manoeuvre, which, if the benefits of such a procedure can be demonstrated is likely to encourage equipage. Even with the need for TIS(-B) the local nature of the application means the investment on the ground will not be too great to provide the system at key airports. The issues of responsibility are also more straightforward than is potentially true for other ASAS applications.

The benefits that an aircraft operator will gain from the investment required to fit with the equipment necessary to take part in ASAS applications will need to be clearly identified. The total benefit from the initial applications must be sufficient to drive equipage. It is therefore important to identify all of the potential near term ASAS applications before beginning the first stage of implementation.

Illustrative procedures have been developed for the SKA application. This procedure will need to be formalised in order for the manoeuvre to be implemented and procedures developed for any other ASAS applications being considered.

In terms of the technical issues, the choice of medium for TIS(-B) is discussed and the three main candidates (VDL Mode 4, 1090 MHz and UAT) are all capable of supporting the system. There are certain technical issues which must be resolved in each of the media in order to be able to support the TIS(-B) system. Once the TIS-B specification is finalised airborne equipment which is preferably both ADS-B and TIS-B capable needs to be developed. Clearly then aircraft need to equip but this relates to the institutional issues. Given the need for a TIS(-B) system to support ASAS implementation the ground equipment to provide this service must be provided. As discussed, certain ASAS applications are, by their nature, local and so a single airport providing a TIS(-B) could enable the first implementation of ASAS for such applications.

CDTI functionality, in terms of the way surveillance information is presented to the pilot and what tools will be implemented to aid the participation in ASAS manoeuvres, needs to be developed further from the human factors and technical perspective. The onboard processing, which takes the surveillance inputs and processes them prior to display or use by ASAS tools, is also key and there must be further development of these functions. It may be through this equipment which may be included in the CDTI or the ADS-B/TIS-B transceiver that the parameters mentioned above could be made available for broadcast.

Initial Safety /Separation Modelling

The EMERTA project contained two subwork packages (WP2.2 and WP3.2) in which safety/separation models of two different operational concepts have been assessed:

- WP2.2 investigated safety/separation for a particular AMSS-based operational concept. The modelled operational concept puts strong emphasis on the use of satellite systems for navigation, communication and surveillance. Navigation is based on GPS in combination with IRS. All aircraft are assumed to be equipped for RNP-5 and to fly according to it. Surveillance is through ADS reporting by aircraft to ATC and there is no support from radar systems. The air traffic controller has FPM alerts but no STCA. Aircraft are assumed to be not equipped with TCAS. Air-ground communication is by SATCOM-voice, there is no back-up assumed from VHF, HF or CPDLC.
- WP3.2 investigated safety/separation for a particular ASAS by ADS-B operational concept. The modelled ASAS by ADS-B concept has the type of navigation in common with the AMSS concept: it is also based on GPS and IRS and assumes that all aircraft fly according to RNP-5. However, in this concept all aircraft are equipped with ASAS by ADS-B. The ADS-B reports are displayed to the pilots on a CDTI. There is no radar surveillance by ATC. Aircraft are not equipped with TCAS. They do have automation support that detects conflicts and gives resolution advisories which the pilots confirm and then fly. There are no other communication means like VHF, HF or datalink.

Both the AMSS and the ASAS-based operational concepts have been modelled on safety versus spacing for a specific encounter type. The specific encounter type considered is due to aircraft flying at the same flight level along two parallel opposite direction lanes in a sector in the southernmost area of the Marseilles Flight Information Region. The lanes are spaced at a distance *S* from each other, where *S* is varied between 5 and 45 NM. The methodology used for the safety/separation modelling of both concepts is TOPAZ (Traffic Organization and Perturbation AnalyZer). This methodology follows several steps, leading from identification of the operational concept, via hazard identification, past stochastic dynamical modelling and analysis, to accident risk and safety criticality evaluation.

The safety/separation results are presented as a series of curves, displaying accident risk as a function of spacing *S*. Also displayed is a horizontal line representing the target level of safety (ICAO). For the safety criticality evaluation, the accident risk results are split up into a sum of contributions to risk due to different factors. The findings of the safety/separation modelling are:

- Both the AMSS-based curve and the ASAS by ADS-B-based curve pass the target level of safety at a significantly lower spacing *S* than the curve for the baseline operation in which there is no ASAS or ATC surveillance. For the AMSS model, a safe spacing improvement of about 45% is attained and for the ASAS by ADS-B model an improvement of 30% is achieved.
- If navigation performance is improved from RNP-5 to RNP-4, then the modelled safe spacing would reduce another 20% for both concepts.
- In the AMSS-based concept model only, the failure probability of satellite communication and the delays of the decision making loop, which include SATCOM delays, contribute significantly to the collision risk at the safe spacing value. Unfortunately, even making use of CPDLC as a back-up for SATCOM-voice failure in the AMSS-based operational concept is expected to have a negligible effect.

- For ASAS by ADS-B, the failure probabilities typical for aircraft technical support systems like CDTI computer, ADS-B equipment, IRS and autopilot appear not to be safety critical in the model.
- Modelled failure probabilities of airborne equipment overload of the pilots are not safety critical due to their low probability of occurrence. This applies for both the AMSS-based model and the ASAS by ADS-B model.

These findings provide basic insight into ATM conceptual design, as long as the hypothetical nature of the assessments is kept in mind. It is clear that these initial risk assessment results are not intended to answer the general question if airborne based separation is better than ground based separation. Many important airborne separation assurance aspects are simply not covered, such as different encounter scenarios, the release of fixed route structures, extension of the modelling to more demanding airspace such as continental Europe, and a large number of complex institutional issues. These aspects remain subject for further study.

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1. Introduction

1.1 Project EMERTA overview

The European Commission Fourth Framework programme covers all the Research and Technical Development (RTD) activities carried out by the European Union during the period 1994-1999. Nineteen specific programmes are part of the Fourth Framework programme. Project EMERTA (EMERging Technologies, opportunities and impact on ATM) is part of the Transport programme.

Project EMERTA was initiated in response to the Air Transport Research Task 4.1.2/19 in the fourth call for proposals by the European Commission (EC) Fourth Framework programme.

The work of Project EMERTA is centred on the implications of two emerging technologies and associated concepts for aeronautical use, Next Generation Satellite Systems (NGSS) and Automatic Dependent Surveillance-Broadcast / Airborne Separation Assurance System (ADS-B/ASAS). This scope was chosen for the following reasons:

1. It would clearly be impossible to cover the whole of CNS to any depth within the scope of the present call; hence the decision to restrict the Project's scope to the two aspects mentioned above.
2. Advances in communication technology enable a wide range of applications, including those in the air-ground and air-air communication and surveillance domains. The NGSS technologies have been identified as an essential enabler and an important area for study.
3. To build on the work achieved by the Project EMERALD and specifically from the detailed ADS-B/ASAS RTD plan. The more general, 'technology watch' element was covered by Project EMERALD; hence, a complementary, more focused activity is appropriate in response to the present call.

This report provides a high level summary of the work of Project EMERTA and includes the main findings and recommendations of this work.

1.2 Project EMERTA Objectives

The objectives of the EMERTA project are:

1. To establish the feasibility of using emerging NGSS services 'as they are' to meet Air Traffic Service (ATS) and Airline Operation Centre (AOC) requirements.
2. To support a European input to international standardisation activities in such forums as ICAO and RTCA/EUROCAE, insofar as they are concerned with the technologies and concepts covered by Project EMERTA.
3. To provide inputs to the specification of detailed requirements for a second generation of Low/Medium Earth Orbit (LEO/MEO) satellite systems and services, for deployment beyond the year 2005.

4. To assess the practical feasibility of the early introduction, in the European ATM environment, of one or more selected ADS-B/ASAS application scenarios, paying particular attention to safety and transition aspects. This will be supported by an outline indication of the cost/benefit issues associated with the scenario(s).
5. To develop initial indications and guidelines on how to deploy ADS-B in Europe, in the context of the ASAS concept, in terms of the potential requirement for reserved airspace and how best to deal with a mixed aircraft population (where some aircraft have an ASAS capability, but others do not).

1.3 NGSS activities

On the basis of the EATCHIP Communication and Surveillance strategies towards the future EATMS, EMERTA Work Package two explored the application of emerging NGSS for safety-related communications. As a second priority, the requirements associated with Airline Operational Communications (AOC) were also considered.

The work package, reported on in section 2 considered:

- The ATS and AOC applications that an NGSS may support
- The technical capabilities of emerging NGSS systems
- The airborne architecture required to support the introduction of NGSS
- The cost and institutional issues raised by the proposed introduction of NGSS
- The future requirements for aeronautical communications

In addition, a safety/capacity assessment of a particular scenario including the use of NGSS was conducted. This assessment is discussed in section 4.

1.4 ADS-B/ASAS activities

The second technology domain focuses on the use of the emerging ADS-B technologies and associated ASAS operational concept, leading towards the EATMS concept of Free Flight Airspace (FFAS). These technologies and the related concepts have already been addressed by the Project EMERALD which produced a detailed ADS-B/ASAS Research and Technological Development (RTD) Plan [To be done].

Project EMERTA followed up specific aspects of that RTD Plan. In particular, EMERTA has addressed transition issues within European airspace where, inevitably, there will be a period of many years with an environment with aircraft of with and without ADS-B equipage and ASAS capability. This transition issue further complicates the safety issue, inherent to ATC, which is the overriding constraint in developing co-operative ATC concepts. Co-operative ATC is a novel operational concept, whereby responsibility for maintaining separation is temporarily delegated to aircraft crews, in designated airspace and under specific operating rules. Co-operative ATC is intended to increase ATM capacity and efficiency, whenever and wherever flight safety is not compromised.

The objectives of studying this technology domain are:

1. to investigate transition issues, by building upon the User Requirements Analysis phase of the EMERALD RTD plan, and including an assessment of associated benefits and constraints; and
2. to carry out a high-level safety assessment of the applications developed by the EMERALD project, using hazard identification techniques.

1.5 Document Structure

The remainder of this document consists of the following chapters:

- Chapter 2 describes the work done regarding NGSS activities (work packages WP2.1, WP2.3 and WP2.4).
- Chapter 3 describes the work done regarding ASAS/ADS-B activities (work package WP3.1).
- Chapter 4 describes the initial safety/capacity results for both concepts (work packages WP2.2 and WP3.2).
- Chapter 5 summarises the conclusions and recommendations from the project.

2. NEXT GENERATION SATTELITE SYSTEM STUDY

2.1 WP2 objectives

This chapter summarises the findings of WP2 which was concerned with assessing the ability of Next Generation Satellite Systems (NGSS) to provide aeronautical communications for safety and regularity of flight as part of a future Aeronautical Mobile Satellite [en-Route] Service (AMS[R]S). A full summary of WP2 is provided in [1]

The EMERTA's NGSS study-programme contained four main work packages:

- WP2.1 – Emerging NGSS
- WP2.2 – Safety Assessment
- WP2.3 – Costs and Institutional Issues
- WP2.4 – Long Term Benefits

The first three work packages are concerned with the application of NGSS technologies in the near term (2000 to 2005 timeframe). At the onset of the EMERTA work-study, the NGSS operational scenario dealt primarily with Europe's peripheral areas, where NGSS can provide a service where traditional ground infrastructure is not available.

2.1.1 WP2.1 Emerging NGSS

WP2.1 was conducted in four parts:

- WP2.1.1 identified ATM and AOC application requirements [2]
- WP2.1.2 identified the expected capabilities of emerging NGSS. [3]
- WP2.1.3 investigated the avionics required for emerging NGSS. [4]
- WP2.1.4 matched the perceived capabilities with the identified requirements. [1]

2.1.2 WP2.2 Safety Assessment

In WP2.2 a safety assessment was conducted of a particular scenario involving NGSS mediated communications. The selected scenario involved sequences of aircraft on two opposite direction parallel lanes on the same route and same flight level separated via ADS monitoring outside radar control, in the Southern Mediterranean airspace. The scenario has the benefit of increasing that route's ATM capacity.

The TOPAZ safety assessment conducted in the WP 2.2 includes the selection of an ATC operational situation. This work is summarised in section 4 and detailed in [5].

2.1.3 WP2.3 Costs and Institutional Issues

Work package 2.3 [7] included investigations of both:

- Costs related to the introduction of NGSS [6]; and
- Institutional aspects including a brief account of events which have affected the NGSS industries over the last 5 years or so since the inception of NGSS work by the ICAO AMCP panel.

2.1.4 WP2.4 Longer Term Benefits

Work package 2.4 [8] considered the long term (beyond 2005) and investigated future ATM concepts which may enabled by new communication services supported by advanced communications systems such as the emerging NGSS. A first cut at defining requirements for both voice and data transmission in a top-down “clean-sheet approach” is also presented.

There has been a recent realisation that European civil aviation will be facing a serious air-ground communication issue within the next 5 to 10 years with the congestion of its aviation VHF frequency band. Hence, WP2.4 considered both Europe’s peripheral low air-traffic areas and the high-density ‘core’ continental airspace.

2.2 Communications Requirements

The output of task WP2.1.1 [2] is an inventory of identified ATS and AOC services, which are considered in four major areas:

- Air-Ground ATS Data Communications
- Air-Ground ATS Voice Communications
- Air-Ground AOC Communications
- Air-Air Communications.

2.2.1 Air-Ground ATS Data Communications

Air-ground ATS data communication services were divided in 3 different categories:

- Pre-ATN (Aeronautical Telecommunications Network) services use an Aircraft Communications Addressing and Reporting System (ACARS) format, are character-oriented and do not require an ATN environment. These services could be implemented on an "ACARS over NGSS" support. Their counterpart in an ATN environment is also looked at in the third category (full ATN).
- FANS-1/A services also use an ACARS format but through an ARINC 622 layer which provides bit-oriented messages.
- Future ATN services assume a completed ATN deployment. They are presented as defined by ODIAC.

2.2.2 Air-ground ATS voice communication services

Future CNS/ATM concepts mainly rely on the use of data link as the primary means of direct air/ground communications, as opposed to the use of voice communication services in today's ATM systems. In the case of low-orbit satellite-based communications, voice services will be used mainly as a back-up in case of an outage of the data link service, and for distress, urgent, non-routine communications. Basic characteristics of satellite voice communications include circuit-switched operation, channel establishment delay, speech propagation delay, full duplex operation, priority and pre-emption systems.

Satellite voice service will have three major uses as:

- Replacement of HF voice communications in the medium-term.
- Back-up and complementary means to data link communications in the longer term.
- Complementary and/or back-up to VHF voice communications.

2.2.3 Air-ground AOC communication services,

Airline Operational Control (AOC) communications accommodate the functions of the Dispatch and Flight Operations departments of an airline, and interface with other departments including Engineering, Maintenance, Scheduling and Commercial.

AOC functions operate via air-ground communications through the cockpit crew or directly with airborne systems or sensors such as Flight Management System, Digital Flight Data Acquisition Unit, Central Maintenance Computer, Centralised Aircraft Monitoring System.

Use of AOC varies between airlines, and the on board system is highly customised, by the equipment manufacturer, to the airlines requirements.

2.2.4 Air-to-air communication requirements.

Current ATM practice does not require pilot-pilot communications. Future concepts, particularly those based on ASAS, may however require direct negotiations between two aircraft. The initial basis for such negotiations would be ADS-B derived traffic information. The requirements for direct air-air communications are not well defined. An example is considered, based around a scenario where two aircraft exchange detailed intent information in order to resolve a potential conflict.

2.2.5 Communications Requirements Summary

For each service considered, the following information was gathered insofar as it is available from published sources, and analysed as relevant to Project EMERTA:

1. Operational description, including: scope, objective and operating concept; a typical set of messages being exchanged during the execution of the service, including logical acknowledgements, is listed. Each message is clearly defined and stated.
2. Performance requirements, including: message size, connection set-up time and transfer time, throughput, integrity, availability, number of messages per flight. A typical flight is considered for dimensioning ATS and AOC applications and services, and coherent with the operational scenario chosen in EMERTA.

The following table 2.1 is a simplified presentation of the final table presented in [3], which summarises the relative weights and data volume of the different services considered, for a typical in- or out-bound Europe flight of three hours duration.

Application	Transactions per flight	Octets per transaction	Total octets // kbits transmitted
ATS Data			
Pre-ATN : (ACARS)			
DCL : Departure Clearance	1	526	526
ATIS : Airport Terminal Information System	4	218	872
OCM : Oceanic Clearance	1	609	609
WPR : Way-point reporting	12	218	2616
S/total Octets// kbit	**18**		**4623//3.7**
FANS-1/A:			
CM/DLIC: Context Management/ Data Link Initiation Capability	7	238	1666
ADS : Automatic Dependant Surveillance	36	187	6732
CPDLC : Controller Pilot D/L communications	36	508	18288
S/total Octets// kbit	**79**		**26686// 21.3**
ATN:			
ACM : ATC COMMUNICATION MANAGEMENT	6	264	1584
CIC : Clearance and Information Communications	36	227	8172
DCL : Departure Clearance	1	360	360
DSC : Down Stream Clearance	1	257	257
CAP : Controller Access Parameters	30	56	1680
D-OTIS : Data link Operational Terminal Information Service	15	203	3045
D-RVR : Data link Runway Visual Range	3	152	456
D-SIGMET : Data link SIGnificant METeorological information	3	178	534
DLIC : Data Link Initiation Capability	1	540	540
ADS : Automatic Dependent Surveillance	36	56	2016
FLIPCY : FLIght Plan ConsistencY	3	872	2616
DYNAV : DYNamic route AVailability	3	454	1362
S/total Octets// kbit	**138**		**22622// 18.1**
ATS Voice			
Position reports	12		
Pilot/Controller exchanges	18		
VHF	1 max.		

Application	Transactions per flight	Octets per transaction	Total octets // kbits transmitted
AOC			
OOOI : Out, Off, On, In	4	98	392
NOTAMs Request	2	102	204
NOTAMs	2	276	552
Free Text	1	296	592
Weather Request	2	86	172
Weather	2	276	552
Position/Weather Report	1	261	261
Loadsheet Request	1	96	96
Loadsheet	1	176	176
Flight Status	2	98	196
Engine Performance Reports	1	713	713
Maintenance Items	1	888	888
Flight Plan Request	1	117	117
Flight Plan Data	1	4128	4128
S/total Octets// kbit	**22**		**9039//7.2**

Table 2.1 SUMMARY FOR AN IN/OUT – BOUND EUROPE FLIGHT of 3 hours duration.

Table 2.2 gives a similar summary, but for an intra-European flight of typical 80 minute duration and in the ATN environment assumed to be available (from 2005 onwards). In the latter table the amounts of data traffic and voice communications are given separately for the en-route phase, in upper airspace and for the whole of that flight

Table 2.2 : **TYPICAL INTRA-EUROPEAN FLIGHT PROFILE AND COMMUNICATION LOADING (HIGH ASSUMPTION)**

Average flight duration : 80 mn	**En-route flight duration: 40 mn**										
ATC Unit / Controller (2)	PRE-FLIGHT	GND	TWR	APP-DEP	E/R-ACC DEP	E/R-ACC-SECT1	E/R-ACC – SECT1	E/R –ACC-ARR	APP-ARR	TWR	GND + APRON
Datalink service	DLIC(1)	ACL	ACL	ACL	ACL	ACL	ACL	ACL	ACL	ACL	ACL
	DCL	FLIPCY	CAP : 1	DSC	D-OTIS	CAP 2x	DSC	DOTIS	CAP : 2x	CAP : 1	
	ACM	D-OTIS	ACM	CAP : 2x	DYNAV	ACM	D-SIGMET	CAP 2x	D-RVR	ACM	
		ACM		ACM	CAP 2x		CAP 2x	ACM	ACM		
					ACM		ACM				
Nr of octets, 2-way transmitted, in ea. ATC Unit	1164	1566	547	860	1260	603	1038	806	755	547	227
Volume of data for the en-route, upper airspace, flight phase, in octets and kbits					3707		29,7				
Average kbits/mn of flight and bps					0,7	and	12,4				
Volume of data over whole flight, in octets and kbits					9373		75				
Average kbits/mn of flight and bps					0,9	and	15,6				
Number of VOICE exchanges in each ATC unit	2	4	3	5	6	4	6	5	5	3	1
En-route, Upper Airspace total VOICE exchanges					**21**						
TOTAL R/T VOICE exchanges for the whole flight.					**44**						

Notes : **Datalink services acronyms** : see table 1

ATC Unit/Controller (ATCU) : (Airport)Pref-flight, GND ; Ground, TWR : Tower ; APP-DEP : (Airport) Departure ; E/R-ACC-DEP :En-Route ACC departure, SECT1 : Upper Airspace Sector 1 ; E/R-ACC –ARR : E/R …Arrival,

2.3 Avionics architecture requirements and constraints

For details refer to WP2.1.2 report

2.3.1 FANS and the associated challenges to aircraft manufacturers

The ICAO-selected FANS (Future Air Navigation System) concept for CNS/ATM promotes an extensive use of digital communications, GNSS navigation, and associated global surveillance capabilities via ADS.

Airlines see in this concept the promise of significant long term operational benefits, but they are also hoping to reap benefits with the early implementation of on-board architectures developed from the start to comply with the introduction of FANS. The architectures considered must enable incremental upgrades including modular software approvals.

The benefits expected by the airlines are:

- Reduced avionics acquisition and life cycle costs.
- Flexible software updates.
- Fleet commonality.
- Additional avionics systems capacity.

In pursuit of such objectives, the main tasks of aircraft manufacturers are to adapt their products to the different and changing environments the airlines are expected to face in time, on their air routes and in the specific world regions they operate in.

The upgrades and modifications must be organised to minimise confusion associated with the multiplicity of choice in avionics faced by the airlines.

Airlines should be assisted by the aircraft integrators in minimising retrofits, organising the compatibility between standards, minimising the impacts on peripheral equipment, and integrating smoothly the modifications required to Human-Machine Interfaces (HMI).

Moreover, to be compliant with all-applicable regulations and current aeronautical practices, installed systems must conform to ARINC equipment characteristics. They must also include BITE (Built In-Test Equipment) features and the means to communicate with the aircraft maintenance system.

According to the relevant standards, their software must be developed according to EUROCAE ED-12/RTCA DO 178 which covers software development. This is important because it is one major reason which prevents the re-use of already developed sub assemblies with integrated software used in ground systems. Furthermore, as for other avionics equipment, it is the airframer's responsibility to check that any new system, or part of it, installed on board, is:

- free of malfunctions caused by other on-board equipment, e.g. radiated emissions, conducted interference, aircraft electrical network transients, switching and short time power outages, and
- it does not generate perturbations to the other aircraft systems.

2.3.2 The SATCOM system and the on-board architecture constraints

A major on-board element of FANS is the satellite communications system, SATCOM, and referred to as the AES (Aeronautical earth Station) by ICAO and ITU. It was originally – in the late 80s - designed primarily, for Pilots-Air Traffic Services (ATS) communications, for both voice or data, even though to-day its major usage is the support of AOC and APC (Airline Passenger Communications).

The function of the AES avionics is to transmit and receive signals via satellites and to provide standardised data and voice interfaces with the remainder of the aircraft equipment. The system provides capabilities for all aeronautical satellite communication requirements that are external to the aircraft. To-day, with only the INMARSAT AMSS in use, a single AES is used for voice and data communications, either for safety and technical exchanges between ground and cockpit (ATC, AOC) or for commercial and private passengers communications (AAC and APC). This may not be the case in the future with the advent of NGSS.

Avionics architectures for satellite communications are standardised by AEEC Air/Ground Communications Subcommittee under Characteristics ARINC 741 "Aviation Satellite Communication System" and ARINC 761 "Second Generation Aviation Satellite Communication System, Aircraft Installation Provision". The second characteristic standardises systems which can be configured for several Satellite Communication systems such as INMARSAT AMSS or LEO/MEO NGSS. The NGSS considered are Iridium, GLOBALSTAR and ICO constellations, others systems being potentially usable provided they comply with recommendations set forth in the characteristics.

The standardised airborne Satellite Communications system, shown hereafter, is connected to between one and three Multi-purpose Command and Data Units (MCDU), one or two Communication Management Units (CMU) or Air Traffic Service Units (ATSU) or ACARS Management Unit for data link, the Central Maintenance System, the Audio Management System (2 channels), the Cabin Telecommunication Unit, the Inertial Reference System and other systems for discrete information (Flight/Ground, etc, as illustrated in the figure hereafter).

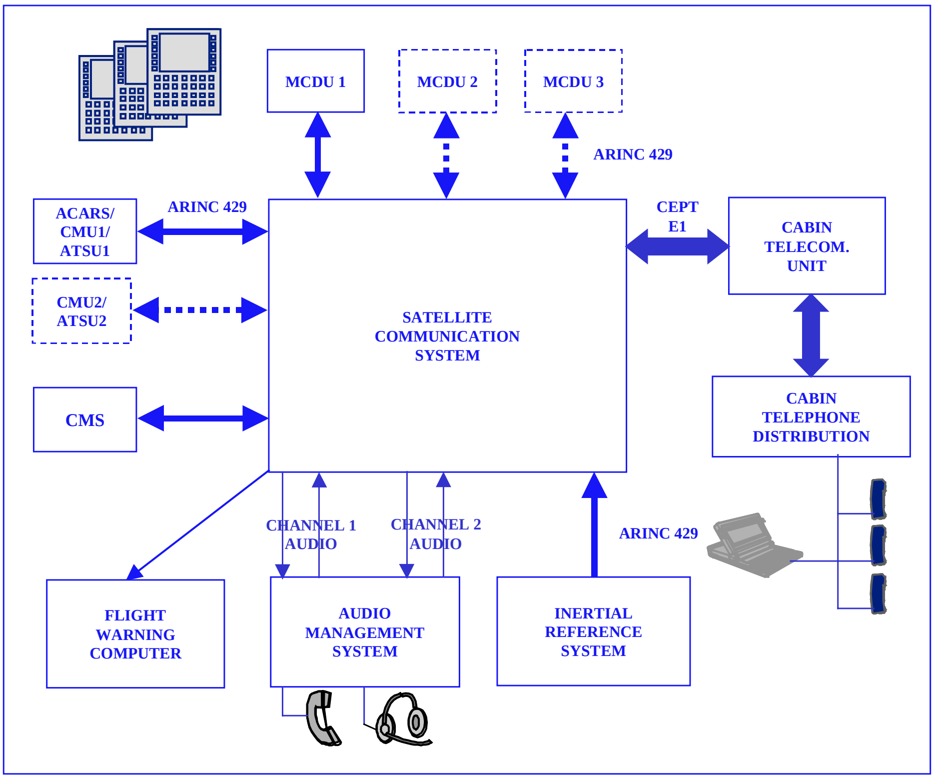

Figure 2.1 On board satellite communications system overview

2.4 Emerging NGSS capabilities

(For details refer to WP2.1.3 report)

During recent years, there has been an explosion of interest in the use of Satellites to provide global personal communications systems. Several of the associated service providers have suggested that they will offer an aeronautical service.

2.4.1 LEO/MEO Characteristics

Low Earth Orbit (LEO) Satellites fly at an altitude of up to 2000 km with an orbital period varying between 90 minutes and two hours. The expected lifespan of a LEO spacecraft is 7 years.

Medium Earth Orbit (MEO) Satellites operate at an altitude of around 10,000 km. The orbital period at this altitude is approximately 6 hours. As the satellites fly at a higher altitude than LEO spacecraft, less are required to cover the globe. The expected lifespan of a MEO spacecraft is 12 years.

This is compared to Geostationary Orbit (GEO) satellites which operate at an altitude of 35,786 km above the earth. A GEO satellite will appear to be fixed above the surface of the earth. Near global coverage of the Earth can be achieved using three GEO spacecraft (between latitudes $\pm 75^{o}$). The expected lifespan of a GEO satellite is typically 15 years.

The LEO/MEO system aims to provide global handheld low data rate voice, data, fax and paging services. These services operate at L-band (1.6 GHz) and S-Band (2 and 2.5 GHz) and aim to provide mobile terminal installations for vehicles, ships and aircraft as well as handheld. Most of the handheld systems are being offered in a dual ‘terrestrial’ (e.g. GSM, AMPS, PDC) and satellite mode terminal.

A large number of LEO/MEO systems were originally proposed, but these have now reduced to the ELLIPSO, GLOBALSTAR, ICO and IRIDIUM constellations who have filed for applications to build a system for operation. The future of IRIDIUM is rather vague, and is discussed in greater detail in work package 2.3.

In addition to LEO/MEO systems, 'Super LEO Systems' have also been proposed. These aim to provide global small terminal medium to high data rate 'Internet in the Sky'; type services. These systems plan to use Ka (20/30 GHz) and Ku-Band (12/14 GHz) operation for small terminal to small terminal and broadcast data operations. A number of systems were originally proposed but they have now merged or collapsed to leave TELEDESIC and SKYBRIDGE.

The following table 2.3 summarises the overall characteristics of the emerging LEO/MEO satellite systems.

. **Table 2.3 Summary of the emerging LEO/MEO overall NGSS characteristics**

System	**Globalstar**	**ICO**	**Iridium**
Orbit	LEO Circular 1414km	MEO Circular 10390km	LEO Circular 780 km
Number of Satellites	48 + 16 spares (8 in orbit, 8 on ground) in 8 planes	10 + 2 spares distributed in 2 planes equally spaced by 72o	66 + 6 spares in 6 planes
Inter Satellite Links	No	No	Yes – 23.18 – 23.38 GHz (Ka-band)
In Service Date	Initial Service October 1999 Full Service 1Q2000	October 2000	4Q1999
Data Rate	Up to 9600bps	2400 bps voice and data High Speed Circuit Switched Data 9,6 to 38.4 kbs. 64 kbps and higher under consideration (New-ICO)	2400 bps Voice and Data
Modulation Type	QPSK	QPSK, GMSK, BPSK	QPSK
Access Type	CDMA		TDMA
Frequencies	User Uplink 1610 – 1626.5 MHz (L-band) User Downlink 2843.5 – 2500 MHz (S-band) Feeder Uplink 6484 – 6675.5 MHz (C-band) Feeder Downlink 5158.5 –5350 MHz (C-band)	User Uplink 1985 – 2015 MHz (L-band) User Downlink 2070 – 2200 MHz (S-band) Feeder Uplink 5150 – 5246 MHz (C-band) Feeder Downlink 6075 – 7074.4 MHz (C-band)	User Uplink 1616 – 1626.5 MHz (L-band) User Downlink 1616 – 1626.5 MHz (L-band) Feeder Uplink 29.1 – 29.3 GHz (Ka-band) Feeder Downlink 19.4 – 19.6 GHz (Ka-band)
Services Offered	Voice, Messaging, Paging, Fax, Data and Position Location	Voice, Data, Paging, Fax, SMS	Voice, Fax, Data, Paging
Coverage Area	72^{o} North and 72^{o} South	Global	Global
Number of Earth Stations	16 including 6 TT&C sites	12	20
Beams per satellite	16	163 (700km footprint for each beam, extending to 1000 X 2500 km at the edge of satellite coverage).	48
Capacity	140 Users/Beam (600km footprint) (2200 circuit per satellite)	4500 circuits per satellite (if circuit mode only, to be revise under New-ICO)	236 users/Beam (700km footprint)

System	**Ellipso**	**Teledesic**	**Skybridge**
Orbit	Concordia Equatorial Circular – 8040km Equatorial Elliptical Apogee – 8040km Perigee – 4200km Borealis: Inclined Elliptical Apogee 7846km Perigee 520 km	LEO Circular 1375 km	LEO Circular, 1450 km
Number of Satellites	Concordia Equatorial Circular: 6 in 1 plane + 1 Spare Equatorial Elliptical 4 in one plane Borealis: Inclined Elliptical 8 in 2 planes + 2 spares	288 in 12 planes (24 satellites in each plane plus spares)	80. 2 sub-constellation of 40 with 20 planes, 4 satellites in each, Each plane 53o inclined to the equator
Inter Sat. Links	NO	Yes	No
In Service Date	Equatorial 2001 Global 2002	2004	2001 with 32 satellites 2002 with 64 satellites
Data Rate	Voice 2400bps Data 200 bps to 9600 bps	Mobile Terminal up to 2Mbps per target 5.54 Gbps per satellite maximum	Downlink up to 20Mbps Uplink up to 2Mbps per user
Modulation Type	OQPSK		Not Known
Access Type	CDMA		Not Known
Frequencies	User Downlink 1610 – 1621.5 MHz	Uplink 28.6 – 29.1 GHz or 27.6 to 28.4 GHz Downlink 18.8 – 19.3 GHz or 17.8 – 18.6 GHz	User Terminal Ku-band Gateway Ku-band
Services Offered	Store and Forward E-mail, Paging, Voice, Fax, Position Location	Point to Point packet and circuit switched data connectivity. Bandwidth on demand	Interactive broadband data – internet, teleworking, telemedicine, entertainment, voice, video conferencing.
Coverage Area	2001: ±40^{o} North and South 2002: 90^{o} North, 40^{o} South	Global	Latitudes ± 68^{o} North and South
Earth Stations	Not Known	Gateway concept not used	250 gateways world wide
Beams Per Satellite	6	16 (dynamic coverage over a 2200km area in 80 km spots)	18 (700km footprint)

2.4.2 Standardisation framework

In consideration of the development approach adopted so far by the NGSS industries, primarily motivated to offer general mobile services, outside the aeronautical domain, the international civil aviation organisation, ICAO at its AMCP/6 meeting in 1999 issued a set of minimum performance and acceptability criteria to be met by any NGSS candidate for the provision of safety-related communication services to the Aeronautical Community.

On the principle that if one system could be successfully assessed by the AMCP experts as passing those criteria, which was the case of IRIDIUM in 1999, it was then decided by ICAO to recognise that commercial NGSS have the potential to offer AMS[R]S and accordingly to develop SARPS needed for the development of the additional NGSS features needed to provide safety-related communications service. Given these systems overall design and performance levels disparity, it was decided to develop two levels of ICAO standard documentation :

1. Generic High level SARPs, of regulatory nature and focusing on the minimum set of service - the AMS[R]S requirements.
2. Systems-specific appendices specifying the functional and performance details, with adequate design and functional description, covering the physical and functional interfaces to the aviation users infrastructure including the airborne equipment and the ground ATS and AOC facilities.

Since the demise of IRIDIUM, the standardisation activity has been left at the stage of the development and ICAO endorsement of the high level SARPS, known as the Annex 10 Volume 1 part III, Chapter 12 SARPS. Formal commitment to the provision of AMS[R]S from the NGSS Industry is required before ICAO/AMCP resumes activity on the second level of system-specific documentation.

2.5 Assessment of emerging NGSS

For details refer to WP2.1.4 report

2.5.1 Comparison NGSS and current AMSS

When comparing, from the avionics point of view, aeronautical NGSS to geostationary systems, the following points may be highlighted:

- The link budget is better for NGSS. A simple omni-directional antenna is sufficient for NGSS as opposed to the high gain antenna with complex beam steering required for GEOs.
- The required RF output power is far less for NGSS than for GEOs. This allows savings on energy consumption (of both electrical power and cooling/ventilation), and on installed mass on board the aircraft.
- Packet data communication protocols are not part of the services offered by NGSS. In general, these systems have been designed for circuit switched voice, fax and data communications, even if service providers have announced their plans to emulate packet communications on switched circuits. Note however, that NewICO has recently announced plans to offer aeronautical packet communications services by year 2003.

- Polar coverage is provided by ICO, while GLOBALSTAR coverage is limited to 70° latitude and GEOs are limited to less than 75 ° latitude,
- GEOs are compliant with ICAO SARPS, while any NGSS compliance has yet to be established with regard to the provision of safety aeronautical communications and furthermore on a long-term service basis. The recent (year 2000) and abrupt service termination by IRIDIUM has fully illustrated this point. As a result, full demonstration of service compliance and long-term availability from any NGSS operator is an absolute requirement prior to any decision by both aircraft manufacturers and their airline customers to commit themselves to the large investments necessary for installation and certification of such systems on board and on ground.

2.5.2 High-Level assessment: An Aviation Authority Perspective

The differences between LEO/MEO NGSS and the current INMARSAT AMSS mainly lie in the area of:

(a) communication handovers from beams to beams and satellites to satellites; and

(b) provisions for priority management of safety-related versus non safety transmissions.

Subsequently, using the documentation released by IRIDIUM and GLOBALSTAR promoters, some essential points can be highlighted:

- Current NGSS are not an appropriate solution to be used as a communication media for surveillance applications such as ADS-Broadcast, insofar as they are designed to support point to point communications with no obvious way to emulate a broadcast mode.
- As far as voice is concerned, through their conference capabilities, NGSS can create small groups of users, in view of supplementing ADS-B with air-air communications in relation with co-ordination attached to de-conflicting.
- The end-to-end performance levels are not easy to assess as the NGSS service provider might not fully master the characteristics of the Public Switched Telephone Network (PSTN) used in ground to ground transmission.
- As part of their cellular architecture, all these systems feature a mobile users' mobility management scheme, whereby their respective ground earth stations have to locate and keep track of their users' geographical position. This function is performed with varying degree of potential accuracy, ranging from a few hundred of meters - to several kilometres depending whether they feature multi-satellite coverage (as is the case for GLOBALSTAR and ICO). This position information could be provided to state authorities, maritime or aeronautical for Search and Rescue, with the advantage that the determination of position provided by these systems is completely independent of any navigation equipment onboard the aircraft.

The demise of IRIDIUM (see section 2.7.2 below) has deprived the Aeronautical Community of the practical experience it was expecting from system operations. For example, tests performed by the Canadian Department of Defence have shown a likely correlation between drop of voice communications and satellites hand-overs. Unfortunately, it may never be known if this flaw was related to a system still in its infancy or rather a genuine problem, of direct relevance to the Aeronautical Community.

The analysis of the documentation released by both, IRIDIUM and GLOBALSTAR has identified many instances of poor visibility in their technical design and performance. As an example, the commitment of IRIDIUM, made formally at ICAO AMCP/6 in 1999 to provide, in the future, compatibility of their system, with the ICAO-defined ATN was not backed up by any detailed information, susceptible of clarifying the path they would have followed to emulate switched virtual circuits, over circuit-mode telephony channels needed for packet data transmission.

2.6 Economics considerations

(For details refer to the WP2.3.1 report)

2.6.1 Objective and approach

The objective of this work package was to perform a comparative cost assessment of different alternatives, including NGSS-based alternatives, for the provision of European voice communication services on the one hand, and data communication services on the other. The study focused on the services defined in WP2.1.1 as short/medium term i.e. from year 2003 onwards. As the services are proposed before the deployment of ATN, no ATN environment related costs are taken into account.

The comparison exercise was a positioning study for the NGSS against alternatives that are already operational or at least very mature while NGSS operators have still to define their aeronautical services.

The lack of information about NGSS aeronautical services available during the study meant that the exercise proved to be more difficult than initially planned. The most precise elements came from Iridium; but were not used due to the demise of the system.

Different potential alternatives either for voice communication and data communication were initially listed but as the analysis period starts in the short-term, and because many potential alternatives are not mature enough or are not planned to provide a full European service, only a few alternatives were selected for further study These are the following:

- GLOBALSTAR
- INMARSAT AMSS
- VDL Mode 2

For each of those alternatives, costs for the ATS providers and costs for the airlines were studied separately.

2.6.2 Economic Assessment Conclusions

The cost comparison found that:

- The VDL Mode 2 alternative does not require big investments be either ATS providers or airlines. Transmission charges are relatively “cheap”. However, there are two major constraints: the coverage is limited compared to satellite based alternatives, and there is the potential problem of VHF spectrum congestion which is partially solved by the introduction of 8.33 kHz channel spacing.
- Concerning the AMSS alternative, the proposed services are more expensive than those of VDL Mode 2, but the coverage is nearly global. Consequently, the main interest of this service appears where there is no VHF/VDL coverage.

Given these findings and the likelihood that GLOBALSTAR performance and associated costs are unlikely to be better than those of VDL Mode 2; its promoters should target first to provide services wherever poor or no VDL services are provided, i.e. in low/medium density continental areas, and in oceanic areas. In this context, it is in fact in direct competition with AMSS.

Then, in a second objective, GLOBALSTAR could also expect to take a market share in higher density airspace for non-critical applications, in particular as a back-up to existing VHF/VDL services which are threatened by the VHF spectrum congestion.

Finally, it seemed more interesting to use NGSS in en-route phase than in the other phases of flight, for the following reasons:

- in en-route phase, the more stabilised flight configuration allows performance similar to VHF, in terms of transfer delay and access time,
- the freed up VHF frequencies would be more efficiently used in lower airspace.

Communication costs have then been compared to the other operating costs of the aircraft. This exercise pointed out that the communication costs estimated in the study for En-route represented less than 1% of the "cash direct operating cost" (which includes fuel costs, engines and aircraft maintenance costs, crew wages, landing charges, navigation and communication charges).

2.6.3 Initial market sizing for AMS[R]S communications over Europe

Traffic statistics (cf. EUROCONTOL CRCO) indicate that there were approximately 7.9 million IFR flights in Europe in 1999. With a yearly increase of 6% (average experienced in the 1990s), this traffic should reach about 11.2 million IFR flights in 2005 and 13.6 million by year 2008, assuming a somewhat reduced rate of growth from 2005 onwards, down to 4% (year 2008 quoted here as the target date for the generalised datalink services in Europe under the EUROCONTROL-co-ordinated LINK 2000+ programme)

In 1999, the proportion of intra-European flights out of the total number of IFR flights in Europe was in the order of 85% (from STATFOR).

The typical out-of-Europe and intra-European flight profiles and communication throughputs have been assessed in section 2.2 for ATS and AOC data on per flight basis and are summarised in the table below:

Type of communications	Volume in Octets per flight	Volume in kbits per flight
ATS comms on intra-Flight	3707	29.6
ATS comms in an out-of-Europe flight	22 622/6 (1)	30.1
AOC comms on intra-Flight	2456 (2)	19.6
AOC comms in an out-of-Europe flight	2456 (2)	19.6

Table 2.4 : En-route ATS & AOC data volume per flight

Notes:

1. The table 2.4 amount is for 3 hours, hence the dividing factor by 6, corresponding to 30 mn of within upper European airspace flight
2. The types and frequencies of AOC messages, shown in table 3-1 do not vary much with flight duration, hence the same value taken for both the intra and out-of-Europe flights. The figure of 2456 octets corresponds to the AOC s/total, minus the 4128 for “flight Plan data”, as this communication occurs infrequently and divided by 2 to consider data transmitted over Europe.

To get financial estimates of the communication market, different assumptions concerning the communication unit costs and avionics equipage can be made:

- a low assumption based on today’s ACARS cost-rate, which is 0.1 EUR per kilobit, bearing in mind that the current AMSS unit cost is in the range of 0.3 to 0.5 (depending on data volume) and aircraft avionics equipage of 30%.
- a conservatively high assumption based on today’s comms cost rate and a 90 % avionics equipage.
- a high assumption based on today’s AMSS comms cost-rate of 0.3 ME/kbit and a 90 % avionics equipage

All the assumptions, main parameters and results are of this market evaluation are summarised below:

Assumptions and main parameter values	Unit	Value
Year 1999 total IFR traffic in Europe	Million movements	7.9
Yearly traffic increase in the 2000-2005 period		6%
2005 total IFR traffic in Europe (movements)	Million movements	11.2
2008 total IFR traffic in Europe, (4% growth)	Million movements	13.6
En-route ATS data volume per intra-Europe flight (85% of flights)	kbits	29.6
En-route ATS data volume for out-of-E flight (15%)	kbits	30.1
En-route average ATS data volume per flight	kbits	29,6
En-route AOC data volume per flight	kbits	19.6
Total en-route com data volume per flight	kbit	49.2
Low communication cost rate assumption	EURO/ kilobit	0.1
High com cost assumption	EURO / kilobit	0.5
Low avionics equipage rate assumption, in year		30 %

2008		
High avionics equipage rate assumption in year		90%

Table 2.5 : AMS[R]S market size analysis

Results : annual data communication market sizes, in year 2008 under different assumptions:		
Low comms cost and avionics equipage rates	Million EURO	20
Low comms cost and High avionics equipage rates	Million EURO	60
High comms cost and low avionics equipage rates	Million EURO	60
High comms cost and high avionics rates	Million EURO	180

Table 2.6 : AMS[R]S market size analysis

2.7 Institutional aspects

(For details refer to the WP2.3.2 report)

2.7.1 Background

Institutional considerations were first elaborated by the ICAO FANS (Future Air Navigation Systems). As the result, a set of guidelines to assess the adequacy of provision of Aeronautical Mobile-Satellite Service (AMSS) were reviewed by the attendants of the 10th ANC and subsequently endorsed by ICAO.

These guidelines were drafted under the technical context of the day: that GEO-stationary satellites were to be developed and operated by inter-governmental agencies. INMARSAT was the most prominent, and over which the Civil Aviation Authorities were believed to benefit from some degree of control, via their INMARSAT signatories, which were mostly State-owned telecommunications organisations.

By 1994, with the emergence of NGSS, such as IRIDIUM, GLOBALSTAR, and ICO further institutional issues arose:

- NGSS were to be operated commercially not by intergovernmental organisations.
- A multitude and heterogeneity of NGSS in terms of standards, space infrastructure and airborne equipment emerged.
- The long-term availability of the proposed aeronautical communication services, by essence safety-related and hence expensive to develop and run, would be at the mercy of purely commercial, general-purpose communications services - and indeed market forces.

These points have been expanded by a EUROCONTROL-funded study [9].

2.7.2 AMSS and NGSS evolving scene

During the project, there have been several developments within the NGSS scene, the principle developments were:

- The demise of IRIDIUM
- The privatisation of INMARSAT
- The emergence of NewICO

- The ESA-funded AMS[R]S developments

Each of these developments is discussed in turn.

Demise of IRIDIUM

The demise of IRIDIUM is one of the most significant events since ICAO decided at the 4th meeting its AMCP in 1995 to look into the feasibility of using next generation satellite systems for the provision of AMSS -systems and services - bearing in mind that the IRIDIUM promoters were quite instrumental in promoting to ICAO and its AMCP the undertaking of such a task.

The IRIDIUM constellation and associated ground segment were fully deployed in the 2^{nd} half 1998, but then its operators had to file for bankruptcy proceedings and protection against creditors' claim in the summer of 1999. The resulting court proceedings culminated in the decision, reached in the spring of 2000 to affirm bankruptcy, to cease operations and to de-orbit all the constellation satellites (66 plus spares).

This demise was amply documented in the general and specialised press, starting summer of 1999. It came as the result of an initial take-up of IRIDIUM general communication service by its intended customers, falling significantly short of the original IRIDIUM business plan forecasts by a factor in the range of 1 to 10 and even 1 to 100. Hence, the inability to meet financial commitments arising from its large development debt (in the order of 6 Billion USD) whereas incoming annual revenues flow actually materialised in few 100 k$ range.

In retrospect such an unfortunate turn of events can be attributed to :

- A misjudgement of the system's market target and size, aimed at " the Roaming Business Man" - since equipment and communication costs were set quite high by comparison to other competing satellite systems such as GLOBALSTAR and ICO.
- Failure to anticipate the rapid global deployment of terrestrial mobile telephony, on a word-wide basis, particularly that of GSM standard. Such a failure is easily explainable considering the IRIDIUM development decision was taken at the end of the 1980s, when nobody could have possibly predicted the phenomenal growth rate of terrestrial GSM experienced by the end of the 1990s,
- A system design and architecture optimised for (but constrained to offer only) circuit-mode telephony with limited bandwidth and therefore unable to be reconfigured for wide-band data services - for INTERNET users -which is the business strategy adopted since then by the competing (privatised) INMARSAT and (new) ICO systems.

Privatisation of INMARSAT

INMARSAT was set up in 1979 as an international government co-operative, whose member "signatories" representing member-states, with most of which of government or administrative status, since they were the then PTT - i.e. state-owned Post and Telecommunications organisations.

INMARSAT's main obligation under its original charter was limited to provide maritime satellite communications for "safety of life at sea", on a world-wide basis. INMARSAT then sought, by the end of the 1980s from its council of signatories, the approval to also offer land and aeronautical mobile communications services.

Having obtained such an approval, the organisation proceeded to develop today's AMSS currently deployed on 1800 aircraft world-wide. INMARSAT was instrumental in securing AMSS position as an international standard, within aviation fora (RTCA, ARINC) and ICAO, known in the latter case as AMSS Standards and Recommended Practises (SARPs).

At the time of AMSS ICAO standardisation, the thinking among the aviation community - aircraft owners, airline operators and ATS service providers - was that it was sensible to entrust INMASAT as an inter-governmental "treaty" organisation with the responsibility of developing and maintaining AMSS as an open standard system to provide AMS(R)S as a "safety of flight" service and that INMARSAT as an "international treaty organisation " would carry on safeguarding the interests of civil aviation as regards satellite communications, for the foreseeable future.

However with the generalised change of status of most of INMARSAT signatories from state-owned PTTs to privatised communication service providers, pressure grew in the 90s' on INMARSAT to change its own status to that of a privatised commercial entity. Such a move was approved by its Council in April 1999 together with the setting-up of an inter-government organisation, the International Maritime Satellite Organisation (IMSO) which inherited the former INMARSAT's duties with respect to international maritime communications and co-operation between States in public matters such as safety of life at sea and specifically the provision of GMDSS (Global Maritime Distress and Safety System).

Contrary to the previous intergovernmental INMARSAT organisation, IMSO has no technical expertise and limits itself to act as an "Treaty" Organisation with competence limited to administrative control of how the new INMARSAT "PLC" implements and runs the GMDSS service on behalf of IMSO. Accordingly the new INMARSAT provides IMSO with regular reports on the performance of its public service obligations and IMSO has open access to all relevant INMARSAT information.

Of concern to the Aviation community, starting with ICAO, is that the obligation found in the original 1976 international INMARSAT convention - whereby INMARSAT, was to take into account Standards and Recommended Practises of ICAO, in addition to that of the International Maritime Organisation (IMO), is no longer part of the new IMSO Convention. IMSO reserves its right to forward to ICAO eventual parts of the INMARSAT PLC activity reports dealing with AMSS SARPS compliance status [Ref project of agreement between ICAO and IMSO, minutes of ICAO Council, 160th session].

There is another major concern for aviation beyond the absence of a clearly formulated AMS[R]S legal obligation. Bearing in mind that the revenues INMARSAT draws from its aeronautical mobile communications service is limited to a few percent (less than 2 %) of its total revenue - the bulk of which comes from maritime communications and that usual financial market pressures on PLC organisations translate into obligations to serve their share-holders with an adequate rate of return on their investment, there is a well-founded concern on how long the new privatised INMARSAT will be able to expand or even maintain its existing AMSS operations and performance in the long run, in absence of better AMS(R)S economic prospects.

Up to now the thinking among the Aviation community regarding aeronautical SATCOM, as developed in the 80s and early 90s, can be summarised along the following lines:

- The cost of aircraft equipage and operations is high (300-500K USD for avionics, and possibly as much again for actual aircraft fitting), and since there has been little need for ATS use so far and slightly more for AOC communications, its economical justification could only come from sales of communication services to passengers. Hence, the strong insistence on the part of airlines for an AMSS providing all functions: ATS, AOC, AAC and APC for purely economic reason.
- If the avionics class certification issue is widely recognised - the conflicting safety classes ranging from "critical" to "essential" classification for ATS versus the "non interference basis" for AAC and APC - it has so far attracted little attention. If addressed at all, it was in the restrictive context of AMSS being used in conjunction with another communication system being available aboard the aircraft. The consequence is that AMS S could justifiably but restrictively be used over oceanic or deserted areas, devoid of terrestrial communications means.

The wisdom at that time was that there was no other alternative for SATCOM deployment than the so-called "generic" AMSS, to be financed through revenue streams from non essential, APC services, in order to provide for AOC needs and later for ATS, if and when ATS requirements materialise in earnest.

Since the mid 1990s, three important developments have taken place:

- the needs for Passengers communications, with the requirement for generalised and fast INTERNET access is increasingly viewed as part of the so-called IFE (In-flight Entertainment), characterised by significantly higher bandwidth requirements - in the 10 kHz to MHz range) and less stringent in-flight availability requirement;
- rapid growth and increased significance of AOC to the individual aircraft flight and overall fleet management, with the projected rapid decrease of SATCOM costs - both equipment and operations - starting with the INMARSAT AERO-I generation - by a factor of at least 3 compared to first AERO-H AMSS equipment;
- advances in and demonstration of mobile satellite communication permitting usage of low-cost omni antenna, paralleled by emergence of high performance - in terms of transmitted power and reception sensitivity - spot-beam aboard a new generations of GEO satellites.

Hence, the minority but growing recognition among some airline management boards that in the future two classes of avionics, with distinct performance and certification needs are likely to emerge:

- "cabin"' equipment, more akin to IFE,
- "cockpit" SATCOM equipment, essential for the safe and efficient conduct of flight operations.

IFE typically requires high level of performance in terms of data throughput – up to Megabits/s – but less demanding quality of service (QoS); whereas Cockpit-dedicated ATS/AOC units need less bit rate – a few hundreds bits per second at most – but demand stringent QoS and the highest certification standards.

It is worth noting that some airlines are in the process of equipping with the lower cost AERO-I, with justification for such an investment being for cockpit use only, most notably SWISSAIR.

Emergence of NEW-ICO

New ICO completed its refinancing and reorganisation in May 2000. Significant achievements so far include:

- Satellite control and network management centres in place
- 11 of 12 satellite access nodes (SANs) established
- ICONET ground network under test
- Cellular roaming agreements signed with more than 70 network operators
- Operating licences or their equivalent secured in more than 10 countries
- Introduction of global satellite service scheduled for 2003

The ICO system consists of a space segment and a dedicated ground network. Called the ICONET, the ground network will link the satellites and terrestrial networks.

The New ICO space segment will consist of 10 high-performance satellites (plus two in-orbit spares) operating in medium Earth orbit (MEO) at an altitude of 10,390 km (6,400 miles). Divided equally between two orthogonal planes, each inclined at 45 degrees to the equator, the satellites will provide complete, continuous overlapping coverage of the Earth's surface. Each satellite covers 30% of the earth’s surface Aeronautical Services.

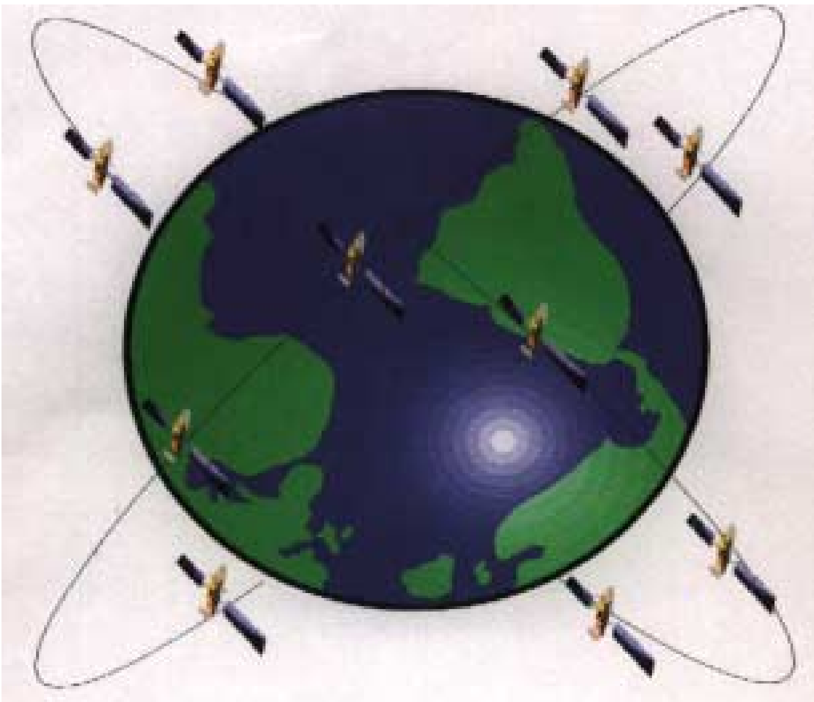

Figure 2.3 - The ICO constellation of satellites

Introduction of global satellite service scheduled for 2003. New ICO is planning a global telecommunications network enabling customers to communicate seamlessly from both fixed and mobile locations anywhere on Earth. A suite of global Internet Protocol (IP) services, including Internet connectivity, data, and voice will be developed.

Building on the mobile voice capabilities of its existing design, New ICO will also offer a family of services that are the satellite equivalent of third-generation wireless services, including wireless Internet and other packet-data services.

The New ICO system will route information from terrestrial networks through the ICONET and then up to the satellites for delivery to New ICO subscribers.

New-ICO is planning to serve commercial, private and government aircraft with a range of advanced, cost-effective services – essentially a suite of office-like communications and entertainment for passengers, as well as voice and data cockpit communications for administrative/ operational communications and air traffic services. Additional details of NewICO are presented in [10].

ESA-funded AMS[R]S activities

In 1994 The European Space Agency (ESA) undertook to study the applicability of using the experience and results collected in their experimental work - in the area of lightweight mobile satellite terminals for the transport industry - referred to as Mobile Satellite Business Networks (MSBN) towards the feasibility of a second generation aeronautical SATCOM system for the flight safety-related air/ground communications of Civil Aviation, in technical terms first, and then economically.

In contrast with the initial target of the present AMSS which has been focusing on oceanic airspace environment, the ESA study deliberately addressed the service requirements corresponding to all types of airspace, including high traffic density continental airspace. The view was also to make the service accessible, in terms of avionics requirements and operation costs, to all commercial aircraft, including (possibly) General Aviation.

Accordingly, several feasibility study contracts were awarded:

- In 1994, to a consortium led by ALCATEL ESPACE of France, which achieved a comprehensive technical investigation of the concepts for the proposed AMSS SDLS (Satellite Data Link System) using a variety of designs although mainly focusing on geostationary satellites. An economic analysis followed which established that SDLS as a next generation AMSS could, from a performance vs. cost point of view, be a credible competitor to terrestrial CNS over continents, for air-ground datalink and ADS-type surveillance, with a global world-wide coverage [ref 4]
- A further contract under the name "Synchronous Satellite Link for ATM" was placed by ESA in 1996 with NATIONAL AVIONICS LTD of Ireland with the view of refining the concept of introducing AMS(R)S "Specific Services" as a possible complement to ATN compliant services for those applications, which are time critical and highly repetitive, such as the aircraft position reporting (APR) to complement or even replace radar surveillance

In the mean time the final field test results of the MSBN experimental system successfully demonstrated the feasibility of a two-way full duplex data link, with a 4.8 kbit/s error free user data rate or high quality vocoded voice, using a lightweight terminal equipment with an omni antenna and the Global Beam of the Indian Ocean INMARSAT. This was a highly significant achievement: it demonstrated the feasibility of using low-cost aeronautical terminal equipment for both voice and data, which furthermore, because of its omni antenna allows for the simultaneous communications with two or more satellites and hence demonstrates high reliability.

Finally, based on the results mentioned above, ESA has reached the conclusions that a second generation SATCOM system:

- using primarily the regional spot-beams, (and also satellite global beams wherever spot-beams coverage is not available) as currently provided by geostationary satellites,
- using low cost aeronautical terminal, with omnidirectional antenna without expensive electronic beam-steering,
- providing a decentralised network architecture capability - Ground Earth Station (GES) co-located with the ACCs based on Very Small Aperture Terminals (VSAT) technology.
- meeting the performance and availability requirements of "primary means" systems through provision of full redundancy by means of satellite diversity, i.e. with two satellites always simultaneously in view of aircraft and associated GES,
- dedicated to the provision of aeronautical safety communications (ATS and AOC)
- could be implemented world-wide in compliance with ICAO SARPS regarding the implementation of the Aeronautical Mobile Satellite (en Route) Service as they have been subsequently endorsed by ICAO/AMCP7 for insertion in ANNEX 10, Chapter 12, Volume III, part 1.

As a consequence, taking into consideration the interests shown by several European CAAs, by EUROCONTROL as well as by European industry, ESA placed a contract after a competitive ITT, starting early 2000 for a ceiling amount of 4 million Euro with an industrial group led by ALCATEL Space Product industry. This contract is for the development of an SDLS technology demonstrator, with both voice and data transmission capabilities, with high performance - in terms of short transmission delays, integrity and dependability - to serve high air-traffic density core areas.

2.8 NGSS/AMS[R]S future requirements and key features

The AMS[R]S future requirements, are proposed in this chapter as the result of looking at the European ATM from both an ***operational concept*** and ***RF-resources limitation*** viewpoints.

On the conceptual level, within EMERTA, a high-level review of the relevant ATM long term strategy and research activities (among the most noteworthy, ATM2000+, EUROCONTROL CNS Strategies, PHARE, FREER, Fourth Framework programmes – such as EMERALD and TOSCA- and US FAA NAS Architecture) led to the preliminary identification of the following desirable characteristics for an aeronautical communications system:

1. Fully integrated voice and data services.
2. Mixed Services: ATS, AOC with a suitable priority, precedence and pre-emption mechanism
3. Full segregation between application and communication equipment levels to give operators complete transparency over the communication architecture
4. Inclusion of up-to date HMI technologies
5. Security provision and interference protection
6. Multicast communication within closed user groups
7. Broadcast mode for wider geographical/operational applications
8. Possibility to exchange large file sizes
9 Air-Air (in addition to Air-Ground) Services

Another major ATM concern stems from the examination of the demands placed on the aeronautical VHF band (119-138 MHz, which inexorably points to its congestion within the next few years. Today this band is mainly used for air-ground radio-telephony - voice service - although a few channels, of 25 kHz bandwidth, are assigned for ACARS data transmission essentially for AOC. With the rapid growth of air-traffic experienced worldwide in the last decade, both VHF radio-telephony and ACARS are being increasingly used to the point where their saturation can be predicted within the next 5 to 10 years and accordingly new aeronautical communication systems needs to be researched **now**. And this on account of the extended time - aviation history shows -it takes to define, validate and deploy any CNS, in order to avoid that ATM in Europe, already facing the prospects of ATM-capacity limitations, be further constrained by lack of RF-spectrum resources, mainly due to the spectrum-inefficiency of the current VHF R/T.

2.8.1 Context : forthcoming congestion of the aeronautical VHF Frequency band:

- There is little scope for significant improvement in spectrum efficiency of the aviation terrestrially based systems due to intrinsic limitations in frequency re-use[1] and this applies specifically to the current aeronautical VHF R/T system. Besides this system is obsolete, spectrum-inefficient, vulnerable to spurious interference and malevolent intrusion and thus putting flight safety at risk
- On might recall that ICAO in 1995 decided to standardise and approve the use of 8.33 kHz channel spacing as the way of finding new VHF frequencies, for deployment when it is most critically needed i.e. in the European region. It also decided that VDL Mode 3, with its TDMA scheme offering 4 separate channels on 25 kHz, was the way of the future.
- Since November 1999, the use of the so-called 8.33 kHz spacing has been made mandatory in the upper airspace over the Core Area of North Western Europe, where

[1] linked to the size of the protection area allowed for a given frequency, itself dependant on the flight level aircraft are flying at, and which is typically of 800 km diameter for flight level 30000 ft

the air-traffic density is at the highest. Voluntary action is being encouraged, under the auspices of Eurocontrol to expand the usage of the 8.33 channel spacing arrangement, both horizontally, i.e. onto the periphery of the core-area States and vertically, to lower ATC airspace. Nonetheless, with the relentless growth of air-traffic, resulting into ATCOs plans for airspace "resectorisation" into finer ATC sectors, each requiring their specific VHF frequency, and with the introduction of datalink within the ECAC area under the EUROCONTOL-defined LINK 2000+ programme, the prospect of running out of available frequencies is now predicted to materialise in less than 10 years. This has been formally established this year (2000) with an action paper to the EUROCONTROL ATM/CNS Advisory Group[2]. This paper states that starting year 2005, not every demand for new VHF frequencies will be met and by year 2010, only half of those demands will be met at best, irrespective of the success and extent of the 8.33 kHz spacing scheme expansion.

- As regards the deployment of VDL Mode 3, following the ICAO 1995 decision, what was not anticipated at that time, was the difficulty to reshuffle regional frequency plans to make room for new 8.33 and TDMA 25 kHz channels[3], nor the potentiality of reverting to 25 kHz spacing, once whole chunks of the spectrum region between 119 and 137 MHz would have been totally allocated to make room for the 8.33 channel introduction. As the result the deployment of VDL mode 3, might turn out not feasible after all. In addition, airlines who have fitted their aircraft with 8.33 radios for operations in Europe strongly advocate their use on a world-wide basis and are reluctant to re-equip or upgrade for VDL Mode 3 regional deployment

2.8.2 Need for an advanced aeronautical communication system in a fully integrated voice and data environment:

The Air Traffic Management community is on the verge of introducing datalinks into the operational domain for future communications systems under the EUROCONTROL-co-ordinated LINK 2000+ initiative. Assuming LINK2000+ gets formally endorsed by end of year 2000, the first datalink to be deployed for operational use is expected to be VDL Mode 2 and its implementation to become effective from end of 2007 onwards.
The selection of a successor to VDL Mode 2, needs to be decided with a choice of either VDL Mode 3 or VDL Mode 4, the latter two currently at the stage of SARPS validation, as part of the Aeronautical Telecommunications Network (ATN). It should be borne in mind that VDL Mode 3 provides both voice and data services, which is not the case of VDL mode 4, limited to data transmission

However, even as these new systems are introduced, now is the time to look forward to other emerging technologies. The role of communications, and in particular integrated voice and data services, is growing within all business domains, and the same can be said for ATM

2.8.2.1 Clean sheet approach to defining communication requirements from the end-users' point of view

Under a "clean sheet" approach, and on the basis of background and collective experience reported by the ICAO AMCP, one can generate a set of mandatory requirements and key features expected for a future aeronautical communication system [refer to WP2.4]. These are

[2] … EUROCONTROL AP /ACG/8/9 under Agenda Item 14b, 24-25 May 2000

[3] with wider guardbands for protection against adjacent channel interference

expected to apply either to terrestrial or satellite-based (refer to EMERTA WP 2.4.1.2 report). Compared to today's aviation VHF and satellite-based AMSS infrastructures, such a system will provide for the following benefits:

a) **High performance**: its performance level will be adequate to serve high air-traffic density airspace regions, typical of Central Europe (so-called "Core Area") in terms of communication set-up times and delays, as well as capacity to accommodate air-traffic, at the projected levels beyond year 2010 and throughout an aircraft whole flight phase profile,
b) **Both VOICE and DATA** services to be provided services, with voice priority over data - These two services will be provided in a highly integrated application and radio sharing environment, thus allowing more efficient HMI, hence greater end-users' comfort and confidence, and accordingly, enhanced ATM safety and operation productivity,
c) **Segregation of the ATM applications level from communication infrastructure:** it will provide a communication architecture, at the service/application upper levels, capable of supporting an ATM airspace organisation optimised for air-traffic flow efficiency, independently from the radio architecture and resources (e.g. frequencies) management constraints inherent with today's VHF analogue system,
d) **SECURE Communications**: It will bring in secure communication capabilities by providing robustness to spurious signal interference and protective features to guard against intrusion by unauthorised users, including possible use of encryption techniques,
e) **Relief of VHF band congestion pressures**: In the case of satellite-based system, the use of the ITU AMS[R]S spectrum allocation would ease up the forthcoming congestion of the aeronautical VHF (108-137 MHz) band.

2.9 Expansion of SATCOM use to upper airspace over continental areas

2.9.1 Availability of RF-Spectrum under ITU Radio-Regulation

By contrast to the terrestrial VHF systems nearing spectrum congestion satellite-based systems benefit from an ITU AMS[R]S frequency allocation for safety and regularity of flight communications services – twice 10 MHz, in the L-band region for the earth to space and space to earth directions of propagation - on a priority basis compared to other aeronautical mobile non-safety users, under the Radio Regulation (RR) terms granted by ITU-WRC 97; (prior to 1997 WRC the AMS[R]S allocation was on an exclusive basis). Moreover and contrary to terrestrially based systems, the spectrum efficiency of satellite-borne systems can be made more performing as traffic increases by implementing finer and finer satellite spot-beam footprints on the Earth surface[4], and by re-using frequencies in a way analogous to mobile telephony cellular architecture. This spectrum is available to Aviation, provided Aviation authorities commit themselves to making effective use of it- otherwise that band will be claimed at ITU WRC [5]by MSS (Mobile Satellite System) –non-safety users under authority allowed to those latter users by the same RR terms referred to above.

2.9.2 Satellite spot-beam technology potential benefits to aviation

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[4] the size of those foot-prints- originating from large dimensions (> 10m) GEO-based satellites- are expected to be equivalent or even smaller than those of the protection areas needed for aircraft flying at 30 000 feet levels – see note above

[5] World Radio Conferences

The emergence of narrow spot-beam satellite technology brings in the additional benefit of higher receive sensitivity (G/T ratio) and transmission power of such levels that they permit the use of low-drag and low-cost omnidirectional antenna aboard aircraft and therefore of affordable avionics.

Accordingly one can readily anticipate that by year 2010 onwards, satellite communications (SATCOM for short) service could become an attractive option compared to frequency-congested VHF systems, particularly for upper-airspace air-ground communications, for the following reasons:

a) ***loosening up the VHF band congestion***: assuming that they are in the vicinity of 100 to 140 upper airspace sectors over continental Europe, use of SATCOM would free up some 100 VHF frequencies, for reuse by lower airspace sectors. And given that those latter sectors require significantly smaller protection areas, the frequency reuse gain would even be more significant,
b) ***fully integrated Voice + Data***: SATCOM provides an integrated Voice and Data environment, with up to date communication technology and standards and with all the flexibility of modern communication architecture, whereby the technical management of that architecture's communication resources, such as frequencies, is totally transparent to its end-users - Controllers and Pilots; this is not the case with none of the existing ICAO VHF standards, i.e. 8.33 kHz double-side band AM, VDL Mode 2 or 3, nor VDL mode 4
c) ***protection against intrusion and interference***: SATCOM technology, with its degree of sophistication compared to terrestrial systems, use of digital techniques and higher frequency bands, brings in a much higher level of protection against both intentional and hostile interference than the current analogue VHF technology which dates back in conception from the 2nd world war era.

2.10 Other potential NGSS benefits : Aircraft Independent Surveillance and SAR:

- With the exception of IRIDIUM, all NGSS offer multi-satellite paths diversity, and therefore the potential for providing mobile and more specifically aircraft position determination, through ranging measurements simultaneously carried out on two or more satellites communications paths. If this position determination is less accurate than that of GNSS[6] its main benefit is its total independence from the aircraft navigation sources of data and as such, it can provide a valuable integrity information on any ADS-type surveillance
- The small size and power consumption of NGSS terminals combined with possibility of achieving NGSS mobile location determination could also be put to profit for the provision of SAR (Search and Rescue) operations

2.11 Obstacles to overcome and R&D needs /Plan

The expanded use of NGSS/AMSS over continental high air traffic density areas raises a number of challenges, since in the eyes of most ATM stake-holders to-day, the current AMSS is limited in performance and expensive to own and operate. Obviously there are a number of prerequisites before SATCOMs- expected to be part of a future Advanced Aeronautical

[6] Global Navigation Satellite System

Communication System (AACS) - can establish themselves as a credible principal air-ground communication means over high air-traffic density areas. Among the most prominent, they need to demonstrate:

- (quasi*) immediate access* and *negligible* transmission delays,
- high level of overall *dependability* with readily availability of back-up systems, e.g. VHF R/T in case of catastrophic communication failures;
- *economic affordability*, supported by an evolutionary and scalable development/deployment process
- *transition path* from today' predominantly analogue VHF/HF communication environment to a future digital - terrestrial and satellite based - communication environment, acceptable from the ATC safety point of view

2.11.1 demonstration of technical performance capabilities

Foremost, they are two areas of technical performance where significant improvements compared to the current SATCOM capabilities, have to be made:

- ***quasi instantaneous access***: To-day aeronautical users, controllers and pilots- enjoy to immediate access to the communication VHF medium, through a simple microphone "push-to-talk" action. By contrast Current AMSS is really a "telephony system" using the establishment of a circuit mode to "channel" the message or conversation to its intended users and it typically takes 20 to 30 seconds to establish a communication circuit prior to its uses. This is clearly unacceptable for controllers in busy ACCs and a new mode of granting telecommunication access, with response time of no more than at maximum needs to be implemented and offered to the controller. It is expected that the gain on quality, due to fully digitized voice, enhanced protection against interference and hostile intrusions, would somehow compensate for increased access delays compared to-day's VHF generation.
- ***overall availability and dependability***: they need to feature a highly redundant architecture to allow for the recovery from a satellite catastrophic failure with minimal impact on flight-safety: This implies "hot redundancy", with a minimum of two satellites in view of any aeronautical mobile. More specifically enough satellite *coverage redundancy* needs to be provided, so that one satellite failure would affect a limited area so that only a few VHF back-up frequencies would suffice to restore air-ground communications.

2.11.2 Economic affordability : modular architecture and cost sharing with other satellite services

The AMSS evolution or NGSS needs to be conducted in a manner ensuring that there is both cost visibility and justification in terms of rendered services to end-users, and economic affordability to their system and service promoters. Progressive phased deployment needs to be planned to enable the recovery of investment costs on a short/medium term basis as air-traffic and communications means expand.

a) modular approach for system architecture and progressive deployment
Accordingly system sizing, and associated development and deployment planning, need to be performed on a step by step modular approach, with well focused service objectives at each phase to assist in the associated business case planning. The scope of service need to be pan European for system sizing, with traffic loading projected over the whole life development

and deployment cycle. It also needs to be scalable to smaller areas and air-traffic loads so that at each incremental step of deployment a way to economic sustainability can be assured.

b) search for cost sharing with other satellite services:

- Fixed communication services: investigate feasibility of installing and operating a mobile communication satellite payload on GEO-based satellite or LEO/MEO constellations to spread the space segment costs (satellite development, in orbit launch and on orbit operations) among its many users

- Navigation satellite services: investigate feasibility of fitting an AMS[R]S payload on the satellites of the future European GALILEO satellite navigation systems

From the institutional viewpoint the search for suitable cost sharing would need to investigate the combined Public and Private Partnership (PPP) scheme for funding the necessary fr(?)ont-end investments. As regard technical performance, in order to guarantee the aviation customer an agreed level of service, the design of shared satellite platform would need to include a Priority, Precedence and Pre-emption scheme as defined by ITU and ICAO standards, so that communications resources would be always be made available to AMS[R]S on a priority basis in case of contention for those resource between safety and non-safety related service requests.

2.11.3 Acceptability by end users : Human Machine Interface Adaptation Challenge

Currently terrestrial air-ground communications employ techniques, which are simple to master from a technical and operational standpoint, and with a clear distinction between voice and data communications. However, being fully analogue their main advantage is to provide immediate access (“on the air”) to operators in a “Push to Talk” mode operations, but with all the pros and cons of “party line” operations, i.e. controller and pilots sharing a voice channel in a full duplex mode. Such a “party-line" sometimes brings benefits to pilots for increased situational awareness, but at others, confusion of call-signs and misunderstanding of clearances and thus putting flight-safety at risk

Introduction of a fully integrated “Data plus Voice” environment will inevitably bring changes to the operators working environment, possibly more so for ATC controllers than for pilots but at the same time bring in definite opportunity to raise the controllers work productivity. Current ATCO[7]s attention–demanding and repetitive tasks such as:

a) aircraft symbol designation on a radar screen ,
b) flight-plan selection on an TID (Touch Input Device),
c) data message or voice-call initiation

can be simplified and/or combined by taking full advantage of modern HMI features using voice, sign and pattern recognition (as well as ergonomically proven selection of visual symbols and aural signals with associated choice of colours and display fonts). Obviously, the opportunities brought by digital communication require some adaptation on the part of ATC personnel. The traditional “party-line” can even be recreated selectively, i.e. one-way from ATCO to all pilots – or even two-way with all air-originated communication being copied to all pilots.

[7] ATC Officer

The introduction of such advanced HMI features will have to be validated by ATC Officers, and their operations procedures adapted accordingly with the double objective of enhancing safety and productivity.

Furthermore the transition from the existing « manual », « analogue » and fragmented communication infrastructure to the future one, will have to be tackled as early as possible, for both the technical and operational aspects, as soon as its technical characteristics become sufficiently established

2.11.4 Safe transition from the current analogue to the future digital communication environment

In addition to taking into account air-traffic - and resulting communication loading - demands to the future Advanced Aeronautical Communication System (AACS), NGSS/AMS[R]S architecture need to deal with the transition issue from the current to the future communication environments, from both the ATC safety standpoint. This implies:

i) an early look at certification requirements applying to both the on-board and ground ATC segment,

ii) recognizing the need, early on in the study process, for system diversity and specifically ensuring continuous availability of back-up VHF frequencies

2.12 Conclusions

2.12.1 Study findings overview

The key findings of the EMERTA NGSS study can be summed up as follows:

- NGSS are being assessed in the current SATCOM context under which the INMARSAT AMSS is used on a daily basis on about 2000 aircraft. So far the use of this SATCOM technology has been restricted to oceanic/remote areas, on account of both high airborne equipment costs and communication charges. This may explain why AMSS has so far experienced a rather slow uptake of its safety related service, i.e. the AMS[R]S.
- NGSS since their inception in the mid 90s have given rise to expectations of bringing a better and cheaper AMSS service to the aviation community. These expectations have not materialised at the time of writing of this report.
- ICAO in its 6th AMCP meeting in 1999 formally endorsed the conceptual feasibility of the use of commercial NGSS for the provision of AMS[R]S and subsequently, in year 2000 decided to develop appropriate SARPS needed for deployment world-wide. These SARPS are two-tier, comprising (a) a **generic** set of high-level regulatory and **service** definition standards applicable to all systems and (b), **system-specific detailed specifications** of performance and interface characteristics with airborne avionics and ground ATM/AOC infrastructure.
- However with the recent demise of IRIDIUM, the NGSS Industry effort needed to develop the second level has stopped until such a time another system's promoter, formally offers AMS[R]S and is willing to contribute the significant level of efforts within ICAO's panels required for such a development, and also to assist RTCA/EUROCAE to generate the usual aviation industry standards - MASPS and MOPS.

- There are serious doubts about the long-term availability of the AMS[R]S service of satellite systems mainly developed to serve a bigger evolving mobile communication markets, beyond the specific needs of civil aviation - which is a small but difficult market in comparison
- With the demise of IRIDIUM, there is only a single LEO/MEO NGSS project with plan of offering AMSS/AMS[R]S: i.e. New-ICO. It is worth noting that this New-ICO offer is based upon granting access to its new packetized data transmission service, making use of the TCP/IP protocols suite starting with the AOC provision. If such an offer succeeds, there will be pressure on ATS authorities to move towards, or be compatible with, the generic TCP/IP INTERNET for ATSC in addition to AOC, instead of deploying the ICAO-standardised ATN
- The ESA/SDLS concept based on the use of geostationary satellites and dedicated to the provision of AMS[R]S is now proposed as the next generation AMSS with the capabilities to serve high-density airspace in addition to oceanic/remote areas. A technical demonstrator is currently under industrial development, as a first step to establish this new concept credibility.
- The AMS[R]S data market, over Europe by year 2008 is estimated to be in the range of 20 to 60 millions EURO, at a the charging rate of 0.1 EURO per kilobit and under avionics equipage varying from 30 to 90 % of the commercial aircraft fleet.

2.12.2 Recommendations for future R&D activities

- In high density airspace, over the European north-western core-area and in the US north-east area, the available aviation VHF spectrum is now predicted to be totally used up within 8 to 10 year by new ATC sectors R/T needs, even under assumption of "aggressive" deployment of the 8.33 kHz channel spacing scheme. Consequently the civil aviation authorities, operating in these regions, can not escape having to make difficult decisions regarding:

  a) the implementation of datalink as a way to release the ATC Controllers from time-consuming routine R/T communications with the objective to improve their productivity thus avoiding further airspace resectorisation,
  b) the search of a successor to the current VHF R/T system, which is obsolete, spectrum-inefficient, vulnerable to spurious interference and malevolent intrusion and thus putting flight safety at risk. This successor could be the ICAO-standardised VDL Mode 3, if implementable after all - it requires 25 kHz channels, which would no longer be available under generalised deployment of the 8.33 kHz spacing, in Europe and beyond due in particular to airlines' pressure already equipped with 8.33 kHz radios. In upper airspace, SATCOM with improved capabilities, could provide the alternative to VHF R/T, in order to free up today's VHF frequencies for re-using them in lower airspace ATC sectors.
- The above set of requirements needs to be developed and validated by operators - both pilots and ATC personnel. In pursuit of such requirements the ATM community must ensure adoption of new communications and HMI technologies as they become available. Accompanying those actions is the need to engage in the corresponding Human Factors and HMI studies to validate technical development choices and generate the associated training and operating procedures.
- The aviation community needs to look into the economic feasibility of AMS[S]S dedicated systems as an option for securing their long-term availability. The

ESA/SDLS is such a potential candidate system. As a prerequisite, its technical capabilities as a second generation AMSS optimised for use in high density airspace need to be demonstrated - in terms of performance, access and transfer delays and also, dependability.

- As an alternative, and at minimum to ensure availability of back-up communication systems, the aviation community ought also to carry on looking into the feasibility of using New-ICO AMSS + AMS[R]S offer as it takes shape.
- Investigate feasibility and options for cost-sharing, (1) with other satellite systems and (2) between aviation users and industry suppliers, including by setting-up Public Private Partnership financial and institutional arrangements; specifically look into ways of sharing costs with other satellite systems such as GALILEO.
- The rather low utilisation of today's (INMARSAT) AMSS points to the under-utilisation of the corresponding spectrum allocated by ITU. As the result such an allocation is under threat from the mobile communications industry, at future World Radio Conferences (WRC), of being reallocated to the Mobile Satellite Service, with no obligation to carry safety-related communications. Accordingly it is critical for civil aviation to come up to the ITU WRC where such frequency spectrum allocations are discussed and agreed internationally, with credible plans and projects for AMS[R]S deployment
- Confirm/validate the benefits for aviation of an NGSS-provided aircraft independent surveillance scheme obtained via multi-satellite paths ranging, towards ADS integrity checks and the provision of Search and Rescue services

2.12.3 Recommendations towards short term AMSS/NGSS development

In the short term the following programmes are considered to be of value to the future of ATM:

1. Aeronautical Frequency Review: Development of a consensus of the frequency requirements for ATM in to the future and adoption of strategy, co-ordinated at European level to ensure continuous access to RF spectrum for both AMSS and terrestrial systems,

2. Develop a back-up RT Strategy using SATCOM Voice: Trials of existing SATCOM voice services as a backup voice system.

3. Experimentation and use on pre-operational basis of NGSS demonstrators, i.e. of the New-ICO and ESA/SDLS types in order to both asses technical performance and the impact on operational personnel’s (ATC and pilots) acceptability and work-procedures

4. Look into the feasibility, both technical and economic of a combined safety-related communication and satellite navigation mission, specifically on GALILEO

3. ASAS in a co-operative ATC environment

3.1 WP3 Overview

WP3 is composed of several elements. These are summarised in Figure 1.

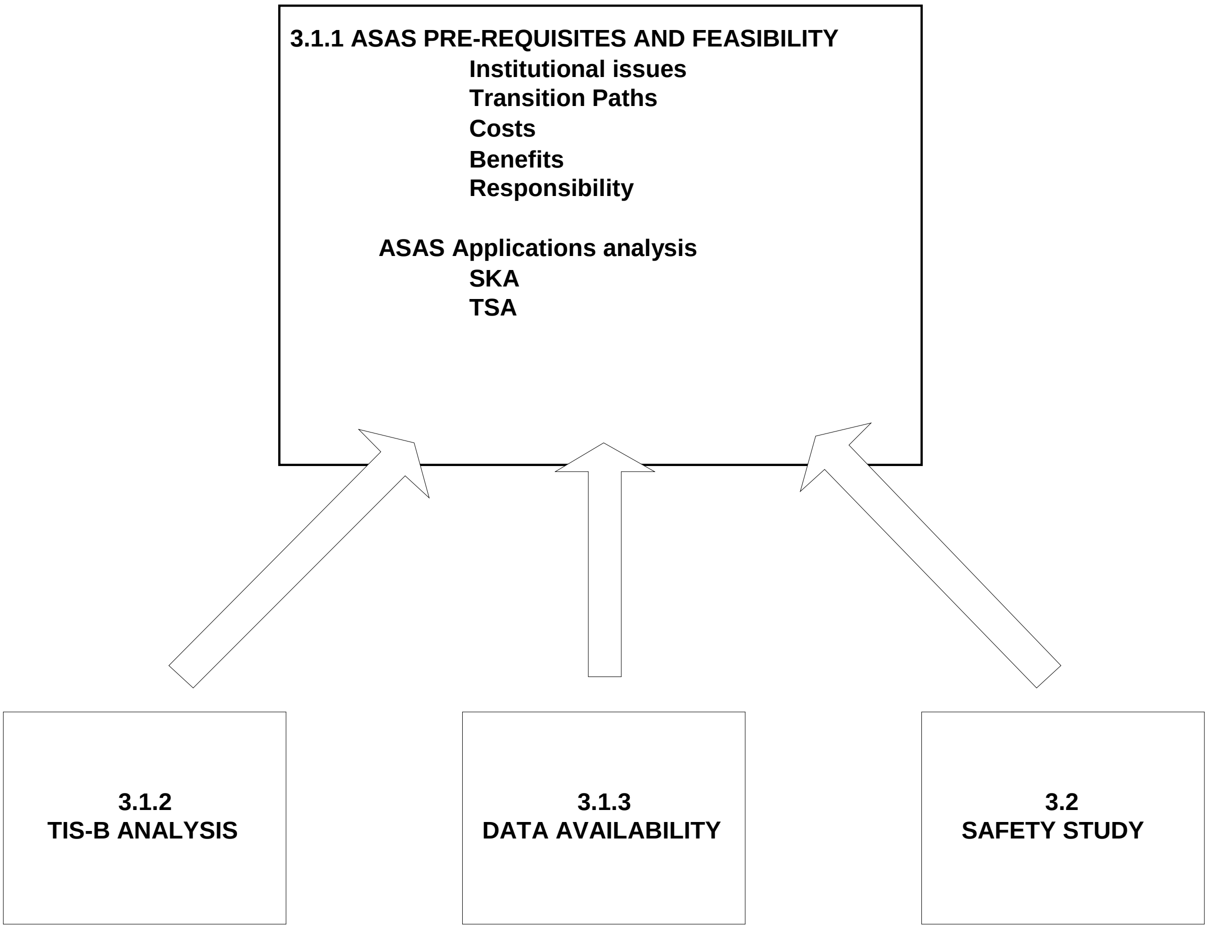

Figure 3.1 EMERTA WP3.1 structure

The feasibility and transition issues study is underpinned by the technical work of:

- WP 3.1.3 Data availability on aircraft
- WP3.1.2 TIS-B Study
- WP3.2 Safety study

The work on transition issues and ASAS feasibility is presented in the WP3.1 report [12] and the remainder of this chapter. The Safety Assessment conducted in WP3.2 is reported on in [13] and section 4 of this report.

3.2 Definition and Scope of ASAS

Airborne Separation Assurance Systems (ASAS) covers a range of concepts where the responsibility for separation from other aircraft is either partially or wholly delegated to the pilot.

ASAS applications are being evaluated by RTCA SC 186 WG 1 and by ICAO's SSR Improvements and Collision Avoidance System Panel (SICASP). At SICASP/6, ASAS was defined as:

'The equipment, protocols, airborne surveillance and other aircraft state data, flight crew and ATC procedures which enable the pilot to exercise responsibility, in agreed and appropriate circumstances, for separation of his aircraft from one or more aircraft' [14].

The scope of ASAS is also described in the SICASP/7 report [15] as follows:

"ASAS encompasses applications seeking to increase flight crews' situational awareness related to traffic, and applications providing airborne separation assurance."

"However ASAS does not address the flight crews' complete situational awareness, which also includes weather, proximity to the ground, structure of the airspace (i.e. classes, restricted areas), aircraft state/control and many other aspects."

It is within this scope that ASAS has been considered in EMERTA WP3.1.

Whilst it is recognised that the VFR ASAS applications - categorised in EMERALD as Traffic Situation Awareness (TSA) - do not have the element of transfer of responsibility; it is clear that this type of application provides a valuable step towards 'true' ASAS implementation and are therefore considered in some detail within this work-package.

3.3 ASAS applications analysis

The work of EMERTA was concerned with potential near-term ASAS applications in European airspace. The consortium chose to develop two near-term applications, with potential realisable benefits during the transition period. The benefits issue was felt to be important, since EMERTA attempts to capture transition issues, with a view to increasing the chances of near-term equipage. This is only likely to occur if airlines can see clear benefits in equipping.

TSA applications are seen as a potential first step towards ASAS implementation. Many trials are taking place that make use of this type of application. They are seen as an early implementation of CDTI-based situational awareness. Within TSA, 'Enhanced Visual Acquisition (EVA) of other traffic for see-and-avoid' was chosen due to the low risks associated with it and the lack of responsibility transfer issues. EVA was seen as a good candidate for the early implementation of ASAS.

The other application had to be one that is realisable in the near-term. Of the potential applications it is more likely that an ASAS Tactical Collaborative application that utilises shadowing (e.g. station keeping) rather than distancing (e.g. crossing procedures) is easier to implement. The issues of safety-criticality, procedural definition and responsibility are more straightforward in the case of distancing applications rather than for shadowing applications.

Following stakeholder feedback at the EMERTA workshop in April, Station Keeping on Approach was selected for further study because:

- There are current trials including this type of application; including NUP and Safe Flight 21)
- It may bring early realisable and potentially localised airport benefits.
- There is some evidence that pilots are already utilising the existing TCAS traffic displays for some degree of self-spacing on final approach. The ASAS application would provide tools to conduct such a procedure in a more controlled manner.
- The nature of the application is such that full equipage will not be required in order for benefits to be realised.

Based on a SICASP template, RTCA developed a standard template format that identifies pre-determined areas for analysis for any ASAS application. This format has been used to investigate the applications chosen for project EMERTA. [12]

3.4 Aircraft data availability

ASAS requires access to aircraft data, the nature of which will be subject to international standardisation. The sources of this data are the disparate avionics systems installed on modern aircraft.

A review was made of all of the parameters which could potentially be studied in more detail. This list was refined in terms of the ASAS requirements to form a set of parameters for further study as follows:

- Barometric Altitude
- Roll (Bank) Angle
- True Track Angle
- Ground Speed
- Track Angle Rate
- True Airspeed
- Magnetic Heading
- Indicated Airspeed
- Mach
- Barometric Altitude Rate
- Inertial Vertical Velocity
- Horizontal Position

There are a number of different aircraft systems which have the ability to provide some or all of these parameters. A review of these potential data sources was carried out which included:

- Air Data Computer (ADC)
- Air Data Inertial Reference System (ADIRS)
- Vertical and directional gyros (VG and DG)
- Attitude and Heading Reference Systems (AHRS)
- Inertial Reference Systems (IRS)
- Global Positioning System (GPS)
- Flight Management System (FMS)

The WP3.1 report includes a review of each type of avionics equipment. The parameters available from each of these systems were considered together with the data characteristics for each parameter in terms of resolution, update rate and ARINC label.

The paper also reviewed in some detail typical equipment configurations and potential ASAS aircraft architectures. This focused on the modern commercial aircraft type.

Following this analysis of the parameter data sources, a review was made of the actual data availability from a representative sample of aircraft. Fifty-three United Kingdom operators were contacted to investigate the possible provision of data by airborne systems, with responses being received from 52. This resulted in information on 1203 aircraft.

The types of aircraft in the survey were quite diverse and range from aircraft with small twin piston engines with a passenger capability of 4 to very large modern commercial aircraft capable of carrying 450 passengers.

The different categories of aircraft in the survey were as follows (with some examples):

- **Large commercial -** Boeing 737, 747, 757, Airbus A300, A320, A340
- **Regional jets** - BAe 146, Embraer 145, Bombardier RJ
- **Business jets –** BAe 125, Cessna Citation, Dassault Falcon 20
- **Regional props -** ATR 42, ATR 72, BAe ATP, Bombardier Dash 8
- **Other props –** Cessna Caravan, Embraer Bandeirante, Piper Navajo

The large commercial jet aircraft were found to have a very high availability of all the parameters included in this study, even taking into account all civil air transport aircraft, which includes regional jet and propeller aircraft the availability figures were still well over 50% for all of the parameters. In contrast the smaller propeller aircraft showed very low parameter availability with most having no data available at all.

The key parameter identified as being required for the ASAS applications studied but which was not available was *speed change rate*. When this parameter is required it could be calculated either on the aircraft of interest (possibly as part of an ASAS processing functionality) and then sent via ADS-B or air-ground data-link (for retransmission on TIS(-B)). Alternatively, it could be calculated on the receiving aircraft based on the received velocities, although this method would be less accurate. This is an issue which needs further consideration.

The requirements also show a need for an indicator of the quality of the position and velocity data being provided by the aircraft. This may take the form of a figure of merit or an indication of the accuracy, integrity etc that the data can be relied on as having. Work within RTCA SC186 has developed the Navigation Uncertainty Category (NUC) concept. This work has since been refined and is being considered within SC186 WG4. No aircraft can currently provide this navigational uncertainty information. It is assumed that this information will be provided via functionality to be included in the ASAS equipment itself.

There are also a number of non-aircraft state parameters that have not been considered in this work. These include call sign, aircraft type and emergency status; all of which are likely to be needed for ASAS operations. These are not currently available and would need to be made available through the FMS or via the airborne processing equipment designed to support ASAS on the aircraft.

3.5 Provision of Traffic Information in a Partial equipage Environment

A traffic information service is a system which uplinks information concerning proximate traffic to suitably equipped aircraft. This information can then be used to support a cockpit display of traffic information (CDTI) as well as to support specific ASAS applications.

Whilst it is often assumed that a TIS system supporting partial ADS-B equipage will be a TIS-B system it is not necessary for a traffic information service to be broadcast. It is perfectly feasible under certain conditions to make use of an addressed data-link to provide this information to a participating aircraft.

Whilst most of this analysis was carried out with a broadcast system in mind there are circumstances where an addressed system would be appropriate. The term TIS(-B) is subsequently used to mean a traffic information system that is most likely to be a broadcast system but could, in certain circumstances, have the option of being supported by an addressed system.

There are a number of aspects that need to be assessed and for any potential TIS(-B) system and these are discussed in detail in the following sections:

- Ground infrastructure requirements
- Airborne equipment requirements
- Message format and precision
- Data-link Capacity
- Update period, latency and integrity
- Surveillance Data Sources
- Coverage
- Service Volume

Of these the Service Volume (SV) is key to the system specification. This is the area or volume of airspace for which traffic information is provided. The need for a service volume is such that an aircraft receiving the TIS has knowledge of the extent of the available information. It is a prerequisite that the surveillance information (e.g. radar) must be available for the entire service volume. This would allow for a guarantee that within the service volume a complete air picture will be provided to suitable equipped aircraft.

It is possible, depending on the mode of operation of TIS(-B), that multiple service volumes may overlap. This has implications both on the TIS(-B) concept and for the candidate technologies.

One of the fundamental decisions that needs to be made is what role will a TIS-B system fulfill. There are various options as to what will be the function of a traffic information service. Some of the potential roles which are discussed further include:

- To support transition to ADS-B equipage as a ‘gap filler’
- To support a multiple link ADS-B implementation
- Surface Movement surveillance information broadcast
- As an ADS-B validation method to improve integrity.
- As the primary data source for ASAS.

Any combination of these roles is possible and the issues surrounding them need to be looked at in some detail, in particular through an analysis of the applications which will make use of the traffic information service. This work-package of the EMERTA project is specifically concerned with transition issues and the support of a partial equipage environment but it is important to look at the full role of the TIS(-B) system as this will impact on any cost/benefit considerations. As discussed in the previous section, two key applications have been chosen for further analysis within the EMERTA study. These are Enhanced Visual Acquisition (EVA) and Station keeping on Approach (SKA) and are assessed in more detail in the WP3.1 report with respect to which roles of TIS(-B) may be of use. It is also relevant within the context of the transition phase to look at ways in which TIS(-B) may increase the integrity of airborne surveillance data and confidence in the early days of ASAS implementation.

An important issue for any TIS(-B) activity is to establish if there is a need for this type of service and, if so, what are the requirements that will be placed upon it.

There is a very close link between TIS-B and ASAS, in fact it is through the development of the airborne situational awareness and ASAS concepts that the requirements for a TIS-B service can be derived. It would be very difficult to separate the definition of the traffic information service itself from the way the information it provides to the aircraft will be used.

There are a number of sources of requirements which support a range of ASAS applications, some of these requirements relate specifically to TIS(-B), but those general application requirements can easily be applied to TIS(-B). These include the RTCA ADS-B MASPS [16], the European commission NUP project, the SICASP WG2 ASAS circular [15] as well as other activities such as the US safe-flight 21 programme. More generic requirements come from higher level strategy documents such as the EUROCONTROL ATM2000+ [17] where ASAS is cited as being important as part of the future ATM system with the condition that the airborne surveillance data made available to the pilot must be consistent with the surveillance information being used by the controller.

The basis of this requirement analysis is the consideration of the two key applications, EVA and SKA, selected for study within the EMERTA project.

The WP3.1 Report goes on to give a summary of the main characteristics of each candidate TIS(-B) medium, presenting the anticipated capability in terms of the identified requirements.

Three of these options are also candidates being considered as potential ADS-B data-link media. The compatibility of the TIS-B system with the ADS-B system is important and so the choice of medium is not one that could be made in isolation. If a multiple link ADS-B environment emerges, which is distinctly possible, this itself implies a role for TIS-B as well as clearly requiring a TIS-B system for any of the media which will be implemented.

3.6 Technical Feasibility Issues

The ASAS work within project EMERTA assessed the practical feasibility of the early introduction, within the European ATM environment, of selected ASAS application scenarios. This section highlights the technical issues which hinder operational implementation of four example ASAS applications:

- EVA – Enhanced Visual Acquisition of other traffic for see-and-avoid
- SKA – Station Keeping on Approach
- LSK – Longitudinal Station Keeping
- CSPA – Closely Spaced Parallel Approaches

The ASAS scenarios addressed in EMERTA were selected on the basis of being among the most feasible to be introduced in the near term in European airspace.

The selected scenarios were analysed in terms of the supporting technology, data availability and operational implementation. The study also reviews the generic technical issues facing ASAS implementation, including data-link media considerations, and airborne equipment issues.

One of the main conclusions reached is that although the technologies which have the capability support ASAS implementation have been developed, there are still technical issues which need to be resolved before operational use could be achieved. This study did not attempt to make recommendations for a preferred data-link; that was outside the scope of the EMERTA project.

From the point of view of the applications, EVA, using ADS(-B), is currently not feasible in the GA market due to a lack of digitally capable aircraft. In order to make the aircraft state parameters available for these aircraft, radar based surveillance information would be required which could then be uplinked via a suitable TIS(-B) system. This would clearly not supply the full set of parameters but would be enough to support a limited EVA application. However, single avionics box incorporating GPS receiver, ASAS functionality and ADS-B transceiver (of whichever data-link), specifically aimed at the GA market could be developed which may overcome these problems leading to early ASAS equipage in the GA community.

The SKA procedure was shown to be feasible in the near-term transition environment. With the application possibly leading to an increase in capacity at some airports, clear benefits are visible to the airlines should they equip. Since it is such a local implementation, cost-benefit analyses need to be carried out for each airport wishing to support the application. In particular the capability of this type of application to maintain capacity under less favourable meteorological conditions is worthy of further investigation. The added issue which may encourage airline equipage is the fact that often an airline's operations are focussed at a single airport, thus the implementation of the application at this key airport could lead to significant benefits to that airline, even if it is the first to equip.

SKA requires high update rates, integrity and accuracy; as such, TIS (potentially an addressed form) was considered to be a primary candidate to support this application. Also TIS carries the advantage of the pilot being able to view non-ASAS equipped aircraft during the transition period.

3.7 ASAS Transition Issues

ADS-B is commonly assumed to be an enabler for ASAS, however whichever technology is used it unlikely that the equipment will be mandated. This means that there is likely to be a protracted transition period (perhaps even permanent) in which some aircraft are equipped to carry out ASAS manoeuvres and others are not.

An ATM operational concept, defined within ICAO, should address international implementations of airborne separation assurance applications. In particular, this would identify the agreed and appropriate circumstances in which specific ASAS applications could be used. Given the differences between airspace regions, and also the different concerns of aircraft operators, the same ASAS applications will not necessarily be adopted in all regions. Nevertheless, an international consensus through ICAO standards is required to provide the potential for ASAS applications to be implemented on a world-wide basis.

Standardisation activities relating to ASAS related equipment are currently being conducted by numerous bodies including ICAO, EUROCAE and RTCA. This activity is at an advanced state, with MOPS for the various media either being available or ready for publication.

Certification is a key element in the development of any avionics equipment. The higher the level of certification, the greater the cost that is associated with that equipment. RTCA / DO-178B Software Certification Requirements defines 5 levels of certification from most severe Level A for software whose anomalous behaviour could cause a catastrophic failure to Level E for software whose anomalous behaviour would have no effect on aircraft operational capability.

The level of certification for ASAS equipment will depend upon the type of applications to be supported as shown in Table 3-1.

Application	**Level**	**Rationale**
TSA	D/E	The equipment will be used as an aid to the pilot who will then assess the situation and achieve separation visually. In case of failure of the ASAS equipment the primary means of maintaining separation is unchanged; it remains visual acquisition by the pilot.
TC	B/C	During manoeuvre, responsibility for maintaining separation rests with the pilot. Accordingly the system must have a high level of integrity and availability for this to be achieved. Nevertheless, should the system fail, the procedures should allow for the controller to resume responsibility for separation; this mitigates the risk.
SC	A	Aircraft has responsibility for separation assurance.

Table 3.1 : Certification Levels for ASAS Applications

The following table defines the anticipated costs for equipping an aircraft for each class of ASAS application:

Application Class	Certification level	Cost
TSA (GA)	E	$6k-$10k
TSA (commercial)	D	$100k
TC	B or C	$100k-$150k
SC	A	$ TBD

Table 3.2 : Costs for airborne ASAS Equipage

For TSA applications, the costs are based on integrated avionics supporting all ASAS functions – including CDTI, ADS-B Transmit/Receive and ASAS processing function. Two levels of cost are shown above, one for GA and one for commercial transport.

For TC the costs are significantly higher. The cost of a transponder suitable for ASAS applications is ~ $25 to 30k. Two such transponders will be needed, together with a CDTI, ASAS processing function and associated installation costs. Some of these costs may be defrayed against the costs of installing transponders for air-ground surveillance purposes. The costs of re-wiring older aircraft are not considered as they are likely to be prohibitive.

No estimate of the costs for SC applications has been established. The full complexity and certification issues surrounding this type of application are yet to be determined. The costs will depend greatly on these issues. Indeed, as the potential deployment date of SC applications is considerably longer term, improvements in our understanding of these issues facilitated by operational use of TSA and TC applications may lead to a more reasonable cost than would be currently envisaged.

The cost of TIS-B is dependent on the implementation selected. There is dependency between the range of coverage of a TIS-B site and the number of ground stations that are required. It is assumed that TIS-B will require networking (e.g. integration into the surveillance system via ARTAS). Assuming that TIS-B is collocated with a radar station the cost for a TIS-B ground station could be as low as ~ $50k. The airborne costs associated with TIS-B can be minimised assuming that the avionics are the same as those required for ADS-B.

The early implementation of ASAS applications is technically feasible. TSA Applications, such as EVA, can be supported using relatively cheap avionics. This means that suitable avionics for all aircraft types, including General Aviation, could be developed.

The early introduction of TSA applications will require the deployment of a Traffic Information Service, probably using a broadcast medium, to support operations in a partial equipage environment. The transition to full equipage could be a lengthy process, which may indeed never end. The potential benefits that could be derived from TSA applications relate to enhanced pilot situational awareness leading to improved safety for VFR operations. Whilst it has not been investigated in detail, with the introduction of new VHF communication systems, such as VDL/3 and VDL/4, the introduction of TSA application may provide some compensation to the pilot for the loss of party-line. In addition in the longer term, the experienced gained from using this type of ASAS application may lead to greater confidence in the use of ASAS for more critical IFR applications.

Whilst, TC Applications require a higher level of avionics, they are capable of leading to greater benefits. The SKA application, by its nature, is local to a specific airport – and may be implemented without all aircraft using the airport being equipped. A Traffic Information Service may be used to extend the applicability in that the lead aircraft need not be equipped. The decision to implement such an application needs to be based on the local situation. It is possible SKA could lead to an increase in airport capacity, or to maintain capacity under less favourable meteorological conditions. Airports and fleets need to implement and equip together (e.g. SAS and Arlanda) for the full benefits to be realised.

3.8 EMERTA WP3 Conclusions

The key conclusions resulting from EMERTA WP3.1 regarding the feasibility of ASAS are as follows:

- In terms of the initial implementation of ASAS, the ‘transition’ is key. It is not merely the environment in which the initial use of the first ASAS applications will be introduced. As discussed, it is likely to be of indefinite duration, and therefore the environment in which ASAS will continue to exist.
- A ground based traffic information service (TIS(-B)) will be needed to support a partial ADS-B equipage environment, which is unavoidable in the transition period. The ‘gap filler’ role can also provide some backup in the event of ADS-B equipment failure. Additionally, the integrity of ADS-B surveillance information might not be sufficient for it to provide the sole basis of ASAS applications, which could imply an ongoing role for TIS-B in the ASAS environment.
- The data available on board the majority of aircraft is sufficient to support the requirements of the chosen initial ASAS applications. In particular the use of a traffic information service to support a partial equipage environment means that those aircraft that have the data available, primarily the modern jet aircraft, will be able to take part in ASAS without the need for older aircraft to equip. There are a number of non-aircraft state parameters such as call sign, aircraft type and emergency status that need to be made available either through the FMS, or via the airborne equipment which will support ASAS on the aircraft (ASSAP).

The early introduction of some initial ASAS applications is feasible given that a number of prerequisites are satisfied, these can be split into institutional and technical issues:

Institutional Issues

- ❑ The initial applications must be chosen carefully.
- ❑ The relevant procedures must be developed.
- ❑ The extent and nature of any transfer of responsibility for separation assurance must be analysed, and will require careful negotiation with policy authorities and operational staff.
- ❑ The benefits must be demonstrable and sufficient to justify the required investment.

Technical Issues

- A specification for TIS(-B) must be prepared.
- The technical data-link issues must be closed.
- Suitable airborne equipment must be developed, certified and available.
- The aircraft involved must be suitably equipped.
- Appropriate supporting ground systems must be implemented.
- CDTI functionality and related HMI issues must be addressed.

As has been discussed, the choice of initial ASAS applications is crucial to the feasibility to the introduction of the ASAS concept. The two applications chosen for analysis in EMERTA both have key features that admit them as candidates for early implementation.

The TSA application is one where ASAS is used almost without consequence, it is a VFR tool on which there is no reliance other than being used to improve the see and avoid principle. While this means that this application is easily certifiable, and therefore a good candidate for early implementation, it also has the problem that, because it is only a VFR application, the benefits to be gained are unlikely to drive equipage in the air transport community. GA pilots may find the potential safety enhancement to their normal VFR operations a benefit, which will hopefully inspire investment by individuals. For airlines, operating almost exclusively IFR, it will not.

The SKA application is by its nature a local application and does not require full equipage in the environment. Any suitably equipped aircraft can take part in this manoeuvre, which, if the benefits of such a procedure can be demonstrated, is likely to encourage equipage. Even with the potential need for TIS(-B), the local nature of the application means the investment on the ground will not be too great to provide the system at key airports. The issues of responsibility are also potentially more straightforward than those for other ASAS applications.

The benefits that an aircraft operator will gain from the investment required to fit the equipment necessary to take part in ASAS applications will need to be clearly identified. The total benefit from the initial applications must be sufficient to drive equipage. It is therefore important to identify all of the potential near term ASAS applications as soon as possible.

Illustrative procedures have been developed for the SKA application in Appendix C. The procedures are key to ASAS applications, and require careful negotiation and standardisation before the applications can be implemented.

In terms of the technical issues, EMERTA chapter 4 looks in some detail at the TIS(-B) system and proposes one potential TIS-B concept specification. The choice of medium is discussed and the three main candidates are all capable of supporting the system. There are certain technical issues which must be resolved in each of the media in order to be able to support the TIS(-B) system.

Once the TIS-B specification is finalised, airborne equipment, which is preferably both ADS-B and TIS-B capable needs to be developed.

Given the need for a TIS(-B) system to support ASAS implementation, the ground equipment to provide this service must be provided. As discussed, certain ASAS applications are, by their nature, local and so a single airport providing a TIS(-B) could enable the first implementation of ASAS for such applications

CDTI functionality, in terms of the way surveillance information is presented to the pilot and what tools will be implemented to aid the participation in ASAS manoeuvres, needs to be developed further from the human factors and technical perspective.

The onboard processing, which takes the surveillance inputs and processes them prior to display or use by ASAS tools, is also key and there must be further development of these functions. It may be through this equipment that the parameters such as call sign, emergency/priority status etc. could be made available for broadcast.

4. Safety / separation modelling

4.1 Introduction

Over decades, the aviation industry has been able to compensate the increase in traffic with a decrease in accident risk per flight hour. In view of the rapid growth of air traffic and its technological and organisational complexity, this has been a major accomplishment. Unfortunately, at present it is unclear how to continue such compensation. In particular, the safety impact of emerging, capacity increasing technologies is not well known. Due to the limited availability of accident and incident data, statistical analysis alone is not sufficient to understand safety in complex situations. By now, there is a broad consensus that appropriate safety models are needed to understand the relation between accident risk and ATC procedures, human responsibilities and technical systems. Such models may guide the decision process over the most efficient improvements in ATM.

The EMERTA project is centred on the implications of two emerging technologies for aeronautical use. In this context, two work packages are included which evaluate safety versus separation using models for operational concepts based on these emerging technologies:

- in WP2.2 a safety/separation model has been developed for a concept based on Aeronautical Mobile Satellite Systems (AMSS) to establish ADS surveillance by ground based Air Traffic Control (ATC),
- in WP3.2 a safety/ separation model has been developed for a concept based on ASAS (Airborne Separation Assurance System) by ADS-B (Automatic Dependent Surveillance - Broadcast).

A detailed account of the safety/separation models developed in these work packages is provided in the EMERTA WP2.2 and WP3.2 reports. In this section a summary of these studies and a comparison of their modelling results is provided.

Section 4.2 describes the methodology used for the safety/separation modelling. Section 4.3 summarises the AMSS-based operational concept that was selected for the model of WP2.2. Section 4.4 summarises the ASAS by ADS-B operational concept for the model of WP3.2. Section 4.5 describes the encounter scenario that was considered for both concepts. Section 4.6 describes the results of the AMSS safety/separation model. Section 4.7 describes the results of the ASAS by ADS-B safety/separation model. Section 4.8 compares the results of the safety/separation models for the two operational concepts. Section 4.9 summarizes the commonalities and differences identified for both concepts. Section 4.10 addresses the question ASAS or ATC? Section 4.11 gives recommendations for further study.

4.2 TOPAZ safety assessment methodology

Both an AMSS-based and an ASAS by ADS-B based operational concept have been evaluated with the TOPAZ (Traffic Organization and Perturbation AnalyZer) accident risk assessment methodology (Blom et al., 1998, 2000). This methodology is based on a stochastic modelling approach towards risk assessment and has been developed to provide designers of an advanced ATM operation with safety feedback in a (re)design cycle. Basically, the assessment cycle consists of four stages.

Stage 1: Identification of operation and hazards
Identify the time horizon and boundaries of the operations and encounter types, gather traffic flow characteristics and specific statistical data available, identify human responsibilities, operational procedures and functioning of the technical systems, gather information about non-nominal behaviour of the operation.

Stage 2: Mathematical modelling
Develop a stochastic dynamical model of the operation that incorporates both all nominal and non-nominal events of the operation and the encounter type(s) selected. During this stage all model assumptions adopted are systematically specified.

Stage 3: Accident risk assessment
Based on the mathematical model of stage 2, quantify the accident risk. In addition, perform a qualitative analysis of the model assumptions.

Stage 4: Feedback to operational experts
Discuss the results of the quantitative safety assessment with the designers and operational experts in order to allow an effective feedback to the operation design and the validation of the mathematical model used in stage 3.

Stages 1 through 3 are addressed within EMERTA WP2.2 and WP3.2. Stage 4 is not performed within these EMERTA work packages.

4.3 AMSS-based operational concept selected for safety/separation modelling

The aim of EMERTA work package 2.2 is to investigate the safety/separation benefits of utilising AMSS in Europe’s peripheral airspace, such as the Mediterranean. In this region, there is only limited radar and VHF R/T coverage. The satellite communication provided by AMSS can be utilised for Automatic Dependent Surveillance (ADS), as well as for pilot controller voice service (SATCOM-voice) and data linking via Controller Pilot Data Link Communication (CPDLC). These systems allow the introduction of ground ATC in areas where no ATC radar surveillance is available.

The AMSS-based operational concept identified for WP2.2 is described in document (Delrieu, 1999). Although the description was sufficiently detailed, it appeared that within the scope of this operational concept there were still different operational concept options that could be considered. Sixteen options were identified, based on combinations of four ATC concepts and four CNS concepts:

- The four ATC concepts identified were: A) concept without ATC support through surveillance, B) concept where ATC reacts to STCA alerts only, C) concept where the ATCo routinely monitors the radar screen to detect and correct aircraft severely deviating from the expected paths and D) concept which combines routine monitoring with an FPM alert, based on additional down-linked aircraft state information.
- The four CNS concepts have in common that navigation is by GPS and IRS and surveillance is by ADS reporting through AMSS. Differences are in pilot-ATCo

communication: 1) VHF R/T communication, 2) SATCOM-voice communication, 3) CPDLC communication, and 4) both SATCOM-voice and CPDLC communication.

As a first step, each of the resulting sixteen (4×4) combinations was qualitatively analysed for its expected improvement with respect to a procedural control setting. Options A1 through A4, B2 through B4 and C3 were expected to offer no or minor improvement. Options B1, C2, C4 and D3 were expected to perform reasonable, and options C1, D1, D2 and D4 were expected to perform good to very good. Eventually, option D2 (ATC routine monitoring enhanced by FPM, with SATCOM-voice as sole means of communication) was chosen for safety/separation evaluation in the remainder of the study. Reasons for this choice include the incomplete coverage of VHF R/T for the airspace under consideration and the expectation that addition of CPDLC as back up for SATCOM-voice hardly would improve the communication. (This issue is further discussed in Section 4.6).

A summary of the selected AMSS-based operational concept is given in Table 4.1. A functional representation of this AMSS-based operational concept is provided in Figure 4.1. The most important actors, technical systems and other influencing factors are represented by boxes. The most important relations and information flows are represented by arrows.

Table 4.1: *Summary of AMSS-based operational concept evaluated*

Summary of EMERTA WP2.2 scenario	
C1.	All aircraft are equipped for flying RNP-5 routes and nominally fly according to it. Navigation is based on GPS and IRS. There is no navigation via VOR/DME. The aircraft equipment excludes TCAS and ASAS.
C2.	The pilot is responsible for a safe and efficient flight, according to a predefined flight plan. He is also responsible for timely implementation of ATCo instructions.
C3.	Every minute, the surveillance system receives an ADS report from each aircraft via AMSS. The surveillance system provides the ATCo with ADS/tracking information on the estimated position of aircraft, and a number of other aircraft state parameters. All aircraft are equipped with ADS and all aircraft use the same satellite systems. The ATC system contains a Flight Path Monitoring (FPM) tool, which gives an alert if an aircraft deviates too much from its planned trajectory. No STCA tool is provided.
C4.	The ATCo is responsible for the provision of safe and efficient use of airspace. The ATCo routinely monitors the traffic situation and detects deviations between actual and planned aircraft positions. The ATCo is supported by the FPM tool and reacts immediately to an FPM alert. The ATCo guides aircraft deviating too much back to their routes. The shelter level procedure (for aircraft whose ADS system does not work) is not used.
C5.	The ATCo and the pilot communicate by SATCOM-voice. There are no other voice communication means, such as VHF or HF R/T, present. There is also no CPDLC.
C6.	There is one straight route, with two parallel lanes on a single flight level, in one en-route sector. The directions of the air traffic flows in both lanes are opposite. There is no influence of traffic from other sectors.

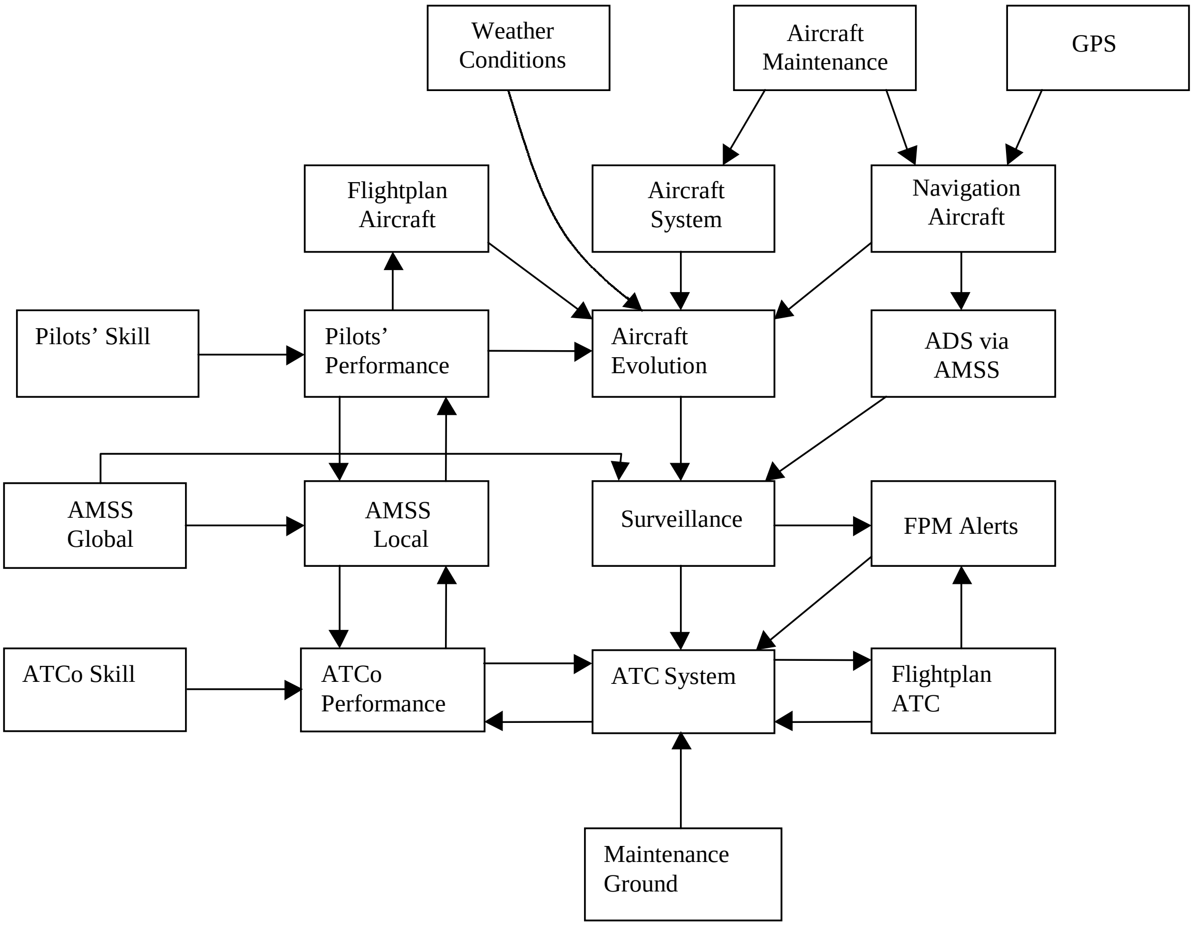

Figure 4.1: *Functional representation of the AMSS-based operational concept*

4.4 ASAS-by ADS-B operational concept selected for safety/separation modelling

The aim of EMERTA work package 3.2 is to investigate the safety/separation benefits of utilising emerging ADS-B technologies and associated ASAS operational concepts, leading towards the EATMS concept of Free Flight Airspace (FFAS). The first task of this work package was to identify an ASAS-based operational concept to be assessed. At an early stage of this task, the idea was to consider a concept where ASAS is used for Traffic Situational Awareness (TSA). Full responsibility for separation was to be with ATC and the pilots were to get a tool that enables them to see the surrounding traffic. However, during the elaboration of this operational concept, it appeared that the identification of a proper distribution of tactical responsibilities and roles between ATC and pilots was more difficult than expected. Since a pilot is responsible for a safe flight it is reasonable to expect autonomous pilot reaction upon information provided by ASAS. In view of this, we considered ASAS-equipped aircraft where responsibility for tactical separation is fully with pilots. In order to allow comparison with the TOPAZ safety/separation modelling in EMERTA WP2, the ASAS-equipped set up has been evaluated in this report for usage in combination with a fixed route structure. It should be remembered that the aircraft are still supposed to follow a certain given route through their sector, hence this is not free flight (see Section 4.5). A summary of the selected ASAS by ADS-B-based operational concept is given in Table 4.2. A functional representation of this concept is provided in Figure 4.2.

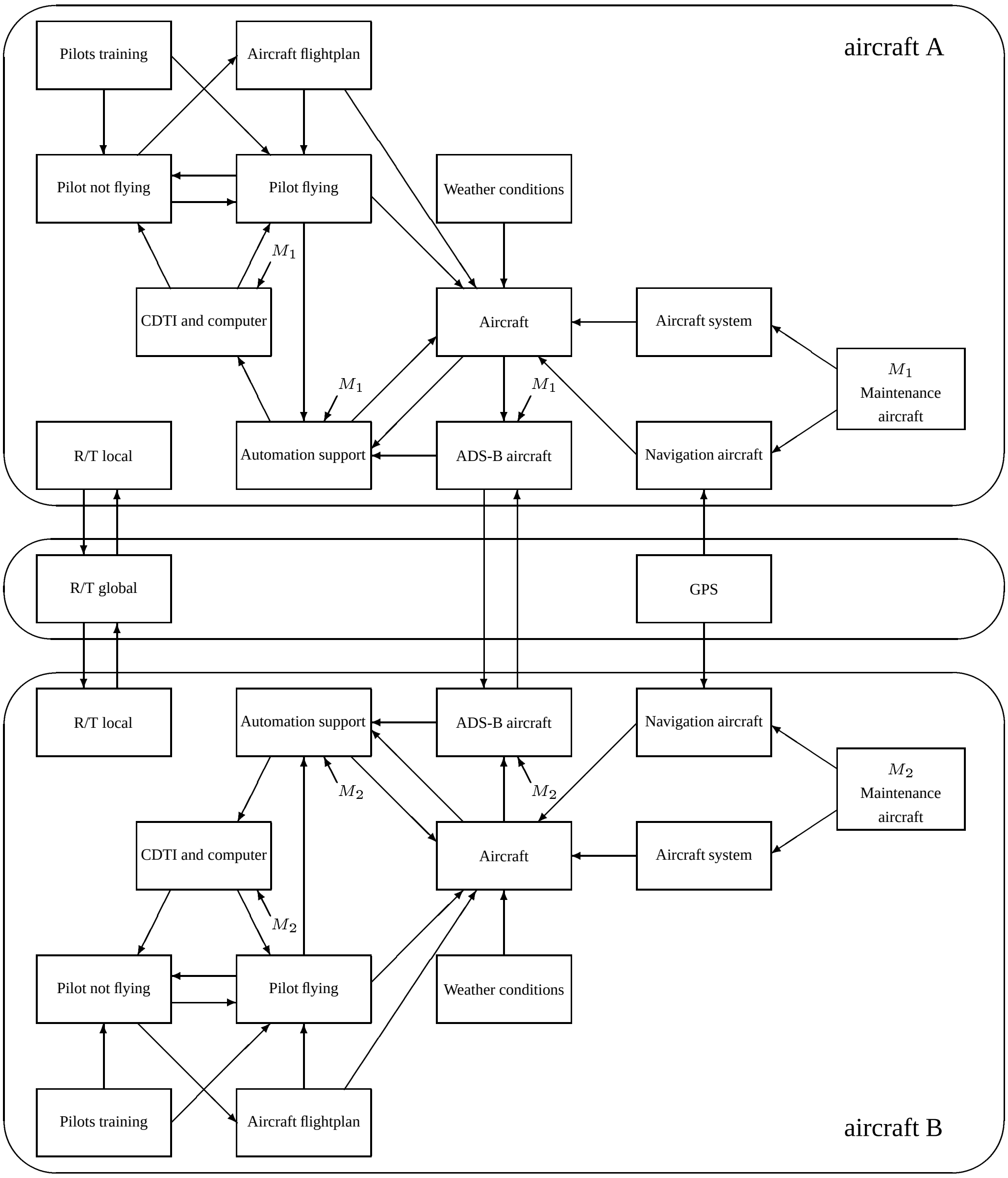

Figure 4.2: *Functional representation of the ASAS by ADS-B operational concept for two aircraft (A and B).*

Table 4.2: *Summary of ASAS by ADS-B-based operational concept selected for evaluation*

THE OPERATIONAL CONCEPT SELECTED FOR TOPAZ EVALUATION IN EMERTA WP3.2	
C1.	All aircraft perform nominally and are adequately equipped for flying RNP-5 routes. Navigation is based on GPS and IRS. We assume there is no navigation via VOR/DME.
C2.	No TCAS is available.
C3.	Every few seconds, the ASAS system is updated with ADS-B reports from each aircraft. The information is displayed on a CDTI and includes the estimated position of aircraft, and a number of other aircraft state parameters. All aircraft are equipped with ASAS by ADS-B.
C4.	The aircraft has ASAS conflict probe and resolution advisory equipment. Each time new ADS-B information arrives, this equipment checks whether a separation conflict is expected to occur within the next minutes. If so, then the equipment will provide the pilots with a resolution advisory, which they confirm and fly.
C5.	The pilot is responsible for a safe and efficient flight, according to a predefined flight plan.
C6.	It is assumed that ATC has no direct influence on aircraft behaviour, i.e. ATC does not give additional instructions to the aircraft on the route considered.
C7.	There are no air-air back-up communication possibilities, such as datalink, VHF or HF R/T.
C8.	There is one straight route, with two parallel lanes on a single flight level, in one en-route sector. The directions of the air traffic flows in both lanes are opposite.

4.5 Encounter scenario considered for both concepts

For the safety/separation modelling, the two operational concepts described in the previous two subsections are evaluated for one particular encounter scenario. This hypothetical encounter scenario considers one straight route with two opposite traffic lanes on a single flight level, with a distance *S* between the centre lines (see Figure 4.3). The assumed traffic flow is 3.6 aircraft per hour for each lane.

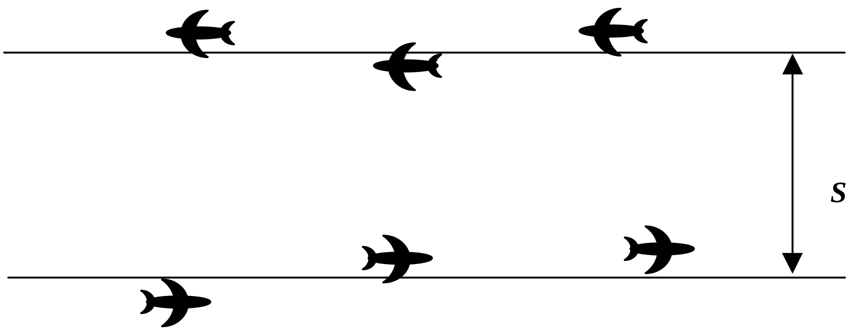

Figure 4.3: Top view of traffic route with two parallel opposite direction lanes at a separation distance S.

Table 4.3: **Assumptions made during the modelling of the AMSS-based operational concept**

Id	Assumption
1.	Due to a distraction by an alert an ATCo does not forget what he was doing
2.	Co-ordination between adjacent centres and flow control is working
3.	ATCo does not switch off FPM
4.	ATCo does not ignore FPM alerts and does not consider them as being possibly false
5.	FPM functionality is working if ATC system is up
6.	ATCo stays trained in monitoring skills
7.	Aircraft are not TCAS equipped
8.	ATCo gives priority to handling FPM alerts over all other activities
9.	ATCo does not fall back to procedural control when ATC system fails
10.	Unless there is a DAP via AMSS based FPM alert, we assume that the ATCo stays working as if DAP via AMSS does not function
11.	ATC tracker is robust against outliers in downlinked course/course rate
12.	No RNP-5 significant bias errors in global & local navigation systems
13.	Short term conflicts are represented, monitored and treated as if they are large deviations
14.	There is no STCA system
15.	ATCo neglects secondary conflicts when giving an avoidance instruction
16.	There are no military a/c in the en-route sector considered
17.	ATCo does not give off-sets
18.	Pilot does not disconnect the autopilot deliberately
19.	No strong turbulence is considered
20.	Neighbouring sectors have B-RNAV routes as well
21.	No lightning, windshear, clouds considered
22.	No strong changes in wind velocity at different heights
23.	No unnoticed gradual increase of speed considered
24.	There are no test or training flights in the airspace considered
25.	System for distribution of weather details is functioning
26.	Monitored severe deviations are solved with priority to the largest deviation
27.	Aircraft do not join track in the opposite direction
28.	On average, 15 aircraft are flying in the sector under control of the ATCo at the time
29.	No outliers in track data
30.	There is no CPDLC
31.	Flight plan is not lost in Flight Management system
32.	Failure of a GPS satellite affects all aircraft in the sector equally
33.	The inaccuracy of the position estimate obtained using GPS can be neglected with respect to the navigation error due to RNP-5
34.	Failure of an AMSS satellite affects all aircraft in the sector equally
35.	HF R/T is not used as a communication back-up facility
36.	AMSS is not used as a positioning back-up facility
37.	No primary or secondary radar is available for surveillance
38.	No VOR/DME is available for navigation
39.	Pilots do not fly off-set from their route
40.	All aircraft are equipped for RNP-5 and fly according to it
41.	Aircraft does not run out of fuel
42.	GPS based navigation does not change presentation of information to pilots
43.	3.6 aircraft pass each lane per hour

4.6 Safety/separation model of AMSS-based operational concept

For the AMSS-based operational concept (introduced in Section 4.3), a brainstorm session with operational experts of various backgrounds was organised to identify an extensive list of hazards. This list was complemented with relevant hazards from the TOPAZ hazard database. Next, a mathematical model was set up, which accounts for the procedures and related pilot and controller behaviour, the technical systems considered, the hazards identified and the encounter type selected. Assumptions made during the modelling are listed in Table 4.3.

Based on the mathematical model, the collision risk between a pair of aircraft was evaluated as the sum of products of probabilities of specific events and the conditional probabilities of collision given these specific events. All factors in the products were assessed by Monte Carlo simulations and various additional mathematical analysis and numerical techniques. Finally, the collision risk per aircraft pair was multiplied with the number of head-on encounters per flight hour.

The collision risk was evaluated for various values of the spacing *S*, i.e., the distance between the two parallel lanes on which the aircraft fly in opposite direction. The result of the safety/separation model is a sequence of combinations of spacing and accident risk per flight hour, which are shown in Figure 4.4. The horizontal dotted line in Figure 4.4 represents the Target Level of Safety (TLS), which is equal to 5×10^{-9} aircraft accidents per flight hour (ICAO). The accident risk curve crosses the TLS at a spacing of S = 18 NM.

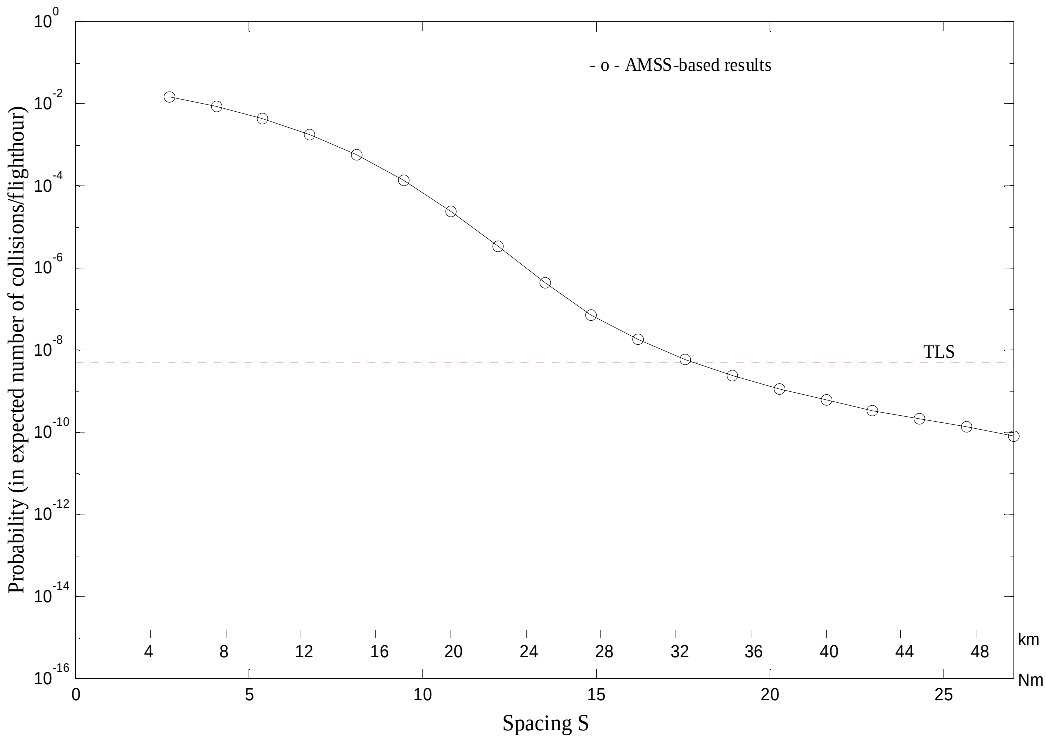

Figure 4.4: *The expected number of accidents occurring per aircraft flight hour as a function of lane spacing for the AMSS-based concept. The horizontal dotted line represents the adopted Target Level of Safety.*

Next, the safety/separation model was used to analyse which events of the ATM concept evaluated are safety critical. An event is defined to be safety critical if it has a relatively high contribution to risk near the spacing *S* where the risk equals the target level of safety. The results of this safety criticality analysis are summarised in the following paragraphs.

Decision Making loop

The decision making loop consists of the aircraft and satellite technical systems which facilitate SATCOM-voice communication, the technical systems which facilitate surveillance, the pilot and the ATCo. If one or more of these elements are failing, the ATCo cannot give surveillance-based instructions to the aircraft and the decision making loop is said to be failing. Furthermore, during operation with a functioning decision making loop, specification and implementation of ATCo clearances is delayed due to delays of the satellite communication system, aircraft-related AMSS components, pilot performance and ATCo performance. It follows from the model evaluations that situations where the decision making loops of two aircraft in an encounter situation are both failing give the highest contribution to the accident risk. In the model, this event of impaired communication for a couple of aircraft is almost completely caused by the temporary failure of the communication satellite system. The probability of this event was assumed conservatively as $P=0.01$. Reduction of the assumed failure probability of the satellite communication system does, however, not result in a major reduction of the safe spacing, since events where the decision making loops of both encountering aircraft are functioning nominally also provides a significant contribution to the accident risk, due to considerable communication delays incurred by the communication satellite system. In conclusion, it follows from the safety/separation model that both the failure probability of the satellite communication system and the nominal communication delays contribute significantly to the overall collision risk. The developed model provides an excellent way to evaluate the impact of such variables in AMSS performance.

Potential impact of CPDLC

Based on the previous result, we can reason about the accident risk that would be obtained for a particular AMSS-based operational concept enhancement. Suppose CPDLC can be used by the ATCo as a back up to communicate with the pilots in cases when SATCOM voice fails. The first effect would be that the resulting communication loop fails less frequently. However, since the risk from situations where the communication loop have not failed are only a small factor lower, the introduction of CPDLC as a back-up allows only a marginal reduction of safe spacing. A second effect of the introduction of CPDLC is that several new hazards are introduced. This may lead to an increase in risk, which may even reduce the small positive effect of the introduction of CPDLC. For this reason, the initial assumption of no CPDLC is judged not to have a significant effect for the operation at a spacing of S = 18 NM.

GPS

The effect on safe spacing of temporary failure of GPS is negligible. This conclusion is based on the modelling assumptions that navigation nominally uses the combination of GPS and IRS, and the aircraft nominally fly according to RNP-5. In particular, the drift of the aircraft positions due to temporary navigation based only on IRS was found to be small in comparison with the position deviations allowed by RNP-5. The model provides a profound basis to analyse the impact of variation of GPS parameters and RNP values on safe spacing distances and the safety criticality of GPS.

Aircraft evolution

According to the model, an aircraft can be in one of three evolution modes: Nominal (in which navigation and aircraft systems are working properly, leading to off-lane deviations according to RNP-5), Non-nominal (in which a navigation or aircraft system fails, leading to off-lane deviations exceeding RNP-5) and Sharp turn (in which the aircraft flightplan deviates from the parallel lane, leading to a rapid deviation from the lane). It follows from the model analysis that the typical probability of situations in which both aircraft are in a Non-nominal or Sharp turn mode are such low that they are not safety critical. Situations in which both aircraft are flying nominally provide the main contribution to risk. This conclusion holds for the operational concept in which the aircraft nominally fly according to RNP-5. Assessment of the accident risk for other RNP values or related aircraft evolution parameters is facilitated by the developed model.

4.7 Safety/separation model of ASAS by ADS-B-based operational concept

Similar to the procedure for the AMSS-based operational concept, a hazard identification brainstorm session was organized for the ASAS-by ADS-B based operational concept (discussed in Section 4.4). The resulting list was extended with relevant hazards from the TOPAZ hazard database. Next, a mathematical model was developed for this operational concept, which accounts for the procedures and related pilot behaviour, the technical systems considered, the hazards identified and the encounter type selected. Assumptions made during the modelling are listed in Table 4.4.

Subsequently, collision risk was decomposed to allow for conditional Monte Carlo simulations. The collision risk of a pair of aircraft was evaluated as the sum of products of conditional risks and the probabilities of occurrence of the conditions. All factors in the products are assessed through Monte Carlo simulations and various additional mathematical techniques. Finally, the collision risk per aircraft pair was multiplied with the number of head-on encounters per flight hour.

Table 4.4: *Assumptions made during the modelling of the ASAS concept*

Id	Assumption
1	There is no restricted airspace in the area considered
2	No conflicts with non-existing aircraft are detected
3	There is no influence from military traffic in the airspace considered
4	There are no formations of same airline
5	ADS-B is assumed fully developed
6	Aircraft do not purposely enter conflict such that resolution is to their favour
7	There is no communication between crews
8	There is no TCAS
9	There are no priority flights
10	No strong changes in wind velocity at different heights
11	No strong turbulence is considered
12	No lightning, windshear, clouds considered
13	There is GPS with IRS based navigation only
14	There are no test or training flights in the airspace considered
15	Aircraft do not join the track in the opposite direction
16	Pilots do not fly off-set from their route
17	Pilot does not disconnect the autopilot deliberately
18	No unnoticed gradual increase of speed considered
19	Direct routing across military airspace is not given
20	System for distribution of weather details is functioning
21	Neighbouring sectors have B-RNAV routes as well
22	No outliers in ADS-B position reports
23	If GPS is available, then all aircraft have RNP 5 navigational performance
24	Aircraft does not run out of fuel
25	3.6 aircraft pass each lane per hour
26	GPS based navigation does not change presentation of information to pilots
27	Level of performance variations of Pilot-Flying and Pilot-Not-Flying are independent of variations in the performance of technical systems.
28	Failure occurrences of Mode-S transmission and reception equipment are assumed to be independent
29	GPS equipment on board an aircraft is always working
30	Pilots do not use visual contact
31	Pilots follow instructions given by ASAS resolution advisory (i.e. no pilot improvisation)
32	The responsibilities of the pilot-flying are focused around the correct implementation of aircraft manoeuvres; the responsibilities of the pilot-not-flying include surveillance. It is assumed that the pilots do not take over each other's role
33	Mode S transponder frequency for ADS-B is never blocked
34	As long as one of the pilots is inactive, then an ASAS advised conflict resolution will not start

The procedure to assess the collision risk was followed for various values of the spacing *S*. The result of the safety/separation model is a sequence of combinations of spacing and accident risk per flight hour, which are shown in Figure 4.5. The accident risk curve crosses the target level of safety at a spacing of *S* = 23.5 NM.

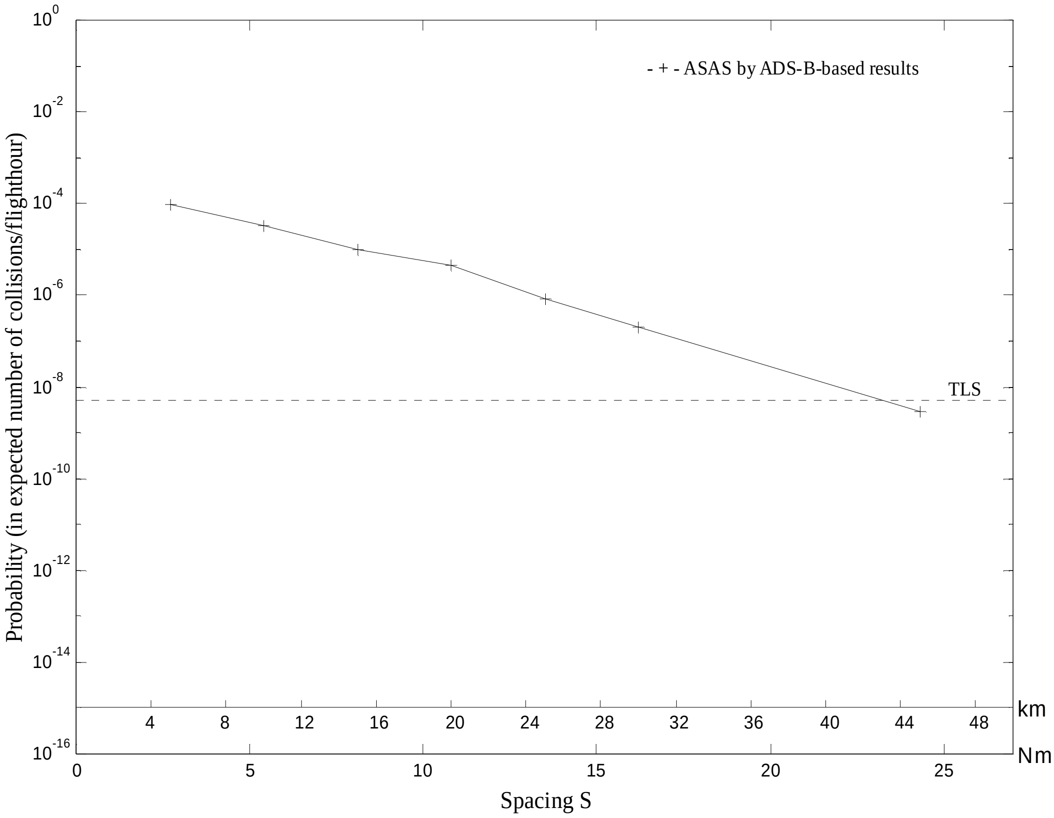

Figure 4.5: *The expected number of aircraft accidents occurring per aircraft flight hour as a function of lane spacing for the ASAS by ADS-B concept. The horizontal dotted line represents the Target Level of Safety.*

Results from the safety criticality analysis for the ASAS by ADS-B concept are discussed in the following paragraphs.

Decision making loop

This ASAS by ADS-B scenario uses air-air communication and the decision making loop consists of the pilot who is flying, the pilot who is not flying, the CDTI and computer, ADS-B reception equipment of the own aircraft, and ADS-B transmission equipment of the intruding aircraft. If one of these decision making loop elements fails, the aircraft does not observe the intruding aircraft and does not react in case of a possible conflict. It follows from the model evaluation that situations in which the decision making loop fails occur infrequently enough to cover for the higher risk associated with them. These situations are thus not safety critical in the model considered.

GPS

Similar to the conclusion for the AMSS-based operational concept, the effect on the safe spacing of temporary failure of GPS is negligible for the ASAS by ADS-B concept. This conclusion is based on the modelling assumptions that navigation nominally uses the combination of GPS and IRS, and the aircraft nominally fly according to RNP-5.

Aircraft evolution modes

In the model of the ASAS by ADS-B operational concept, the aircraft can be in either one of two modes: Nominal and Non-nominal. The latter case models situations with degraded aircraft equipment (e.g., navigation) or flightplan errors, leading to off-lane deviations exceeding RNP-5. It follows from the model evaluation that the most safety critical situations are those where one or both aircraft fly in the Nominal mode.

4.8 Comparison of the model results for the AMSS and ASAS by ADS-B concepts

In this section, the safety/separation results of the AMSS-based model and the ASAS by ADS-B model are compared. It should be remembered that the results apply to the models made of the two applications, under the sets of assumptions adopted. Both models were verified and analysed by modelling experts, but remain to be validated with support of operational experts.

Figure 4.6 shows the accident risk as function of the spacing *S* for the two operational concept models. In addition, it shows the results of a model for a baseline operational concept, in which the aircraft fly according to the parallel route scenario, navigating with GPS and IRS, but there is neither surveillance by ATC nor through ASAS. It can be seen that both the AMSS-based curve and the ASAS by ADS-B-based curve pass the TLS at a significantly lower spacing than the curve for the baseline operation. For the AMSS model, a safe spacing improvement of about 45% is attained and for the ASAS by ADS-B model an improvement of 30% is achieved.

Furthermore, it can be observed in Figure 4.6 that for small spacings (up to about 13 NM), the ASAS by ADS-B-based model performs better than the AMSS-based model, while for large spacings (exceeding about 13 NM) the AMSS-based model performs superiorly. In particular, the curve for the AMSS-based model cuts the TLS at a lower spacing. Thus, in spite of the high level of automation in the ASAS by ADS-B-based operational concept and its smaller communication delays, the AMSS-based model outperforms the ASAS by ADS-B model at the TLS. The lower collision risk for large spacings of the AMSS-based model is due to the smaller probability of large off-lane deviations in the AMSS-based model in comparison with the ASAS by ADS-B based model. This difference is effectuated by the anticipative correcting actions of the monitoring ATCo in the AMSS-based model, which are absent in the ASAS by ADS-B model, where a reactive conflict avoidance strategy is used. Stated differently, at large spacings conflicts get little chance to occur in the AMSS-based model, since such conflicts are preceded by a large deviation and these are usually detected and corrected by the ATCo at a relatively early stage. In the case of small spacings, the delays in the decision making loop of the AMSS-based model relatively often prevent timely corrective actions to be implemented, such that the fast implementation of collision avoidance manoeuvres in the ASAS by ADS-B model is relatively effective in comparison with the results of the AMSS-based model.

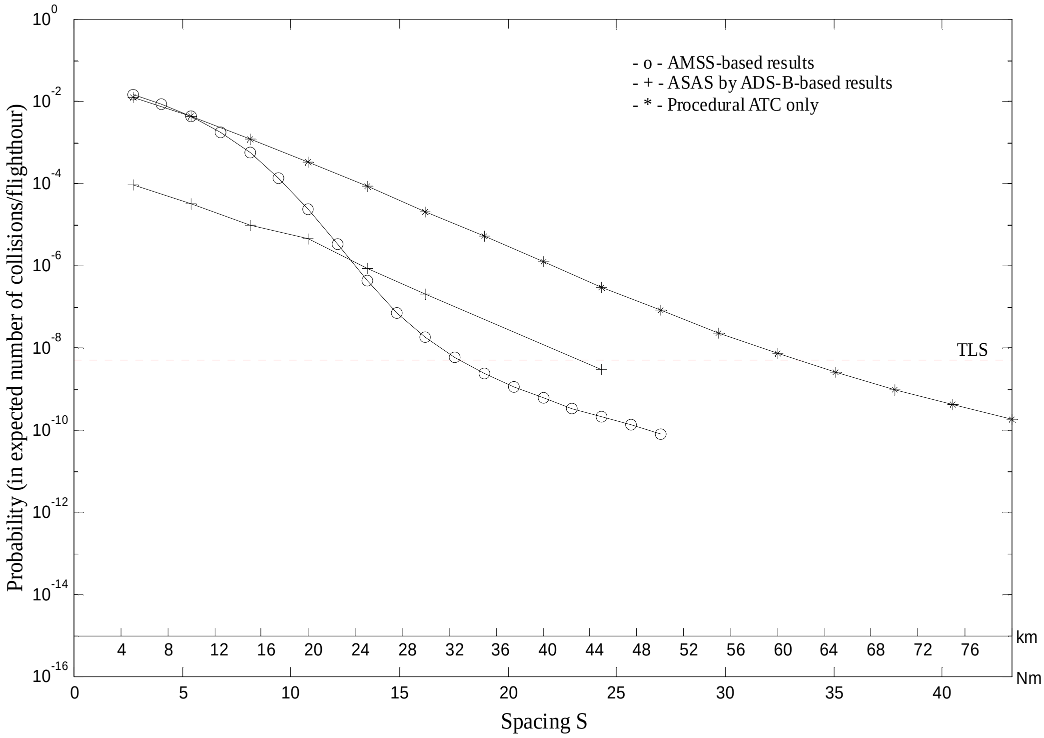

Figure 4.6: *The expected number of aircraft accidents occurring per aircraft flight hour as a function of lane spacing. Results are given for three operational concepts: the AMSS-based operational concept, the ASAS by ADS-B based operational concept, and the baseline concept, using procedural ATC only.*

4.9 Summary of safety/separation differences

- The AMSS-based model achieves the target level of safety (TLS) of 5×10^{-9} expected collisions per flighthour for a distance between the two parallel lanes of *S=18* NM. The ASAS by ADS-B model achieves the TLS for *S=23.5* NM. A model of the same operational concept but with only procedural ATC achieves the TLS for *S=33* NM. The actual present situation is procedural control with a lateral separation distance of *S=60* NM (see Table 4.5). For all modelled situations the safe distance is thus significantly smaller than the actual present situation. Furthermore, both the models of the AMSS and the ASAS by ADS-B operational concepts provides a significant improvement in the spacing with respect to the model of procedural ATC only.

Table 4.5: *Comparison of the present lateral separation and the modelling results.*

Situation considered	Distance between lanes *(S)*
Present situation	60 NM
Procedural ATC model	33 NM
AMSS-based model	18 NM
ASAS by ADS-B based model	23.5 NM

- The effect on safe spacing of temporary failure of GPS is negligible for both the AMSS-based model and the ASAS by ADS-B based model. This conclusion is based on the modelling assumptions that navigation nominally uses the combination of GPS and IRS, and the aircraft nominally fly according to RNP-5.
- Modelled failure probabilities of airborne equipment overload of the pilots are not safety critical due to their low probability of occurrence. This applies for both the AMSS-based model and the ASAS by ADS-B model.
- In the AMSS-based model only, the failure probability of satellite communication and the delays of the decision making loop, which include SATCOM delays, contribute significantly to the collision risk at the safe spacing value $S=18$ NM. Unfortunately, even making use of CPDLC as a back-up for SATCOM-voice failure in the AMSS-based operational concept is expected to have a negligible effect.

4.10 Tactical conflict resolution by ASAS or by ATC?

The findings summarised in the previous subsections provide basic insight into ATM conceptual design, as long as the hypothetical nature of the assessments is kept in mind. It is clear that these initial risk assessment results are not intended to answer the general question if airborne based separation is better than ground based separation. Many important airborne separation assurance aspects are simply not covered, such as:

- With airborne separation assurance concepts a possibility is that the pilot-not-flying monitors the traffic.
- Airborne separation assurance concepts are aimed at aircraft to fly outside fixed route structures and without a procedural clearance.
- Encounters, with e.g. climbing, descending or manoeuvring traffic should also be assessed.
- The choice between ASAS or ATC also depends of the solutions to be identified for a large number of complex institutional issues.

Reasonably, these aspects have to be understood before one could make a final safe separation comparison between ASAS based or ATC based tactical conflict resolution. This asks for additional risk assessment studies. However, at this moment both concepts have shown to be valuable for further ATM development.

4.11 Recommendations

- The first task of each work package was to define an operational concept to be analysed on safety/capacity. Especially for ASAS by ADS-B, it became clear that this task was more demanding than expected, where it concerns procedures for sharing responsibilities between ATCo's and pilots. During future research, the development of such procedures requires significant attention.
- During the modelling, several assumptions have been adopted, listings of which have been presented in this report. The results obtained should always be interpreted in the light of these assumptions. They remain to be assessed with

support from operational experts on severity and effect on safety/separation as part of a further validation of the developed model.

- In this report, the safety/separation models were directed to specific AMSS and ASAS by ADS-B based operational concepts and one encounter scenario (opposite direction parallel routes). The modelling should be extended to other AMSS and ASAS by ADS-B based concepts and encounter types.

5. Conclusions and recommendations

5.1 NGSS – Recommendations for future work

In high density airspace, over the European north-western core-area and in the US north-east area, the available aviation VHF spectrum is now predicted to be totally used within the next 8 to 10 years by new ATC sectors R/T needs, even under assumption of "aggressive" deployment of the 8.33 kHz channel spacing scheme. Consequently the civil aviation authorities, operating in these regions, can not escape having to make difficult decisions regarding:

- The implementation datalink as a way to release the ATC Controllers from time-consuming routine R/T communications with the objective to improve their productivity thus avoiding further airspace resectorisation.
- The search of a successor to the current VHF R/T system, which is obsolete, spectrum-inefficient, vulnerable to spurious interference and malevolent intrusion and thus putting flight safety at risk. This successor could be the ICAO-standardised VDL Mode 3, if implementable after all - it requires 25 kHz channels, which would no longer be available under generalised deployment of the 8.33 kHz spacing, in Europe and beyond due in particular to airlines' pressure already equipped with 8.33 kHz radios. In upper airspace, SATCOM with improved capabilities, could provide the alternative to VHF R/T, in order to free up today's VHF frequencies for re-using them in lower airspace ATC sectors.

Accompanying those decisions is the need to engage in the corresponding Human Factors studies and HMI activities to validate technical development choices and generate the associated training and operating procedures

- The aviation community needs to look into the economic feasibility of AMS[S]S dedicated systems as an option for securing their long-term availability. The ESA/SDLS is such a potential candidate system. As a prerequisite, its technical capabilities as a second generation AMSS optimised for use in high density airspace need to be demonstrated - in terms of performance, access and transfer delays and also, dependability.
- As an alternative, and at minimum to ensure availability of back-up communication systems, the aviation community ought also to carry on looking into the feasibility of using New-ICO AMSS + AMS[R]S offer as it takes shape.
- Within EMERTA, a high-level review of the relevant ATM long term strategy and research activities led to the preliminary identification of the following desirable characteristics for an aeronautical communications system:
  1. Fully integrated voice and data services.
  2. Mixed Services : ATS, AOC with a suitable priority, precedence and pre-emption mechanism
  3. Full segregation between application and communication equipment levels to give operators complete transparency over the communication architecture
  4. Inclusion of up-to date HMI technologies

5. Security provision and interference protection
6. Multicast communication within closed user groups
7. Broadcast mode for wider geographical/operational applications
8. Possibility to exchange large file Sizes
9. Air-Air (in addition to Air-Ground) Services

- The above set of requirements needs to be developed and validated by operators - both pilots and ATC personnel. In pursuit of such requirements the ATM community must ensure adoption of new communications and HMI technologies as they become available, including the use of generic, non ATN communication network protocols, such as the TCP/IP protocol suite.
- The rather low utilisation of today's (INMARSAT) AMSS points to the under-utilisation of the corresponding spectrum allocated by ITU. As the result such an allocation is under threat from the mobile communications industry, at future World Radio Conferences (WRC), of being reallocated to the Mobile Satellite Service, with no obligation to carry safety-related communications. Accordingly it is critical for civil aviation to come up to the ITU WRC where such frequency spectrum allocations are discussed and agreed internationally, with credible plans and projects for AMS[R]S deployment

In the short term the following programmes are considered to be of value to the future of ATM:

- Aeronautical Frequency Review: Development of a consensus of the frequency requirements for ATM in to the future and adoption of strategy, co-ordinated at European level to ensure continuous access to RF spectrum for both AMSS and terrestrial systems ,
- Develop a back-up RT Strategy using SATCOM Voice: Trials of existing SATCOM voice services as a backup voice system.
- Experimentation and use on pre-operational basis of NGSS demonstrators, i.e. of the New-ICO and ESA/SDLS types in order to both asses technical performance and the impact on operational personnel’s (ATC and pilots) acceptability and work-procedures

5.2 ASAS – Recommendations for future work

- A subset of key initial ASAS applications needs be produced, it is important to involve airlines and the aircraft operators in general in this process. Outline procedures need to be developed for these applications. Following this, a detailed Cost Benefit Analysis need to be carried out focused on these applications.
- In order to support these key applications a TIS(-B) specification must be finalised. Work is ongoing in RTCA and in NUP. It is important to produce a harmonised specification which can be internationally agreed.
- The equipment which will support the ASAS functionality must be developed and standardised. This equipment must include ADS-B and TIS-B receive/transmit functionality as well as that processing required to support the ASAS applications.

Included in this is the CDTI and pilot interface requirements which also need more European input to the agreement of an international standard.

- This is all dependent on a suitable ground system to support the ASAS implementation, in particular through TIS(-B) implementation plans so it is important to advance this in parallel with the above.
- The choice of ADS-B (and therefore TIS-B?) medium is an activity which has high priority. However, without the proper consideration of how we will make use of these new capabilities we will not make a sound first step towards the implementation of ASAS.

5.3 Safety Study work recommendations

The EMERTA safety studies discussed in this report addressed the safety/separation modelling of two operational concepts: 1) AMSS based ATC, and 2) ASAS by ADS-B. The results obtained show that a model-based approach can help to get insight into mechanisms behind collision risk. It can help to learn where safety comes from, how it is influenced and which factors have the highest impact. The results also motivate the following main recommendations:

- The first task of each work package was to define an operational concept to be analysed on safety/separation. For both work packages, and especially for ASAS by ADS-B, it became clear that this task was more demanding than expected, where it concerns procedures for sharing responsibilities between ATCo’s and pilots. During future research, the development of such procedures requires significant attention.
- During the modelling, several assumptions have been adopted, listings of which have been presented in this report. The results obtained should always be interpreted in the light of these assumptions. They remain to be assessed with support from operational experts on severity and effect on safety/separation, as part of a further validation of the accident risk assessment developed.
- The safety/separation models were restricted to a sector in the Southernmost area of the Marseilles Flight Information Region. It would be very interesting to extend the analysis to other, more demanding, areas, such as continental airspace.
- In this report, the safety/separation models were directed to specific AMSS and ASAS by ADS-B based operational concepts and one encounter scenario (opposite direction parallel routes). It would be very valuable to extend the modelling to other AMSS and ASAS by ADS-B based concepts and encounter types.

The EMERTA safety separation findings provide basic insight into ATM conceptual design, as long as the hypothetical nature of the assessments is kept in mind. It has become clear that both ASAS by ADS-B and satellite based ATC provide significant capacity improvements over the Mediterranean. This means that for the Mediterranean both concepts are feasible directions to follow. However, the choice between ASAS or ATC also depends of the solutions to be timely identified for a large number of complex institutional issues that are involved with the introduction of satellite-based ATC or ASAS by ADS-B-based operational concepts over the Mediterranean.

From a more general perspective, it must be clear that these initial risk assessment results are not intended to answer the general question if airborne based separation is better than ground based separation. Many important separation assurance aspects are simply not covered, such as:

- With airborne separation assurance concepts a possibility is that the pilot-not-flying monitors the traffic.
- Airborne separation assurance concepts are aimed at aircraft to fly outside fixed route structures and without a procedural clearance.
- Encounters with for example climbing, descending or manoeuvring traffic should also be assessed.

In general, these aspects have to be understood in order to make a proper comparison between ASAS by ADS-B-based or ATC-based tactical conflict resolution. This clearly motivates the undertaking of additional risk assessment studies.

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Glossary

AAC	Airline Administrative Communications
ACARS	Aircraft Communications and Address reporting System
ACC	Area Control Centre
ADC	Air Data Computer
ADIRS	Air Data Inertial Reference System
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
AES	Airborne Earth Station
AHRS	Altitude and Heading Reference System
AIC	Aeronautical Information Charts
AM	Amplitude Modulation
AM[R]SS	Aeronautical Mobile En-Route Satellite Service
AMCP	Aeronautical Mobile Communication Panel
AMSS	Aeronautical Mobile Satellite Service
ANC	Air Navigation Conference
AOC	Airline Operational Centre (Communications)
APC	Airline Passenger Communications
APR	Aircraft Position Reporting
ARTAS	ATC suRveillance Tracker and Server
ASAS	Airborne Separation Assurance System
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
ATSU	Air Traffic Services Unit
BITE	Built In Test Equipment
B-RNAV	Basic Area Navigation
CDTI	Cockpit Display of Traffic Information
CFMU	Central Flow Management Unit
CMU	Communications Management Unit
CNS	Communication Navigation Surveillance
CRT	Collision Risk Tree
CSPA	Closely Spaced Parallel Approaches
DADI	Datalinking of Aircraft Derived Information
DCPN	Dynamically Coloured Petri Net
DG	Directional Gyro
DME	Distance Measuring Equipment
DM-loop	Decision Making loop
EC	European Commission
EMERALD	EMErging RTD Activities of reLevance to ATM concept Definition
EMERTA	EMERging Technologies, opportunities, issues and impact on ATM
ESA	European Space Agency
EVA	Enhanced Visual Acquisition
FANS	Future Air Navigation System
FIR	Flight Information Region
FMS	Flight Management System
FPM	Flight Path Monitoring
GA	General Aviation
GEO	Geo-Stationary Orbit

GES	Ground Earth Station
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
HF	High Frequency
HMI	Human-Machine Interface
ICAO	Intentional Civil Aviation Organisation
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IMO	International Maritime Organisation
IMSO	International Maritime Satellite Organisation
INMARSAT	International Maritime Satellite Organisation
IP	Internetworking Protocol
IRS	Inertial Reference System
ITU	International Telecommunications Union
LEO	Low Earth Orbit
LSK	Longitudinal Station Keeping
MASPS	Minimum Aviation System Performance Specification
MCDU	Multi-purpose Command and Data Unit
MEO	Medium Earth Orbit
MOPS	Minimum Operational Performance Specification
MSBN	Mobile Satellite Business Networks
MUFTIS	Model Use and Fast TIme Simulation studies
NGSS	Next Generation Satellite System
NM	Nautical Mile = 1852 m
ODIAC	Operational Development of Initial Air/ground data Communications
OSI	Open System Interconnection
PLC	Public Limited Company
PLN	Aircraft Flight Plan
PSTN	Public Switched Telecommunications Network
PTT	Post, Telegraph and Telephone
R/T	Radio Telephony
RNP-x	Required Navigation Precision (within x NM during 95% of time)
RR	Radio Regulation
RTD	Research and Technical Development
SAN	Satellite Access Node
SARP	Standards and Recommended Practice
SATCOM	Satellite Communications
SC	Strategic Co-operative
SDLS	Satellite Data Link System
SICASP	SSR Improvements and Collision Avoidance System Panel
SKA	Station Keeping on Approach
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
SV	Service Volume
TC	Tactical Co-operative
TCAS	Traffic alert and Collision Avoidance System
TCP/IP	Transport Control Protocol/Internetworking Protocol
TDMA	Time Division Multiple Access
TID	Touch Input Device
TIS(-B)	Traffic Information Service (-Broadcast)
TLS	Target Level of Safety
TMA	Terminal Manoeuvring Area
TOPAZ	Traffic Organization and Perturbation AnalyZer
TOSCA	Testing Operational Scenarios for Concepts in ATM

TSA	Traffic Situational Awareness
TSD	Traffic Situation Display
UAT	Universal Access Transponder
USD	United States Dollars
VDL	VHF Data Link
VFR	Visual Flight Rules
VG	Vertical Gyro
VHF	Very High Frequency
VOR/DME	VHF Omnidirectional Range / Distance Measuring Equipment
VSAT	Very Small Aperture Terminal
WP	Work Package
WRC	World Radio Conference

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