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ADS Europe Flight Trials Programme

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ABSTRACT

The world's largest trial of satellite based Automatic Dependent Surveillance (ADS) in the ICAO Aeronautical Telecommunications Network standard environment is being executed in Europe. A Consortium, led by the United Kingdom's National Air Traffic Services, and known as ADS Europe, is currently researching and developing ADS. The research results from a 2 million ECU (2.6 million US $)contract from the European Commission, through its Telematics Applications Programme.
The two other partners in ADS Europe are the Service Technique de la Navigation Aerienne of France, and the National Aerospace Laboratory NLR of The Netherlands. ADS is a datalink-based aeronautical surveillance service which, when using satellite communications, allows aircraft flying outside radar coverage to be accurately monitored and controlled. ADS Europe is investigating the applications and benefits of using satellite communications systems, anticipating the growth in traffic over Europe and the North Atlantic.
ADS Europe equipment was fitted into twelve long haul aircraft, operated by KLM Royal Dutch Airlines, British Airways, Lufthansa German Airlines and Air France, and NLR's Cessna Citation research aircraft.
NLR's research aircraft performed dedicated flights to investigate specific issues which cannot be undertaken by passenger aircraft in regular commercial service.
In this paper the ADS concept is given. The ADS Europe programme is described, related programmes are summarized. Details of the ADS equipment installation in NLR's research aircraft are given.
ADS Europe Flight tests started early 1996 and will run till the end of 1996. The objectives of the flight test programme are summarized, preliminary technical results are mentioned.

Contents

(16 pages in total)

ADS EUROPE FLIGHT TRIALS PROGRAMME[1)]

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Abstract

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1. Introduction to FANS

In 1983 the International Civil Aviation Organization (ICAO) established the Special Committee on Future Air Navigation Systems (FANS). The committee was tasked with developing the concept for the future Communication, Navigation and Surveillance/ Air Traffic Management (CNS/ATM) system to take civil aviation into the twenty first century. The committee finalised its task in 1986 and recommended a concept based on satellites, data communication and

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automation, initially to augment and gradually replace existing systems.
In the following sections the CNS/ATM concept is elaborated. For detailed information see ref. 1, which has been the basis for this chapter.

1.1 Communication - The aeronautical communications system in the CNS/ATM system will extensively use digital data communication to enable different computer systems to communicate with each other automatically (the need for voice communication however will remain for emergency communications a.o). A global telecommunications network is required to interconnect the variety of aircraft and ground based computers. The inter-networking infrastructure for this global network is the Aeronautical Telecommunications Network (ATN). The ATN is based on the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) model, and will link the various air-ground and ground-ground data systems together.

Figure 1 gives an overview of the ATN.

The airborne network will consist of a Communications Management Unit and the (ARINC) data busses.

The air-ground network will contain satellite, VHF, Secondary Surveillance Radar-Mode S (SSR-Mode S), HF and Gatelink communication links.

The ground network will be formed by the Air Traffic Service (ATS) Network, and airline industry private networks.

The routers will direct data messages to their destinations in the ATN, and receive ATN messages adressed to the terminal or network that it serves. Routers will choose the optimum route to get the message to its destination.

1.2 Navigation - The ideal navigation system would be a system providing adequate navigation for all phases of flight under all meteorological conditions and all over the world for airspace users. The Global Navigation Satellite System (GNSS) concept is approaching this ideal. It will provide the aircraft with the capabilities to fly through a predetermined 4-dimensional tunnel from departure to landing.

There are currently two satellite-based navigation systems available that together could be used for the GNSS: the United States Global Positioning System (GPS) and the Russian Federation Global Orbiting Navigation Satellite System (GLONASS). Moreover, several research programs are running to augment GPS and/or GLONASS with signals from communication satellites or from a stationary satellite overlay.

1.3 Surveillance - The surveillance function is needed by the air traffic controller to monitor the separation between aircraft, to manage the airspace efficiently and to assist the pilot in navigating his aircraft safely. In addition, the pilot needs to be aware of nearby aircraft which may represent a collision risk. To fulfil these needs there will be three tools available: Airborne Collision Avoidance System (ACAS), SSR-Mode S and Automatic Dependent Surveillance (ADS) system.

1.3.1 Airborne Collision Avoidance System - ACAS provides back-up to the air traffic services by alerting the flight crew of potential collisions. The system is contained entirely on board the aircraft and is not dependent on any ground-based system. ACAS receives position related information from aircraft in the vicinity, determines potential collision hazards and provides the flight crew with information to assure separation.

1.3.2 Secondary Surveillance Radar-Mode S - Since its adoption by ICAO more than twenty years ago, the use of the Secondary Surveillance Radar (SSR) for surveillance has spread throughout the world. A technique using a unique address (the 24 bits ICAO address) for each aircraft, known as SSR-Mode S has been developed to improve the aircraft identification and provide more aircraft position related information.

1.3.3 Automatic Dependent Surveillance - ADS is an Air Traffic Service (ATS) in which aircraft automatically transmit position related data derived from on-board navigation systems. An ADS based Air Traffic Control (ATC) system will be comprised of:

- the airborne ADS function - establishing the communications route between the aircraft and the ground based ATC centre, and formatting the airborne data in ATC required surveillance information,
- the air-ground data link - transferring the data from the aircraft to the controlling ATC unit,
- the ground based flight data processing system - collecting and processing the received information to be presented to the controller and to probe for potential conflicts.

To provide ADS ATC services, an agreement (contract) between the airborne and ground systems needs to be established before entering the airspace in question. An ATS facility may issue several contracts to a single aircraft at one time:

- a periodic contract under which the aircraft assembles and transmits a message at the interval specified in the contract,
- an event contract under which the aircraft assembles and transmits a message at events, specified in the contract (e.g. altitude change, way point crossing, etc.),
- on-demand reports, in which the aircraft assembles and transmits one message each time it is commanded from the ground.

The ADS message contains one or more pre-defined data blocks. The basic ADS block contains aircraft position and time. The additional data blocks include flight vector, ground vector, flight profile, aircraft intent and associated weather information.

In addition the pilot has the capability to initiate an emergency mode. In this mode ADS reports will be transmitted at a high fixed rate to support ATC alerting procedures and to assist search and rescue operations.

The ADS <u>surveillance</u> function requires the <u>navigation</u> function as well as the <u>communication</u> function of the CNS/ATM concept. As such, ADS trials probe all functions of this concept.

2. ADS Europe

In 1994 the European Commission, within the framework of its Telematics Applications Programme, invited proposals for studies and experiments covering the exploration and promotion of the use of telematic technologies to support communications, navigation and surveillance in the domain of air transport. Large and small airports, satellite systems and research networks were within the scope of these preparatory actions.

A consortium led by the United Kingdom’s National Air Traffic Services, and known as ADS Europe, was formed with the Service Technique de la Navigation Arienne of France/Sofreavia and the National Aerospace Laboratory NLR of The Netherlands as partners.

- National Air Traffic Services (NATS) is jointly responsible to the Civil Aviation Authority and the Ministry of Defence, for the provision of air traffic services in the UK. It is also responsible for the planning, provision and maintenance of radars, navigational aids and communications.

- Service Technique de la Navigation Aerienne (STNA) is the technical and equipment arm of the Direction Generale de l’Aviation Civile, in charge of air traffic control system development and implementation in France. Sofreavia is an engineering company created by the French government to carry out worldwide studies and projects concerning aeronautical and meteorological installations and facilities.

- National Aerospace Laboratory (NLR) is the central institute in The Netherlands for aerospace research. Its principal mission is to provide expert contributions to activities in aerospace and related fields.

ADS Europe was awarded the contract, worth 2 million ECU (2.6 million US $), at the end of 1994. An equal budget was made available by national funding from the partners. The demonstration programme started in January 1995 and will run for a period of 24 months.

In the following sections the objectives of the programme will be detailed. The ADS Europe infrastructure and development will be described. Some related programmes will be identified.

2.1 Objectives - The primary objective for ADS Europe was formulated as "Obtain pre-operational demonstration results for dissemination within the air transport community". This primary objective was sub-divided into the following items.

- Identify shortcomings in any existing standards.
- Propose consequent improvements to standards.
- Assess the quality of service available to ADS applications.
- Identify techniques for ADS data displays that may benefit controllers.
- Identify the operational circumstances and types of airspace in which ADS may be provided to improve traffic flow and safety.
- Provide data for cost-benefit studies of satellite communications and ADS implementation.
- Trials results to be made available to European states to support development of operational ATC procedures which take full advantage of ADS.

Running toward the end of the programme it is claimed that the objectives were or will be met. In this paper the path to reaching some, not all, of the objectives is given.

2.2 ADS Europe Infrastructure - The final ADS Europe systems infrastructure is given in figure 2.
Twelve long haul revenue aircraft, and NLR’s Citation, are fitted with ADS- and satellite communications equipment. Ground Earth Stations (GES) communicate with the aircraft via the INMARSAT satellites. GESs are connected to public X.25 networks. These networks have connections to ATN routers located at experimental ATC stations in Bournemouth (UK) and Toulouse (France). Although ADS Europe only uses one air-ground data link, the Satcom link, an airborne router function is implemented in the ADS equipment.

Three British Airways and three KLM Royal Dutch Airlines Boeing 747-400 aircraft were equiped with ADS units delivered by Racal Avionics Ltd (UK) and Honeywell. SEXTANT Avionique (France) delivered the units for four Air France and two Lufthansa German Airlines Airbus A340 aircraft, and for NLR’s Citation. The selected aircraft were already provided with Satcom equipment for operators and passengers services.

British Telecom provided the network between GESs and the ATN router at Bournemouth, whereas France Telecom served the ATN router at Toulouse, and the interconnection between British Telecom and France Telecom.

A typical sequence of operations is as follows.

- When ATN communication is desired, an aircraft may log-on to its preferred

GES by selecting the INMARSAT satellite with the best visibility.
- Once logged-on, an air-ground sub-network connection is established, allowing the ATN routers their initiation procedures. These procedures establish the paths available for communication via the ADS Europe ATN topology.
- The ADS equipment in the aircraft then establishes communications with both centres in order to announce that the aircraft is available for ADS communication.
- The centres then establish the appropriate ADS contract with the aircraft, depending on the specific trials objective.
- Following this step, routine exchange of ADS data occurs.

2.3 ADS Europe development

2.3.1 General - The initial and perhaps the most crucial design step taken was to establish the functionality and standards basis for both the ADS application and the supporting ATN infrastructure. Since neither the ICAO standards for ADS nor the Standards And Recommended Practises (SARPs) for the ATN were complete at the project start the programme was based on the most likely outcome of the SARPs process. Thus the ADS Europe implementation is a first step, but a substantial one, to an ICAO compliant system.

The basic standards chosen for the ADS equipment were the ARINC Characteristic 745-2 (for the ADS data structure) and RTCA Minimum Operating Standards (for addressing issues, and known as Context Management).
The ICAO ATN Manual was chosen as a basis for the ATN internet.

The ATN communications infrastructure and specifications used to support the ADS Europe programme were described in the ADS Europe Common Technical Specification (CTS). This document was one of the major outputs to the early part of the programme and is considered as one of the key aspects of the success of the programme: it allowed the partners to define interoperability standards, and to incorporate into one document any specification elements deemed essential for systems interoperability.

2.3.2 Avionics system development - Development and integration testing of the ADS equipment by Racal (for the 747-400 aircraft) and SEXTANT (for the A340 aircraft and the Citation) was completed in late 1995. Interoperability testing of the ADS equipment with the Satcom units (Collins and Racal/Honeywell) was completed at the same time.

2.3.3 Ground system development - NATS uses the Trials ATN router developed by Eurocontrol. STNA uses the router developed by the EURATN consortium. Having two different routers provided a valuable input to the ATN SARPs validation process since two independent ATN routers have been shown to be interoperable.

Two different experimental ATC stations had previously been developed by NATS and Sofreavia/STNA respectively in support of their national trials. Both stations were upgraded under national funding to meet the requirements of the ADS Europe CTS. Analysis tools were refined in order to automatically handle the massive amount of data to be expected.

2.3.4 System integration - Systems integration testing between both ADS equipments (Racal and SEXTANT), the Satcom units, the satellite datalink, the public sub-network, the ATN routers and the experimental ATC stations took place during the second half of 1995. A stepwise integration path was followed, starting with a straightforward local setup, and adding complexity and geographically distributed equipment after each step was completed succesfully.

Integration testing took more time than

expected, especially at the early stage of implementation. Errors in the specification and in the implementation were identified and corrected. The additional integration testing time however resulted in an infrastructure which proved to be robust and stable from the beginning of the trials.

2.4 Related programmes - A number of ADS trials programmes are running or are foreseen in near future. Trials may be performed in order to validate parts of the CNS/ATM concept. A more direct goal is to prove benefits, such as fuel savings from flying optimal routes: ADS allows reduced horizontal separation between aircraft, alleviating congestion on routes and enabling the aircraft to fly on its economical altitude.
A selection of trials programmes is summarized in the following subsections.

2.4.1 FANS-1 package - Trials are taking place in the South Pacific with Boeing 747-400s equiped with the FANS-1 package. Using existing 747-400 cockpit systems including the ACARS datalink transmitting messages in the ARINC-622 (character based) standard, FANS-1 is a relatively low cost package. However, its lifetime is considered to be limited, since the ACARS/ ARINC-622 implementation does not comply to the FANS requirements in the field of availability and integrity.

2.4.2 ProATN and EOLIA - The ICAO will complete the CNS/ATM-1 SARPs at the end of this year. This subset includes standards for the ATN internet and for applications such as ADS and Controller-Pilot Data Link Communications.

The European Commission sponsored programme ’Prototype Aeronautical Telecommunication Network’ (ProATN) develops and deploys a pre-commercial, pre-operational prototype of the ATN conforming to the CNS/ATM-1 SARPs.

Another European Commission sponsored programme: ’European pre-Operational data LInk Applications’ (EOLIA) aims at the development, implementation and evaluation of ATC datalink services, using the air-ground communications infrastructure developed by ProATN.

Both programmes were started in the beginning of 1996 and will run through the end of 1999.

2.4.3 Norwegian Modified ADS Trials - This trials programme started September 1996. A number of Norwegian helicopters are fitted with ADS and Satcom datalink equipment. This equipment allows them to be controlled on North Sea flights when they are out or under SSR coverage. The Norwegian programme took the ADS Europe CTS as a basis for their equipment development. Interoperability between the Norwegian equipment and ADS Europe was demonstrated during the Farnborough (UK) Airshow, September 1996.

2.4.4 FarAway - The European Commission partially funds the programme: ’Fusion of radar and ADS data through two way data link’ (FarAway).It aims at demonstrating that in the European airspace over the Mediterranean Sea the introduction of ADS and two way data link leads to:

- improved situational awareness (both in the cockpit and on the ground),
- possibly reduction in separation minima in airspaces not covered by radar, and
- better surveillance in areas covered by (primary or secondary) surveillance radar.

Some core technologies used will be:

- ADS-Broadcast over a self-organizing time division multiple access VHF data link,
- (Differential) GPS for position determination and data link time synchronization,
- fusion of ADS and radar data.

The programme started in March 1996 and will run for two years. The trials will start in the second half of 1997 with the ground test facilities implemented in Rome-ACC (Italy) and the avionics in some Alitalia MD80s.

2.5 ADS Europe trials - In January 1996 the first revenue aircraft fitted with ADS Europe equipment became available, data collection at both STNA in Toulouse and NATS in Bournemouth started. By September 1996 all twelve revenue aircraft were equiped and participating in the programme on a routine basis.

By September 1, 1996 a total of 350 revenue flights has been monitored, resulting in a total of 4000 hours of ADS application data. In figure 3 a typical ADS display is given with ADS position reports once every five minutes. One of the potential advantages of ATM using ADS is clear from this figure: some tracks could have been far more economical.

During the trials NATS and Sofreavia/STNA were able to identify problems and faults which were not found in the integration test phase. A fault reporting procedure was established, and faults were or will be corrected. Moreover, the trials have identified various changes at specification level, which were reported directly to the ICAO ADS panels responsible for publishing the SARPs for data link applications.

2.6 Trials results - At the start of the programme, a guess was made for the initial transport timer settings, based on ARINC 745 values and the best engineering knowledge at that time. Transport timers are values which determine re-transmission times, the number of re-transmission tries, time-out timers, etc. in the various components of the network. Based on trials results, these values were refined at the end of July 1996, and will be implemented in the components.

In the following subsections trials results are given, based on data collected from the start of the trial up to September 1, 1996. The actual data collection period ended at the end of October. Thus, the results have a preliminary character, but will be indicative for the final figures. The implementation of the refined transport timer values may improve the results.

2.6.1 End to end reliability - The end to end reliability is estimated by comparing the actual number of ADS messages received in the experimental ATC station during a log-on period with the number of messages that were expected during this period. The initial percentage appeared to be low : a little over 80 %. Fixing faults will raise this percentage.

2.6.2 Downlink times - Downlink time is calculated from the time the report is generated in the aircraft to the time it is received at the ground station. Downlink time is the appropriate parameter for the automatic mode. For short messages (24 bytes) a mean value of 6 sec. was found. Long messages (>32 bytes) typically took 10 sec.

2.6.3 Round trip delivery times - Round trip delivery time is calculated from the time a request is sent from the experimental ATC station to the time the first position report is received. Round trip time is the appropriate parameter for the initial contract set-up. Two types of messages have been considered.

- Demand messages (messages that require an immediate response): a mean value has been calculated of 16 seconds with a minimum of 11 sec and a maximum of 49 sec.
- Periodic requests (an uplink message requesting a change in message content and/or reorting interval): mean 22 sec, minimum 11 sec, maximum 66 sec.

Although these figures are acceptable for en-route control, they are too long for terminal control. Further analysis showed, that the satellite link bandwith (600 bit/sec) forms a bottle neck. By chance an aircraft with a high capacity satelite channel (10.5 kbit/sec) was monitored and showed a mean round trip time for demand messages of 11 sec, and 12 sec for the periodic requests.

2.6.4 Communication link performance - The data was examined for loss of data because of possible poor coverage from the communication satellites. No indications until now have been found.

2.6.5 Link path switching - When the aircraft flies from the coverage region of satellite A to satellite B, satellite switching may take some time. Also, the ground earth station of satellite B may be connected through another sub-network of the ATN to the experimental ATC station. Values of up to 1.5 min. have been found. However, no data was lost.

2.6.6 Satellite link loading - Studies, carried out by Inmarsat and Eurocontrol indicate that air traffic services data would only represent 7-10 % and 20 % respectively of the total data traffic in the year 2000. The ADS Europe results to date do not contradict these figures.

2.6.7 ADS data verification - ADS data (position, speed, etc) as recorded on the experimental ATC stations, were compared with data recorded onboard the aircraft (Flight Data Recorder). Some initial errors (e.g. formatting errors) were corrected in later software releases.

With the help of the Scottish Oceanic Control Centre, comparisons were made between the ADS track/predicted route and the data used by Oceanic for live ATC purposes. Results are not available yet.

2.6.8 Aircraft installation differences - Some aircraft in the programme are equiped with top Satcom antennas, other with conformal antennas. Also, antennas and Satcom equipment was delivered by different avionics manufacturers. No performance difference has been identified however.

3. Special trials aircraft

NLR's Cessna Citation II research aircraft is a twin turbofan aircraft with a maximum take-off weight of 14,100 lbs and a maximum endurance of 5 hr 30 min. The aircraft is equiped with a number of flight test sensors such as an Inertial Reference System (IRS), Digital Air Data Computer (DADC), GPS receiver, a high performance data acquisition and recording system and data link facilities (Satcom data-2, SSR-Mode S, ACARS, UHF, L- and S-band). Figure 4 gives an overview of the standard flight test instrumentation system together with the ADS Europe equipment.

For the ADS Europe programme the aircraft was additionally equiped with an ADS unit and a Gateway unit. The Gateway unit allows the ADS unit to operate at the Inmarsat data-3 standard (selected by ADS Europe).

The ADS unit is connected to the aircraft's Flight Management System (FMS) and to the flight test IRS, DADC and GPS, and selects parameters from their datastreams. The selected parameters are relayed to an experimental ATC station where they are recorded. In addition, they are recorded in the aircraft, enabling post-flight comparison.

Besides from position data, the GPS receiver delivers (absolute) system time both to the ADS unit and to the flight test instrumentation system. Since the ground earth stations, the ground based routers and the experimental ATC stations also are synchronized to absolute time, not only round trip delivery times can be determined, but also the components which sum up to the round trip time, enabling a detailed analysis of the round trip times.

The Citation was used to investigate those aspects of the SARPs which could not be undertaken by revenue aircraft because of the required (more extreme) experimental conditions. Test flights for the following purposes were or will be carried out:

- On 24 April 1996 the aircraft cooperated in the ADS Europe demonstration at the IATA ATN seminar held in Brussels, Belgium.
- A flight was carried out in order to investigate lock/loss-of-lock aspects with the communications satellite. Special headings were flown and turns with varying banks were carried out in order to force loss-of-lock.
- The transition from SSR-Mode S to ADS position reporting was investigated during a flight in the Toulouse (France) area.

Besides in dedicated flights, the ADS equipment operated when the aircraft was flying for other purposes, adding to the data base with information from the revenue aircraft.

4. Conclusions

A consortium was formed, led by the United Kingdom's National Air Traffic Services with Service Technique de la Navigation Aerienne of France/Sofreavia and the National Aerospace Laboratory NLR of The Netherlands as partners. The consortium subcontracted airlines, avionics manufacturers and communications services providers to carry out the ADS Europe programme with the objective to obtain pre-operational demonstration results on Automatic Dependent Surveillance for dissemmination within the air transport community.

The programme used standards being developed within the framework of the ICAO Communication, Navigation and Surveillance / Air Traffic Management concept.

Shortcomings and improvements in the standards have been identified during the development phase and during the trials phase, and have been reported to the relevant ICAO panels responsible for defining the standards.

The Common Technical Specification, developed early in the programme, has been taken as the basis for other programmes related to ADS.

The programme was executed with three aircraft types with different avionics manufacturers, several service providers, router developers, and experimental Air Traffic Control stations. This variety of equipment did put a positive pressure on making the systems interoperable.

Performance figures of the network were established with a low (13 aircraft), but significant loading of the network.

Trials data will be made available to European states to support further development of an operational Air Traffic Management structure.

By working together in this fruitful programme, NATS, STNA and NLR demonstrated the feasibility of a large scale collaborative project between agencies and commercial enterprises of different European countries, initiated and financed by the European community.

Reference

1. FANS Manual, Overview and Benefits, 1st edition version 1.1 effective May 1995, IATA.