SATELLITE NAVIGATION AND COMMUNICATION SYSTEMS: AIRCRAFT INTEGRATION

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Introduction

Air traffic has been steadily increasing for several years and the control systems, most of which were designed just after the Second World War, can no longer meet requirements. Congestion in cruise (mainly in Europe) or congestion in the terminal area (in the USA in particular), the consequences are the same for the airlines and their passengers: delays, waits, costs.

The ICAO has been aware of this problem since 1983 and has requested the FANS group to propose a plan to get back to an acceptable situation. This plan was accepted in September 1991 and confirmed the following year. The name FANS (Future Air Navigation System) was changed to CNS/ATM to indicate the three domains concerned: communication, navigation and surveillance and the intended objective: ATM (Air Traffic Management).
The problem to be solved is vast, many new functionalities must be considered and the implementation to obtain an operational system will take some time.

An important decision made with the implementation of FANS was to use satellite technology both for navigation and communications. The corresponding satellites already exist and it is possible at this time to incorporate some of the new functions on board aircraft. These functions and the implementation method must be chosen to obtain a rapid return on investment and to allow a transition towards the final system which must be as flexible as possible. Indeed, the ground and satellite parts can only evolve slowly and the aircraft systems must progressively adapt to their changes.

Aerospatiale is the Airbus Industrie partner in charge of avionics. A program has been established to progressively change from the current environment to the one required around 2015 for ATM. Our presentation will therefore describe what has already been done and present the next steps for the Airbus family of aircraft.

PART 1 : Satellite navigation

ICAO's decision is based on an ideal satellite navigation system called GNSS (Global Navigation Satellite System) the heart of which is the GPS (Global Positioning System).

Let us recall that the GPS cannot act as the GNSS for the following reasons:

- accuracy not sufficient for precision approaches (95% guaranteed performance is 100 meters horizontally and 150 meters vertically, with the S/A (Selective Availability) function active).

  NOTE: S/A corresponds to the possibility of downgrading the accuracy of the system voluntarily.

- integrity not sufficient (certain failures can remain hidden for up to 2 hours).

- availability not sufficient (in spite of the 24 satellites in operation, the probability of having 4 satellites in correct configuration is not 100% the world over 24 hours per day).

- continuity of service not guaranteed as the satellites being non-stationary on 6 different orbits, the configuration is continuously changing and may become unsuitable for providing the required performance (this is foreseeable). Also, the system belongs to the American military authorities which raises an institutional problem for the whole civil aeronautical community since GPS signal can be switched off in case of conflict.

Solutions are under study and some are being experimented to overcome these shortcomings:

- differential techniques, whether used locally (LADGPS: Local Area Differential GPS) or over larger areas (WADGPS: Wide Area Differential GPS) allow an improvement in accuracy: they measure the GPS error at precise points on the ground and transmit it by radio to the aircraft. The datalink for this transmission has not yet been chosen, but communication satellites will necessarily be used within the scope of the WADGP.

Other techniques, based on analyzing the GPS signal carrier phase, theoretically allow accuracies of a few centimeters to be obtained; their real-time use on board aircraft still poses several technological problems.

- integrity can be increased autonomously (by the Receiver Autonomous Integrity Monitoring (RAIM) function), but this requires more than 4 satellites in correct geometry. This technique is therefore used to the detriment of availability.

An alternative solution is to have the ground stations perform the monitoring and transmit an alert signal to the aircraft when downgraded operation is observed. This will be achieved by the GIC (GPS Integrity Channel) function which, to cover the ocean and/or desert areas, will also use the communication satellites to transmit the alert signal.

- as communication satellites can have two functions related to the GPS, as we have just seen, it is still possible to ask them to act as additional GPS satellites. This is the "ranging" function. Note that the new generation of INMARSAT satellites, the first example of which will be available in 1995/1996, can integrate all these functions (the corresponding payloads are planned but their activation has not yet been decided on).

- when the various GPS complements that we have just described are in place, the service continuity problems should be solved (apart from the institutional problem on which the President of the United States has given guarantees). Solutions are however being studied, such as pseudolites (ground beacons behaving like satellites thus guaranteeing continued service in the area covered by their range).

(NOTE: we have voluntarily not mentioned the GLONASS system, the Russian GPS equivalent ; the uncertainties concerning the continuing availability of this system do not at present allow us to consider it as the complement that the GPS requires even though it has the capabilities).

In terms of certification, navigation systems are classed into three categories:

* supplemental means added to conventional redundant systems. Their integrity is ensured by comparison with the latter.

* primary means meeting all navigation criteria, except in terms of redundancy. A secondary conventional system therefore remains necessary to cover failure cases of the primary means.

* sole means of navigation systems allowing conventional systems to be eliminated.

Current regulations relevant to GPS only allow operational use of "supplemental means" and "primary means". These are AC's (Advisory Circulars) 20-130 and 20-XX making reference to TSO (Technical Standard Order) C129. There are no European equivalents to these American regulations. Only an interim policy is being drawn up on the basis of the US regulations. Only the cruise, terminal area and non-precision approach flight phases are covered. For precision approach, specific regulations (FAA order 8400) allow differential GPS experimentation during operational flights. This is called SCAT 1 (Special Category 1 Approach).

Work is at present being undertaken both on the use of the GPS as the sole means of navigation (RTCA group SC 159) and on the use of differential GPS for precision approaches (FAA tunnel concept).

Application to Airbus :

The ARINC 743 definition of the GPS, that is a dual system with GPS position and inertial position hybridization has been certificated on the A340 as a supplemental system. This was the first aircraft in the world to be certificated for this on the basis of TSO-C129 (the configuration corresponds to class C3 of this TSO). The same architecture is offered on the A330s and its certification is in progress for the whole A320 family (A319/A320/A321).

As the receiver has no RAIM function, monitoring is ensured in the FMS by an algorithm comparing GPS, IRS and radio (VOR/DME) position information. This type of use provides piloting comfort (it is the GPS position that is used as long as it is inside the monitoring threshold) and increases safety with respect to possible errors in the FMS navigation database (it is then the pilot who will remove doubt on the deviation detected).

Operationally speaking, the implementation of the function has led to adding some information in the MCDU (see figures). The aircraft has been certificated with equipment supplied by Honeywell and Litton

The development of the RAIM function and the way the integrity information that it supplies will be used in the aircraft have been achieved. Their implementation is in progress and class C1 certification is planned for mid-95 both for the A320 family and for the A330/A340s.

For the Airbus A300/A310s, a configuration that was more economical to produce had to be developed even if potential performance was poorer. On Honeywell's proposal, a so-called "autonomous" architecture was therefore defined : it avoids having to modify the inertial systems. The goal is class C3 certification for mid-95 (this configuration also has the potential to be certificated class C1).

As far as precision approaches are concerned, Aerospatiale is conducting two experimentations, with the support of Airbus Industrie, one on the A320 with a Sextant GPS receiver, the other on an A340 with a Litton GPS receiver. The aim of these experimentations is twofold: to identify possible interoperability problems as the same Wilcox station is being used in both cases, and to study the characteristics of the datalink in order to achieve category 2 performance and, even, if possible, category 3.

PART 2 : Satellite communications

The current systems have reached their limits on account of the increase in traffic on one hand and the increase in requirements in links between aircraft and ground on the other.

Solutions are possible to increase the number of frequencies available in the VHF band and work is currently being undertaken in Europe to reduce channel separations.

Also, HF work is being undertaken to obtain systems which automatically find the best frequencies taking the state of ionization of the atmosphere into account, which would make this radio facility more operational.

These are solutions which could be considered to be valid if all they had to provide was the ATC communications related to air traffic control. However, the number of requests for air/ground links is considerable. We were acquainted with the VHF AOC voice links between the aircraft and its operational base; these have been enhanced over the last few years by the ACARS datalink whose applications are increasing in addition to the transfer of maintenance data: flight plan, pre-departure clearance,oceanic clearance, weather data, etc.. Now, in addition, both administrative (AAC) and passenger (APC) requirements are to be met. Within its studies, the ICAO FANS group forecast the explosion of these communication needs which must be met at all times, thus requiring the use of satellites (in the current situation, the INMARSAT satellites will provide this function but certain countries, such as Japan, have already planned to have their own satellites).

In the CNS/ATM concept, it is intended to integrate all the communication means between the aircraft and ground into a network: this is the ATN (Aeronautical Telecommunication Network) concept designed around OSI standards, well known by ground communication specialists. This would lead, in the aircraft, to a new function improperly called CMU (Communication Management Unit) as, although an item of equipment has been standardized under this name by ARINC, it is probable that the function will not give rise to an item of equipment but will be integrated into existing equipment (the FMS and the ACARS are potential candidates but we will see that there are other possibilities).

A particularity of the ATN is that it will have to support applications of very different types, some (ATC) directly related to flight safety and others (APC) governed more by economical considerations. The manufacturing standards and regulations being prepared on the basis of the RTCA and the EUROCAE work take this particularity into account, leading, for example, to application priority rules.

Satellite communications have already entered the cabin and passengers can now telephone at all times on a certain number of aircraft. The progressive availability of multichannel systems (three, then six channels) allows several simultaneous passenger conversations and a channel can even be reserved for ACARS links.

The introduction of SatCom into the cockpit is slower for two reasons :

- firstly, there is no need to monopolize channels for the cockpit until the ground centers have been equipped,

- secondly, a specific man-machine interface must be developed so that ground-aircraft data exchanges will be comprehensible for pilots accustomed to vocal exchanges.

In spite of this slowness, the movement is irreversible because it both improves performance (increase in data flow rates possible) and the associated safety (even though pilots are accustomed to vocal exchanges, misunderstandings can still occur if only because people speak different languages with different accents. Exchanges by datalinks will solve these problems).

<u>Application to Airbus</u>

The ARINC 741 standard which specifies the SatCom system has evolved considerally and one of the criticisms, made from the start, is the fact that it is more an equipment catalog than a real standard. This is especially true from an antenna viewpoint as it covers a whole family that can be characterized by :

- low-gain antennas (0 dB, low-rate data transmission: 600 bauds) or high-gain antennas (12 dB, voice and high-rate data transmissions: 9600 bauds),

- mechanically or electronically slaved roof antennas, or conformal lateral antennas.

The standard also provides for a complete series of possible single or redundant architectures. Oriented more towards AAC/AOC/APC applications than ATC applications, the pilot interface aspects were dealt with only slightly or not at all.

The analysis of the initial situation led Aerospatiale to set up with Airbus Industrie and its customers, a task force whose work led to a proposal to ARINC to change two parts of its standard :

- a fully redundant architecture for data transmission,
- interfaces with systems in relation with the cockpit.

The latest issue of ARINC 741 takes these changes, which are essential for future ATC users, into account and the A330/340s have the corresponding provisions installed.

Over and above this definition work, Aerospatiale is conducting a research program on the ergonomics of the function in the cockpit and the EPOPEE research simulator is extensively used to define the implementation of future SatCom applications.

As far as the cabin is concerned, from the beginning of the A330/A340 program, Airbus Industrie has developed a mock-up of a "communication system" which is under the responsibility of Aerospatiale's German partner. Continued coordination with our Deutsche Airbus colleagues will enable proper future integration of all applications to be ensured. Partial applications have already been achieved, with Aerospatiale as prime contractor for the radio part. We can thus cite :

- the Brunei A310 :
  Honeywell single-channel electronics
  Racal low-gain antenna

- the Air Afrique A300-600
  Honeywell three-channel electronics
  Bendix/Dassault Antenna

- the A340
  Honeywell three-channel electronics
  Dassault Electronique high-gain
  conformal antennas
  (NOTE 1/ Collins six-channel
  electronics with the same antennas is
  going through the certification process.

  NOTE 2/ The Toyocom antenna
  installation study is in progress).

PART 3 : Satellite Navigation/Communications association

The association of satellite navigation, which provides higher accuracy for position and especially time (single GPS time reference) with satellite communications, which provide world coverage and high, dependable data flow rates, enables new air traffic control functions to be provided.

The first is ADS (Automatic Dependant Surveillance) which allows the aircraft to inform the ground not only of its position (4D) but also its intentions (predictions given by FMS on next waypoints of flight plan followed). The aircraft can also transmit the weather conditions it encounters by the same function.

The FIS (Flight Information Services) application of the TWDL (Two-Way Data-Link) function will enhance the ADS in that the ground will be able to inform the aircraft of the weather conditions that it will be encountering or those that it could encounter by changing level; this information will have been obtained from data transmitted by other aircraft and will improve in forecasting, which in itself will globally optimize air traffic.

Many other applications are still possible but it would be tedious to describe them in detail here. All have the same aim: to replace the current notion of traffic control by one of traffic management ; this is the fundamental aim of the ATM concept (initially called FANS, let us remember).

Application to Airbus

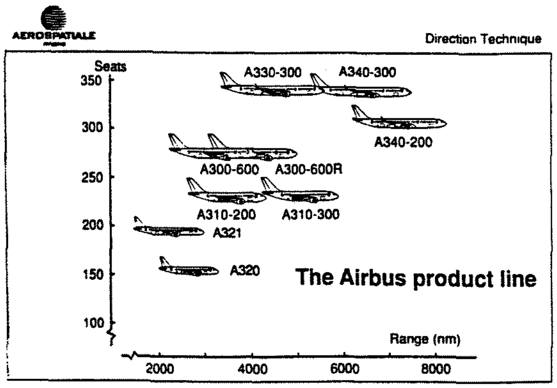
Implementation of FANS requires simultaneous evolution of the ground and airborne installations. Today, this can only be done locally as, for the time being, there is no world consensus on the way to perform a global switchover.

Various experimentations have been conducted, some using the mode-S datalink channel (valid for continental flights. An Air France Airbus is participating in these types of tests in collaboration with Aerospatiale), others use the SatCom channel (for instance, the European experimentations over the North Atlantic and the South Pacific experimentations between the USA, Australia and New Zealand).

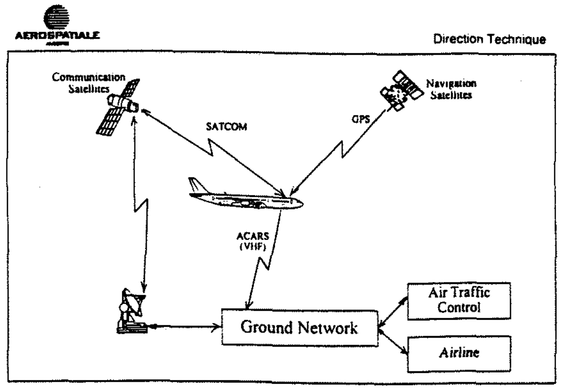
The South Pacific experimentations will very rapidly move from the experimentation stage to become truly operational as the control centers must be equipped by around 95/96. In this perspective, Aerospatiale, with the support of Airbus Industrie, has launched the ATSU (Air Traffic Services Unit) concept which differs from the solutions proposed by the competitors in that it provides high flexibility for changes, which is necessary as functions always evolve as experience is acquired. This concept also minimizes repercussions on the FMSs: there will therefore be no need to provide a new generation of this complex and expensive equipment.

The ATSU specification as perceived by Aerospatiale is being finalized and will eventually include the CMU (Communication Management Unit) when the ATN network is operational. The target for certification of the first definition of the ATSU (FANS-A functions equivalent to those of FANS-I of the B747-400s) is delivery of the first A340s in the South Pacific region.

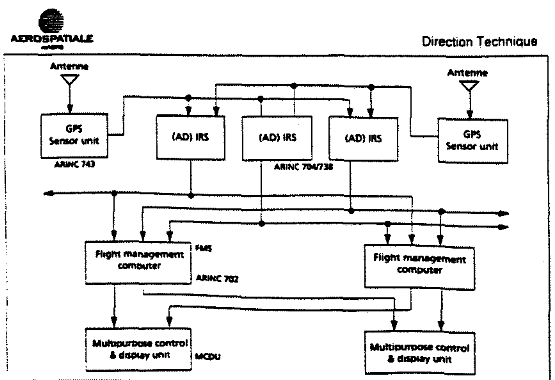
It is to be noted that the A340 passed all the SatCom/GPS non-interference tests. These systems work in the same frequency band, and as they have to operate simultaneously to provide the functions envisaged, it was important to check that they did not interact.



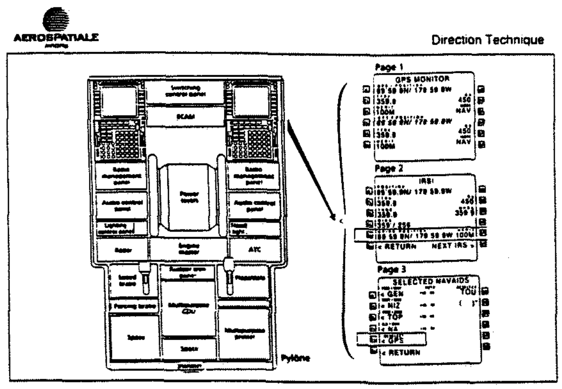
AEROSPATIALE
Direction Technique
Seats
A330-300
A340-300
A340-200
A300-600
A300-600R
A310-200
A310-300
A321
A320
The Airbus product line
Range (nm)
350
300
250
200
150
100
2000
4000
6000
8000



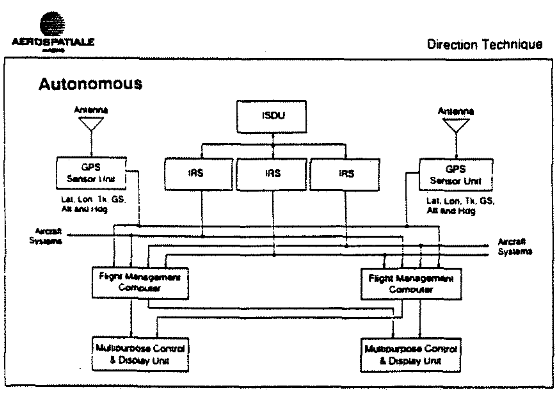
AEROSPATIALE
Direction Technique
Communication Satellites
Navigation Satellites
SATCOM
GPS
ACARS (VHF)
Ground Network
Air Traffic Control
Airline



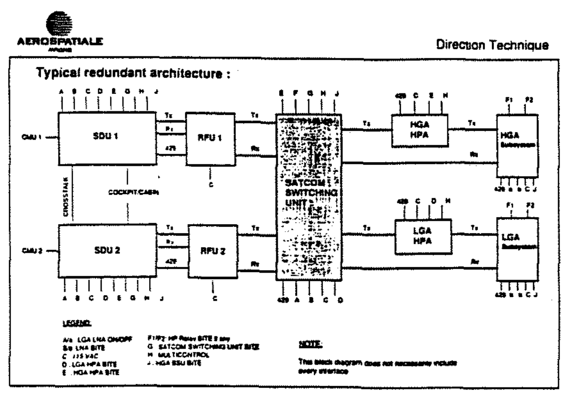
AEROSPATIALE
Direction Technique
Antenne
GPS Sensor unit
ARINC 743
(AD) IRS
ARINC 704/738
Flight management computer
FMS
ARINC 702
Multipurpose control & display unit
MCDU



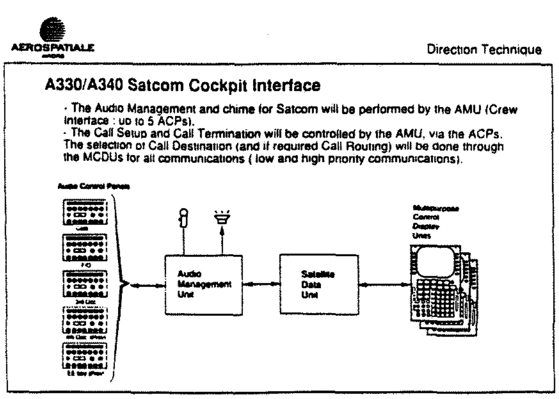
AEROSPATIALE
Direction Technique
Page 1
GPS MONITOR
Page 2
IRS
RETURN
NEXT IRS
Page 3
SELECTED NAVAIDS
RETURN
ATC
Pylône



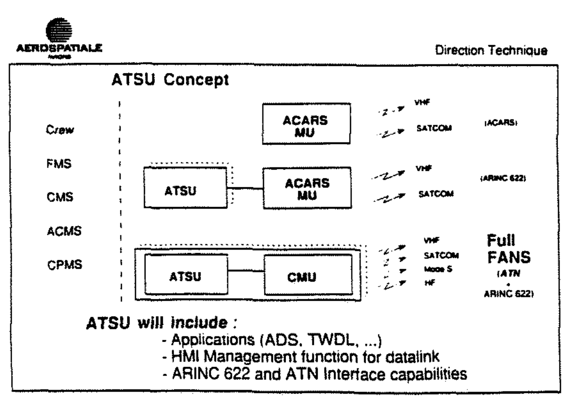
AEROSPATIALE
Direction Technique
Autonomous
Antenna
ISDU
GPS Sensor Unit
IRS
Lat. Lon. Tk. GS, Alt and Hdg
Aircraft Systems
Flight Management Computer
Multipurpose Control & Display Unit



AEROSPATIALE
Direction Technique
Typical redundant architecture :
CMU 1
SDU 1
RFU 1
COCKPIT/CABIN
CROSSTALK
CMU 2
SDU 2
RFU 2
SATCOM SWITCHING UNIT
HGA HPA
HGA Subsystem
LGA HPA
LGA Subsystem
LEGEND:
NOTE:



AEROSPATIALE
Direction Technique
A330/A340 Satcom Cockpit Interface
- The Audio Management and chime for Satcom will be performed by the AMU (Crew Interface : up to 5 ACPs).
- The Call Setup and Call Termination will be controlled by the AMU, via the ACPs. The selection of Call Destination (and if required Call Routing) will be done through the MCDUs for all communications (low and high priority communications).
Audio Control Panels
Audio Management Unit
Satellite Data Unit
Multipurpose Control Display Units



AEROSPATIALE
Direction Technique
ATSU Concept
Crew
FMS
CMS
ACMS
CPMS
ACARS MU
ATSU
CMU
VHF
SATCOM
Mode S
HF
(ACARS)
(ARINC 622)
Full FANS
(ATN + ARINC 622)
ATSU will include :
- Applications (ADS, TWDL, ...)
- HMI Management function for datalink
- ARINC 622 and ATN Interface capabilities

Glossary

AAC: Aeronautical Administrative Communications
AC: Advisory Circular
ACARS: Aircraft Communications Addressing and Reporting System
ADS: Automatic Dependant Surveillance
AOC: Aeronautical Operational Control
APC: Aeronautical Passenger Correspondence
ATC: Air Traffic Control
ATM: Air Traffic Management
ATN: Aeronautical Telecommunication Network
ATSU: Air Traffic Services Unit

CMU: Communication Management Unit
CNS: Communications/Navigation/Surveillance

DGPS: Differential GPS
DME: Distance Measuring Equipment

FAA: Federal Aviation Agency
FANS: Future Air Navigation System
FIS: Flight Information Services
FMS: Flight Management System

GIC: GPS Integrity Channel
GNSS: Global Navigation Satellite System
GPS: Global Positioning System

HF: High Frequency

LADGPS: Local Area DGPS

MCDU: Multipurpose Control and Display Unit

OSI: Open System Internetwork

RAIM: Receiver Autonomous Integrity Monitoring
RTCA: Requirements and Technical Concepts for Aviation

S/A: Selective Availability
SCAT 1: Special category 1

TSO: Technical Standard Order
TWDL: Two-Way Data-Link

VHF: Very High Frequency
VOR: VHF Omnidirectional Range

WADGPS: Wide Area DGPS