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ASPASIA Final Activity Report

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PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Reference document

[RD1] ASPASIA D 1.2: Satcom requirements specification for GS/AS applications

[RD2] ASPASIA D1.1 - Detail of the Selected GS/AS Applications

[RD3] ASPASIA D3.2/D3.4 - Test Report

[RD4] Communications Operating Concept and Requirements for the Future Radio System, Eurocontrol/FAA, COCR Version 1.0

1 Executive Summary

ASPASIA project

ASPASIA (Aeronautical Surveillance and Planning by Advanced Satellite-Implemented Applications) is an international project co-funded by the European Commission within the Sixth Framework Programme (2002- 2006).

The main objective of ASPASIA is the investigation of new advanced Satellite Communications (SatCom) technology as a complementary ADS-B (Automatic Dependent Surveillance- Broadcast) / TIS-B (Traffic Information Service-Broadcast) data link in the provision of surveillance applications.

ASPASIA plays a role in the Single European Sky initiative by introducing a system that makes accurate information available to all operators at all times, thanks to its global features.

The assets developed and demonstrated by ASPASIA project can be synthesised and proposed as contributions to ICAO technical process for the assessment of the feasibility to integrate new satellite communication systems in the next aeronautical mobile communication infrastructure.

Selected Applications

ASPASIA project has investigated key issues for the application of SatCom to surveillance applications. In particular, ASPASIA has selected four Package I GS/AS applications to study the applicability of SatCom for surveillance purposes:

- Enhanced Sequencing and Merging Operations (ASPA-S&M). The objective of the ASPA-S&M application is to redistribute tasks related to sequencing and merging of traffic between the controllers and the flight crews. The controllers are provided with a new set of instructions enabling them to direct flight crews to establish and to maintain a given time or distance from a designated aircraft.
- In-Trail Procedure in oceanic airspace (ATSA-ITP). The ITP procedure enables an aircraft to perform a climb or descent to a requested Flight Level through one intermediate Flight Level that is occupied by a ‘reference aircraft’, taking advantage of a distance-based ITP longitudinal separation minimum. The application does not change the core roles of flight crew and controllers.
- ATC Surveillance in Non-Radar Areas (ADS-B-NRA). The ATC surveillance in non-radar areas (ADS-B-NRA) application enables an Air Navigation Service Provider (ANSP) to provide radar-like separation services in non-radar areas.
- Aircraft Derived Data for ATC Tools (ADS-B-ADD). The ADD (Aircraft Derived Data) applications refer to the provision of avionics data extracted from aircraft systems to various ground-based and/or airborne end-users or tools.

In addition TIS-B (Traffic Information Service-Broadcast), considered as an additional service, is envisaged for the redistribution to aircraft of the surveillance information gathered on ground.

Test-Beds

ASPASIA project has developed five test-beds, one for each selected ASAS application and TIS-B service, in order to demonstrate the operation of the selected applications in a SatCom context:

- ASPA-S&M Test-Bed, composed of ASAS Manager, ASAS Target Selection, ASAS Sequencing and Merging and Upload Aircraft Performance Characteristics;
- ATSA-ITP Test-Bed, composed of the Aircraft Module and the ATC Module;
- ADS-B-NRA Test-Bed, composed of an Aircraft Module and an ATC Module;
- ADS-B-ADD Test-Bed: ASPASIA has used MAESTRO, provided by Egis Avia, as arrival manager making use of aircraft derived data. It is composed of FDPS Connection, RDPS Connection, Trajectory Predictor, Scheduler and Controller Interface. The air and ground traffic generators simulating the aircraft and ATC environments are based on SCANSIM;
- TIS-B service, whose test-bed comprises an Aircraft Module and an ATC Module.

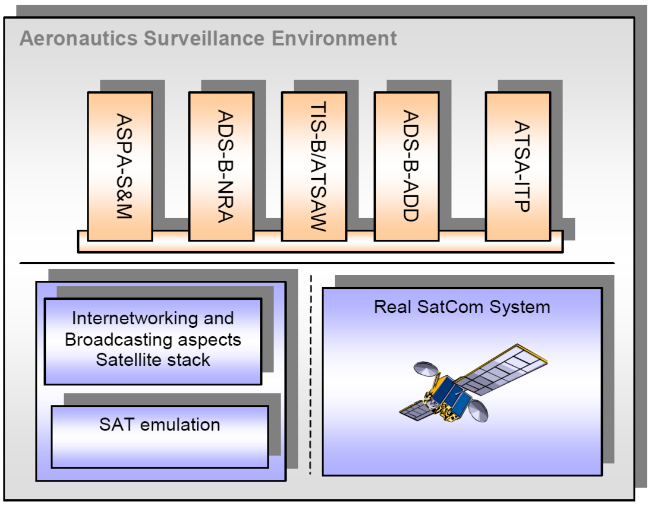
A Cockpit Display of Traffic Information (CDTI), an onboard display unit that provides the crew with all the information concerning the surrounding traffic, has also been used to support the ASPA-S&M and the ATSA-ITP applications, as well as the TIS-B service.

The end-to-end test-beds consist of the integration of the surveillance applications on the framework of the validation platform to validate the feasibility of employing SatCom technology to provide ADS-B/TIS-B applications.

Validation Platforms

Two independent validation subsystems have been considered in the ASPASIA validation platform: a simulation platform and a real satellite communication system.

The real SatCom demonstration system, provided by Thales Alenia Space, is located in TAS-F Toulouse premises. The DVB-RCS system provides "IP" connectivity between the satellite network nodes, and supports unicast and multicast. For the external applications, it can be seen just as an IP router.



Test-beds and validation platform subsystems

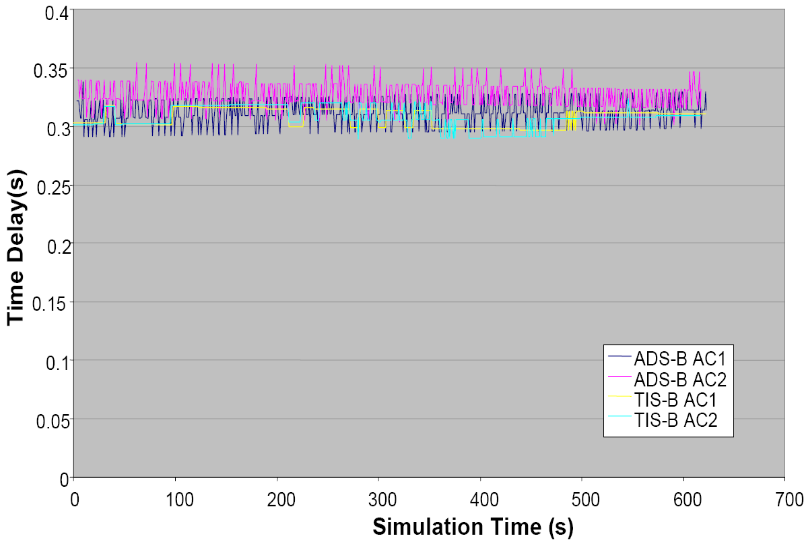
The SatCom Sim system is composed of the Satellite Link Emulator, the Broadcast Server, the Control & Management subsystem, the Network Time Subsystem, the Logging & Monitoring subsystem, and the file sharing subsystem containing the XML configuration, the monitoring files and the logs of the SatCom Sim system.

Test Results

ASPASIA project has carried out several tests focused on demonstrating the capacity of SatCom to complement existing ADS-B technologies, providing an appropriate means to transmit surveillance information.

The tests demonstrated the viability of the satellite data link as an ADS-B enabler. The performed tests covered the implementation of the Thales DVB-RCS SatCom Demonstrator Platform and several test-beds: ASPA-S&M, ADS-B-NRA, TIS-B service, ADS-B-ADD, and ATSA-ITP.

The ASPA-S&M Test-Bed confirmed that the calculation of speed demand was perfectly working over the range of SatCom performance parameters and in the presence of induced datalink artefacts. This was inferred by the system accepting the manoeuvre, and the spacing remaining within acceptable limits and the speed demand being progressive and controlled.



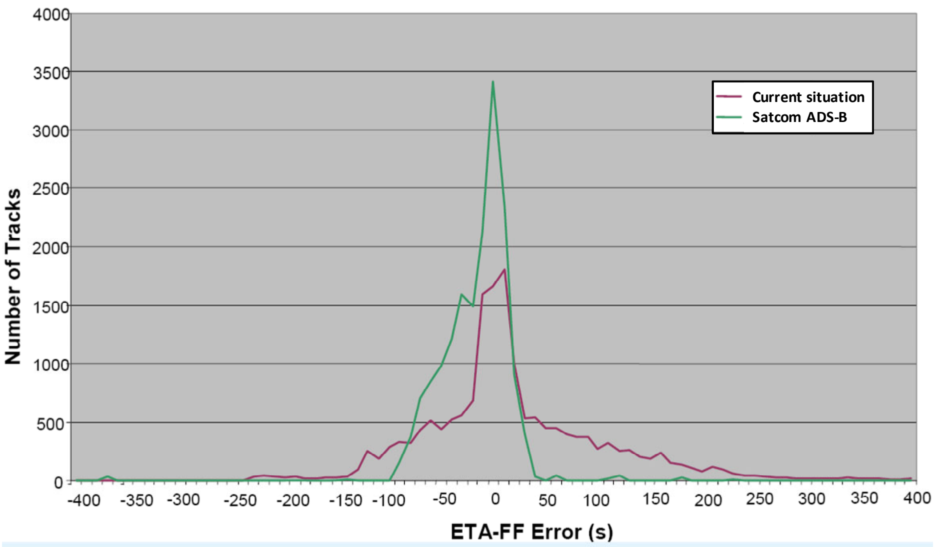
TIS-B/ATSAW Test Results – Transmission Time

Both the ADS-B-NRA and the TIS-B/ATSAW test results focused on three main metrics: data latency, data integrity and data timeline and missing packet assessment.

The average message time observed during the tests for ADS-B-NRA and TIS-B/ATSAW was always in the order of 0.3 s and no errors in data were detected throughout the whole simulation. With regard to missing packet assessment, there was a low percentage of missing messages in all studied cases.

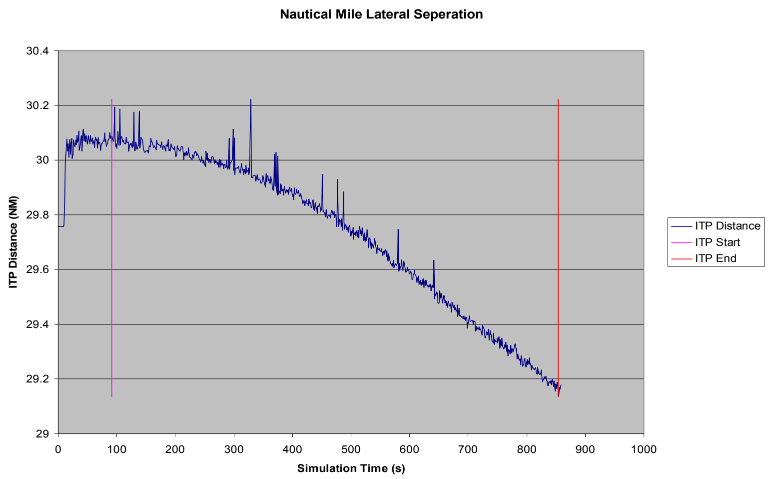
In the case of ADS-B-ADD test, one of the most significant metrics for the test was the measure of the estimated error when the Estimated Time of Arrival at the Feeder Fix (ETA-FF) is computed based on either trajectory intent data provided by ADS-B-ADD or on radar tracks data. The test results demonstrated the capability of the satellite datalink to transmit the necessary ADS-B information that allows MAESTRO to estimate the ETA-FF based on trajectory intent data, leading to a more homogeneous error distribution and error estimation narrowed around zero.

As it is shown in the graphic, the error distribution is more random and widely spread when the ETA-FF is computed based on radar tracks. The test results also demonstrated a more accurate sequence of arrival at the feeder fix and at the runway threshold when computed with SatCom ADS-B data.



ADS-B ADD Test Results – ETA-FF Error Distribution

The ATSA-ITP test results focused on a simple but significant metric, the ITP distance, a measure of the lateral separation (in NM) between the ITP Aircraft and the Reference Aircraft, which allows to assess the conflict-free status of the ITP manoeuvre. The tests were based on four different ITP use-cases, related to four different kinds of ITP manoeuvres depending on the initial configuration of the 'ITP aircraft' with respect to the 'reference aircraft' (i.e. a leading or a following 'reference aircraft') and considering whether the 'ITP aircraft' desires to climb or descent.



The graphic shows the result of a leading climb manoeuvre with only one reference aircraft, which broadcasts his position and other data through an ADS-B type message through SatCom. The third party traffic is broadcast through SatCom, and communication between the 'ITP aircraft' and ATC is via CPDLC. There is a 1200ms delay on the SATCOM simulator. The measured ITP distance gives a maximum of 30.222 NM and a minimum of 29.135 NM.

The assessment of this particular test case and all the other ITP test cases ensures that the variance in the separation during the test-run does not create a conflict scenario. Therefore, the result is, again, a confirmation that SatCom performance is perfectly suited for the requirements of the selected applications.

Demonstrations

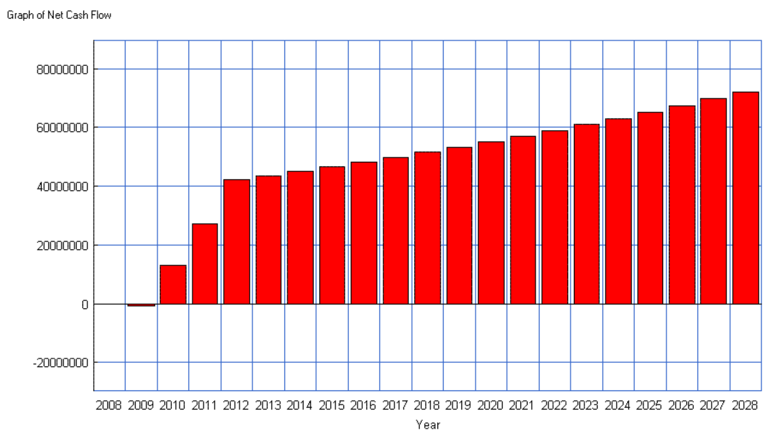
The ASPASIA Demonstrations took place at Thales Alenia Space premises in Toulouse, the first one on December 12th 2007, and the second one on May 28th 2008.

The prototypes of surveillance applications enabled by satellite ADS-B and TIS-B datalink were presented during the Demonstrations. Before the applications demonstration itself, the main aspects of the project were summarised and presented to the audience through several presentations.

The demonstration scenarios were based on ASPA-S&M, ADS-B-NRA, ADS-B-ADD, ATSA-ITP applications and the TIS-B service, running over the satellite platform provided by Thales. The Demonstrations were attended by ESA, Eurocontrol, European Commission, and members of private companies strongly related to the different project activities.

Cost Benefit Analysis

ASPASIA Project has aimed at assessing the advantages and benefits of using Satellite system for aeronautical surveillance activities, complementing the existing ADS-B technologies. Appropriate scenarios for the provision of ADS-B surveillance through satellite datalink, potential benefits of the use of Satellite technology and SatCom added value, as well as costs related to this new technology have been analysed in outline within the project.



The economical study has been focused in ANSP´s and Airlines as stakeholders and Net Present Value (NPV) has been offered whenever possible, depending on the availability of data, and following EMOSIA methodology. In the cases where it has not been possible to get an economical output, at least conclusions and recommendations for future exercises have been offered. To obtain the NPV it has been necessary to describe different scenarios. In each case, the most probable scenario has been described, including its baseline and hypothesis (technical and economical) to develop the economical model.

Conclusions

The selected GS/AS applications illustrate the applicability of SatCom as an alternative means of communicating surveillance data. For the ATSA applications, a SatCom service would provide enhanced range performance for ADS in both the air-to-air and air-to-ground information exchanges. The deployment of SatCom as a complementary system to the other ADS enabling technologies provides benefits in terms of safety, capacity, environment, efficiency, and security.

SatCom is a valid data transmission medium for ground and airborne surveillance applications, however, the constraints imposed by the current RFG definitions of the selected applications limit the scope of SatCom to provide clear benefits over existing ADS-B technologies. In fact, the current RFG definitions are very much aligned with the capabilities of existing ADS-B technologies.

SatCom technology makes sense when the scenario is global, that is, when the same service offered by the satellites could be used by a lot of stakeholders and applications. Under those conditions, and taking the most conservative assumptions, SatCom is profitable and benefits are very high.

The Steps Forward

ASPASIA Project has paved the way for the consideration of SatCom as a potential complementary technology for surveillance applications. Offering the innovative approach of using a satellite technology for aeronautical surveillance activities, ASPASIA is in line with the future operational needs recommended by SESAR. Through the different GS/AS applications analysis and the test-beds results, ASPASIA has made way for a more in-depth study of the satellite datalink characteristics and performance, suitable for the provision of ADS-B and TIS-B services.

2 Activities

2.1 Analysis of Requirements

For detailed analysis of ASPASIA requirements, please refer to [RD1]

2.1.1 Mission improvements

ASPASIA project is placed in the framework of improvement and complement of surveillance applications, more concretely Airborne Separation Assistance Systems (ASAS) and Approach Management systems (AMAN), using Satellite Communication systems (Satcom).

Satellite systems have the potential to provide improvements to aeronautical surveillance activities by complementing existing ADS-B technologies, such as

- VHF Data Link Modes,
- Universal Access Transceiver (UAT)

and

- Radar Mode S Extender Squitter.

Satcom will also provide new capabilities that these above technologies cannot easily offer. Some of the benefits identified are:

- Extension of sky region survey without deployment of additional ground stations, due to satellite capacity to provide global coverage. This should enable worldwide dissemination of procedures based on ASAS applications, including oceanic and desert areas.
- Allow ATM processes in which separated regions are involved (removal of ground systems coverage limitations, and allow ATM process structured by traffic flows characteristics instead of geographical borders).
- Extension of Traffic Information Service Broadcast (TIS-B) functionality, allowing Air Traffic Control Centre to send situational awareness information to aircraft that are not ADS-B equipped.
- Capacity complement to ADS-B technologies (Mode S extended squitter, UAT, VDL Mode 4) that are limited by the shortage of spectrum resources available for data links in the aeronautical bands. Especially owing to the Satcom ability to efficiently solve the problem of simultaneous and region-wide distribution of aircraft-derived flight data (positions and intents of aircraft) to all interested parties.
- Reduction of ATCO communications latency times and provision of optimum flight levels in NAT airspace due to satellite capacity to provide pseudo-real time high-resolution surveillance services with global coverage.
- Increase of the 4D resolution of ATM surveillance coverage, extending well beyond the geographical limits of current ground based systems, thus providing enhanced en-route flexibility according to the current Target Levels of Safety (TLS).

2.1.2 Operational Needs

Following Eurocontrol/FAA developments (see [RD4]), operational needs are analysed according to the following airspace classification:

- Airport Surface (APT),
- Terminal Manoeuvring Area (TMA),
- En-Route (ENR),
- Oceanic, Remote and Polar airspace (ORP),
- Autonomous Operations Area (AOA).

Further, [RD4] proposes scenario of operational introduction and deployment in the different airspaces of datalink enabling services, including advanced "Surveillance" applications. Table 1 below has been constituted by extracted surveillance related elements from [RD4], with two-time horizon considered: phase 1 [2005-2030], phase 2 [from 2020].

This evaluation is discussed here-after:

- Satellite is not foreseen to contribute to Airport operations.
- In TMA, although other media should be more adapted, satellite may play a role if spectrum is congested, or as a contributor to the global availability performance.
- In ENR satellite has certainly a role to play thanks to extra coverage and capacity.
- Satellite already provides surveillances services in ORP (ADS-C). The services will probably be maintained at the foreseen time horizons.
- Satellite could be an essential element in ORP and AOA for new surveillance services.

Service (Phase1/Phase2)	APT	TMA	ENR	ORP	AOA
ADS-C	- / -	- / -	- / -	X / X	- / -
ADS-B	X / X	X / X	X / X	X / X	- / X
AIRSEP	- / -	- / -	- / -	- / -	- / X
ARMAND	- / -	- / -	X / X	- / -	- / -
C&P	- / -	X / X	X / X	X / X	- / -
ATSA-ITP	- / -	- / X	- / X	X / X	- / -
PAIRAPP	- / X	- / X	- / -	- / -	- / -
ASPA-S&M	- / -	X / X	X / X	- / X	- / -
TIS-B	X / -	X / -	X / -	X / -	- / -

Above Colour codes indicate a qualitative level of interest in Satcom for the different usages (grey: discarded, green: possible alternative, blue: credible alternative, red: high potential).

Table 1. Service Deployment Scenario

With the proposed scenario, Satcom enabled services can be envisaged as a complementary means in supporting GS/AS applications in phase 1 and in phase 2 in TMA/ENR/ORP areas, and in phase 2 in AOA.

2.1.3 System level requirements

2.1.3.1 Functional Characteristics

ASPASIA is broken down at the highest level into 4 main functions:

- Elaborate Surveillance Data,
- Distribute Surveillance Data,
- Receive Surveillance Data,
- Assist Separation.

Mapping to these functions is as follows:

ASPASIA System Function	System Domain	Generic Architecture Component
F1: Elaborate Surveillance Data	Transmit Aircraft Domain Ground Domain	STP ADS-B Receive subsystem & other surv. data
F2: Distribute Surveillance Data	Transmit Aircraft Domain Ground Domain	ADS-B Transmit Function (incl. Satcom AES) TIS-B Processing and Transmit S/S (incl. Satcom GES)
F3: Receive Surveillance Data	Receive Aircraft Domain Ground Domain	ADS-B/TIS-B Receive Function (incl. Satcom AES) ADS-B Receive subsystem & other surv. data (incl. Satcom GES)
F4: Assist Separation	Receive Aircraft Domain Ground Domain	ASSAP / CDTI ATC processing / ATC Display

Table 2. Function to Components Mapping

2.1.4 Satellite Role in Airborne Surveillance Data Broadcast

Figure 2-1 below, identifies the potential role of satellite in airborne surveillance data broadcast (e.g. distribution of TIS-B reports).

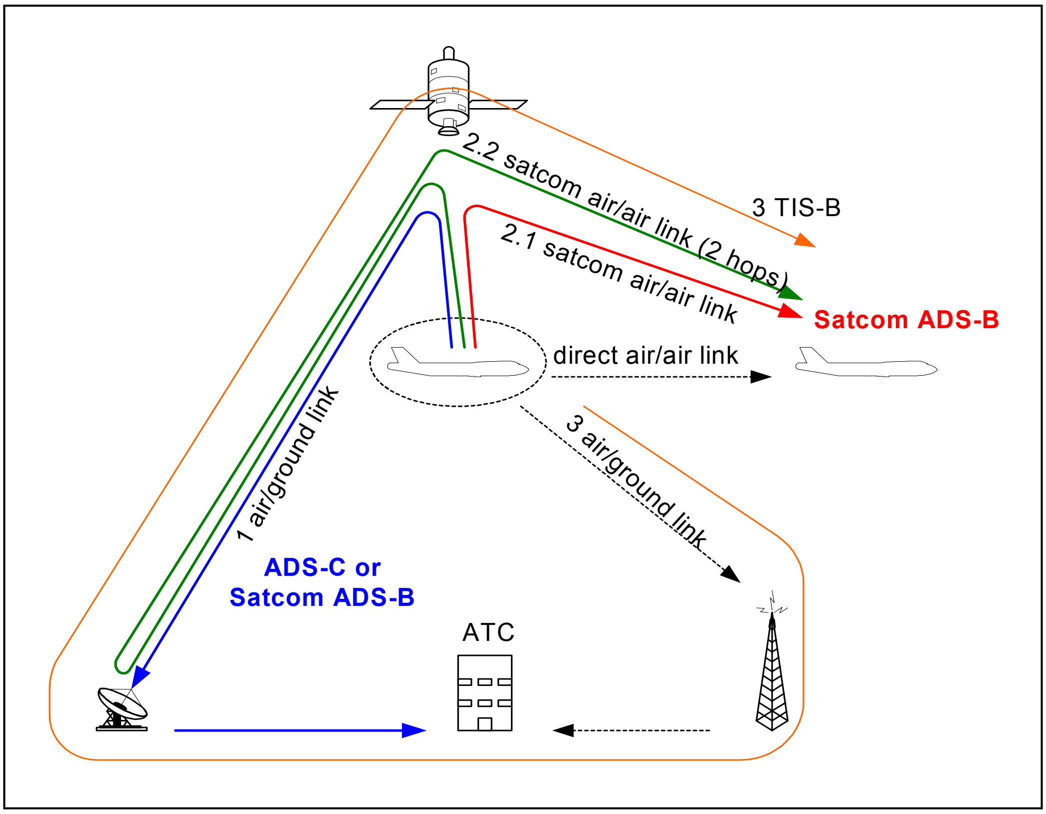


Figure 2-1. Satellite role in airborne surveillance data broadcast

Several alternatives are identified to distribute ADS-B reports to ground and to surrounding traffic using the satellite media:

1) Broadcast to Ground (ADS-B-SAT)

- Capability to distribute to multiple ground entities
- Redundancy with other ADS-B links

2) Broadcast to Air (ADS-B-SAT)

- Capability to distribute to surrounding traffic
- Star or meshed topology
- Redundancy with other ADS-B links
- Solution for aircraft equipped with different existing ADS-B technologies (VDL, 1090ES, UAT) or not equipped with any of them (interoperability)

3) Re-broadcast

- Direct re-broadcast of ADS-B ground Rx
- Same benefits as 2)

2.1.5 Satellite Role in Ground Surveillance Data Broadcast

Figure 2-2 identifies the satellite role in ground surveillance data broadcast.

This satellite enables:

- Broadcast/Multicast TIS-B-SAT
- Distribution of consolidated traffic information
- Redundancy with other TIS-B links
- Solution for non ADS-B in equipped aircraft (interoperability)
- Solution for oceanic & remote (no ground ADS-B stations)

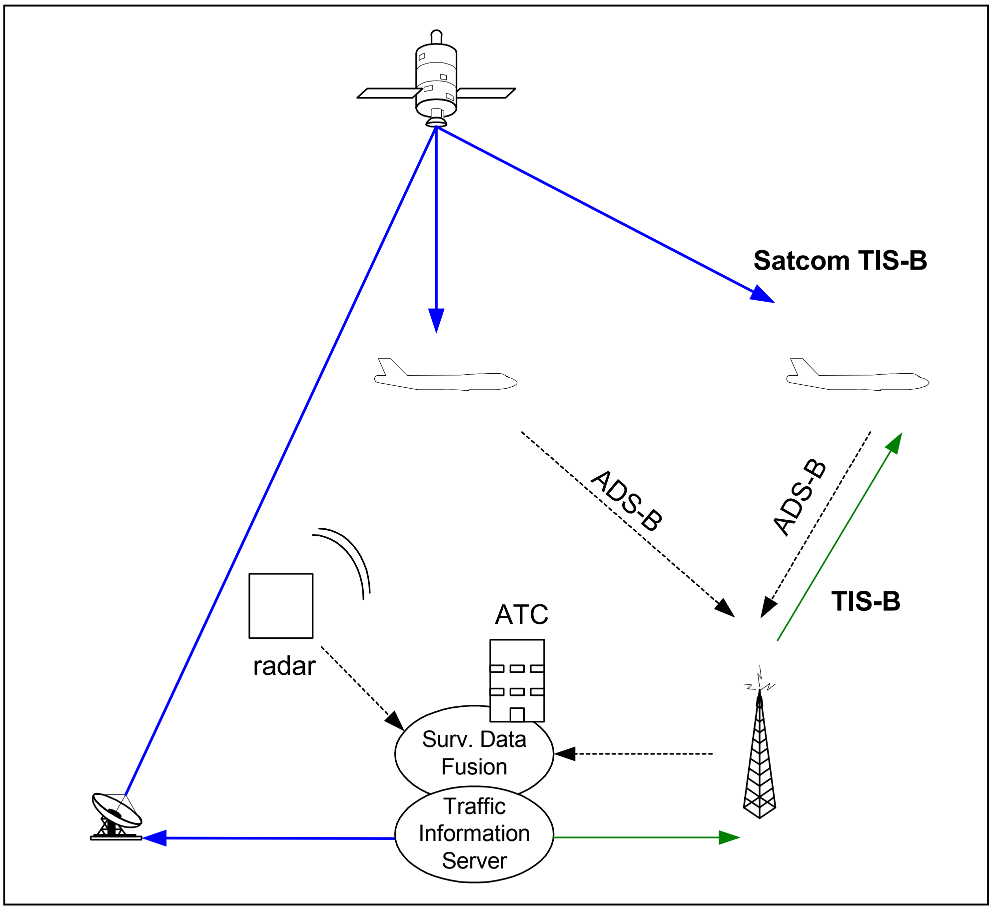


Figure 2-2. Satellite role in Ground Surveillance Data Broadcast

2.1.6 Applications Level Requirements

2.1.6.1 Mission

The mission of the “Applications” is to process ADS-B/TIS-B surveillance data to implement new surveillance concepts, categorised in the following domains:

1. Ground Surveillance,
2. Airborne Spacing,
3. Airborne Traffic Situational Awareness,
4. Airborne Separation,
5. Airborne Self-Separation.

2.1.6.2 Required services

The services required are specific to each application. In [RD2], details of the required services are given for several applications. Four of them, ASPA-S&M, ATSA-ITP, ADS-B-NRA, ADS-B-ADD (AMAN), have been further considered for ASPASIA experiments.

Those applications have been selected for their potential of applicability to Satcom environment (according experts judgement), their relative level of maturity, as well as availability of background or experimental data from the different partners involved in ASPASIA, or industrial sharing considerations. Additional justifications on selection of the Satcom for ASAS applications are provided into specific document (deliverable D1.5).

The service provided by ASPA-S&M, is assistance to the flight crew for autonomous spacing insurance during sequencing and merging manoeuvres.

The service provided by ATSA-ITP enables an aircraft, which may not be longitudinally separated from each other, to climb or descent through each other’s flight levels, using a distance-based ITP longitudinal separation minimum.

The service provided by ADS-B-NRA application enables an ANSP to provide radar-like separation services in non-radar areas.

The service provided by ADS-B-ADD (AMAN), is an assistance given to the Airport Arrival Controller for optimal management of the aircraft landing sequence.

In Table 3, the requirements means, in terms of surveillance data communication is expressed for each ASPASIA experiment application.

Surveillance Function	ASPA-S&M	ATSA-ITP	ADS-B-NRA	ADS-B-ADD
ADS-B in	Yes	Yes	No	No
ADS-B out	Yes	Yes	Yes	Yes
TIS-B	Yes	No	No	No

Table 3. Mapping between Applications and Surveillance Data

2.1.7 Satcom System level requirements

2.1.7.1 Satcom Interfaces Requirements

The Satcom System is classically broken down into:

- Ground segment,
- Space segment,
- User segment
- Support segment

The external interfaces of the Satcom system are identified in Figure 2-3.

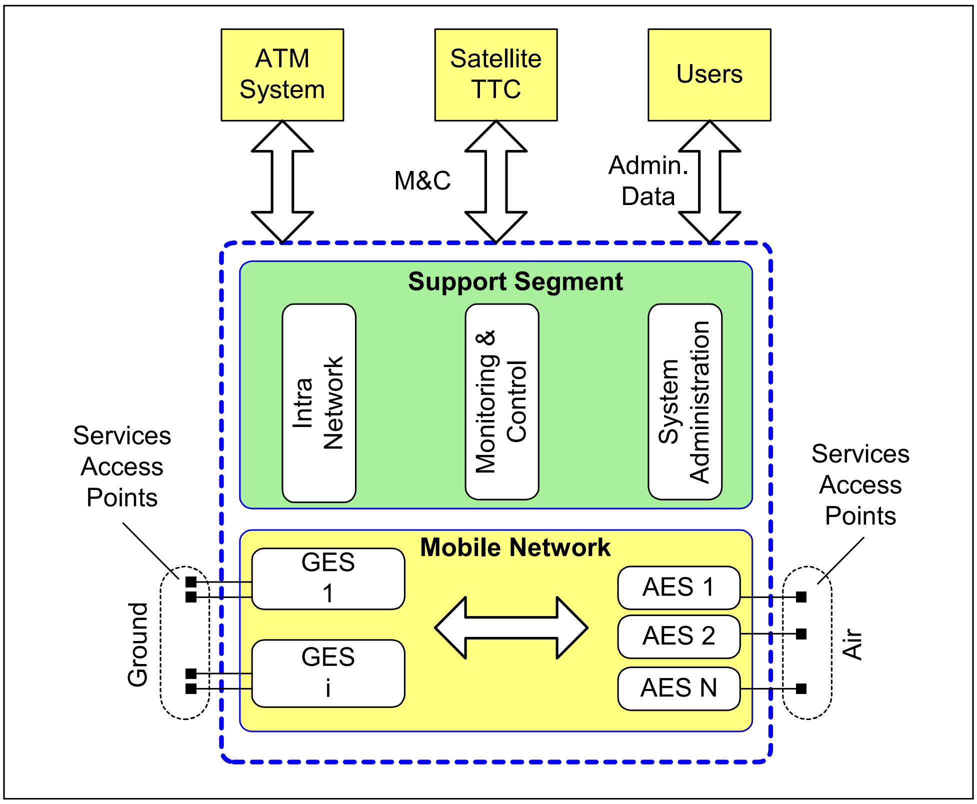


Figure 2-3. Satcom System External Interfaces

Satcom System level requirements are defined into following domains:

- System Quality factors (RAMS)
- Security Requirements
- Environmental Conditions
- Operational Requirements

2.1.8 Requirements coverage

In order to conclude, the Satcom Aero System Requirements are defined in the following domains:

- Mission requirements
- Overall Systems Requirements
- Operational Requirements
- Design Requirements
- Applications (ASPA-S&M / TIS-B / ADS-B-NRA / ATSA-ITP) Level Requirements
  - Functional Performance Requirements
  - Communication Interfaces Requirements
  - Update Rates
  - Latency
  - Integrity
  - Availability
  - Continuity
  - Accuracy
- Overall SATCOM Systems Requirements

The full view of Satcom Aero System Requirement identification and traceability is defined in annex of [RD1] and synthesise in the table below:

Requirement Identifier	Traceability	Applicability in ASPASIA Experiment		
		Architecture Experiment		Standard Architecture
		SatCom Platform	Simulation platform	
ASPASIA System				
General_010 – System Context	ASPASIA Objective	Partial	Partial	Yes
General_020 – Supported Airspaces	Internal	No	No	Yes
General_030 – Applications Std		Yes	Yes	Yes
General_040 – Datalink Std	ICAO AMCP Acceptability Criteria F, E	Yes	Yes	Yes
General_050 – Resources		No	No	Yes
General_060 – OSED		No	No	Yes
General_070 – Design		No	No	Yes
Satcom System Level				
SATCOM-010 Services	ICAO AMS(R)S core SARPS 4.2.1.2	Partial	Yes	Yes
SATCOM-020 Topology	Internal	Yes	Yes	Yes
SATCOM-030 QoS	COCR v1.0	No	Yes	Yes
SATCOM-040 3P	ICAO AMCP Acceptability Criteria B, and Core SARPS	No	No	Yes
SATCOM-060 Coverage1	COCR v1.0	Yes	Yes	Yes
SATCOM-070 Coverage2	ICAO AMS(R)S core SARPS 4.6.1.1	No	No	Yes
SATCOM-080 Usage	COCR v1.0	No	No	Yes
SATCOM-090 Standard	ICAO AMS(R)S Core SARPS	No	Yes	Yes
SATCOM-100 Spectrum	ICAO AMS(R)S Core SARPS 4.3.1	No	No	Yes
SATCOM-510 System Table	Internal	Yes	No	Yes
SATCOM-520 Log-on	Internal	Yes	No	Yes
SATCOM-530 Mobility	Internal	No	Yes	Yes
SATCOM-540 Resource Management	Internal	Yes	Yes	Yes
SATCOM-550 Redundancy Mtg	Internal	No	No	Yes
SATCOM-570 ATN-OSI	Internal	No	No	Yes
SATCOM-580 ATN-IPS	Internal	Yes	Yes	Yes
SATCOM-590 APR	Internal	No	No	Yes
SATCOM-595 AVS	Internal	No	No	Yes
SATCOM-600 Transport	Internal	Yes	Yes	Yes
SATCOM-700 Perf-Mon	ICAO AMCP Acceptability Criteria AA	No	Yes	Yes
SATCOM-710 Tech-Mon	Internal	Yes	No	Yes
SATCOM-720 Resource Planning	Internal	Yes	No	Yes
SATCOM-730 AES supervision	ETSI	Yes	No	Yes
SATCOM-740 System supervision	Internal	Yes	No	Yes
SATCOM-105 Capacity	COCR v1.0	No	No	Yes
SATCOM-110 European Capacity	Internal	No	Yes	Yes
SATCOM-130 ATN	ICAO AMS(R)S Core SARPS 4.6.4.1	No	No	Yes
SATCOM-140 ATN-ISO	ICAO AMS(R)S Core SARPS 4.7.2	No	No	Yes
SATCOM-150 ATN-IPS	Internal	Yes	Yes	Yes
SATCOM-160 APR	Internal	No	No	Yes
SATCOM-170 ICAO-@	ICAO AMS(R)S Core SARPS 4.7.2	No	No	Yes
SATCOM-180 User-IF	Internal	No	No	Yes
SATCOM-190 ATM-IF	ICAO AMCP Acceptability Criteria AA	No	No	Yes
SATCOM-200 TTC-IF	Internal	No	No	Yes
SATCOM-205 AVIONICS-IF	Internal	No	No	Yes
SATCOM-210 Reliability	Internal	No	No	Yes
SATCOM-220 Availability	Internal	No	No	Yes
SATCOM-230 Maintainability	Internal	No	No	Yes
SATCOM-240 Safety	Internal	No	No	Yes
SATCOM-250 Security1	ICAO AMS(R)S Core SARPS 4.6.6.1	No	No	Yes
SATCOM-260 Security2	ICAO AMS(R)S Core SARPS 4.6.6.2	No	No	Yes
SATCOM-270 Security3	ICAO AMS(R)S Core SARPS 4.6.6.3	No	No	Yes
SATCOM-280 AES-Env1	ICAO AMS(R)S Core SARPS 4.3.2.1	No	No	Yes
SATCOM-290 AES-Env1	ICAO AMS(R)S Core SARPS 4.3.2.2	No	No	Yes
SATCOM-300 AES-Env2	ICAO AMS(R)S Core SARPS 4.3.3.1	No	No	Yes
SATCOM-310 Dynamics	ICAO AMS(R)S core SARPS 4.5.1	No	No	Yes
SATCOM-320 Power	Internal	No	No	Yes
SATCOM-450 Operability 1	Internal	No	No	Yes
SATCOM-470 Operability 2		No	No	Yes
SATCOM-480 Operability 3		No	No	Yes
SATCOM-490 Operability 4		No	No	Yes
SATCOM-500 Operability 5	ICAO AMS(R)S Core SARPS 4.6.2.2	No	No	Yes
SATCOM-510 Operability 6	ICAO AMS(R)S Core SARPS 4.6.2.3	No	No	Yes

Table 4. SATCOM System Requirement identification and traceability

2.2 Design and Implementation

The generic objective of this project is to build a means to investigate key issues for the application of SatCom to airborne surveillance applications, and to investigate those issues in relation to a selection of four representative ADS-B applications from ASAS Package 1. To achieve this objective, WP2 address several design and implementation lines in the following areas:

- **ASAS Applications**: Four ASAS applications (ASPA-S&M, ASPA-ITP, ADS-B-NRA and ADS-B-ADD) and a TIS-B scenario have been designed and developed. Applications from different surveillance groups, GS and AS, have been selected in order to be able to explore the potential benefits of satellite in the different surveillance scenarios.
  - **Enhanced Sequencing and Merging Operations (ASPA-S&M)**. This application developed by BAE, was originally designed for en-route airspace and TMA in a radar environment, primarily in the core area of Europe. The application will now be extended to include consideration of cruise in oceanic airspace. The main expected benefit is increased controller availability by the reorganisation and streamlining of tasks. This should allow acceptance of more aircraft in a given sector or the designing of larger sectors. It is also expected to assure more regular spacing based on actual separation minima and thus an increase in capacity especially in high-density areas. For oceanic airspace, greater flight efficiency in the cruise phase of flight is also achieved by better use of flight routes (utilisation of the jet stream, etc). The use of Satcom in ASPA-S&M application will provide to equipped ADS-B aircrafts with a long range merge (e.g. traffic joining an oceanic track system at an intermediate waypoint), allowing for accurate control of spacing at the merge point and therefore maximising capacity, whilst minimising required speed changes and so minimising cost. Additionally, it would be possible to provide benefit to an airline that wanted to sequence aircraft arriving at a hub airport while the aircraft were still several hours from arrival.
  - **ATC surveillance in non-radar areas (ADS-B-NRA)**. This application developed by UoG, will enable an ANSP to provide radar-like separation services in non-radar areas such as Alaska, Africa, Australia or other remote areas where the installation of radar could not be justified. Subject to safety studies, it is expected that ADS-B separation minima could be smaller than the separation minima for procedural control. This application has no direct impact on the flight crew since ADS-B position reports are transmitted automatically. Within the areas of operation, however, the flight crew may expect new procedures and rules. The full benefits of ADS-B-NRA are possible only when all aircraft operating within a particular region are appropriately equipped.
  - **The Traffic Information Service Broadcast (TIS-B) scenario**. This application developed by UoG, describes a means for traffic information to be broadcast from a base station for use by any receiving aircraft. The original concept was for a ground based transmitter with traffic information being supplied by the ground surveillance system, typically radar. In this type of installation, the ground processing is responsible for extrapolating traffic track information as necessary to ensure that the broadcast positions are consistent with the associated time of applicability. On the airborne side, the received TIS-B messages are processed and displayed in order to enhance the air traffic situational awareness (ATSAW).

- **In-Trail Procedure (ATSA-ITP)**. This application developed by UoG, will enable an aircraft to perform a climb or descent to a requested Flight Level through one intermediate Flight Level that is occupied by a 'reference aircraft', using a distance-based ITP longitudinal separation minimum. The ITP procedure does not modify the core roles of flight crew and controller. The application is designed for non-radar oceanic airspace where aircraft are flying along predefined tracks. Besides, it seems possible to extend this application to non-radar airspace where aircraft are navigating on a fixed route network. An objective of the ITP procedure is to improve the utilisation of the NAT oceanic airspace by facilitating a higher rate of flight level changes, yielding better flight efficiency (e.g. fuel savings, avoiding turbulent flight levels).
- **Aircraft derived data for ATC tools (ADS-B-ADD)**. This application developed by EGIS Avia, will provide additional aircraft derived data through ADS-B to be used for ground applications; for example by the ATC ground system for developing or enhancing ATC tools like displays, MTCD, AMAN, DMAN and ground based safety nets. The use of Satcom in ADS-B-ADD application does not encompass the ground tools themselves; it only provides additional input data for these tools allowing the data reception from the aircraft since its departure from the origin airport.

- **Satellite architecture**: The pre-operational architecture of future Satcom system for supporting surveillance applications had been outlined. This pre-operational architecture has been defined taking into account the application requirements established by ASAS applications in general, and in particular the selected ones, in terms of performance, QoS, mission, integrity, etc. From the very beginning, the scope of communication services enabled by satellite has been defined, considering in phase 1 and in phase 2 in TMA/ENR/ORP areas, and in phase 2 in AOA. These assumptions have been the base in the definition of the pre-operational architecture.

  The architecture presented has taken into account the results of SDLS-Slice 3 study, but also, a review of the alternatives have been performed taking into account the specific requirements of ASPASIA project, and potentially the evolution of the Aeronautical standards and requirements.

- **Satellite Simulator**: A SatCom Simulator SW platform has been designed developed and developed inside the scope of ASPASIA project. The SatCom simulator not only provides Satellite Link emulation, it also implements Broadcasting Applications Protocol(s) for ADS-B and TIS-B required for the applications. The SatCom simulator developed in this project will serve as a way to provide recommendations and guidelines for future developments, and the applicability and expected improvements by encompassing QoS mechanisms. Besides, the SatCom simulator has been designed and implemented to address the following aspects:
  - Identify future implementation issues.
  - Assess the performance usage of a satellite link for broadcasting applications.
  - Assess the achieved improvements experienced from a separate broadcasting service entity that provides the communication services directly to applications.

- Still in the same line of idea of the previous bullet, optimize data fusion tailoring the protocol to satellite link characteristics.
- Develop the multicasting mechanisms that can profit as much as possible from the satellite inherent strengths.

Although, the SatCom Simulator emulates the satellite behaviour at network level, some efforts have been dedicated to simulate the physical layer. Simulations of carrier phase estimation algorithms chosen in step 2 for detecting signal in different burst modes (mini-nominal) and simulations of the synchronization loops either in local and remote needed to keep system synchronized and to withstand in an aeronautical mobile environment with several carrier interferers have been done.

The design and implementation activities done in WP2 have allowed the creation of a testing environment infrastructure able to validate the potential benefits of SatCom as enabler of ADS-B to selected ASAS applications. Moreover, the design and implementation activities done in ASPASIA project have been in line with current in line with current and future standards, as well as to contribute to the ongoing standardisation processes that the main standardisation bodies are carrying out.

2.3 Test and Validation

2.3.1 Scope of validation

ASPASIA project, proposes to demonstrate some satellite benefits (see Mission requirements chapter) via five Use cases selected among group of ASAS Application Scenarios in which satellite based communications provides a means of executing an ASAS manoeuvre where the available aircraft borne information is insufficient for a safe and/or efficient devolved ASAS operation.

The selected scenarios, in which Satcom provides a clear advantage, are the following:

- Enhanced Sequencing and Merging Operations (ASPA-S&M).
- ATC surveillance in non-radar areas (ADS-B-NRA).
- Traffic Information Service Broadcast (TIS-B).
- In-Trail Procedure (ATSA-ITP).
- Aircraft derived data for ATC tools (ADS-B-ADD).

2.3.2 Test configuration

To validate these upper ASPASIA scenarii, it has been necessary to implement a specific SATCOM platform organise around a SATCOM architecture based on DVB-RCS means (see Figure 2-9).

Five test cases have been experimented in the frame of ASPASIA:

- Use Case N°1 **ASPA-S&M**
- Use Case N°2 **ADS-B-NRA**
- Use Case N°3 **TIS-B/ATSAW**

- Use Case N°4 **ADS-B-ADD MAESTRO**
- Use Case N°5 **ATSA-ITP**

2.3.2.1 Use Case N°1 – ASPA-S&M

The ASPA-S&M demonstration involves two aircraft: a leader aircraft that transmit periodically its position and intent through ADS-B reports to the ground and surrounding traffic, and a follow aircraft which objective it to merge behind the preceding traffic. This aircraft implement the ASPA-S&M application that enable such manoeuvre by processing incoming ADS-B data.

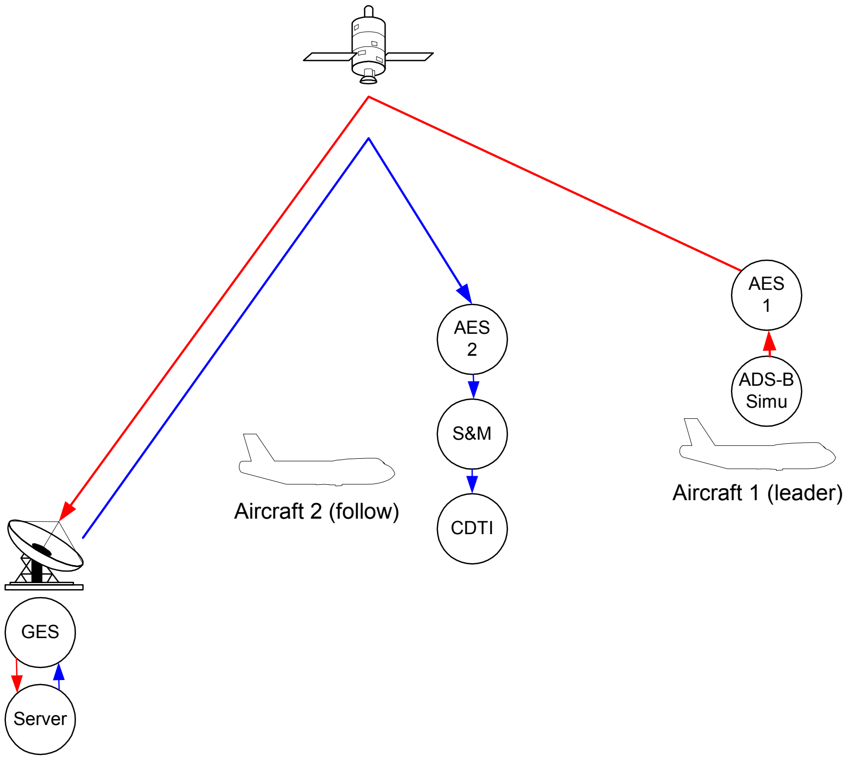


Figure 2-4. ASPA-S&M Scenario: Functional Model

2.3.2.2 Use Case N°2 – ADS-B-NRA

This application enables an ANSP to provide radar-like separation services in non-radar areas, and has no direct impact on the flight crew because ADS-B position reports are transmitted automatically. However, the flight crew may have to accommodate new procedures and rules in the areas of operation of the application, but they will benefit from the improved service from the ANSP. It is likely that the full benefits will only be obtained when all of the aircraft within a given area are suitably equipped.

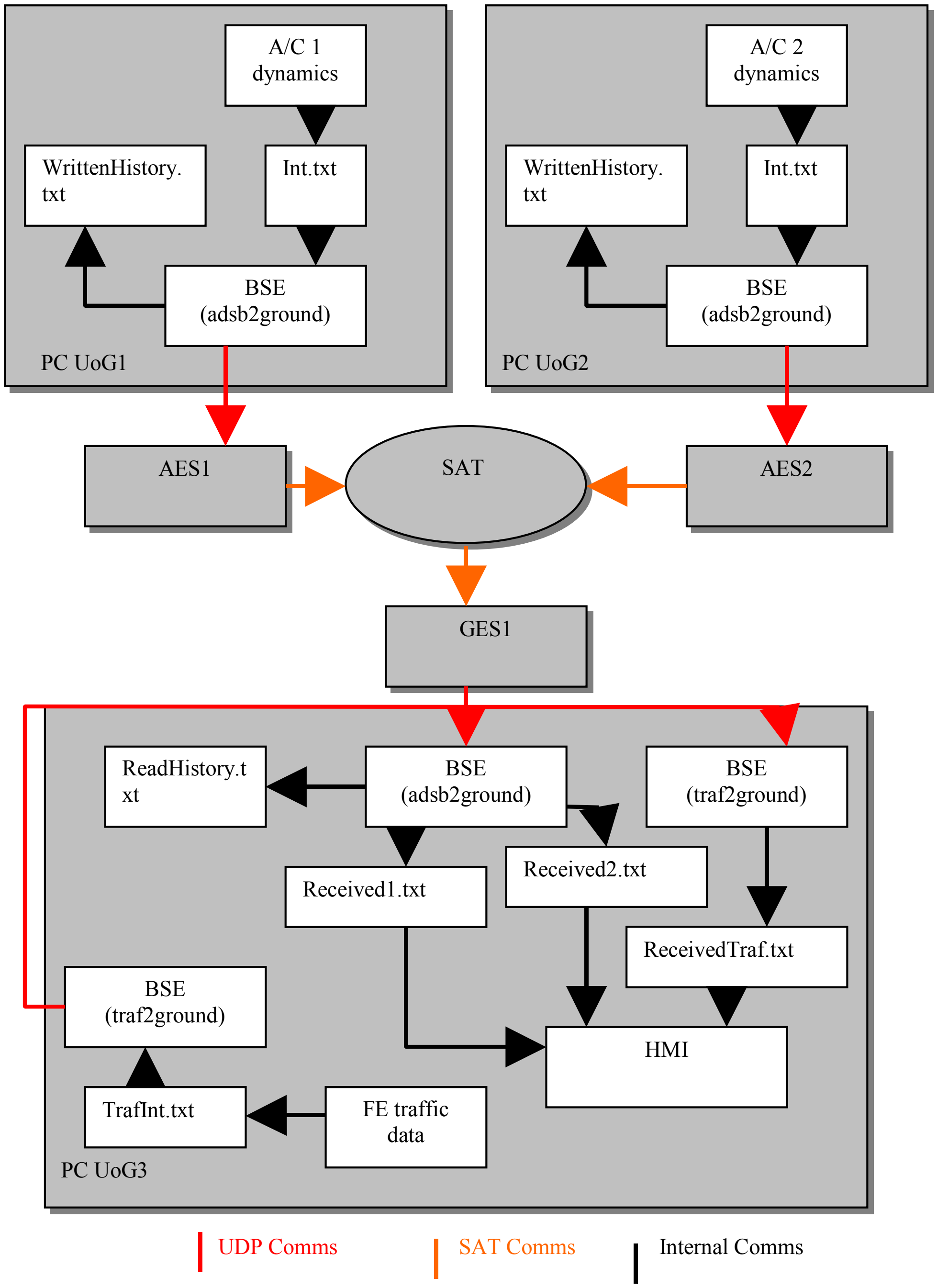


Figure 2-5. ADS-B-NRA Implementation Model

2.3.2.3 Use Case N°3 - TIS-B/ATSAW

The TIS-B concept describes a means for traffic information to be broadcast from a base station for use by any receiving aircraft. The original concept was for a ground-based transmitter with traffic information being supplied by the ground surveillance system, typically radar. In this type of installation, the ground processing is responsible for extrapolating traffic track information as necessary to ensure that the broadcast positions are consistent with the associated time of applicability. If information is broadcast using the 1090MHz datalink as defined in the 1090MHz

ADS-B MOPS, then the time of applicability is the time at which the TIS-B messages are broadcast.

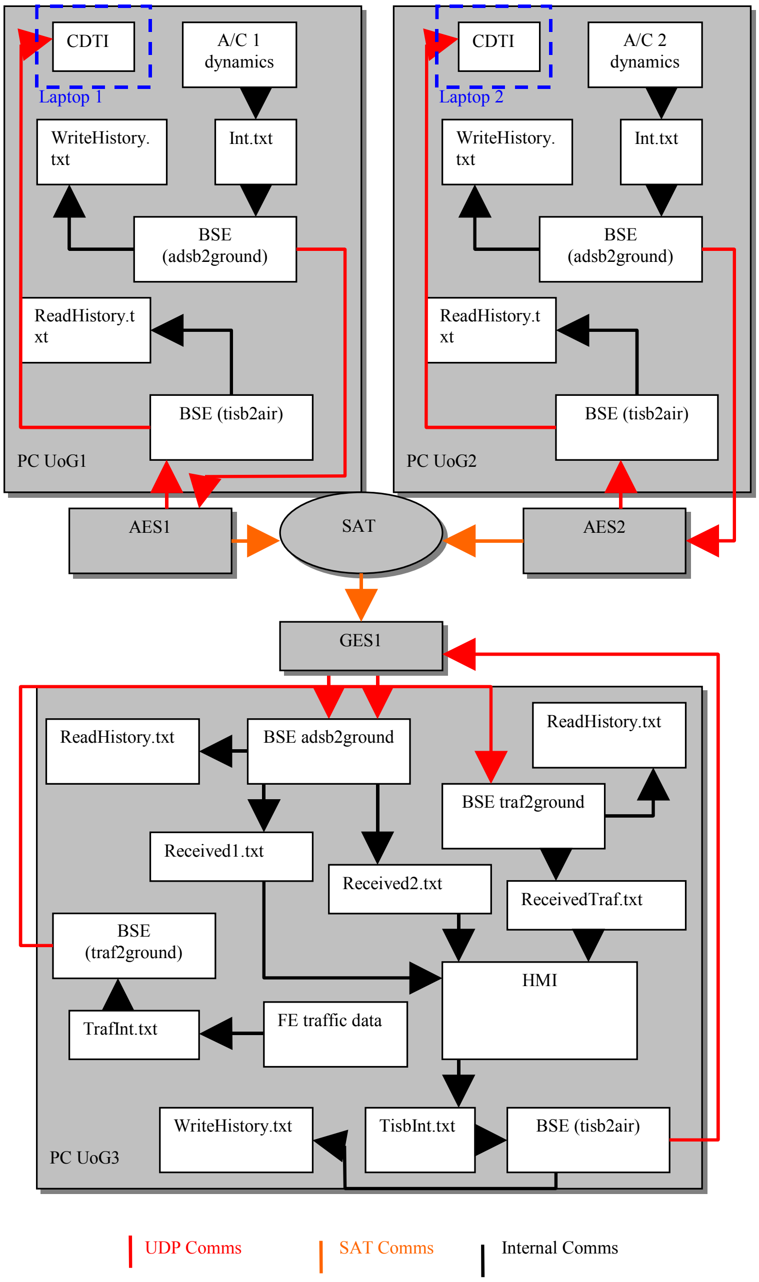


Figure 2-6. TIS-B/ATSAW implementation model

2.3.2.4 Use Case N°4 - ADS-B-ADD MAESTRO

The ADD (Aircraft Derived Data) applications enable the provision of a service delivering avionics data extracted from aircraft systems to various ground-based and/or airborne end-users or tools. The ADD service can support a wide range of user services (controller support tools).

As a particular ADD application, the ADS-B-ADD application enables provision of additional aircraft derived data through ADS-B to be used in ground ATC application systems, typically for developing or enhancing ATC tools, as for instance an AMAN system.

One of the validation objectives with regards to the ADS-B-ADD application is to assess the benefits that could be derived from an AMAN system of the current generation (namely MAESTRO) when fed with Trajectory Intent Data provided through the ADD service.

In order to highlight the main ASPASIA objective that is to assess the benefit of using the satellite component for an ADS-B-ADD application, the selected operational scenario includes areas where the radar coverage is lacking. The use of satellite connections is foreseen to be beneficial in areas where SSR coverage is not available such as oceanic / overseas areas or as complementary means to VHF connections in high-density areas where it becomes saturated.

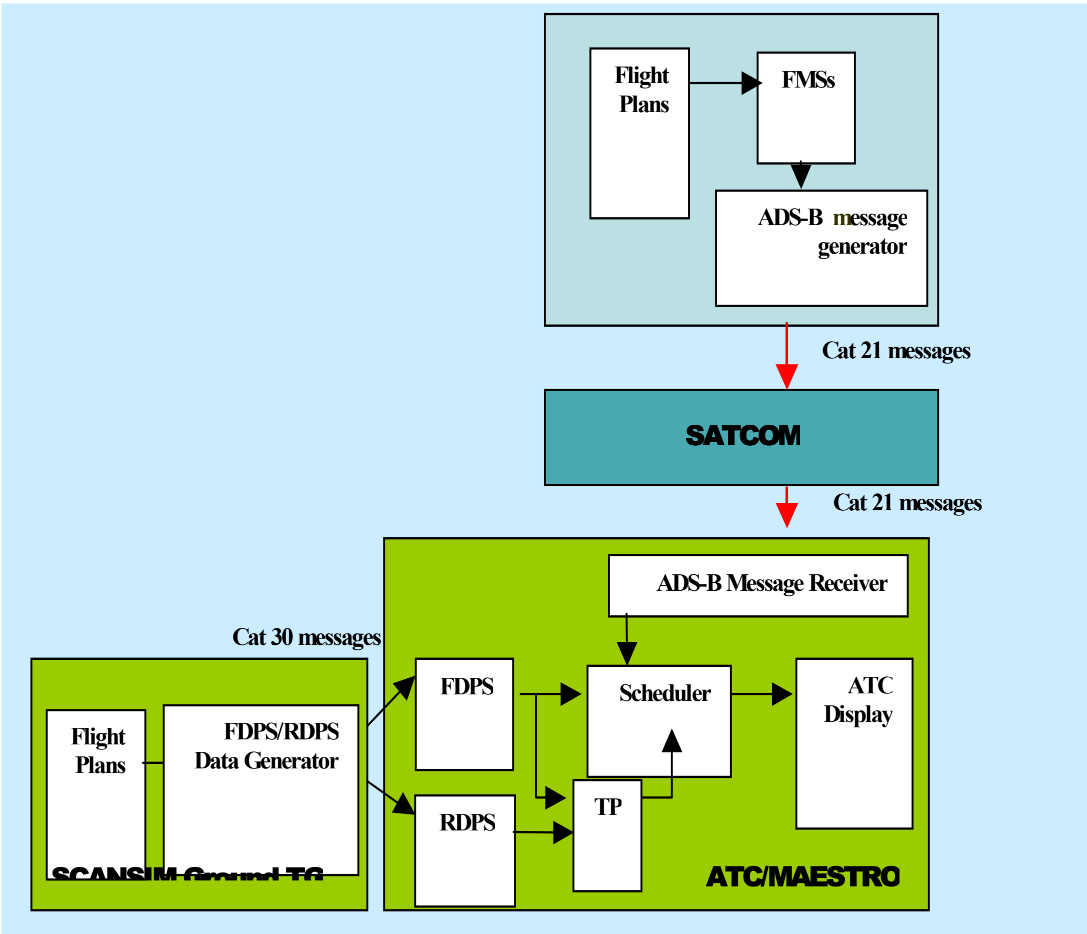


Figure 2-7. ADS-B-ADD Implementation Model

2.3.2.5 Use Case N°5 - ATSA-ITP

The ATSA-ITP (In-Trail Procedure) enables either leading or following Same Track aircraft to perform a climb or descent to a Requested Flight Level through Intervening Flight Levels. The application will require the crew to use information derived on the aircraft to determine if the criteria for applying the ITP procedures are met with respect to one or two Reference Aircraft at Intervening Flight Levels.

The ITP Speed/Distance Criteria are designed such that the estimated positions between the ITP Aircraft and Reference Aircraft should get no closer than the ITP Separation Minimum (10NM) until vertical separation between the ITP Aircraft and Reference Aircraft is ensured. Once these criteria are met, the flight crew may request an ITP, identifying the Reference Aircraft in the request.

The minimum surveillance infrastructure comprises:

- On the ground: CPDLC link is assumed between the ATC and the aircrew.
- Airborne: The ITP aircraft (that is, the manoeuvring aircraft) has to be equipped with ADS-B-in and the reference aircraft have to be equipped with ADS-B-out.

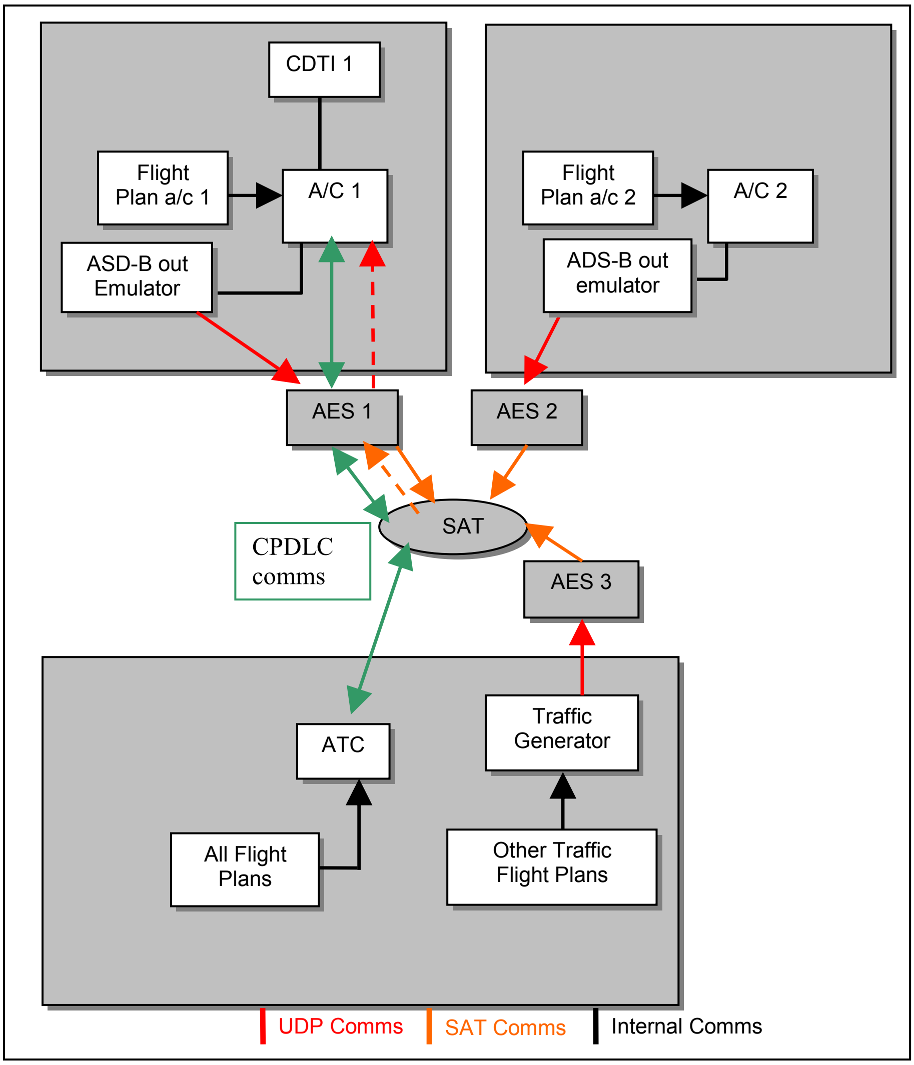


Figure 2-8. ATSA-ITP implementation model

2.3.3 DVB-RCS A9780 HUB ASPASIA SATCOM Test platform

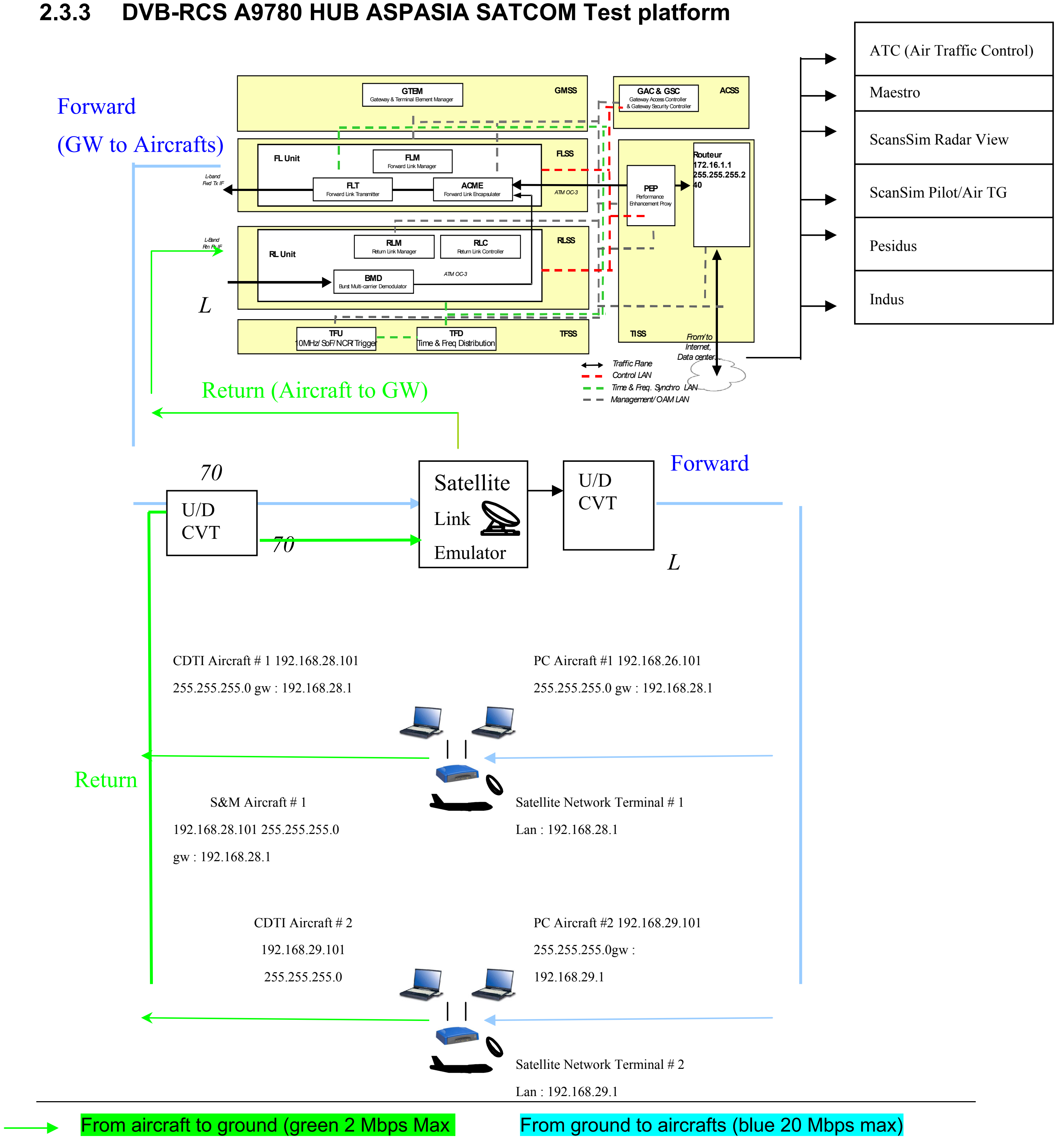


Figure 2-9. ASPASIA DVB-RCS Test platform Configuration

2.3.4 Conclusion of the First and Second validation Test batches

Both Test batches were first performed in Barcelona Atos Origin premises using the SatCom Sim platform, and then in Toulouse Thales Alenia Space premises using the above DVB-RCS gateway platform, except for the ADS-B-ADD test-bed, which due to logistic reasons was only performed over the Toulouse platform.

The first validation Test batch started in Barcelona by the end of October 2007, and was successfully completed on 12th December 2007 in Toulouse.

The second validation Test batch started in Barcelona by the end of March 2008, and was successfully completed on 26th May 2008 in Toulouse.

The detailed tests results can be found on [RD3].

2.4 Cost Benefit Analysis

The objective of the CBA has been to analyse the costs and benefits of the use of Satellite Communication technology instead of ground technology for the selected applications.

The initial hypothesis of the study was to analyse SATCOM technology as a substitute for Ground technology. Finally, for different reasons like security, the consortium considered that probably SATCOM would be a complementary system to Ground Technology. That is, ASPASIA was considered like a redundant system where each GS/AS Applications and TIS-B service could use both technologies: SATCOM and Ground.

Appropriate scenarios for the provision of ADS-B surveillance through satellite datalink, potential benefits and SatCom added value, as well as costs related to this new technology have been analysed in outline within the project.

General and specific benefits of the use of Satellite technology have been taken into account and described.

The CBA identified the most relevant stakeholders:

- Communication Service Provider (CSP): It carries out the biggest investment in the project, developing the ground mission segment which is composed of a set of Ground Earth Station (or GES) and the space segment, which in our scenario will consist of a non dedicated SATCOM space segment.
- ANSP`s: They are the CNS / ATM Service Provider. Their main costs are related to the Operational Cost. There are not is not benefit considered for ANSP´s, given that there are not cost saving (no system is removed, ASPASIA is a complementary or new system)
- Airlines: They assume aircraft avionic equipment costs in order to support Satellite functionality (different types of terminal have been described). Benefits came from the use of Satellite to support the ASAS Application or TIS-B service in each case, and they have been detailed entering in economics terms when it was possible.

The economical study was focused in ANSP´s and Airlines stakeholders; ASPASIA has been considered a system which uses a service provided by a CSP industry, given that, Airlines and ANSP´s will pay for the service to the CSP. Cost Benefit of the CPS industry is out of our scope. However, following the consortium recommendations a description of the CSP investment deployment and costs was included.

Net Present Value (NPV) has been offered when it has been possible, depending of the available data. In this case, the CBA followed EMOSIA methodology.

To obtain the NPV was necessary to describe different scenarios. In each case, the more probable scenario was described, including its baseline and hypothesis (technical and economical) to development the economical model.

For each Application and TIS-B service the following parts were detailed (as far was possible):

- Geographic Scenario
- Baseline

- Cost Data Consolidation
- Benefit Data consolidation
- Economical study (if enough data is available)

In the cases where it was impossible to get an economical output, at least the previous steps have been checked, offering conclusions and recommendations for future exercises.

Benefits for each application due to the use of SATCOM Technology were identified:

- ADS-B-ADD:
  - Benefits due to improved Trajectory Prediction
  - SATCOM enabling:
    - Extended time horizon
    - Flights coming from oceanic areas
  - Quantitative assessment (human in the loop RTS) out of scope of ASPASIA
- ASPA-S&M:
  - Application designed for radar environment
  - No SATCOM benefits to capacity or reduced separations
  - Possible SATCOM benefits to integrity and availability (not quantified)
- ATSA-ITP:
  - Enhanced range capability due to SATCOM
  - Limited relevance due to prescribed time spacing
  - No quantitative benefit provided
- TIS-B:
  - Use of SATCOM can provide extended range allowing enlarged air situation picture
  - Inherent short range character of application
  - No quantitative benefit provided
- ADS-B-NRA:
  - SATCOM can enable ADS-B-NRA in Oceanic areas
  - Radar-like picture provided to ATS: Increased situational awareness
  - Increased capacity: not evaluated in ASPASIA
  - Optimised flight level through reduction of separations and more efficient vertical profiles
  - Economic benefit: Fuel savings

Results in quantitative terms were offered for ADS-B-NRA.

2.5 Dissemination

The effective dissemination of the project results, as well as the interaction and coordination with other related projects and programmes have been considered essential for the ASPASIA Project development. Moreover, the project dissemination objectives have always aimed at capturing the interest of potential stakeholders and maximising the exploitation of results.

Due to its recognised importance, dissemination activities within ASPASIA Project were initiated at an early stage and have been performed during the whole duration of the project.

The following subsections summarize the dissemination instruments that have been used within the ASPASIA, with the purpose of achieving the aforementioned objectives.

2.5.1 Web Site

The ASPASIA Project web-site (www.aspasia.aero) was created with the intention to allow an easy access to information about the project and an easy update of contents and results. The web-site has been designed with the intention of giving the visitor a vision of the project, integrated in the more general context of aeronautical and satellite communication domains.

ASPASIA web-site, operative since July 2006, includes all the relevant information about the project. The web-site also includes specific links to the sites of relevant organizations, both private and public.

The project has also counted on an intranet, used to ease the communication among project partners as well as with the European Commission. ASPASIA partners have been allowed to retrieve and submit technical, managing and financial information through this intranet.

2.5.2 Conferences and Workshops

The attendance to relevant workshops, conferences and congresses is considered, according to the Dissemination Strategy defined within ASPASIA, as an essential means to keep an updated knowledge of the current status of the satellite and aeronautical sector, as well as to ensure an early wide spread of the project expected results. The attendance to this type of events also helps to ensure the coordination and complementarity of ASPASIA with other related projects.

During the whole duration of the project, ASPASIA partners have attended and participated in project related conferences and workshops in representation of ASPASIA. Table 5 summarises the different attended events.

Event	Date	Place	Remarks
ASAS-TN 2nd Workshop	3-5 April 2006	Rome	--
ASAS-TN2 3rd Workshop	11-13 September 2006	Glasgow	Project presentation performed during the meeting
ATC Maastricht Conference & Exhibition 2007	13-15 February 2007	Maastricht	Project leaflet distributed during the exhibition
ASAS-TN2 4th Workshop	23-25 April 2007	Amsterdam	--
AGCFG/4 and NexSAT/9 Combined Meeting	13-14 September 2007	Brussels	Project presentation performed during the meeting
ATC Global 2008	11-13 March 2008	Amsterdam	Project Information Papers distributed during the exhibition

Table 5. Conferences and Workshops attended by ASPASIA partners

ASPASIA Project has also boosted the coordination with other related project through the attendance to CASCADE Programme meetings and workshops.

Apart from the aforementioned, a paper was submitted to be presented during the Seventh USA/Europe ATM R&D Seminar (2-5 July 2007. Barcelona). Unfortunately, the paper was not included in the final papers selection (only 66 of the 146 submitted papers were presented during the seminar).

2.5.3 Publicity Material

The design and production of leaflets, brochures, etc. within the ASPASIA Project has had the objective of extensively disseminate the project concept and achievements, taking advantage of public events attended by ASPASIA partners for its distribution. With this objective in mind, the following material has been produced:

- Five Information Papers, summarising and highlighting the most significant aspects of the project. The first (an more general) of these papers was edited as a leaflet, for distribution during relevant events. The whole collection of Information Papers were distributed during the Project Demonstrations.
- A collection of posters, one for each ASPASIA selected application, which were used as visual support during the Project Demonstrations.

The ASPASIA WP5, responsible of dissemination activities, has also produced a Project Presentation, which outlines the project rationale and objectives, and specifies the project's technical baseline in a style which is accessible to non-specialists. The project presentation is accessible to general public through the project web-site and it has been also presented at relevant events in which ASPASIA members have participated.

2.5.4 Exhibitions

ASPASIA Project has performed two Demonstrations, with the intention to present the project achievements to all kind of interested stakeholders as well as the ASPASIA partners. The Demonstrations consisted on a brief but concise introduction to the project in general as well as to the different test-beds in particular, followed by the real applications demonstration. These demonstrations have contributed to the technical credibility of the usage of SatCom for AS/GS applications.

The ASPASIA First Demonstration took place at THALES ALENIA SPACE premises in Toulouse on December 12th 2007. The operational scenarios for this Demonstration were based on ASPA-S&M, ADS-B-NRA, ADS-B-ADD applications and the TIS-B service, running over the satellite platform provided by THALES. The Demonstration was attended by ESA, Eurocontrol and European Commission members.

At the time of this writing, invitations to the ASPASIA Second Demo have been sent to an even more widespread audience. The ASPASIA Second Demonstration is thus expected to be attended by a big number of potentially interested stakeholders. The operational scenarios for this second demonstration will include the ATSA-ITP application.

2.5.5 Journals

Publication in professional press has given the opportunity to greatly increase the spread of the project by reaching a wider audience, coming either from the aeronautic sector or other relevant sectors.

With this intention, a paper with the title 'The Role of Satellites in the Future Global Air Traffic Management' was submitted to the international quarterly published journal 'Space Communications'. The paper was accepted to be published.

2.5.6 Relationship to other projects and initiatives

ASPASIA project has intended to closely collaborate with the most significant related projects, sharing findings and avoiding duplication of efforts. The participation on international events, mentioned in section 2.5.2, has contributed to this coordination.

ASPASIA project has made a big effort to ensure that the work being performed within the project was in accordance with the work carried out by other international projects.

3 Results

3.1 Satellite Architecture

3.1.1 Satcom key drivers

The major key driver requirements for the Satcom system in the context of Com Aero are:

1. **Coverage**: continuous connectivity over worldwide airspace is a key factor for the optimisation of airspace usage and environmental impact of aviation. Capability to cover large airspace volume, without holes, discontinuities or service level degradation, is a major added value of Satellite solutions.
2. **Communication performance**: Safety considerations impose highly reliable datalink solutions. The system design has to challenge the performance specifications imposed by the surveillance applications. Link availability is one of the most demanding requirements identified. Security requirements, still under consolidation, have also the potential to significantly impact the design of the solution in a near future.
3. **Optimised Avionics**: as a major cost driver of the system, both at investment and operational service level, the avionics terminal definition is a key success factor for the development of Satcom solutions. The avionics terminal must be low weight, low power, low drag, and easily to integrate in the airborne structure. Design trade-offs have to be essentially driven by avionics optimisation.
4. **Spectrum Efficiency**: as competition for spectrum is getting more and more harsh, the aeronautical community requires that any new system would provide spectrum efficiency figures in line with latest standards to secure access spectrum. Spectrum efficiency is also a driver of the service fees. Flexibility with respect to spectrum may likely be an issue in the future. One of the key benefits of satellite in this context is the capability to provide efficient broadcast services that leverage the efficiency of the communication system by some orders of magnitude. The surveillance broadcast applications identified in ASPASIA (based on TIS-B) constitute a perfect use case to demonstrate such benefit.
5. **Interoperability**: ensures best service value for the users, and guarantees return on investment through long term standards sustainability. Interoperability backs seamless operations between regions, and can also allow minimising intra-system overheads thanks to inter-system redundancy alternative schemes.

3.1.2 Satcom System functions

According to the above major key drivers, the specification of the Satcom mobile service is further broken down into three functions as shown below:

- F11: Control Satellite Network,
- F12: Provide Network Services,
- F13: Transceive Signalling and Traffic.

The functions classes cover the following unitary functions:

F11	F12	F13
Control Satellite Network	**Provide Network Services**	**Transceive Signalling and Traffic**
System Tables Maintenance and Broadcast	**Packet Mode Services**	All physical layer and datalink layer functions (to be further refined if necessary)
Log-on Management	• ATN/OSI Unicast Service	
Mobility Management (Spot allocation, Hand-Over)	• ATN/IPS Unicast Service	
Access Control & Signalling	• ATN/IPS Broadcast Service	
Resource Assignations (frequencies / time slots)	• ATN/IPS Multicast Service	
Redundancy Management	• APR Service (TBC)	
	Applicative Services	
	• Messaging	
	• Group Services	

Table 6. Satcom Functions Architecture Mapping

3.1.3 System Architecture & Preliminary Components Specifications

3.1.3.1 Introduction

The Satcom System is broken down into:

- **User segment,**
- **Space segment,**
- **Ground segment,**
- **Support segment.**

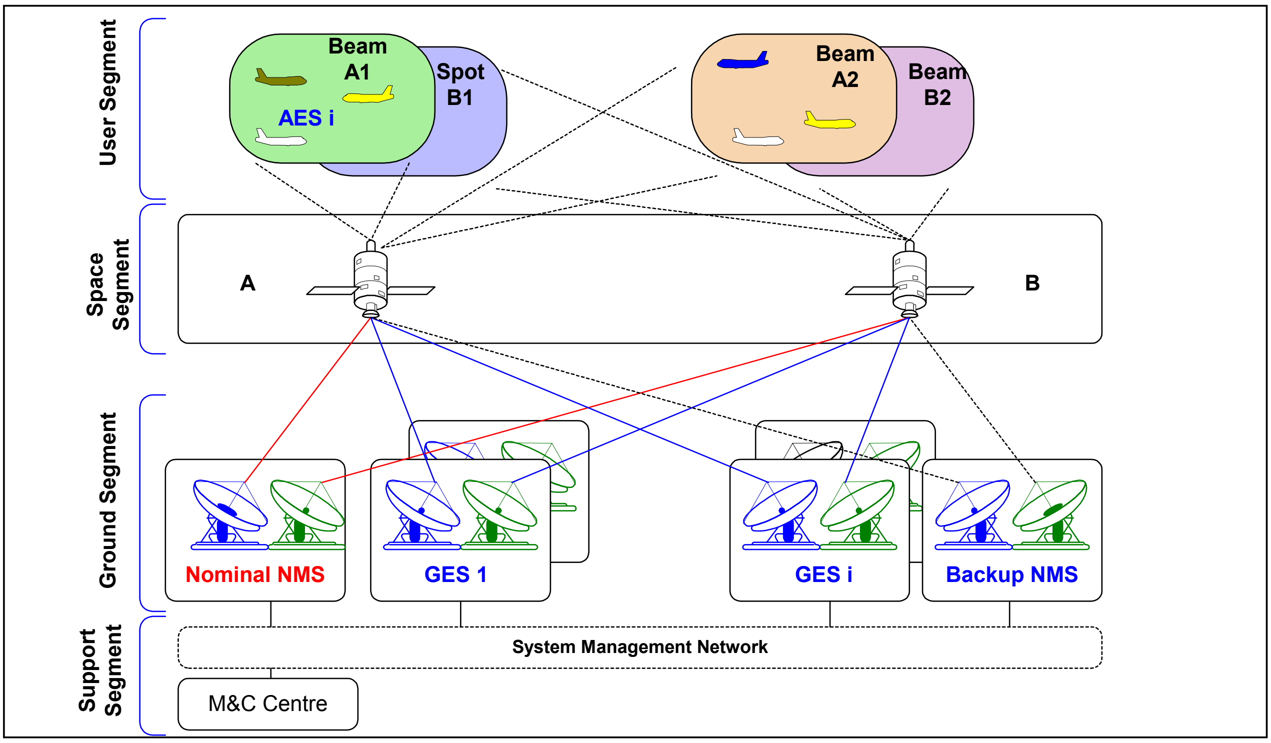


Figure 3-1. Satcom Aero System Segments

3.1.3.2 Space Segment

In baseline, a geostationary space segment is considered to implement ASPASIA system. Three different options could be contemplated:

1. A dedicated ATM mission space segment (type MTSAT model), where the satellite is uniquely designed to serve ATM related mission (Navigation, Communication or Surveillance).
2. A shared space segment option, with a payload specifically dedicated to the ATM mission. The ATM payload is considered to be a piggyback on a large Geo platform supporting other mission (general telecom mission, meteo or other).
3. A shared payload option, or leased option (Inmarsat model). In this model, the resource is shared down to the transponder level, hence reliability of the service cannot be guaranteed with the same level of commitment.

In the two considered cases, i.e. either dedicated platform or piggyback a space segment payload would be dedicated to the ATM Satcom mission.

The specifications of this common element are developed hereafter, with a hypothesis of L-band operation over of spot antenna of 2.4m in diameter (not shown).

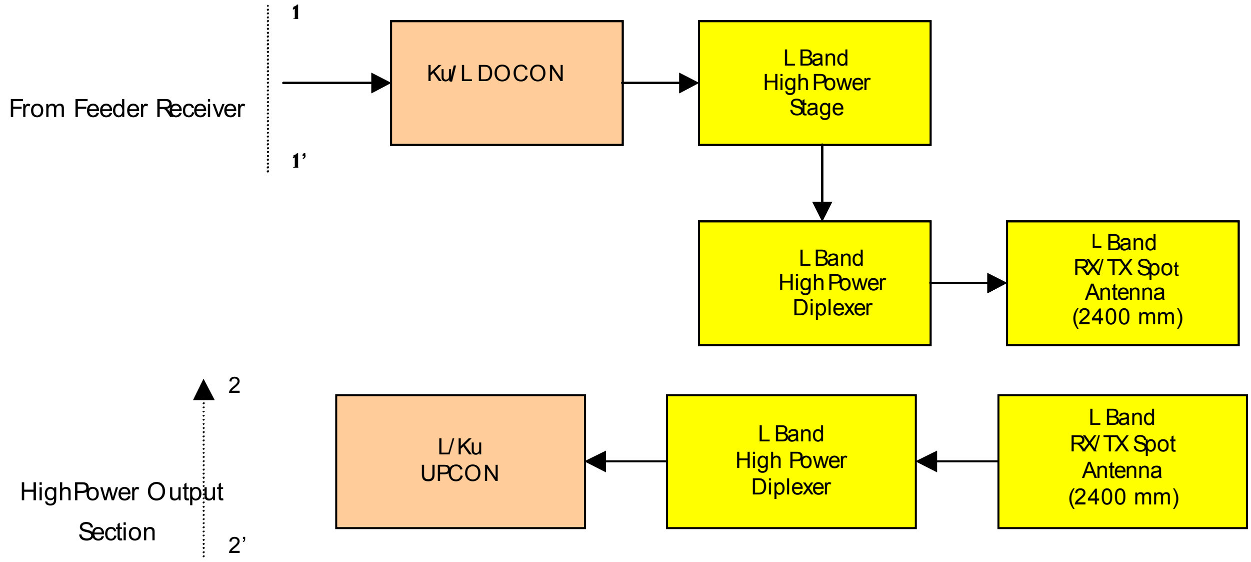


Figure 3-2. Example of Satcom Transponder Section

3.1.4 Physical Layer Design

This section aimed at providing a framework for addressing the synchronization problem in an aeronautical propagation channel used for satellite communications, implementing TDMA/CDMA techniques identified in the SDLS preliminary system design.

Tradeoffs on carrier phase estimation algorithms were carried-out by using the performance requirements of the SDLS project derived now to implement surveillance applications.

3.1.4.1 Scenario impairments

This set of parameters collects the ones related to the impairments defining the actual scenario, including the ones related to the channel and the ones related to the system itself.

The **aeronautical propagation channel** used for satellite communications, implementing TDMA/CDMA techniques, is defined by the next figures.

The broadband RF frequency bands of Aeronautical Mobile Satellite Service (AMSS) are L-Band (1.5 / 1.6 GHz), according to AERONAUTICAL TELECOMMUNICATIONS: Annex 10 (to the Convention on International Civil Aviation) – Volume III (Communication System).

This scenario has a low signal-to-noise ratio (SNR) (3 dB, other several values have also been studied), mainly due to Additive White Gaussian Noise and low level power, due to small antenna sizes and power output constraints (< 40 W). The maximum authorised power dissipation must not exceed 150 W (ARINC 741 recommendation).

Other characteristics taken into account from this scenario are the attenuations due to distance, atmosphere and rain or snow.

The used satellite, station and user (NMS, GES and AES) clocks instabilities characteristics have also been taking into account, as well as, of course, the Doppler effects due to satellites and planes movements.

Another special characteristic of the aeronautical channel is that requires an appropriate model, obtained taking into account all the different contribution of the received signal:

- direct signal (LOS)
- multipath diffusion from aircraft itself
- particular reflections: from ground/sea
- diffuse scattering from ground/sea
- reflected/diffracted contributions from buildings

The aeronautical channel has a set of special constraints. For example, it has three different scenarios depending on the flight phase: "En-route", "Landing/Taking off" and "In the parking area"; each one with its own antenna height, aircraft velocity and reflected / multipath signal contributions.

The study about the contribution to multipath effect of ground and sea specular reflection is based on analytical analysis.

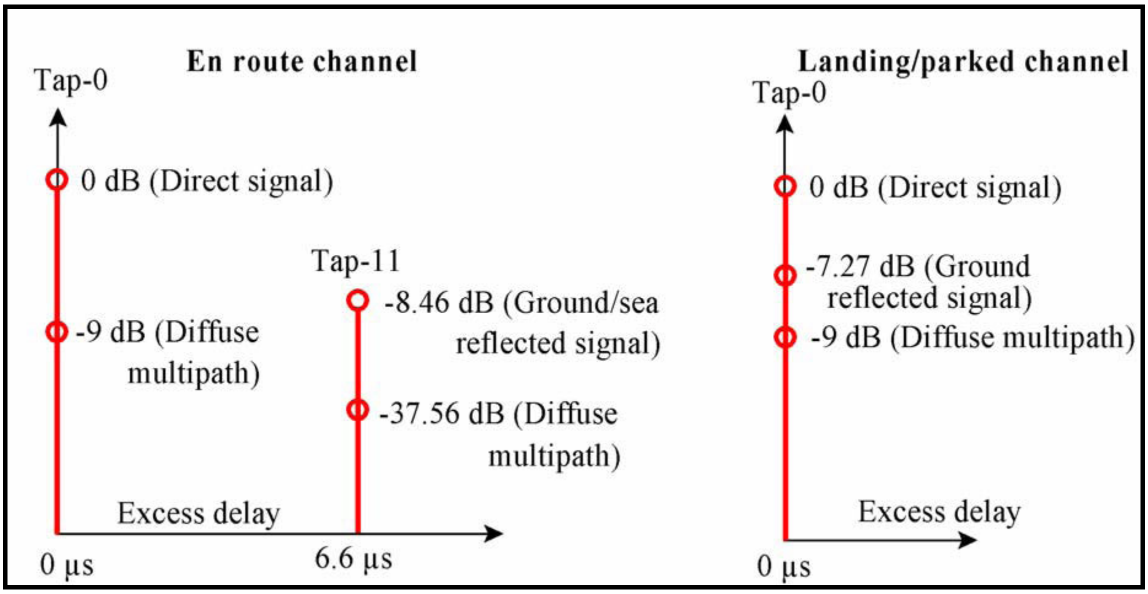


Figure 3-3. Aeronautical Channels Results Obtained

In order to simulate this aeronautical scenario in a pessimistic way (not just a low SNR scenario), carrier frequency variations with sinusoidal profile have been used. The simulated profile has been the variations profile corresponding to the maritime scenario, which has worse characteristics for synchronization process than the aeronautical one. The speed difference between maritime and aeronautical scenarios does not affect the current synchronization scheme, because it has a Doppler precompensation estimation. Just the acceleration has to be taken into account, and acceleration in maritime scenario is equivalent to a "worst case" of acceleration in aeronautical one. This profile is defined by the next numbers:

- Constant carrier frequency error: 10 Hz
- Carrier frequency estimator residual error: sinusoidal (amplitude App = 10 Hz, period T = 6 s) [AFC residual jitter: σ = 0.194 Hz]
- Synchronization remote corrections: 2 Hz steps every second
- Constant value as initial error after acquisition of random carrier: 22 Hz

Besides the parameters related to the channel, the ones related to the **communications system** are defined. On the architectural design, several requirements related to the system itself have been taken into account:

- the existence of several carrier interferers signals form other several aircrafts sharing the same satellite channel slot
- the fact that links must keep synchronized, in frequency and phase, to reference carriers (time $\leq$ 1 s)
- the symbol constellation (QPSK / Dual-BPSK)
- the symbol rate (5.7 ksymbol/s, but obtained results do not depend on symbol rate)
- the system has to work (transmit and detect) two types of signals: continuous and burst traffic signals of ASAS applications (mini-burst with LT < 100 symbols and standard burst with 100 < LT < 1,000 symbols)
- the existence of an un-modulated preamble at the beginning of bursts that has been determined and minimized

3.1.4.2 New algorithm proposed

As conclusion of the tradeoffs, new carrier/code phase synchronization algorithms were proposed to be integrated in the design of local/remote physical layer synchronization loops implemented to perform carrier frequency pre-compensation and signal tracking.

The Carrier Phase Estimator is the algorithm that extracts the symbols (data) from the received signal and, as shown in next figure, can be affected by noise and carrier phase and frequency errors:

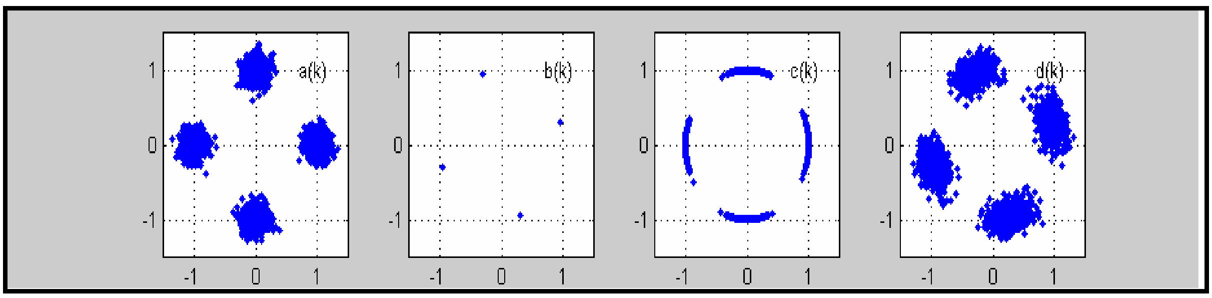


Figure 3-4. Noise and Carrier Phase and Frequency Errors in Carrier Phase Estimation

The previous implementation was the Decision Directed – Feed Forward scheme, ideal for continuous transmissions in medium of high E_s/N_0 conditions. It needs a Carrier Frequency Tracking Loop in parallel.

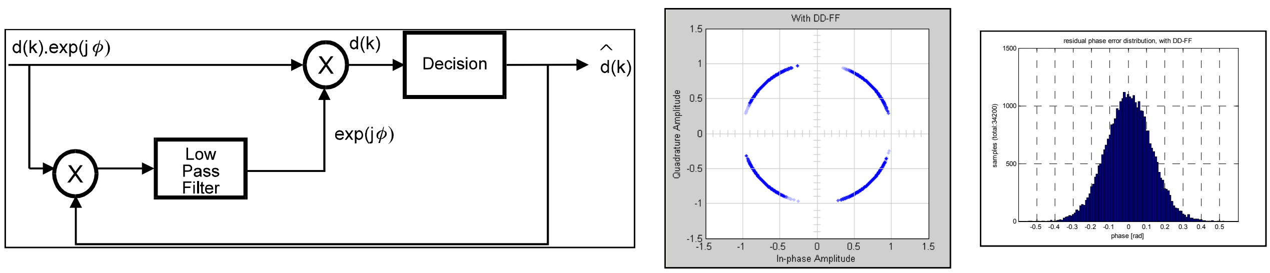


Figure 3-5. DD-FF Scheme and Residual Phase Error and Distribution

The proposed alternative scheme was the Kalman Filter (Extended KF in some cases), which provides the optimal joint phase and frequency estimation, especially in low-E_s/N_0 conditions.

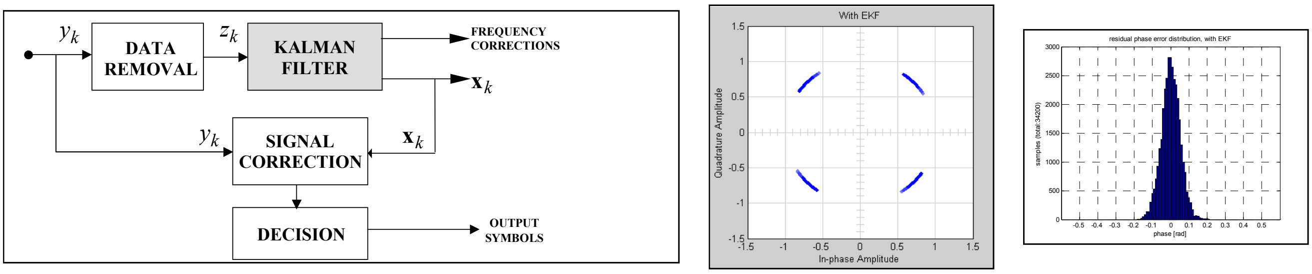


Figure 3-6. [E]KF Scheme and Residual Phase Error and Distribution

3.1.4.3 Simulations

Simulations of the synchronization loops with all the previously identified scenario impairments and several carrier interferers were carried out in continuous and burst mode.

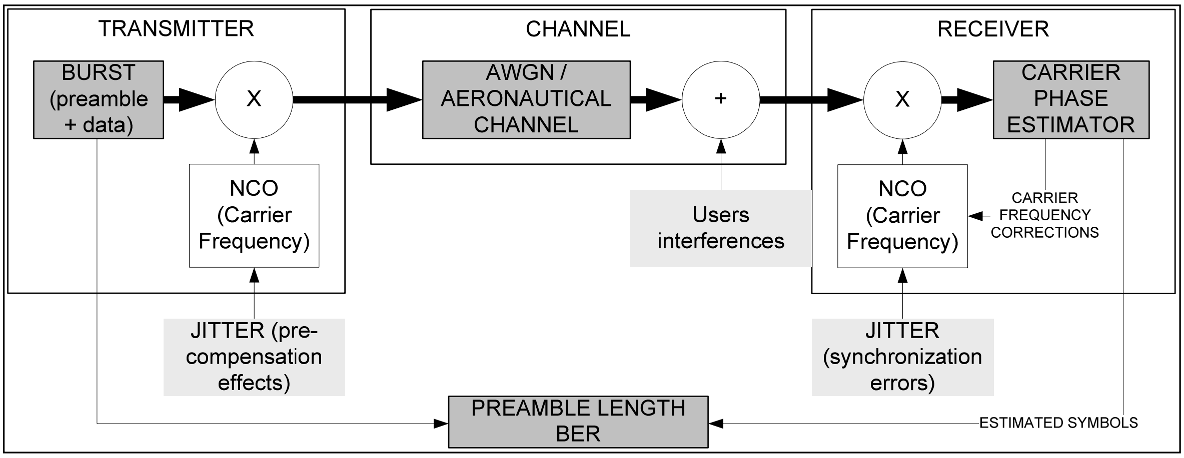


Figure 3-7. Carrier Phase Estimator Simulation Block Diagram

The simulation objective was the selection of the Carrier Phase Estimator scheme and parameter in order to minimize the preamble field length and the data field BER (and BER degradation), taking into account the possible utilization of the scheme in order to help the tracking.

3.1.4.4 Results and Conclusions

The main idea of the physical layer design was the identification of physical layer improvements to be provided to ASAS applications: optimization in resources needed, access time and pilot signal re-acquisition time.

Results were achieved for a big range of E_s/N_0's keeping the data field BER, reducing the preamble field length (from 50 – 70 symbols), guarantying no cycle-slips in a long transmission and reducing the synchronization transient phase convergence time.

Simulations performed with minimum E_s/N_0 scenario of 3 dB, achieving $8 \cdot 10^{-2}$ uncoded BER (proper behaviour of previous synchronization algorithms in receiver chain is not guaranteed with values lower than 3 dB) showed the next results:

- Continuous mode: in AWGN channel, **NDA-EKF** scheme improves DD-FF results without cycle slips nor degradation, and in aeronautical channel is the one and only scheme prepared in front of frequency fluctuations and steps, maintaining residual jitter in long transmissions.
- Burst mode:
  - For mini-burst, **EKF** scheme just needs 30 symbol preamble. In aeronautical scenario, **DD-FF** scheme just 50 symbols. With Convolutional Code ½: BER = $3 \cdot 10^{-4}$.
  - For standard burst **EKF** scheme just needs 20 symbol preamble. In aeronautical scenario, **DAtoNDA-EKF** scheme just 40 symbols. With Convolutional Code ½ and Reed-Solomon: BER = $2 \cdot 10^{-6}$.
- Synchronization transient phase reduced from 300 - 400 to ~ 175 symbols applying at the receiver NCO the carrier frequency corrections generated by carrier phase estimator **DA-EKF** scheme.

There is a requirement to be fulfilled by the communications, Quality of Service. The worse quality figure to be fulfilled has been the one related to BER requested for ADS-B service availability in the ASAS application of Sequencing and Merging. In this service, the availability of the ADS-B shall be greater than 0.99999, taken from DO-242A and anticipates flight operations where ADS-B is being used as a sole means of surveillance. This availability figure corresponds to a required BER = $1 \cdot 10^{-7}$. In order to keep this data field BER, next SNR and channel codification are required depending on burst type, allowing reducing even more the previous preamble length:

- Mini-burst with 22 symbol preamble and Convolutional Code ½: BER = 6.3·10-8 with 5 dB of Es/N0 (this value in reception requires 1.8 dB extra in transmission if interferences and multipath appear).
- Standard burst with 25 symbol preamble and Convolutional Code ½ with Reed-Solomon: BER = 2.7·10-8 with 3.5 dB of Es/N0 (this value in reception requires 1.6 dB extra in transmission if interferences and multipath appear).

As a summary, it can be said that the minimum E_s/N_0 necessary for the proper behaviour of synchronization algorithms (3 dB) is not sufficient to achieve the QoS BER requested for ADS-B service availability ($1 \cdot 10^{-7}$). It takes to increase it 2 dB for mini-burst (100 symbols) and just 0.5 dB for standard burst (1000 symbols).

3.2 Surveillance Applications Developed/Adapted

3.2.1 ADS-B-NRA

The ADS-B-NRA (Non-Radar Areas) application facilitates enhanced air traffic services in areas where radar surveillance does not exist. This application enables an ANSP to provide radar-like separation services in non-radar areas, and has no direct impact on the flight crew because ADS-B position reports are transmitted automatically. However, the flight crew may have to accommodate new procedures and rules in the areas of operation of the application, but they will benefit from the improved service from the ANSP. It is likely that the full benefits will only be obtained when all of the aircraft within a given area are suitably equipped.

Since this is the most mature application, it is used as a reference to analyse the impact on the application requirements when using a satellite data link. It is used also to validate the Satcom system for surveillance applications, and to derive the minimum Satcom system performance parameters.

3.2.1.1 ADS-B-NRA Test-bed Implementation Model

Figure 3-8 is a high-level schematic of the principal ground and airborne modules of the ADS-B-NRA test-bed and their interface to the SatCom emulator.

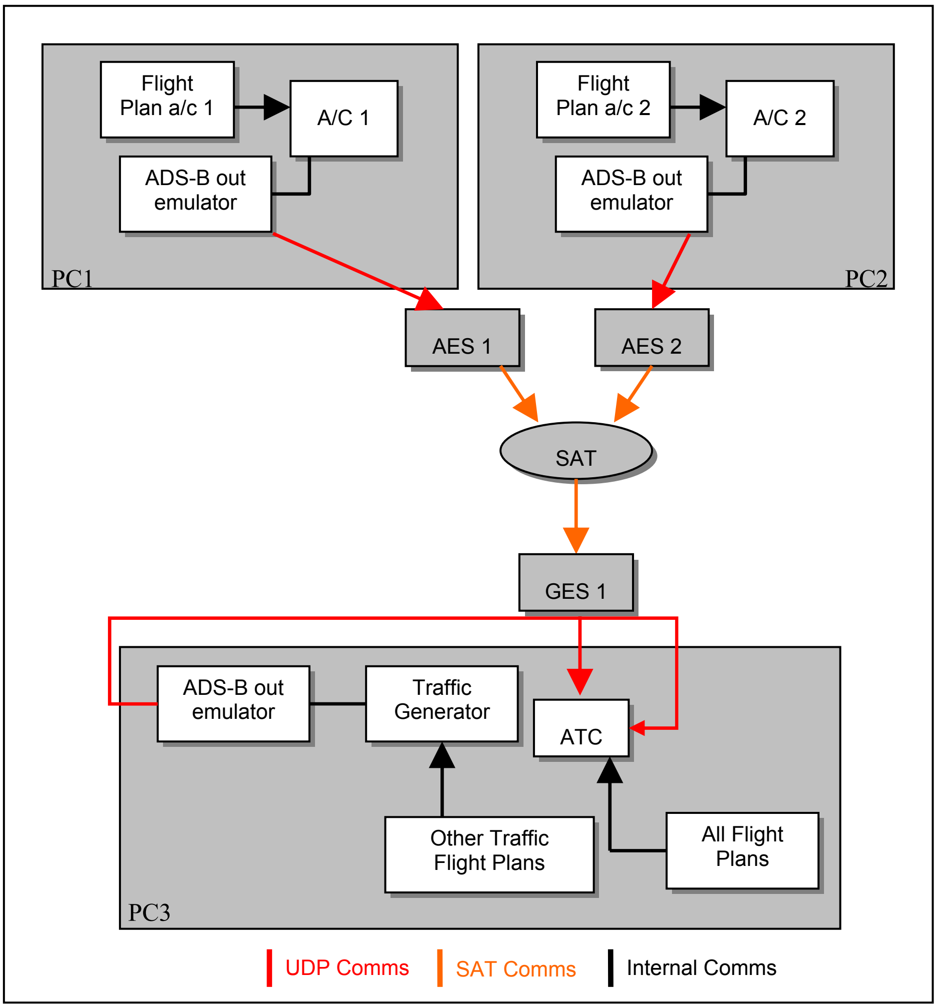


Figure 3-8. ADS-B-NRA Implementation Model

Each aircraft module services ownship ADS-B transmit functionality via SatCom. This is facilitated through ADS-B service emulation. In addition to the aircraft dynamic model there is a global weather generator to ensure coherent weather variables for all aircraft in the simulation environment. The aircraft module is primarily constructed of an installation of a COTS flight simulator. This installation provides the airframe dynamical model, the scenario environment and the platform for aircrew control inputs.

The interface to the AES uses the UDP format based on the NLR BSE protocols. An ADS-B Server Emulator is included in the model to emulate the creation and dissemination of all ADS-B data throughout the aircraft. The paths out, and into, the ADS-B Server on the AES side use the message format defined by the BSE protocols, but on the aircraft side all communication is in the form of TCP/IP connections.

The ATC module is connected to the THALES Gateway/SatCom Sim by means of the Ground Earth Station (GES) as illustrated. The GES receives and broadcasts messages in UDP format following the standards as outlined in the Eurocontrol document *Surveillance Data Exchange Part 12: Category 021 ADS-B Messages*. As with the aircraft module, the messages are created and disseminated using ADS-B server emulation. The ADS-B server retrieves the position, callsign and time stamp data and sends this to a latency filter, which, in turn, sends the message onto the Surveillance Data Processing System (SDPS). This system organises the data into a format that can be displayed onto a HMI viewable by the ATCO.

3.2.1.2 ADS-B-NRA Test Harness

The ADS-B-NRA application uses UDP protocols. The test package includes qualification of this kind of communication. Figure 3-9 shows a schematic of the ADS-B-NRA test harness.

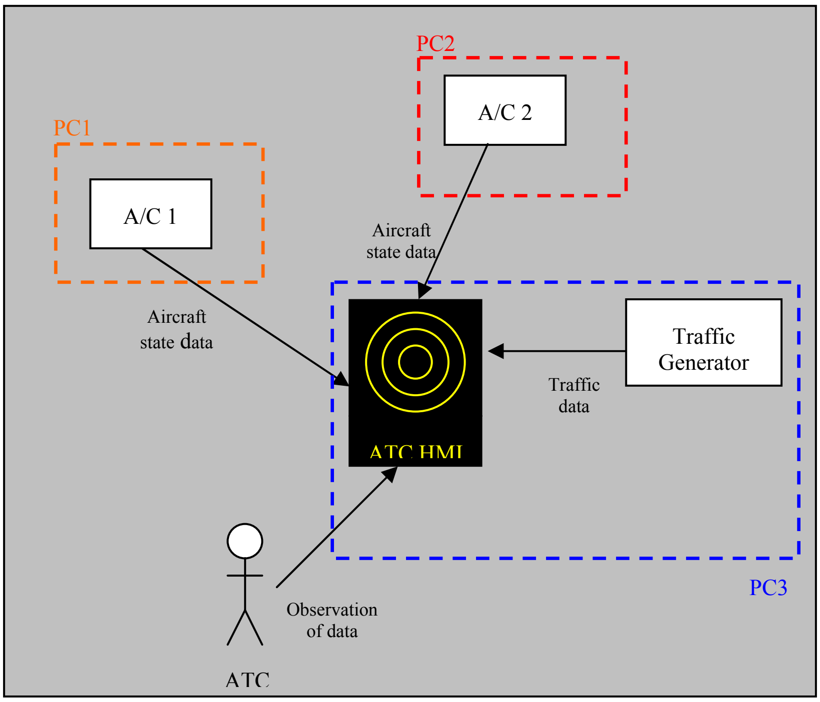


Figure 3-9. ADS-B-NRA Test Harness

3.2.1.3 ADS-B-NRA Validation Objectives

The main validation objective with regard to the ADS-B-NRA surveillance application is to assess the feasibility of ADS-B-like data transmission via SatCom with respect to required measures of completeness, integrity and latency.

3.2.1.4 ADS-B-NRA Test Cases

The principal ADS-B-NRA Use Case is summarised in Table 7:

ADS-B-NRA Use Case	
Use Case	SatCom ADS-B-NRA with non-SatCom Traffic
Use Case ID	NRA_4
Actors	A/C1, A/C2, Traffic
Purpose	A/C1 and A/C2 broadcasting through SatCom / Third party traffic broadcasting through another medium (e.g. 1090ES)
Overview	• A/C1 broadcasts is position and other data through an ADS-B type message through SatCom. • A/C2 broadcasts its position and other data through an ADS-B type message through SatCom. • The third party traffic broadcasts through another medium (e.g. 1090ES).

Table 7. ADS-B-NRA Use Case

Descriptions of the specific test cases, adopted for the ADS-B-NRA Use Case defined in Table 7, are presented in Table 8. The test cases aim to quantify any performance issues resulting from degradation of the SatCom datalink from the baseline case.

Test ID	Test Description
NRA_4.1	Inclusion of a noise generator onto the SATCOM simulator to simulate atmospheric or other fouling of the transmission path. A 270ms delay is included to simulate the transmission time to, and from, the Satellite
NRA_4.2	Inclusion of congestion onto the terminal of the SATCOM simulator to simulate large volumes of network traffic. A 270ms delay is included to simulate the transmission time to, and from, the Satellite
NRA_4.3	Baseline test with no noise on the SATCOM simulator and no congestion on the terminals. A 270ms delay is included to simulate the transmission time to, and from, the Satellite

Table 8. ADS-B-NRA Test Cases

3.2.1.5 ADS-B-NRA Test Results

The corresponding ADS-B-NRA test cases are analysed using three metrics:

- **Data timeline and missing packet assessment** - A simple assessment of the order in which packets have been sent and received, documenting any missing packets.
- **Data Integrity** - An assessment of any errors within a packet (as opposed to a missing packet) that have been caused by the transmission of the packets.
- **Data Latency** - An assessment of the time taken by the simulator to send, transmit and receive each message. This assessment adopts three sub-metrics; the maximum message time, the minimum message time and the average message time.

Table 9 highlights the principal statistical results from the ADS-B-NRA test cases conducted on the Thales DVB-RCS SatCom Demonstrator Platform:

	NRA_4.1		NRA_4.2		NRA_4.3	
	ADS-B from		ADS-B from		ADS-B from	
	AC1	AC2	AC1	AC2	AC1	AC2
Total messages sent	1115	1162	1116	1114	1274	1274
No. of errors in data	0	0	0	0	0	0
No. of missing messages	88	137	85	40	0	0
% of missing messages	7.89	11.79	7.62	3.59	0	0
Average message time (s)	0.340	0.337	0.321	0.337	0.313	0.330
Maximum message time (s)	4.167	4.021	3.491	3.696	0.344	0.358
Minimum message time (s)	0.284	0.287	0.286	0.289	0.283	0.306

Table 9. ADS-B-NRA Test Results

3.2.2 TIS-B

The TIS-B (Traffic Information Service - Broadcast) concept describes a means for traffic information to be broadcast from a base station for use by any receiving aircraft. The original concept was for a ground based transmitter with traffic information being supplied by the ground surveillance system, typically radar. In this type of installation, the ground processing is responsible for extrapolating traffic track information as necessary to ensure that the broadcast positions are consistent with the associated time of applicability. If information is broadcast using the 1090MHz datalink, as defined in the 1090MHz ADS-B MOPS, then the time of applicability is the time at which the TIS-B messages are broadcast. On the airborne side, the received TIS-B messages are processed according to 1090MHz ADS-B MOPS and displayed in order to enhance air traffic situational awareness (ATSAW).

3.2.2.1 TIS-B Test-bed Implementation Model

A high-level schematic of the principal ground and airborne modules of the TIS-B test-bed, and their interface to the SatCom emulator, is depicted in. Figure 3-10:

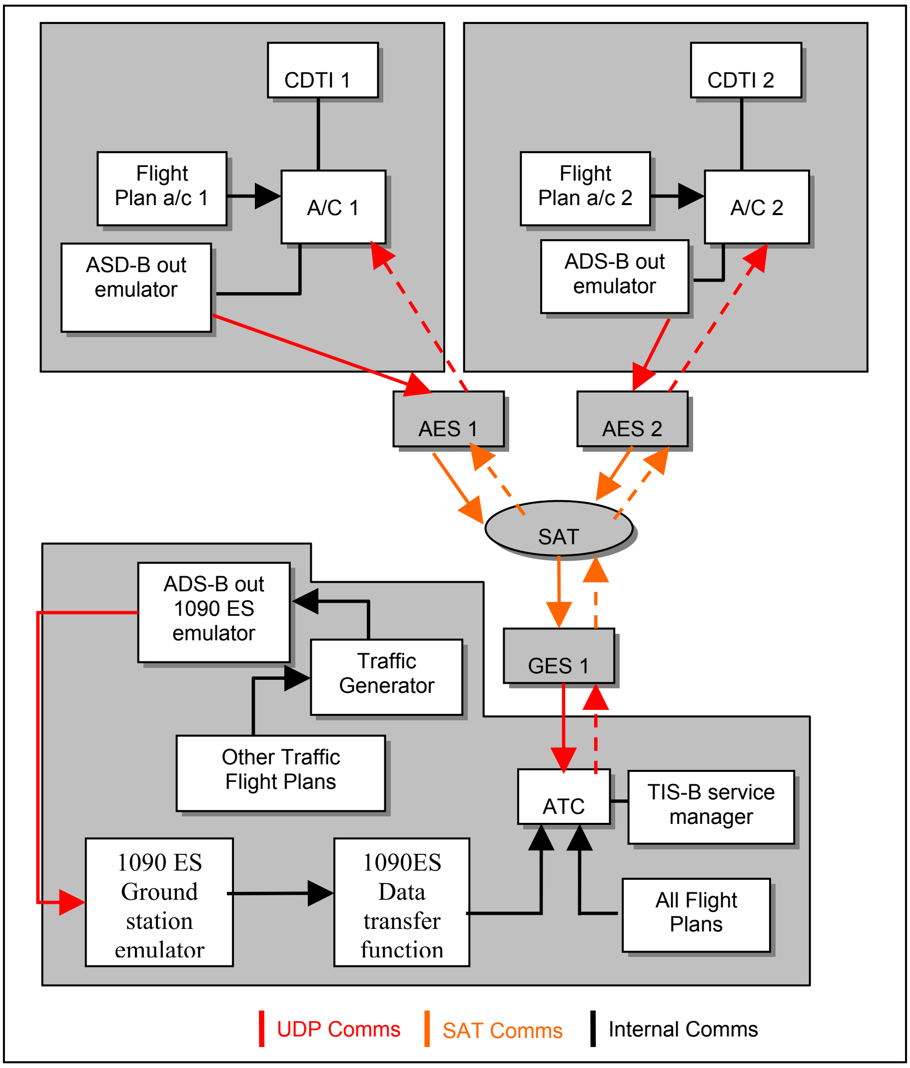


Figure 3-10. TIS-B Implementation Model

For ADS-B SatCom equipped aircraft, the interface to the AES utilises the UDP format based on the BSE protocols. An ADS-B Server Emulator is included in the model to emulate the creation of ADS-B data to the AES. A TIS-B Server Emulator is included in the model to emulate dissemination of TIS-B data to the CDTI. On the aircraft side of both servers, the communication is in the form of TCP/IP connections, apart from communication to the CDTI where the communication medium is in UDP/IP format.

The 1090ES equipped aircraft utilises a UDP/IP format to transmit its data to the ground in the form of UDP messages. These messages are broadcast using the BSE protocols. The interface to the AES also utilises UDP format using the BSE protocols. A 1090ES Server Emulator is included in the model to emulate the creation of 1090ES data through the datalink to the ground station.

The ATC module is connected to the ALCATEL Gateway by means of the Ground Earth Station (GES), as illustrated. The GES receives and broadcasts messages in UDP format where the messages are encoded to comply with the ASTERIX standard as outlined in the Eurocontrol document *Surveillance Data Exchange Part 12: Category 021 ADS-B Messages*.

3.2.2.2 TIS-B Test Harness

The TIS-B application uses UDP protocols. The test package includes qualification of this kind of communication. Figure 3-11 shows a schematic of the TIS-B test harness.

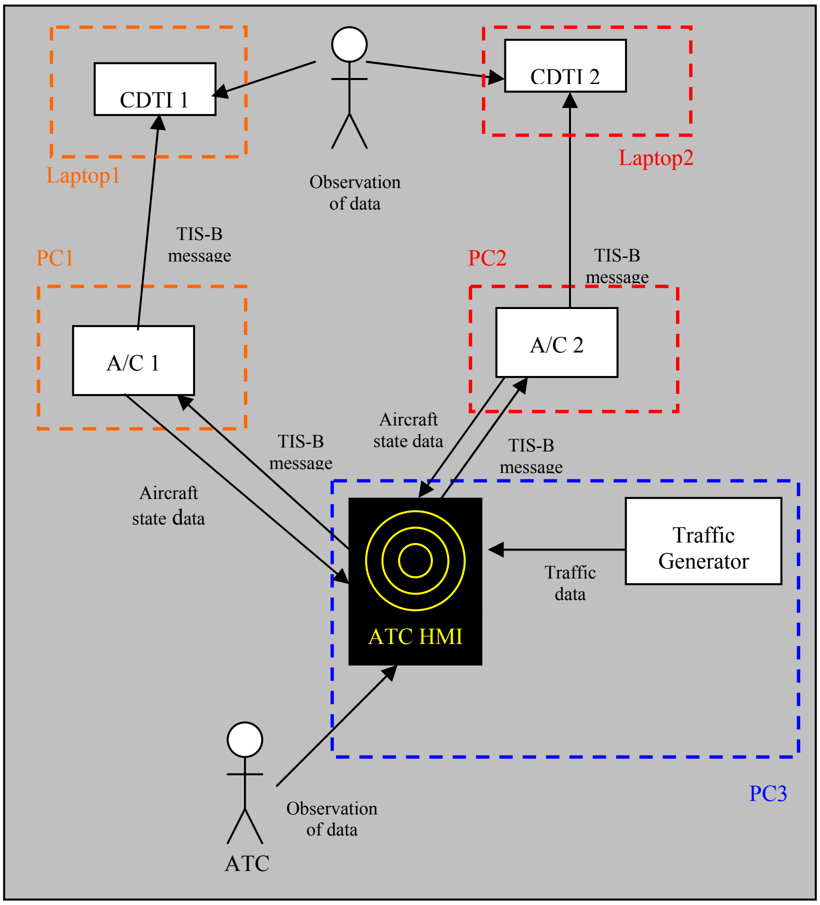


Figure 3-11. TIS-B Test Harness

3.2.2.3 TIS-B Validation Objectives

The main validation objective with regard to the TIS-B/ATSAW surveillance application is to assess the feasibility of ADS-B and TIS-B-like data transmission via SatCom with respect to required measures of completeness, integrity and latency.

3.2.2.4 TIS-B Test Cases

The principal TIS-B Use Case is detailed in Table 10:

TIS-B Use Case	
Use Case	SatCom TIS-B with non-SatCom Traffic
Use Case ID	TISB_4
Actors	A/C1, A/C2, Traffic, ATC
Purpose	A/C1 and A/C2 broadcasting through SatCom / Third Party Traffic broadcasting through another medium (e.g. 1090ES) and both A/C1 and A/C2 receiving TIS-B messages
Overview	• A/C1 broadcasts its position and other data through an ADS-B type message through SatCom. • A/C2 broadcasts its position and other data through an ADS-B type message through SatCom. • The third party traffic broadcasts through another medium (e.g. 1090ES). • TIS-B like message is broadcast via SatCom to A/C1 and A/C2

Table 10. TIS-B Use Case

Descriptions of the specific test cases, adopted for the TIS-B Use Case defined in Table 10, are presented in Table 11:

Test ID	Test Description
TISB_4.1	Inclusion of a noise generator onto the SATCOM simulator to simulate atmospheric or other fouling to the transmission path. A 270ms delay is included to simulate the transmission time to, and from, the Satellite
TISB_4.2	Inclusion of congestion onto the terminal of the SATCOM simulator to simulate large quantities of network traffic. A 270ms delay is included to simulate the transmission time to, and from, the Satellite
TISB_4.3	Baseline test with no noise on the SATCOM simulator and no congestion on the terminals. A 270ms delay is included to simulate the transmission time to, and from, the Satellite

Table 11. TIS-B Test Cases

3.2.2.5 TIS-B Test Results

The corresponding TIS-B test cases are analysed using three metrics:

- **Data timeline and missing packet assessment** - A simple assessment of the order in which packets have been sent and received, documenting any missing packets.
- **Data Integrity** - An assessment of any errors within a packet (as opposed to a missing packet) that have been caused by the transmission of the packets.
- **Data Latency** - An assessment of the time taken by the simulator to send, transmit and receive each message. This assessment adopts three sub-metrics; the maximum message time, the minimum message time and the average message time.

Table 12 highlights the principal statistical results from the TIS-B test cases conducted on the Thales DVB-RCS SatCom Demonstrator Platform:

	TIS-B_4.1				TIS-B_4.2				TIS-B_4.3			
	ADS-B from		TIS-B to		ADS-B from		TIS-B to		ADS-B from		TIS-B to	
	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2
Total messages sent	640	640	855	855	674	679	683	683	619		623	623
No. of errors in data	0	0	0	0	0	0	0	0	0	0	0	0
No. of missing messages	148	64	136	104	0	0	0	0	0	0	0	0
% of missing messages	23.13	10.00	15.91	12.16	0	0	0	0	0	0	0	0
Average message time (s)	0.347	0.366	0.311	0.305	0.315	0.327	0.307	0.311	0.312	0.327	0.308	0.308
Maximum message time (s)	3.608	4.149	0.346	0.331	0.346	0.356	0.329	0.333	0.338	0.355	0.318	0.324
Minimum message time (s)	0.285	0.299	0.301	0.289	0.295	0.296	0.293	0.296	0.291	0.301	0.297	0.289

Table 12. TIS-B Test Results

3.2.3 ASPA-S&M

3.2.3.1 Function Overview

This application was designed for en-route airspace and TMA in a radar environment, primarily in the core area of Europe.

In its intended environment, the objective is to redistribute tasks related to sequencing (e.g. in-trail following) and merging of traffic between the controllers and the flight crews. The controllers will be provided with a new set of instructions enabling them to direct flight crews to establish and to maintain a given time or distance from a designated aircraft. The flight crews will perform these new tasks using new aircraft functions (e.g. airborne surveillance, display of traffic information, spacing functions with advisories).

In its intended environment, the main expected benefit is increased controller availability by the reorganisation and streamlining of tasks. This should allow acceptance of more aircraft in a given sector or the designing of larger sectors. It is also expected to assure more regular spacing based on actual separation minima and thus an increase in capacity especially in high-density areas. For oceanic airspace, greater flight efficiency in the cruise phase of flight can be achieved by better use of flight routes, e.g. by increased utilisation of the jet stream.

There are two types of basic manoeuvres that could be instructed by the controller: *'Remain Behind'*, and *'Merge Behind'*. Further variations of these manoeuvres may be formed by prefixing a radar vector instruction, i.e. *'Radar vector then remain behind'*, or *'Radar vector then merge behind'*. This radar vector instruction is necessary in cases where the required spacing would not be achieved by speed changes alone within the available time or position constraints. Figure 3-12 shows this situation for a *merge behind* application.

Case 1 in the figure shows a situation where aircraft B can decelerate safely and efficiently to meet the controller's constraint to be 5NM behind aircraft A at WPT. The controller instruction may be of the form:

> *"Aircraft B, merge behind aircraft A to be 5NM behind at WPT."*

Case 2 shows a slightly different situation. Here, aircraft A and B have roughly similar distances to run before the merge point. Aircraft B cannot decelerate safely to meet the controller's constraint to be 5NM behind A at the merge point; therefore, the controller gives aircraft B a 'dog-leg' to acquire the necessary spacing (this procedure is used extensively in current operations). The controller instruction may be of the form:

> *"Aircraft B, heading 060, merge behind aircraft A to be 5NM behind at WPT."*

Aircraft B resumes navigation to WPT when the predicted spacing at the merging point equals the desired spacing.

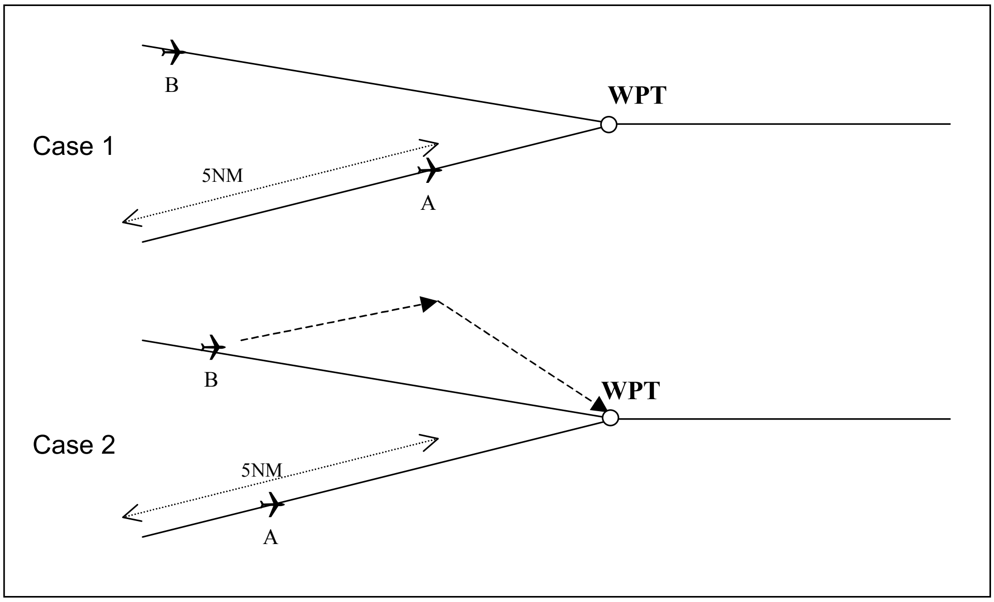


Figure 3-12. Examples of Merge Geometry

Note that the controller specifies the first radar vector instruction, whereas the second turn is initiated by the flight crew as the required spacing distance is met (i.e. the second turning point is an implicit part of the ASPA-S&M procedure). Although the controller does not know the precise time or position at which the aircraft will begin the second turn, their experience with the sector should enable them to mentally estimate them. This is similar to current operations except the controller will actively monitor the aircraft and issue an instruction, e.g. "*Go direct to WPT*", for the second turn.

As in current operations, the controller must take into account the speeds of both aircraft and local wind conditions when deciding whether conditions are suitable for using the spacing application.

3.2.3.2 Description of Application Test Bed

The ASPA-S&M test bed suite of software consists of 3 separate software programs:

- ASSAP (Airborne Surveillance and Separation Assistance Processing)
- GraceSim test harness program
- ACDU (ASAS Control and Display Unit) HMI

Each of the software packages operates in one of the following communications modes:

- Localhost mode (useful for verification testing on a single PC)
- Broadcast mode (standard for BSE messages)

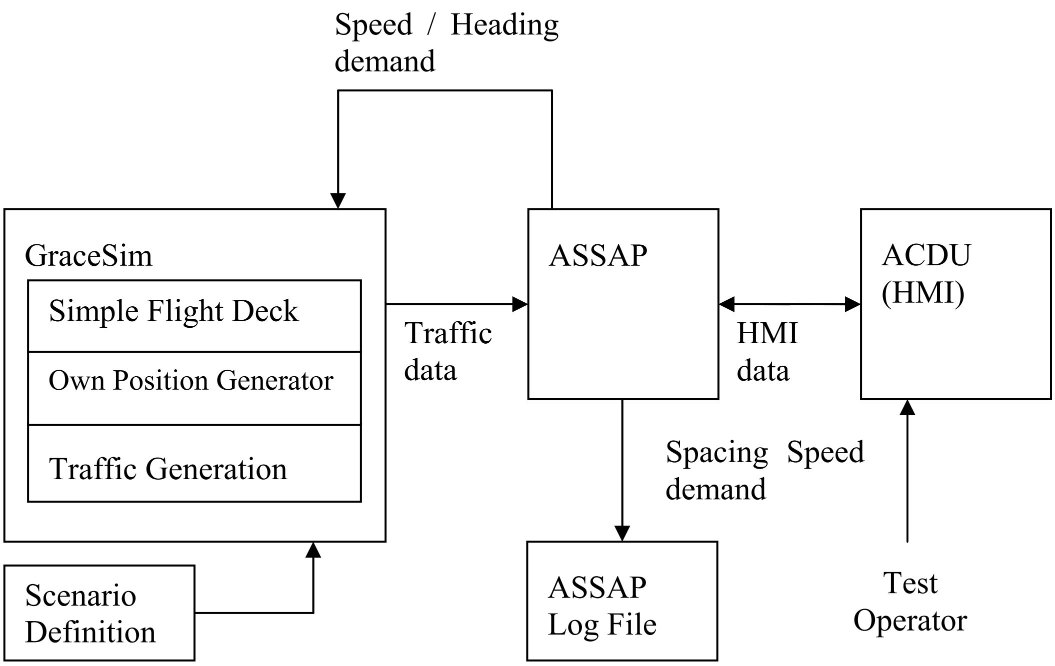


Figure 3-13. ASPA-S&M Test Bed Software Architecture

The heart of the software is the ASSAP program. The ASSAP software functions include:

- Receive own ship and target aircraft position data from the traffic and other data generators (GraceSim in this test environment)
- Calculate spacing
- Calculate speed demand based on spacing
- Transmit speed and heading demand to the FMS (GraceSim in this test environment)

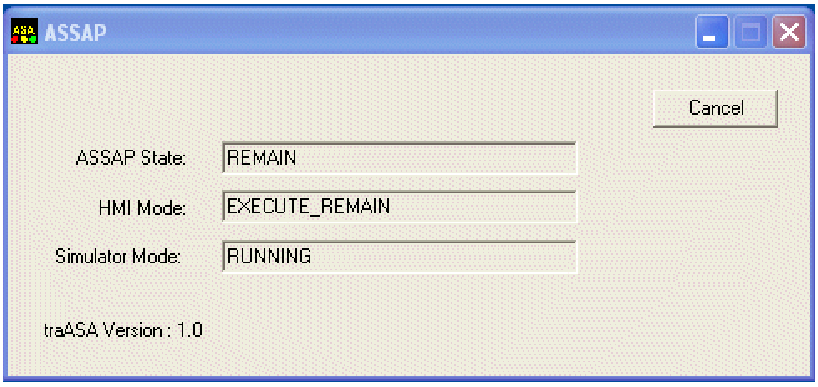


Figure 3-14. ASSAP

The GraceSim software simulates the aircraft environment in which the ASSAP operates, providing external data such as traffic data, FMS data and control and all other aircraft status information.

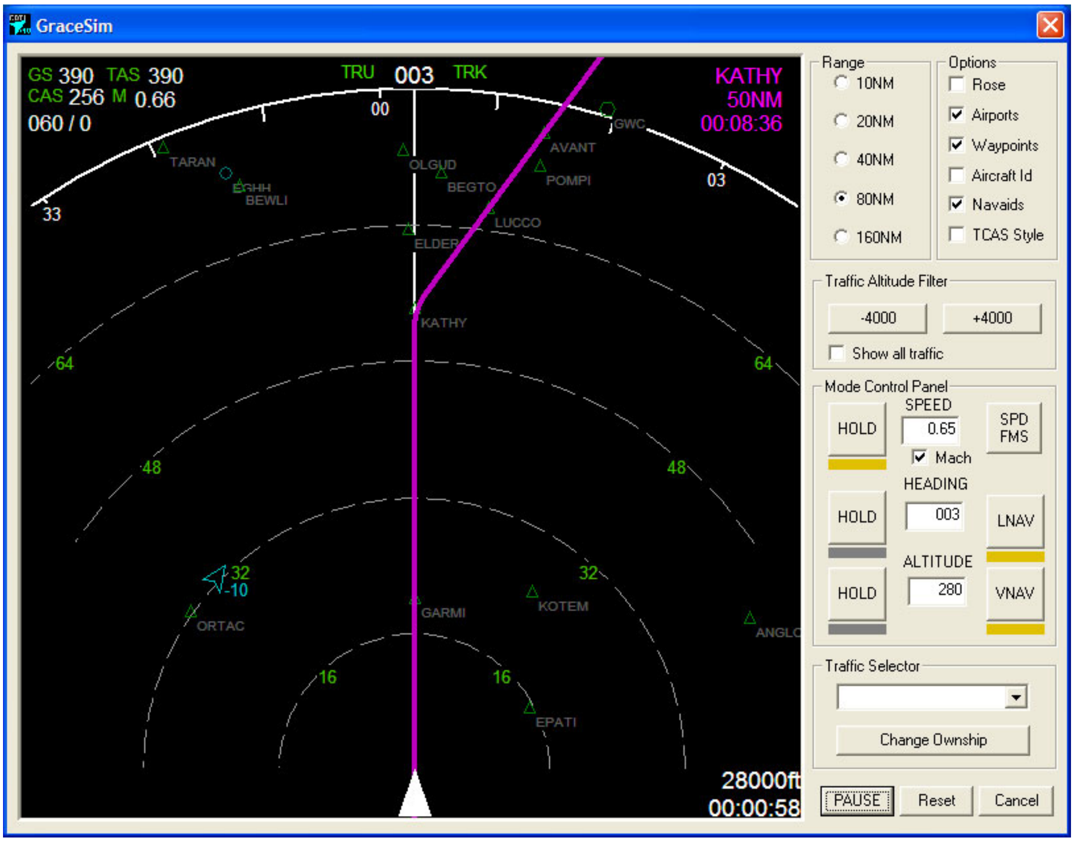


Figure 3-15. GraceSim

The GraceSim simulator manages the environment in which the ASSAP operates. The initial conditions are specified by a text file which is selected by the operator. The GraceSim then manages the environment by following flight plans contained within the text file and any commands issued by the ASSAP. The test operator selects the test scenario for each test.

The ACDU HMI provides all input and shows all status data that would normally be received from or sent to the Flight Deck and the ATC.

Using the ACDU, the test operator acts as the aircraft crew and ATCO. The ACDU HMI simulates the interface to both the Flight Deck and the ATC, allowing commands and control data to be entered, and status data to be displayed, as if there were two separate sources. There are separate pages within the HMI for each of the control panels simulated.

Figure 3-16. ACDU

3.2.3.3 Testing and Evaluation

Two tests were used for the purpose of system verification, and as a basis for evaluation with the SatCom system:

Test AT1: Merge in level flight at merge waypoint; target in cruise with no turns; initial spacing is too large.

Test AT2: Vector, Merge and Remain in level flight at merge waypoint; target in cruise with no turns; go into Remain and then descend in Remain; initial spacing is too small.

The testing checked that the calculation of speed demand was functioning correctly. This can be inferred if the system accepts the manoeuvre, and the spacing remains within acceptable limits and the speed demand is progressive and controlled. If these criteria are not met, a diagnostic message is displayed.

3.2.4 ADS-B-ADD

The ADD (Aircraft Derived Data) applications enable the provision of a service delivering avionics data extracted from aircraft systems to various ground-based and/or airborne end-users or tools. The ADD service can support a wide range of user services (controller support tools).

As a particular ADD application, the ADS-B-ADD application enables provision of additional aircraft derived data through ADS-B to be used in ground ATC application systems, typically for developing or enhancing ATC tools, as for instance an AMAN system.

ADS-B-ADD test bed implementation model

The ADS-B-ADD Test-bed is composed of the following modules:

- SCANSIM Air Traffic Generator (Air TG)
- SCANSIM Ground Traffic Generator (Ground TG)

- MAESTRO AMAN
- Simulation preparation and supervision

The Air TG simulates the aircraft environment enabling the generation of ADS-B messages under ASTERIX Category 21 format to be down-linked by the ADS-B-ADD application. The Air TG is adapted from SCANSIM that is used in that case as an Air Traffic Generator to simulate the aircraft environment - providing air traffic data and FMS data - based on operational aircraft performances and piloting models.
For the purpose of this Air TG, SCANSIM software has been modified so as to generate Cat 21 messages containing aircraft parameters, including the trajectory intent (Cat 21 Item 110) – that is of particular interest for ASPASIA validation - as a list of couples {beacon, ETO}.

The Ground TG simulates the ATC environment enabling to generate ASTERIX Category 30 messages that will provide MAESTRO scheduler - the module that compute sequence data - with FDPS/RDPS data.
In ASPASIA, a parameter of particular interest is the ETO. From the ground side, the ETO generated by Ground TG is extrapolated from flight plan and radar track data.

In the ASPASIA framework, for a given aircraft, MAESTRO AMAN can use two sources of real-time data:

- Cat 21 messages containing data down-linked from the aircraft (ADS-B-ADD)
- Cat 30 messages containing flight plan and radar track data (already handled by MAESTRO)

Using real-time traffic data generated by the Air and/or Ground TGs, MAESTRO:

- Allocates each incoming flight to a destination runway;
- Calculates its optimum Scheduled Time of Arrival at the TMA entry fix (STA-FF) and at the runway threshold (STA) along with the delays to be absorbed with respect with these times;
- Generates and display the sequence in a specific window on Controller Working Positions;
- Supplies the ACC and the Approach controllers with the corresponding control actions to absorb these delays;
- Allows controllers to interact with the system to reflect their strategy.

MAESTRO software has been modified so as to handle both data input sources, to manage the Cat 21 interface with SCANSIM Air TG and to provide indicators for possible measures. When computing the Scheduled Time of Arrival for a given aircraft, MAESTRO will privilege Cat 21 messages using the following algorithm:

If Cat 21

- If ETO is present
    - Directly use down-linked ETO, ignore Cat 30 data
- Otherwise:
    - If Cat 30

    - Ignore Cat 21
    - Calculate ETA based on data input by Cat 30
  - Otherwise
    - Calculate ETA based on data input by Cat 21

The ASPASIA simulation relies on SCANSIM functions to prepare and operationally supervise the air and ground traffic scenarios that provide the data required to feed MAESTRO.

The ADS-B-ADD test bed implementation model in SatCom environment is illustrated in the following Figure:

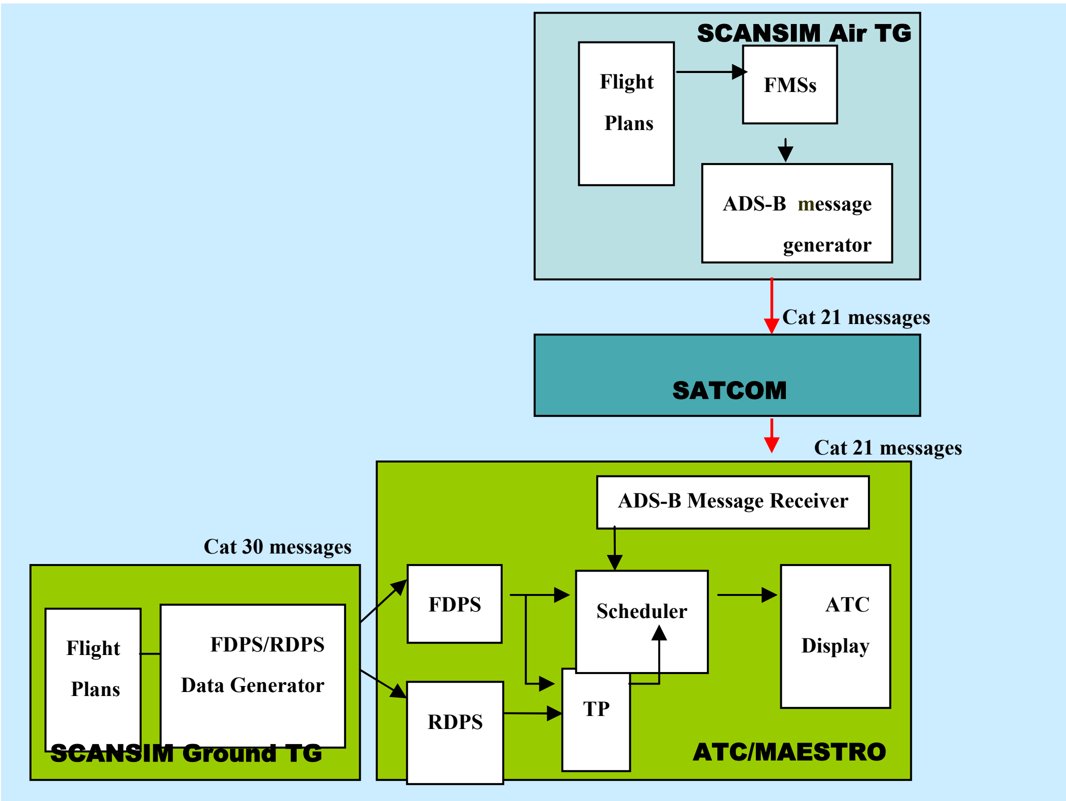


Figure 3-17. ADS-B-ADD Implementation Model

Technical architecture used for the ADS-B-ADD test harness

The following figure shows the technical architecture used for the ADS-B-ADD test harness.

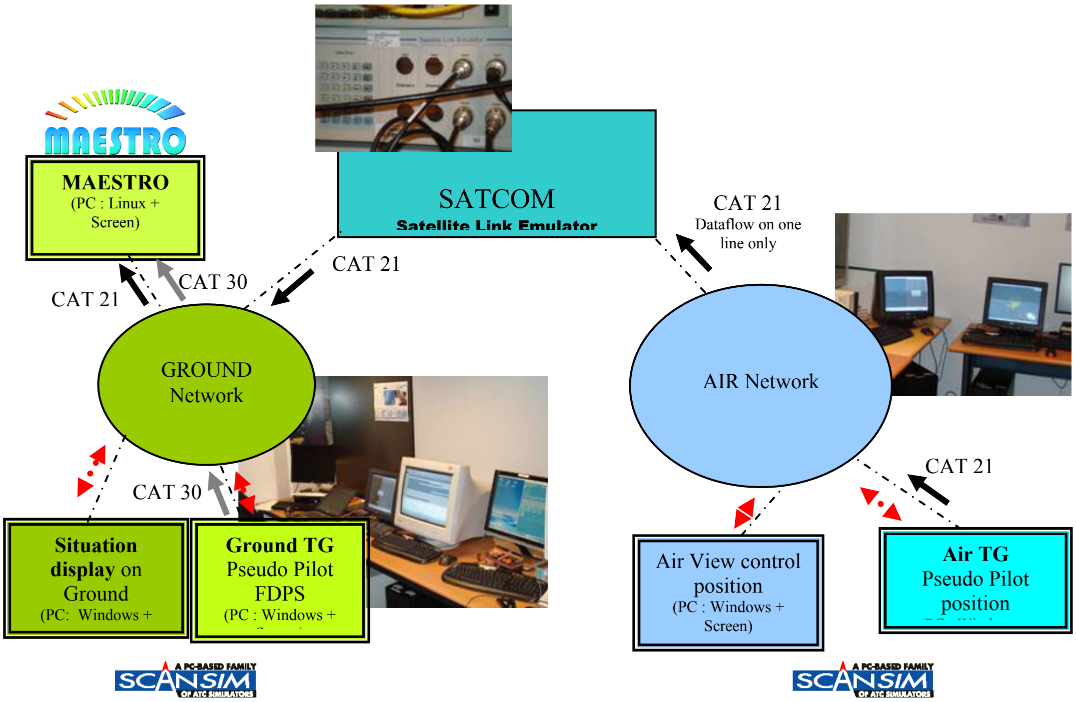


Figure 3-18. ADS-B-ADD Test Platform Technical Architecture

ADS-B-ADD application validation objectives

One of the validation objectives with regards to the ADS-B-ADD application is to assess the benefits that could be derived from an AMAN system of the current generation (namely MAESTRO) when fed with Trajectory Intent Data provided through the ADD service.

In order to highlight the main ASPASIA objective that is to assess the benefit of using the satellite component for an ADS-B-ADD application, the selected operational scenario includes areas where the radar coverage is lacking. Indeed, Aircraft Derived Data (ADD) are foreseen to be used primarily in continental En-Route and Terminal environments in which there usually is multiple SSR coverage already available. The use of satellite connections is foreseen to be beneficial in areas where SSR coverage is not available such as oceanic / overseas areas or as complementary means to VHF connections in high density areas where it becomes saturated.

ADS-B-ADD Test Cases

The VDL/SatCom comparative test cases adopted for the ADS-B-ADD Application consisted in running two parallel simulation sessions with the same air traffic scenario with the following differences:

<table>
<tr><th>Test ID</th><th>Test Description</th></tr>
<tr><td>VDL-like Test Case</td><td>Generation of Cat 30 messages only (i.e, activation of Ground TG only) and limitation of the coverage to 150 -200 NM to simulate radar coverage limitation.
In this traditional case, MAESTRO calculates for a given aircraft, the estimated time of arrival, the schedule time of arrival - and then the sequence of arriving traffic – based on radar tracks provided in Cat 30 messages.</td></tr>
<tr><td>SatCom Test Case</td><td>Generation of both Cat 30 and Cat 21 messages (activation of both Air and ground TGs), assuming that 100% of the active flights are ADS equipped and no limitation of the coverage.

MAESTRO calculates, for a given aircraft, the estimated time of arrival (ETA), the schedule time of arrival - and then the sequence of arriving traffic – based on aircraft derived data provided in Cat 21 messages or on radar tracks provided in Cat 30 messages, given preference to Cat 21 messages according to the following algorithm:

• If ETO is present:
    - Directly use down-linked ETO, ignore Cat 30 data
• Otherwise:
    - If Cat 30:
        i. Ignore Cat 21
        ii. Calculate ETA based on input by Cat 30
    - Otherwise
        i. Calculate ETA based on data input by Cat 21</td></tr>
</table>

Table 13. ADS-B-ADD Test Cases

ADS-B-ADD Test Results

- Error Distribution for Estimated Time of Arrival at Feeder Fix (ETA-FF):
  i. The ETA-FF error shows a nearly homogeneous error distribution for ADS estimate - indicating a systematic error on every flight - whereas the estimate without ADS is more random.
  ii. The error distribution shows a more accurate ETA-FF estimate with ADS narrowed around zero.
  iii. The ETA-FF estimate with ADS is slightly optimistic as it does not integrate the delay to absorb to achieve the Target Time of Arrival.
- The sequence of arrival at the Feeder Fix is more accurate when computed with ADS data than without.
- The trend observed at the Feeder Fix is confirmed and is stronger at the Runway Threshold. Indeed, the sequence of arrival at the runway threshold is more accurate when computed with ADS data than without, with the exact sequence number for all active aircraft.

ADS-B-ADD: Lessons Learnt

As shown by the test results and confirmed by the judgement of our Air Traffic Control expert, the main AMAN Optimisations obtained with ADS-B-ADD application are the following:

- More accurate arrival sequence;
- AMAN time horizon is extended by 25 minutes;
- Earlier stabilisation of the arrival sequence, enabling an extended optimisation phase.

The reasons for these AMAN optimisations:

- More reliable and more accurate knowledge of the Estimated Time Over (ETO) waypoints ; those ETO take in account parameters like airliners speed regulation (speed profile in descent, top of descent …) or calculated wind (issued by on board electronic system). MAESTRO can not reach those data when it is traditionally fed only by RDPS
- Earlier availability of the data input to MAESTRO as it is no more constrained by the radar coverage.
- The use of SatCom is especially beneficial for the Oceanic Area, as the ADS-B-ADD Use Case Test shows that over the Oceanic Area, certain flights are known and available for sequencing whereas flight plan are not activated yet.

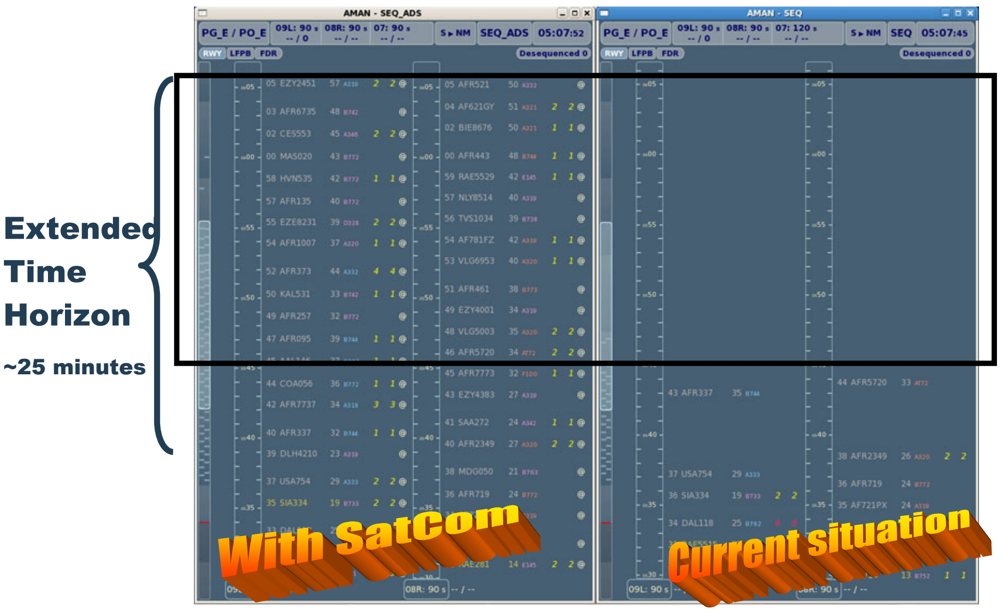


Figure 3-19. Extended AMAN Time Horizon (Runway View)

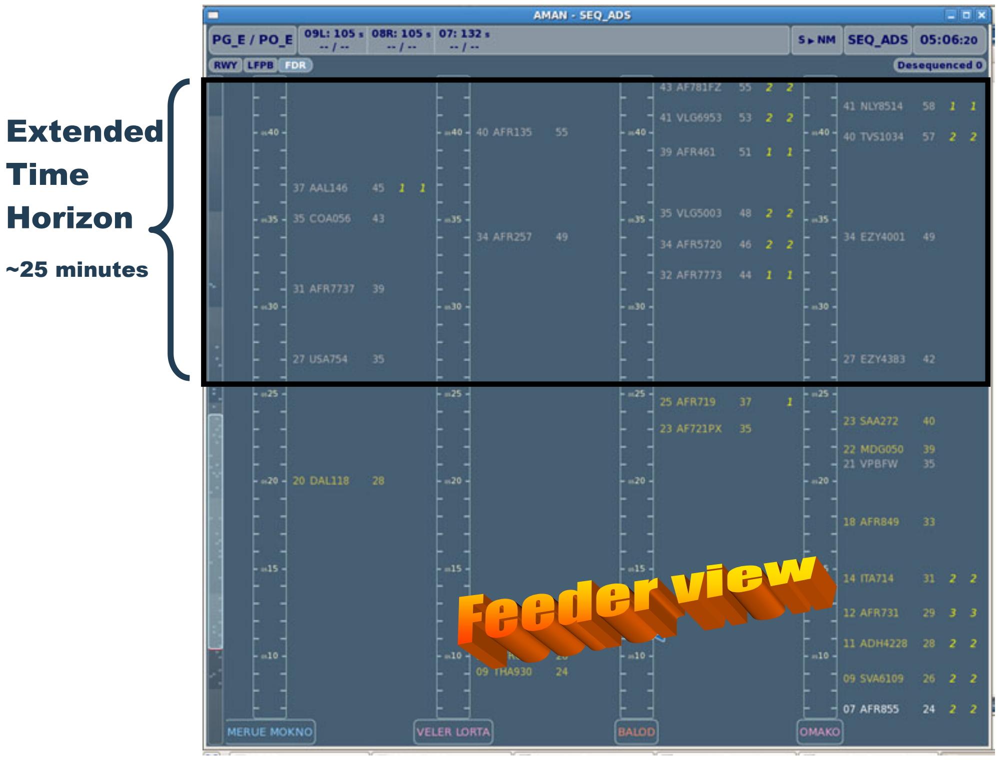


Figure 3-20. Extended AMAN Time Horizon (Feeder Fix View)

3.2.5 ATSA-ITP

The ITP procedure enables an aircraft to perform a climb or descent to a requested Flight Level through one intermediate Flight Level that is occupied by a 'reference aircraft', taking advantage of a distance-based ITP longitudinal separation minimum. The application does not change the core roles of flight crew and controllers. The ATSA-ITP application is defined for non-radar oceanic airspace where aircraft are flying along predefined tracks. The main objective of the ITP procedure is to improve the utilisation of the oceanic airspace by facilitating a higher rate of flight level changes, yielding better flight efficiency (e.g. fuel savings, avoiding turbulent flight levels).

There may be up to six different kinds of ITP manoeuvres depending on the initial configuration of the 'ITP aircraft' with respect to the 'reference aircraft' (i.e. a leading or a following 'reference aircraft', or both) and considering whether the 'ITP aircraft' desires to climb or descent.

3.2.5.1 ATSA-ITP Test-bed Implementation Model

Figure 3-21 is a high-level schematic of the principal ground and airborne modules of the ATSA-ITP test-bed and their interface to the SatCom emulator (a CPDLC communication link is assumed).

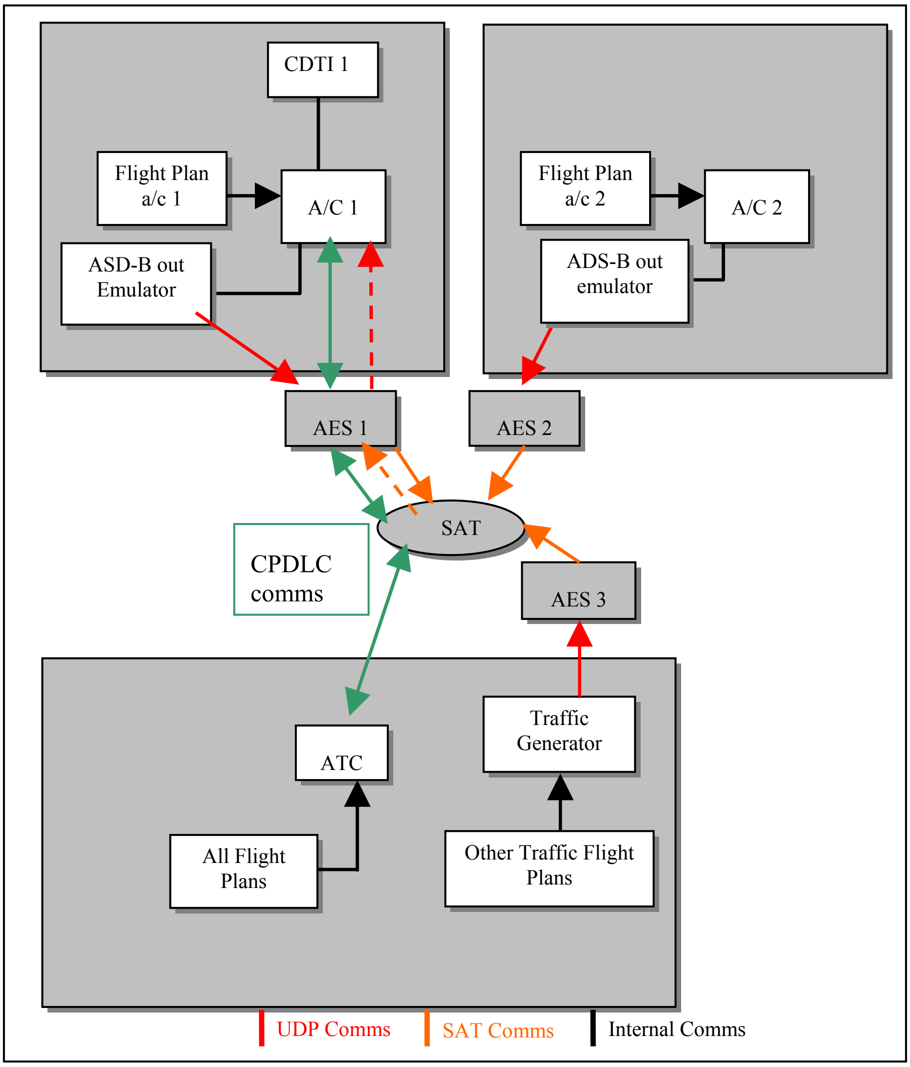


Figure 3-21. ATSA-ITP Implementation Model

Each aircraft module services ownship ADS-B transmit functionality via SatCom. This is facilitated through ADS-B service emulation. The aircraft module is primarily constructed as an installation of a COTS flight simulator. This installation provides the airframe dynamical model, the scenario environment and the platform for aircrew control inputs.

The interface to the AES utilises the UDP format based on the BSE protocols. An ADS-B Server Emulator is included in the model to emulate the creation of ADS-B data to the AES. An ADS-B (in) Server Emulator is included in the model to emulate dissemination of ADS-B (in) data to the CDTI and the FMS. On the aircraft side of both servers, the communication is in the form of TCP/IP connections, apart from communication to the CDTI where the communication medium is in UDP/IP format.

Calculation of the ITP parameters is performed within the FMS and displayed to the pilot.

The ATC HMI module is not connected to the THALES Gateway as the ATSA-ITP application is an airborne application. The aircraft trajectories shown on the HMI are generated by means of extrapolation of data derived from the aircraft flight plans. Communication between the ATCO and the aircrew is by means of CPDLC. Neither the ATC HMI, nor the CPDLC communication link are considered part of the ATSA-ITP surveillance infrastructure.

3.2.5.2 ATSA-ITP Test Harness

The ATSA-ITP application uses UDP protocols. Figure 3-22 shows a schematic of the ATSA-ITP test harness.

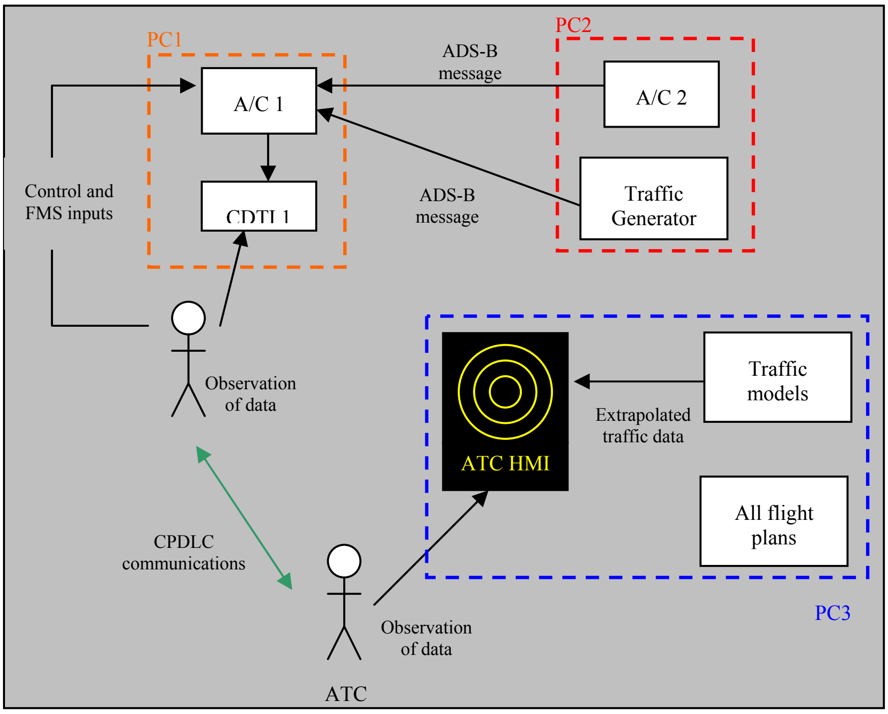


Figure 3-22. ATSA-ITP Test Harness

3.2.5.3 ATSA-ITP Validation Objectives

The main validation objective with regard to the ATSA-ITP application is to assess the safe operation of the ITP manoeuvre when implemented with ADS-B-like data transmission via SatCom.

3.2.5.4 ATSA-ITP Test Cases

The principal ATSA-ITP Use Cases are detailed in Table 14:

ATSA-ITP Use Cases				
Use Case	Following Climb	Following Descent	Leading Climb	Leading Descent
Use Case ID	ITP_1	ITP_2	ITP_3	ITP_4
Actors	A/C1, A/C2, Traffic, ATC	A/C1, A/C2, Traffic, ATC	A/C1, A/C2, Traffic, ATC	A/C1, A/C2, Traffic, ATC
Purpose	All ADS-B broadcasting through SatCom	All ADS-B broadcasting through SatCom	All ADS-B broadcasting through SatCom	All ADS-B broadcasting through SatCom
Overview	• This is a following climb with only one reference aircraft • A/C2 Broadcasts his position and other data through an ADS-B type message through SatCom. • The Third party Traffic is broadcast through SatCom • Communication between A/C1 and ATC via CDPLC	• This is a following descent with only one reference aircraft • A/C2 Broadcasts his position and other data through an ADS-B type message through SatCom. • The Third party Traffic is broadcast through SatCom • Communication between A/C1 and ATC via CDPLC	• This is a leading climb with only one reference aircraft • A/C2 Broadcasts his position and other data through an ADS-B type message through SatCom. • The Third party Traffic is broadcast through SatCom • Communication between A/C1 and ATC via CDPLC	• This is a leading descent with only one reference aircraft • A/C2 Broadcasts his position and other data through an ADS-B type message through SatCom. • The Third party Traffic is broadcast through SatCom • Communication between A/C1 and ATC via CDPLC

Table 14. ATSA-ITP Use Cases

Descriptions of the specific test cases, adopted for the ATSA-ITP Use Cases defined in Table 14, are presented in Table 15:

Test ID	Test Description
ITP_1.1 – ITP_1.4	Following climb ITP (1200ms delay on the SatCom simulator)
ITP_2.1 – ITP_2.4	Following descent ITP (1200ms delay on the SatCom simulator)
ITP_3.1 – ITP_3.4	Leading climb ITP (1200ms delay on the SatCom simulator)
ITP_4.1 – ITP_4.4	Leading descent (1200ms delay on the SatCom simulator)

Table 15. ATSA-ITP Test Cases

Due to the lack of availability of fouling facilities during the ATSA-ITP tests on the Thales Demonstrator, it was not possible to investigate the effect of SatCom degradation on ITP performance.

3.2.5.5 ATSA-ITP Test Results

This test is analysed using one metric:

- **ITP Distance:** The ATSA-ITP application is assessed only on the ITP Distance. This is a measure of the lateral separation (in NM) between the ITP Aircraft and the Reference Aircraft. The assessment takes the form of a review of the distance and ensuring that the variance in the separation during the test-run does not create a conflict scenario.

Table 16 highlights the principal statistical results from the ATSA-ITP test cases conducted on the Thales DVB-RCS SatCom Demonstrator Platform for a representative sample of scenarios from each of the ATSA-ITP Uses Cases.

ATSA-ITP Use Case	Following Climb		Following Descent		Leading Climb		Leading Descent	
	Max	Min	Max	Min	Max	Min	Max	Min
ITP Distance (NM)	39.162	38.397	28.756	27.680	30.067	29.070	27.501	26.541
	28.923	27.682	28.820	27.719	30.045	28.855	27.536	26.647
	28.646	27.809	29.047	27.709	30.222	29.135	27.427	26.533
	28.622	27.566	28.798	27.776	30.205	29.149	27.545	26.524

Table 16. ATSA-ITP Test Results

3.3 Simulator

3.3.1 SatCom Simulator Overview

SatCom Simulator (hereafter referred as SatCom Sim) system is composed by a group of four main components: (1)Satellite Link Emulator (SLE), (2)Broadcast Server (BS), (3)Control & Management, (4) Logging & Monitoring and Network Time Subsystem (NTS).

The main of the SatCom Sim set ups the SatCom's environment to receive and validate the main objectinew requirements of the following four ASAS applications under specific satellite link characteristics:

- ASPA-S&M (both using star and meshed topology, which could not be done using DVB-RCS),
- ADS-B-NRA,
- TIS-B/ATSAW and
- ATSA-ITP.

In order to achieve the application's results and reproduce the required satellite environment, the SatCom Sim emulates the main satellite characteristics that have impact on the application's operations: bandwidth/throughput limitations, packet losses and propagation delay, both in downlink and uplink channels. The above characteristics are configurable, in order to emulate different scenarios for each application. Additionally, it was also implemented a QoS mechanism in the SatCom Sim that processes packets with different priorities passing through the link, according to the applications maximum transit delay requirements. In order to guarantee SatCom Sim traffic feasibility and performance two main components were developed and implemented: the monitoring component, which is responsible for calculating and recording for each uplink and downlink as well as for the entire system, the bandwidth used, the packet lost ratio and the transit delay values. These calculations are made for a single monitoring period as soon as simulation starts; the logging component is responsible for all log activity data collected during one simulation: The status recorded for each log message are been classified as Info, Warnings, Errors and Alerts. The data is saved into a log files. Each of this file is configurable by user. As referred, the aim of these both components in SatCom Sim is to assess the SatCom Sim system performance currently.

The two other main components of SatCom Sim: SLE and BS are the core of the SatCom Sim system and are responsible to emulate the satellite link characteristics and the multicast and Unicats messages delivering.

3.3.2 SatCom Sim Test Bed

SatCom Sim Test Bed is divided in four main areas. For each area a set of test were developed and validated:

Communications: responsible for validating SatCom Sim behaviour regarding the receiving, sending and routing of each message received from the external applications (using both star and meshed topology);

Channel Characteristics: responsible for validating the bandwidth, packet loss rate and transit delay emulated and expected in all channels.

Logging: The test bed contains the validation of the log files: creation and writing as well as logging messages according each status.

Monitoring: the test bed is responsible for validate the correct creation and writing of monitoring files. Also validates the correct calculation of bandwidth, packet loss ratio and transit delay, for each channel and the entire system.

3.3.2.1 Resources and Tools

In order to develop and implement the required test bed, the following tools/resources have been used:

AES stubs: it is responsible for sending messages to SatCom Sim and receives its responses. These stubs are prepared to send any number of messages with the required size and content.

Configuration files: in order to run each test it was used a different configuration SatCom Sim file with the set required parameters.

After run the stubs according the new parameters in configuration file, the results of each test bed were evaluated and validated. The final results are included in D3.1. These results are either outputs of SatCom Sim, or content of files (e.g. log or monitoring files).

3.3.3 SatCom Simulator integration with ASAS applications

The SatCom Simulator platform is located in Atos Origin premises in Barcelona. The SatCom Simulator has been integrated with three (ASPA-S&M, ASPA-ITP, ADS-B-NRA) of the four ASAS applications and with the TIS-B scenario. ADS-B-ADD has been excluded from this integration due to the difficulties of moving and install this application to Barcelona. This integration has been done in two different phases, the first one in October 2007 and the second in March 2008.

The integration done with the SatCom Simulator allowed validating the behaviour of the applications under circumstances are not possible to reproduce or it is more complex under the DVB-RCS platform. For instance: meshed topology, bandwidth limitations, big error rates, customized delays, service priorization, etc. These simulations let us acquire a better knowledge of how satellite channel characteristics influence in the applications behaviour, and what are the limits under the application can operate.

3.3.4 Results

All tests implemented demonstrated that SatCom Sim has the expected behaviour in all main areas, reproducing or emulating each expected characteristics of the satellite link with the possibility of using star or meshed topology. Additionally it was also proved that the SatCom Sim's behaviour was not affected by application's requirements, proving that SatCom Sim is a tool prepared to validate other ASAS applications;

3.4 *Economical Analysis*

For development a perfect economical analysis of the viability of the use of SATCOM in Surveillance Applications it would be necessary to study SATCOM technology in a global sense, that is, if we think in the satellite as a mean of benefit for all stakeholders and applications, we will realize that the benefit could be higher and the cost could be lower (obviously, this could be a fact if the satellite is used by more agents)

The SATCOM technology makes sense when the scenario is global, that is, most of the time the same service offered by the satellites could be used by a lot of stakeholders and Applications (not only for the Applications described in this study)

The ASPASIA project analysed some specific applications, so the ASPASIA Cost Benefit Assessment analysed some scenarios for the implementation of these GS/AS Application and TIS-B service referred to an increased surveillance maintaining the current and planning service in terms of security, safety, capacity, etc (baseline).

A main assumptions was assumed: SATCOM service is provided by a Communication Service Provider

The CBA study intended to develop an analysis of costs and benefits in qualitative terms, and quantitative when it was possible, by the implementations, development and operation of the ASPASIA system

A quantitative economic study for the ADS-B-NRA was development. The economic results were investigated for the ADS-B-NRA application in a chosen period.

The main costs considered in the economical model are in the tables below:

- Airborne costs:

	High	Base	Low	
Airborne Terminal (Narrowband System)	165	82,5	15	K€ per terminal

Table 17. ADS-B-NRA Airborne costs

- SATCOM service cost

	High	Base	Low		Source
ANSP charges	60	50	40	**K€ per year/ANSP**	Inmarsat BGAN & Swiftbroadband
Aircraft: Flat fees per unit	750	450	180	**€ per year/aircraft**	CPDLC

Table 18. ADS-B-NRA SATCOM service cost

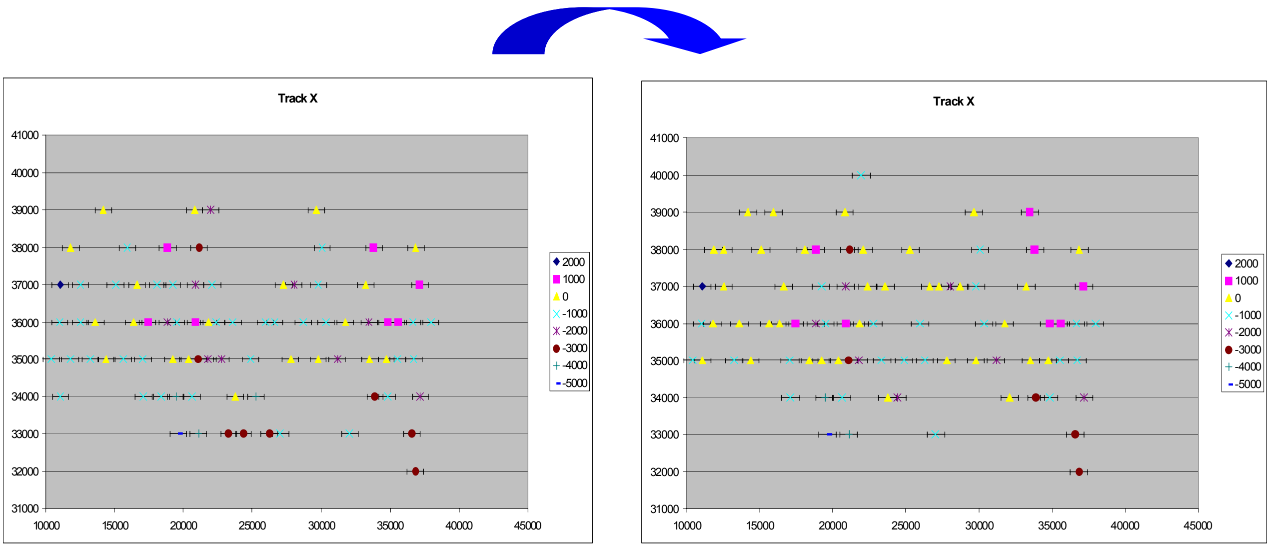
The main benefit associated with NRA in Oceanic Airspace is the potential of reducing separations to allow more efficient operations to the aircraft: As consequence there is a fuel burn savings. NRA would allow more efficient vertical profiles to the aircraft providing the Air Traffic Controllers the capability of issuing clearances to the aircraft to make step climbs.

Only 24% of the aircraft are flying at FMS recommended Altitude at track exit (yellow symbols), making the other 76 % flying at other than the recommended flight level.

Aircrafts flying at non-optimum altitudes are reduced from 76% to 57% allowing for an 18% increase in the number of aircraft flying at optimum profile. Trying to be conservative we will use in our economical study a lower improvement value of 12% of flights improving their flight profiles in an ATSA- NRA environment

Using ADS surveillance, there is a difference between optimum altitude suggested by aircraft FMS and altitude attained at the track exit using ADS surveillance, thus allowing more climb opportunities than in a conventional control scenario 43% of the aircraft would attain optimum flight level at track exit.

ADS applied



Current situation
24% aircraft flying at FMS recommended level

Using ADS surveillance
43% aircraft flying at FMS recommended level

Figure 3-23: FMS recommended level when ADS applied

In order to monetize the benefits previously explained, it was develop the calculation:

- Economic benefit: Fuel savings

Year	% Crec	Annual fligths	12% improve Optimal Flights	Fuel Savings (lb)	Fuel Savings (kg)	Fuel Savings (gal)	Annual savings (USD)	Annual saving (Euros)
2008		466.332	55.960	100.207.285	45.093.278	14.700.409	55.420.541	36.947.027
2009	0,029	479.856	57.583	103.113.297	46.400.984	15.126.721	57.027.737	38.018.491
2010	0,026	492.332	59.080	105.794.242	47.607.409	15.520.015	58.510.458	39.006.972
2011	0,027	505.625	60.675	108.650.687	48.892.809	15.939.056	60.090.240	40.060.160
2012	0,04	525.850	63.102	112.996.715	50.848.522	16.576.618	62.493.850	41.662.567
2013	0,027	540.048	64.806	116.047.626	52.221.432	17.024.187	64.181.184	42.787.456
2014	0,026	554.089	66.491	119.064.864	53.579.189	17.466.816	65.849.895	43.899.930
2015	0,034	572.928	68.751	123.113.069	55.400.881	18.060.687	68.088.791	45.392.527
2016	0,034	592.408	71.089	127.298.914	57.284.511	18.674.751	70.403.810	46.935.873
2017	0,034	612.549	73.506	131.627.077	59.232.185	19.309.692	72.797.540	48.531.693
2018	0,034	633.376	76.005	136.102.397	61.246.079	19.966.222	75.272.656	50.181.771
2019	0,034	654.911	78.589	140.729.879	63.328.446	20.645.073	77.831.926	51.887.951
2020	0,034	677.178	81.261	145.514.695	65.481.613	21.347.006	80.478.212	53.652.141
2021	0,034	700.202	84.024	150.462.195	67.707.988	22.072.804	83.214.471	55.476.314
2022	0,034	724.009	86.881	155.577.909	70.010.059	22.823.279	86.043.763	57.362.509
2023	0,034	748.625	89.835	160.867.558	72.390.401	23.599.271	88.969.251	59.312.834
2024	0,034	774.078	92.889	166.337.055	74.851.675	24.401.646	91.994.205	61.329.470
2025	0,034	800.397	96.048	171.992.515	77.396.632	25.231.302	95.122.008	63.414.672
2026	0,034	827.611	99.313	177.840.260	80.028.117	26.089.166	98.356.157	65.570.771
2027	0,034	855.749	102.690	183.886.829	82.749.073	26.976.198	101.700.266	67.800.177
2028	0,034	884.845	106.181	190.138.981	85.562.542	27.893.389	105.158.075	70.105.383
2029	0,034	914.929	109.792	196.603.707	88.471.668	28.841.764	108.733.449	72.488.966
T Fligths		14.537.926	1.744.551	3.123.967.757	1.405.785.491	458.286.070	1.727.738.484	1.151.825.656
Average per flight				215	97	32	119	79

Figure 3-24: Fuel savings summary

As we can see in the table above, the saving per flight is 79 euros.

Same important assumptions were assumed:

- Investment cost (Airlines equipment) starts in 2009 and end in 2011.
- Operational costs start in 2010.
- Benefits (Airlines in the Optimum level) start in 2010, when the 33% of the fleet has been equipped.
- Benefits increase because the traffic demand grows

These cash flows below indicated were obtained.

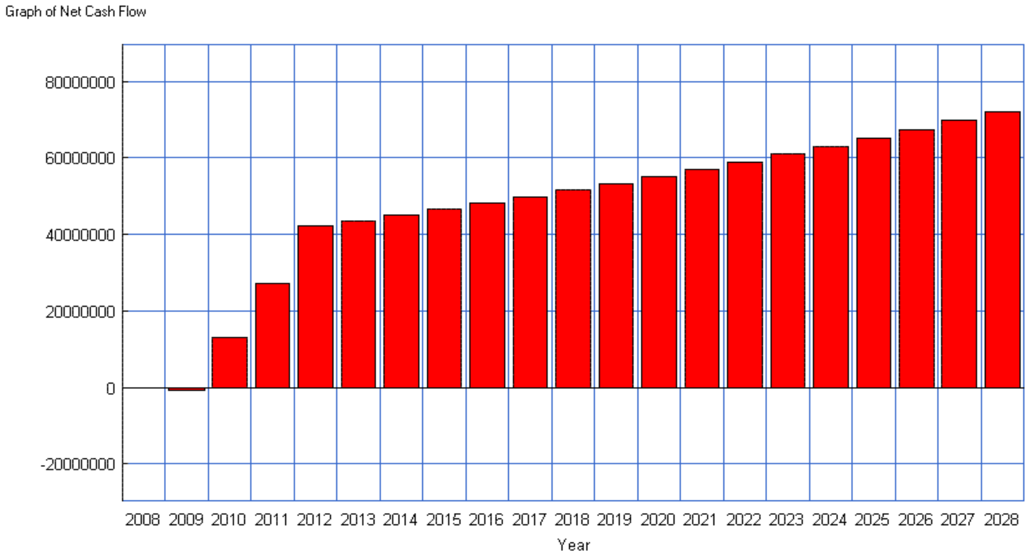


Figure 3-25. Cash Flows

As it can see, taking into account the cash flows, it seems that the use of SATCOM for ADS-B-NRA is in principle positive due to fuel savings.

It was development a sensitive analysis through the Tornado Diagram:

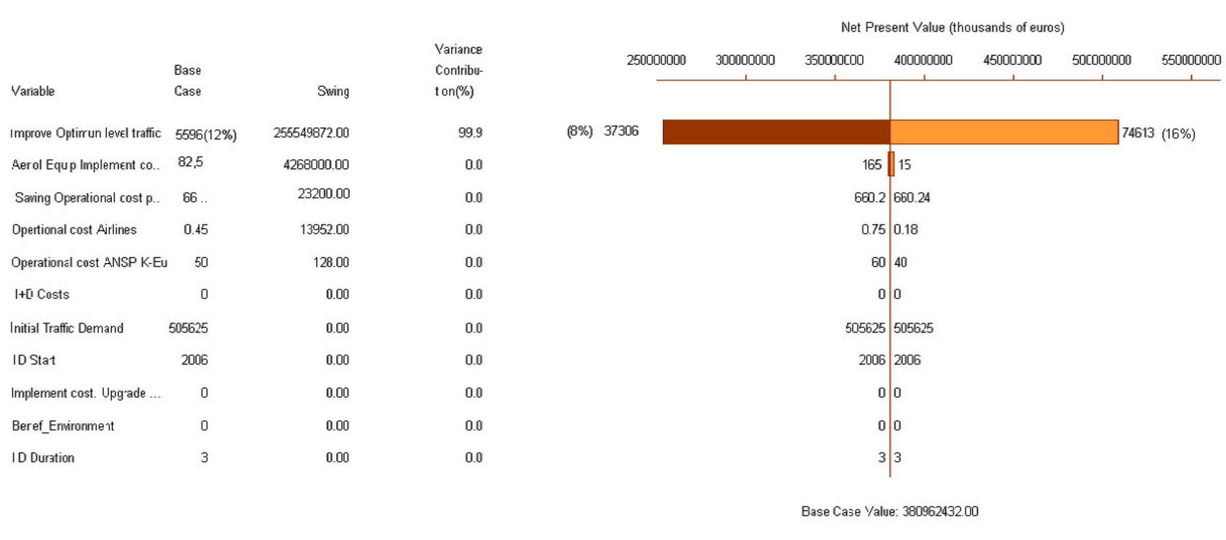


Figure 3-26. Tornado Diagram

The Tornado Diagram shows the change in the output (NPV) when a variable changes from the high to the low value while the other variables are kept constant. It shows too the variable which has the most influence: The improvement of Optimum Level Traffic

In spite of the positive results, it necessary takes into account that further analysis about Safety and other factors is mandatory before implementation.

NPV obtained in this ADS-B-NRA study was a reference which determined that the use of the SATCOM Technology is useful in the scenario described. The most conservative assumptions have been selected, thus it could be said that the use of the SATCOM is profitable for this application and for other applications which benefits of the Satellite link for other uses, other applications or Communications links, etc… provided by the same Satellite.

3.5 Contributions to SESAR

The alignment with SESAR has been considered an essential requirement for the development of the ASPASIA project.

Within the SESAR definition of the future ATM target concept (D3), ADS-B plays a key role as an enabler for future air-air surveillance. Nevertheless, with regard to future operational requirements, SESAR foresees a potential necessary improvement of air-air data capacity, integrity, security and availability, which could imply the complement of current technologies with additional data links.

ASPASIA Project has paved the way for the consideration of SatCom as a potential complementary technology for surveillance applications. Thus, offering the innovative approach of using a satellite technology for aeronautical surveillance activities, ASPASIA is in line with the future operational needs recommended by SESAR.

4 Analysis of Results

This chapter illustrates the results of tests performed on the Use cases detailed on chapter 2.3.2.

It is reminded that five test cases have been experimented in the frame of ASPASIA:

- Use Case N°1 **ASPA-S&M**
- Use Case N°2 **ADS-B-NRA**
- Use Case N°3 **TIS-B/ATSAW**
- Use Case N°4 **ADS-B-ADD MAESTRO**
- Use Case N°5 **ATSA-ITP**

For more details regarding the Use cases test results below, please refer to [RD3].

4.1 Use Case N°1 – ASPA-S&M

Descriptions of the specific test cases, adopted for the ASPA-S&M Use Case are presented below.

Test 1 – Merge, Remain

Test AT1: Merge in level flight at merge waypoint, target in cruise with no turns. End the test after 5 minutes in Remain mode. Initial spacing is too large. The wind speed is zero.

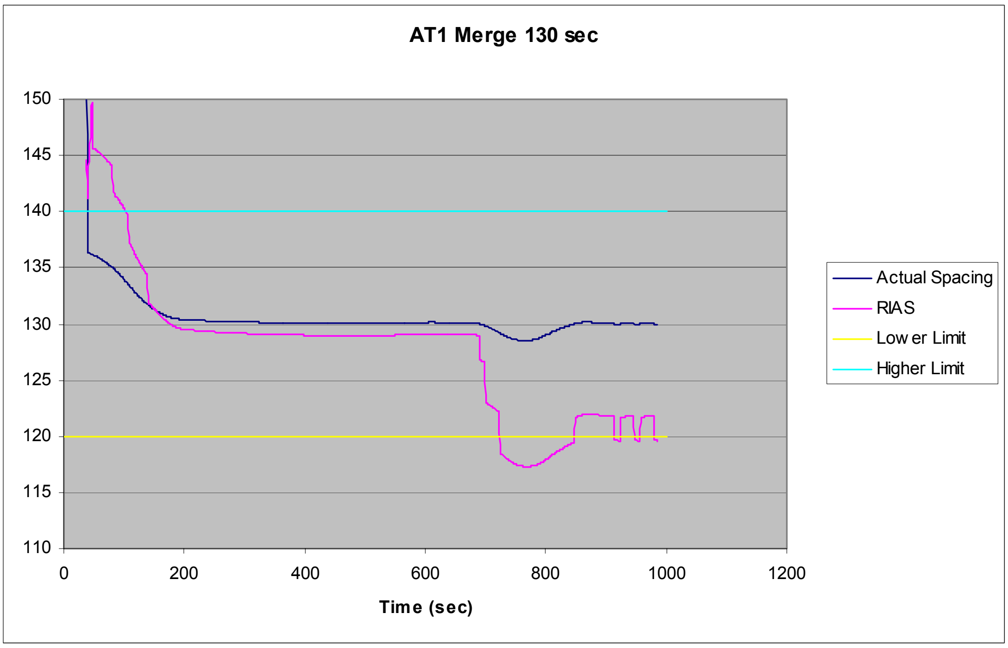


Figure 4-1. Test Results for AT1 – Merge, Remain

Test 2 – Vector, Remain, Descend

Test AT2: Vector, Merge and Remain in level flight at merge waypoint, target in cruise with no turns, go into Remain and then descend in Remain. End the test at waypoint GWC. Initial spacing is too small. The wind speed is zero.

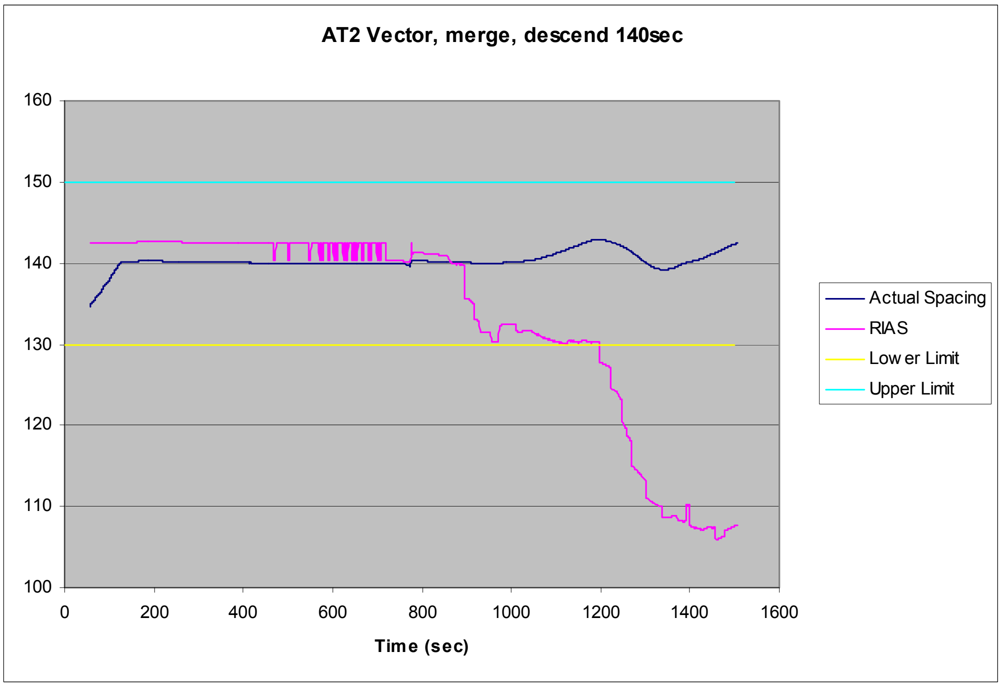


Figure 4-2. Test Results for AT2 – Vector, Merge, Remain, Remain in Descent

The use cases described above were executed several times by using different satellite topologies as well as link configurations (delay, noise, ..) , and after that no differences were observed in the behaviour of the ASPA-S&M application compared to the use case without satellite.

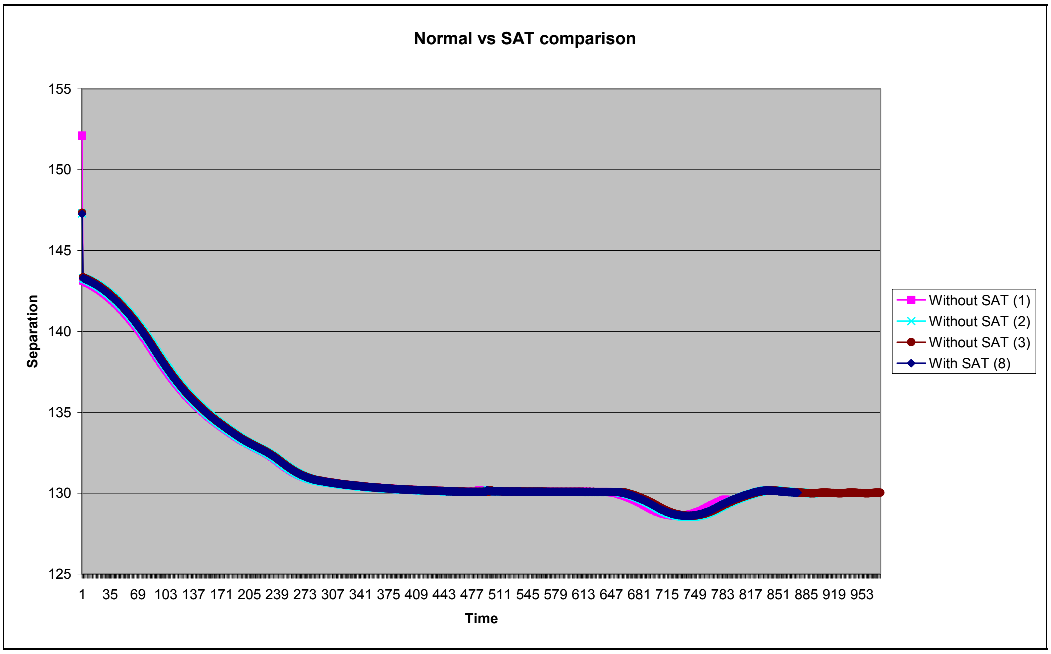


Figure 4-3. ASPA-S&M with and without SAT comparison

4.2 Use Case N°2 - ADS-B-NRA

Descriptions of the specific test cases, adopted for the ADS-B-NRA Use Case are presented below

Test ID	UoG Test No	Test Description	Test Results	ADS-B from AC1	ADS-B from AC2
NRA_4.1	101	Inclusion of a noise generator onto the SATCOM simulator to simulate atmospheric or other fouling of the transmission path. A 270ms delay is included to simulate the transmission time to, and from, the Satellite	Total messages sent	1115	1162
			No. of errors in data	0	0
			No. of missing messages	88	137
			% of missing messages	7.89%	11.79%
			Average message time (s)	0.340	0.337
			Maximum message time (s)	4.167	4.021
			Minimum message time (s)	0.284	0.287
NRA_4.2	103	Inclusion of congestion onto the terminal of the SATCOM simulator to simulate large volumes of network traffic. A 270ms delay is included to simulate the transmission time to, and from, the Satellite	Total messages sent	1116	1114
			No. of errors in data	0	0
			No. of missing messages	85	40
			% of missing messages	7.62%	3.59%
			Average message time (s)	0.321	0.337
			Maximum message time (s)	3.491	3.696
			Minimum message time (s)	0.286	0.289

<table>
<tr>
<td>NRA_4.3</td>
<td>105</td>
<td>Baseline test with no noise on the SATCOM simulator and no congestion on the terminals. A 270ms delay is included to simulate the transmission time to, and from, the Satellite</td>
<td>
<table>
<tr><th></th><th>ADS-B from AC1</th><th>ADS-B from AC2</th></tr>
<tr><td>Total messages sent</td><td>1274</td><td>1274</td></tr>
<tr><td>No. of errors in data</td><td>0</td><td>0</td></tr>
<tr><td>No. of missing messages</td><td>0</td><td>0</td></tr>
<tr><td>% of missing messages</td><td>0%</td><td>0%</td></tr>
<tr><td>Average message time (s)</td><td>0.313</td><td>0.330</td></tr>
<tr><td>Maximum message time (s)</td><td>0.344</td><td>0.358</td></tr>
<tr><td>Minimum message time (s)</td><td>0.283</td><td>0.306</td></tr>
</table>
</td>
</tr>
</table>

Table 19. ADS-B-NRA Test Cases

4.3 Use Case N°3 - TIS-B/ATSAW

Descriptions of the specific test cases, adopted for the TIS-B Use Case are:

Test ID	UoG Test No	Test Description	Test results
TISB_4.1	102	Inclusion of a noise generator onto the SATCOM simulator to simulate atmospheric or other fouling to the transmission path. A 270ms delay is included to simulate the transmission time to, and from, the Satellite	

	ADS-B from AC1	ADS-B from AC2	TIS-B to AC1	TIS-B to AC2
Total messages sent	640	640	855	855
No. of errors in data	0	0	0	0
No. of missing messages	148	64	136	104
% of missing messages	23.13%	10.00%	15.91%	12.16%
Average message time (s)	0.347	0.366	0.311	0.305
Maximum message time (s)	3.608	4.149	0.346	0.331
Minimum message time (s)	0.285	0.299	0.301	0.289

Test ID	UoG Test No	Test Description	Test results
TISB_4.2	104	Inclusion of congestion onto the terminal of the SATCOM simulator to simulate large quantities of network traffic. A 270ms delay is included to simulate the transmission time to, and from, the Satellite	

	ADS-B from AC1	ADS-B from AC2	TIS-B to AC1	TIS-B to AC2
Total messages sent	674	679	683	683
No. of errors in data	0	0	0	0
No. of missing messages	0	0	0	0
% of missing messages	0%	0%	0%	0%
Average message time (s)	0.315	0.327	0.307	0.311
Maximum message time (s)	0.346	0.356	0.329	0.333
Minimum message time (s)	0.295	0.296	0.293	0.296

Test ID	UoG Test No	Test Description	Test results
TISB_4.3	106	Baseline test with no noise on the SATCOM simulator and no congestion on the terminals. A 270ms delay is included to simulate the transmission time to, and from, the Satellite	

	ADS-B from AC1	ADS-B from AC2	TIS-B to AC1	TIS-B to AC2
Total messages sent	619		623	623
No. of errors in data	0	0	0	0
No. of missing messages	0	0	0	0
% of missing messages	0%	0%	0%	0%
Average message time (s)	0.312	0.327	0.308	0.308
Maximum message time (s)	0.338	0.355	0.318	0.324
Minimum message time (s)	0.291	0.301	0.297	0.289

Table 20. TIS-B Test Cases

4.4 Use Case N°4 - ADS-B-ADD MAESTRO

The VDL/SatCom comparative test cases adopted for the ADS-B-ADD Application consisted in running two parallel simulation sessions with the same air traffic scenario with the following differences:

<table>
<tr><th>Test ID</th><th>Test Description</th></tr>
<tr><td>VDL-like Test Case</td><td>Generation of Cat 30 messages only (i.e, activation of Ground TG only) and limitation of the coverage to 150 -200 NM to simulate radar coverage limitation.
In this traditional case, MAESTRO calculates for a given aircraft, the estimated time of arrival, the schedule time of arrival - and then the sequence of arriving traffic – based on radar tracks provided in Cat 30 messages.</td></tr>
<tr><td colspan="2">The objective of the Test is to serve as Baseline Reference for further comparison with the SATCOM Test Case.
The Baseline Reference situation is the current operational situation where MAESTRO is fed by traditional Flight Plan Data and corresponding radar tracks - without using ADS-B-ADD.</td></tr>
<tr><td>SatCom Test Case</td><td>Generation of both Cat 30 and Cat 21 messages (activation of both Air and ground TGs), assuming that 100% of the active flights are ADS equipped and no limitation of the coverage.
Use Cases ADD_1, ADD_2 and ADD_3 are successively used in the course of the test case.
In this case (i.e., ADD_3) MAESTRO calculates, for a given aircraft, the estimated time of arrival, the schedule time of arrival - and then the sequence of arriving traffic – based on aircraft derived data provided in Cat 21 messages or on radar tracks provided in Cat 30 messages, given preference to Cat 21 messages according to the following algorithm:
• If ETO is present:
    - Directly use down-linked ETO, ignore Cat 30 data
• Otherwise:
    - If Cat 30:
        i. Ignore Cat 21
        ii. Calculate ETA based on input by Cat 30
    - Otherwise
        i. Calculate ETA based on data input by Cat 21</td></tr>
<tr><td colspan="2">See results next page</td></tr>
</table>

Test ID	Test Description

The graph represents the number of aircraft that have lost 1, 2 or 3 places (abscise -1, -2 or -3) or gained 1, 2 or 3 places (abscise 1, 2 or 3) in the arrival sequence compare to the actual arrival sequence. Abscise 0 represents the number of aircraft that have their sequence order unchanged compared to the actual arrival sequence. This graph concerns the sequence of arrival at the Feeder Fix. It shows that, at the sequence of arrival at the Feeder Fix is more accurate when computed with ADS data than without.

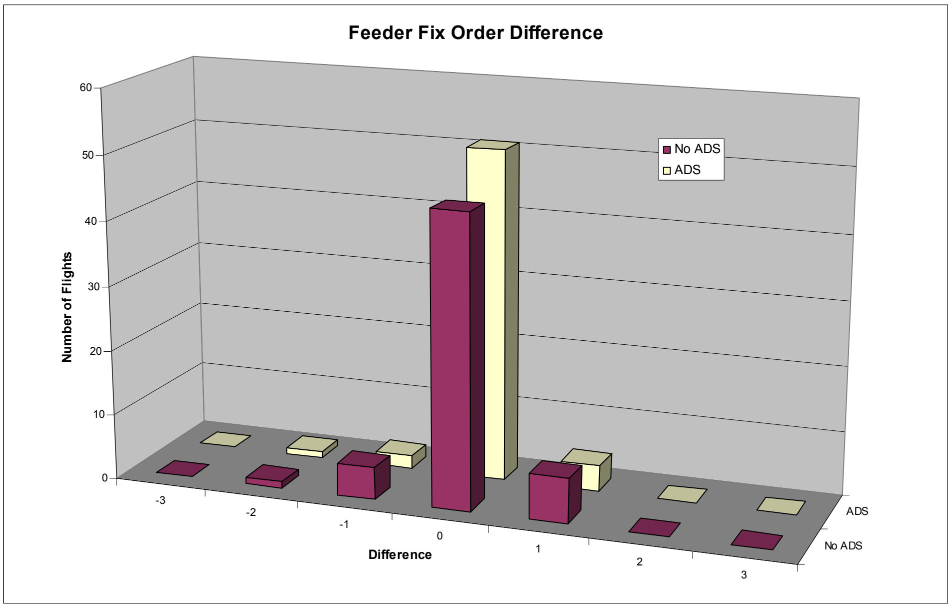


Figure 4-4. Feeder Fix Order Difference

The graph represents the number of aircraft that have lost 1, 2 or 3 places (abscise -1, -2 or -3) or gained 1, 2 or 3 places (abscise 1, 2 or 3) in the arrival sequence compare to the actual arrival sequence. Abscise 0 represents the number of aircraft that have their sequence order unchanged compared to the actual arrival sequence.

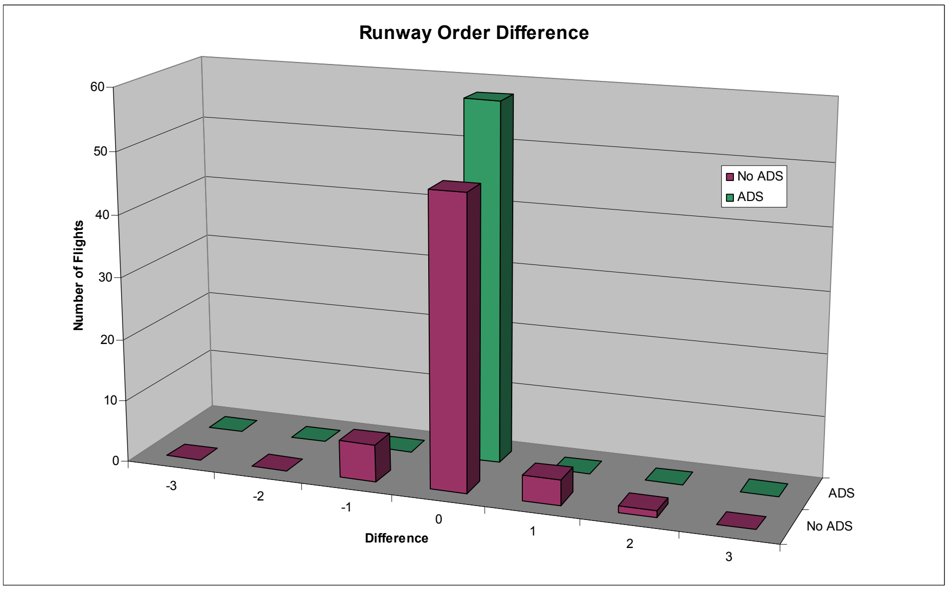


Figure 4-5. Runway Threshold Order Difference

4.5 Use Case N°5 - ATSA-ITP

Descriptions of the specific test cases, adopted for the ATSA-ITP Use Case are presented below

Test ID	UoG Test No	Test Description	Test Results		
				Maximum	Minimum
ITP_1.1	101	Following climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	39.162	38.397
ITP_1.2	102	Following climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.923	27.682
ITP_1.3	103	Following climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.646	27.809
ITP_1.4	104	Following climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.622	27.566
ITP_2.1	201	Following descent ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.756	27.680
ITP_2.2	202	Following descent ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.820	27.719
ITP_2.3	203	Following descent ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	29.047	27.709
ITP_2.4	204	Following descent ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	28.798	27.776
ITP_3.1	301	Leading climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	30.067	29.070
ITP_3.2	302	Leading climb ITP (1200ms delay on the SatCom simulator)	ITP Distance (NM)	30.045	28.855

<table>
<tr><th>Test ID</th><th>UoG Test No</th><th>Test Description</th><th colspan="3">Test Results</th></tr>
<tr><td rowspan="2">ITP_3.3</td><td rowspan="2">303</td><td rowspan="2">Leading climb ITP (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>30.222</td><td>29.135</td></tr>
<tr><td rowspan="2">ITP_3.4</td><td rowspan="2">304</td><td rowspan="2">Leading climb ITP (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>30.205</td><td>29.149</td></tr>
<tr><td rowspan="2">ITP_4.1</td><td rowspan="2">401</td><td rowspan="2">Leading descent (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>27.501</td><td>26.541</td></tr>
<tr><td rowspan="2">ITP_4.2</td><td rowspan="2">402</td><td rowspan="2">Leading descent (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>27.536</td><td>26.647</td></tr>
<tr><td rowspan="2">ITP_4.3</td><td rowspan="2">403</td><td rowspan="2">Leading descent (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>27.427</td><td>26.533</td></tr>
<tr><td rowspan="2">ITP_4.4</td><td rowspan="2">404</td><td rowspan="2">Leading descent (1200ms delay on the SatCom simulator)</td><td></td><td>Maximum</td><td>Minimum</td></tr>
<tr><td>ITP Distance (NM)</td><td>27.545</td><td>26.524</td></tr>
</table>

Table 21. ATSA-ITP Test Cases

5 Future

5.1 Future of ASPASIA

It is obvious that the ASPASIA type SATCOM systems will ease to reach the SESAR performance target as:

- **Performance Target "Capacity" – Traffic will grow**

  As demonstrated in the Use Cases N°3, 4 and 5, thanks to SATCOM and the wide area coverage, the traffic will be addressed and managed more globally (wide horizon).

- **Performance Target "Safety" - Proactively manage safety with the goal of no ATM related accidents**

  As demonstrated in the Use Cases N°1 and 2, thanks to SATCOM, the communication links will be added or duplicated allowing to contribute to a higher level of Safety.

- **Performance Target "Environment" - ATM will deliver its maximum contribution to the environment**

  As demonstrated in the Use Cases N°3, 4 and 5, thanks to SATCOM and the ability to optimise the route, the traffic will be managed more globally according to best flight pass, this contributing to environment protection.

5.2 Future Research

Informal discussions with ANSP's responsible for oceanic airspace (particularly the North Atlantic) indicate a strong interest in the use of SatCom as an integral element of a ground surveillance infrastructure. A ground surveillance infrastructure of this kind is anticipated to facilitate new opportunities to initiate flight-level changes in scenarios outside the scope of current RFG defined ASAS Package 1 applications. Reduced minimum separation requirements resulting from enhanced ATC surveillance are expected to increase the frequency of such flight-level change opportunities with a consequential improvement in flight efficiency and, possibly, capacity in oceanic airspace. To this end, future research activity should be directed to establishing the best use of enhanced oceanic ground surveillance resulting from the global coverage of SatCom both as a surveillance data transmission medium and as a pilot/ATCO communication medium.

5.3 Future of ASPASIA Results

Through the different GS/AS applications analysis and the test-beds results, ASPASIA has made way for a more in-depth study of the satellite datalink characteristics and performance, suitable for the provision of ADS-B and TIS-B services.

This potential future study could be used within ICAO specific panels as a contribution to the development of international standards, with regard to the integration of new satellite systems in the aeronautical infrastructure.

6 Conclusions

The main ASPASIA objective, the investigation of new advanced Satellite Communications technology as complementary ADS-B and TIS-B data link in the provision of surveillance applications, has been developed by

- **validating** SatCom requirements for surveillance applications, and
- assessing the **benefits** of SatCom systems for surveillance applications.

In terms of SatCom validation, all the tests and analysis have clearly showed that SatCom is a valid data transmission medium for ASAS Package 1 ground and airborne surveillance applications. However, the SatCom technology makes sense when the scenario is global, that is, most of the time the same service offered by the satellites could be used by a lot of stakeholders and applications.

The framework in which ASPASIA needs to be considered is the one defined by the International Civil Aviation Organisation (ICAO). The global philosophy is to insure that aircraft can safely operate on a worldwide basis. Different systems can be deployed in different regions of the world (because of different calendars, or different local situations), but global interoperability must be maintained.

In terms of assessing SatCom benefits, and in the particular case of the terminal area, the Arrival Manager (AMAN) is one of the tools that may benefit from SatCom transponded Air Derived Data (ADD) applications. As aircraft approach terminal areas from airspace outside the surveillance zone of the associated TMA Radar, the SatCom ADS-B message would be available for application by the TMA Air Traffic Control AMAN. With a greater time-horizon, the AMAN could have an enhanced capability to develop arrival sequences that avoid airborne holding.

However, the constraints imposed by the current RFG definitions of the selected applications (namely, ADS-B-NRA, TIS-B/ATSAW and ATSA-ITP) limit the scope of SatCom to provide clear benefits over existing ADS-B technologies such as 1090ES. In fact, the current RFG definitions are very much aligned with the capabilities of existing ADS-B technologies.

With this in mind, it would seem appropriate to focus on new applications (for example, in oceanic airspace) in which SatCom offers enhanced ground surveillance opportunities in the current procedural ATC environment. The advantages of the increased range performance may have benefits for the tactical management of air traffic manoeuvring from Radar controlled separation towards procedural separation airspace. The particular feature of this application is the capability of transferring ADS Radar-like data across more than one Radar controlled area.

The Net Present Value (NPV) obtained in the ADS-B-NRA study is a reference which determines that the use of the SatCom technology is useful in this scenario, and shows that benefits are very high because of the increase of the fuel prices and the great traffic demand expected. The most conservative assumptions have been selected, thus it could be said that the use of the SatCom is profitable for this application and for other applications which benefits of the Satellite link for other uses, other applications or Communications links, etc… provided by the same Satellite.