Project no. : 037164

SINBAD

Safety Improved with a New concept by Better Awareness on airport approach Domain

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Final Report

FOR

SINBAD

Safety Improved with a New concept by Better Awareness on airport approach Domain

CONTRACT N° TEN07/FP6AE/S07.69019/037164

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SINBAD
Safety Improved with a New concept by Better Awareness on airport approach Domain

DOCUMENT TITLE:

Final Report

DOCUMENT CONTENT & PURPOSE:

The purpose of this document is to describe the execution of the SINBAD project. It includes a summary description of project objectives, contractors involved, work performed and end results, elaborating on the degree to which the objectives were reached. In particular it provides a description of the implemented system as well as the trials campaigns that were run. It briefly describes the methodologies and approaches employed and relate the achievements of the project to the state-of-the-art. It also explains the impact of the project on its industry or research sector. In the following chapter the complete list of the final documents produced in the project course is provided. These documents are available for downloading on SINBAD website sinbad.edufly.net.

INTERNAL APPROVALS

REVISION: Final issue – f2 01/03/2012	*Signature*	*Date*
WRITTEN BY: Fabrice Orlandi		01/03/2012
APPROVED BY: Sébastien Faivre		09/03/2012

PROGRAM APPROVALS

THALES PROGRAM MANAGER: Fabrice Orlandi		01/03/2012

CHANGES

Rev.	Date	Ecp n°	Description	Responsible
Draft issue– d0	01/12/2010	-	First issue.	F. ORLANDI
Final issue – f1	14/11/2011	-	Final issue	F. ORLANDI
Final issue – f2	01/03/2012	-	Document modified according to “SINBAD, Document D6.2. Final Report, Final Issue- f1, 14.11.2011” reading sheet from Dr. Helmut Schröter.	F. ORLANDI

EXECUTIVE SUMMARY

Project background

The SINBAD project aims to perform the proof of application of a new concept, intended to improve aircraft safety and security in the Control Zone (CTR). Collision avoidance is currently ensured jointly by the air traffic controllers and pilots supported by the Air Traffic Management (ATM) system (people, procedures and equipment) and the Airborne Collision Avoidance System. Both systems actually are ineffective against the risk of accidental or hostile collision by non-cooperative small or low flying aircraft. The main targets of SINBAD to overcome these limitations are:

- to improve the capability of the ATM system to monitor such non-cooperative aircraft, using a breakthrough low cost sensor technology, the Multi Static Primary Surveillance Radar (MSPSR) in its passive (no transmission of energy) version,
- to support controllers by providing them with an Active Hazard Assessment (AHA) capability, to alert them to impending airspace infringements by Non-Cooperative Targets (NCTs) and allowing them in case of a security threat to quickly alert the appropriate authorities and if needed the relevant airliners.

Document objective

This report presents the final results of all the aspects of the SINBAD project. A large part is given to technical results as the other project deliverables on these subjects are confidential to the consortium. However project performances and management are also provided in an appendix.

Main objectives and results achieved by the SINBAD project

The scientific objectives and achievements of SINBAD were:

- the development and test in operational condition of a passive MSPSR system, of the AHA software component and of a test bed that permitted the full system connection to a dedicated ATM tool the EUROCAT-E,
- the assessment of the passive MSPSR performances in detection and localization of non-cooperative small and/or low flying aircraft,
- the assessment of AHA's performances as a verification and validation platform for safety nets functions and services to controllers.

The project also allowed:

- to refine the operational concept and system requirements,
- to develop passive MSPSR new system of sensors and AHA new algorithms, and implement them into a real-time test bed,
- to validate the concept through live trials at Brno airports in the Czech Republic,
- to assess the benefits in terms of safety, security and business efficiency, according to the Eurocontrol-Operational Concept Validation Methodology.

SINBAD's tests campaigns

SINBAD system was composed of one EUROCAT-C test-bed connected to the local ATC infrastructure of Brno airport, AHA functions implemented in two PCs, and the passive MSPSR system. This last item was deployed in the countryside for its 4 receivers systems, while the central unit was also at the airport.
Two main tests campaigns were conducted at Brno airport. The first one identified several design problems in the sensor, as expected for a research project, and the second one enables the verification of the system performances. As such within the 36-month of this project while the consortium was able to fully test the system in Brno, through 2 tests campaigns, it was not possible to move to Frankfurt as initially planned.

The pictures below show (from left to right): a microwave data-link antenna, two passive MSPSR antennas, two receiver boxes and the system installation at the airport:

With these test campaigns SINBAD's sensor was evaluated, in real time, in terms of sensitivity, covered zone, and accuracy on opportunity aircrafts and dedicated flight (small aircraft with RCS down to ~1 m²):

Sensitivity and Pod	Validated in the 0 to 5.000 ft. range in altitude for aircraft of 1 to 2 m² RCS.
Horizontal accuracy	In the order of 40 m, i.e. 2 times better than standard PSR.
Vertical accuracy	Non-uniform, value increase rapidly when altitude decrease, typically at 200 m for an altitude of 400 m.

With an elementary accuracy similar or even better than state of the art PSR, SINBAD's sensor has been field proven, in real time at a regional airport CTR, as a feasible alternative to PSR for non-cooperative ATC.

Furthermore SINBAD's sensor has also demonstrated its capacity to reliably tracked aircraft, even ones with an estimated RCS of 1 m², below 500 ft. of altitude and in particular down to touch down on the airport runway. This capacity is a clear improvement when compared to the PSR available on the market.

SINBAD's sensor performances were then verified in the Brno airport area. While the observed robustness was very good, no failure during the tests, more trials in different environment are required to fully assess the sensor's soundness. Furthermore additional studies are also required on the operational concepts: coverage of CTR or TMA zone or as gap filler for existing PSR …, before going to product level.

AHA was also evaluated with the tests campaigns results but off-line and during workshops with air traffic controllers and system experts. Due to a lack of reference data, a statistical analysis of AHA performance was not possible. As such the validation mainly relies on expert judgment.
The test results show the effectiveness of the AHA monitoring functions and recommendations are presented to reduce the number of false alerts. The tested functions were:

- Area infringement monitoring,
- Area escape monitoring,
- Area conformance monitoring (to monitor speed conformance, especially low speed to help sequencing aircraft),
- Route conformance monitoring (to monitor SID and STAR),
- Flow conformance monitoring (to help finding "suspicious flights" in large amounts of track data),
- Separation monitoring.

The air traffic controllers indicated that besides NCT classification and area infringement monitoring also area escape monitoring, route monitoring and separation monitoring are of interest to them. Area conformance monitoring is of less interest to the controllers, and flow conformance monitoring of no interest to the controllers due to highly flexible routes.

AHA demonstrator has also proven its capacity as a platform for Safety Nets functions verification and validation with a minimal effort in term of design and disturbances of the day to day ATC operations. At the end of the

SINBAD project AHA can be easily plug in parallel to an existing ATC system, with or without Safety Nets functions.

Safety, Security and Costs Benefits Analysis

These three analyses were conducted on the SINBAD's system, with the assumption of the system feasibility. While the tests campaigns have partially proven this assumption soundness, they will have to be rerun during a product development phase.
The results are however outstanding with an estimated Benefits/Costs ratio of greater than 3 only taking into account safety benefits and 10 for security benefits. This last value should be used with care as the security benefits considered are currently not paid for by stakeholders. Given the current trends, where safety improvement and reduction of the costs of PSR coverage leads to an easy business plan, the consortium consider that the security improvements or functions provided by SINBAD shall be difficult to valorised at first

SINBAD's perspectives and recommendations

In short SINBAD successfully fulfilled its objectives and a new kind of Radar is now on its tracks for product development. In this development phase and beyond the present project frame the following recommendations or extensions should be subject of subsequent research:

- Operational concepts: coverage of CTR or TMA zone or as gap filler for existing PSR … Can one type of product be defined to cover all the identified needs?
- Extension of SINBAD airspace domain associated to data acquisition campaigns, with a particular focus on how deployment and vertical accuracy can be optimized,
- Security monitoring of CT (besides NCT) with additional flight plan conformance monitoring,
- Incorporation of conflict monitoring function in AHA that effectively takes into account NCT intentions and manoeuvrability,
- Incorporation of SINBAD's sensor signal processing for improved NCT classification.
- Safety and Security case development activities to further reduced uncertainties about the concept by confirming the stakeholders' ATM needs, and detailing the expected benefits of the SINBAD concept.
- To perform independent review of the Security case methodology defined within the SINBAD project;
- To systematically rerun additional safety, security and CBA assessment for new airports to take into account the specific conditions in which the SINBAD system is to be operational.

Once at product level SINBAD type of Radar should complement, at first, PSR as WAM is complementing SSR, with Europe in leading position. Safety cases are to be refined and transition from standard PSR to MSPSR is still to be defined but with SINBAD the consortium and several interviewed ATM stakeholders consider that the future of PSR functions lays with MSPSR technology.

New analysis methods and SW functions to support safety and security, with Europe in leading position.

SINBAD's sensor and AHA have a clear near and far future, with coastal applications of the sensor that started in 2010 and further follow-up contract are coming.

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1. SCOPE

1.1 IDENTIFICATION

Program Name	:	SINBAD
Document Name	:	Final Report
Work Package Number	:	WP600 deliverable
CDRL Number	:	D.6.2
THALES Number	:	TR6/SR/PST-418/10
Revision	:	Final issue – f2
Revision date	:	01/03/2012
File Name	:	SINBAD_D62_Final report_- f02b.doc

1.2 PROGRAM OVERVIEW

SINBAD aims to perform the proof of application of a new concept, intended to improve aircraft **safety and security** at airport approach to 2010 horizon.

Collision avoidance is currently ensured jointly by the Air Traffic Management System (ATMS), and the Airborne Collision Avoidance System. Both systems actually are ineffective against the risk of accidental or hostile collision by **non-cooperative** small or low flying aircraft.

The main targets of SINBAD to overcome these limitations are:

- to improve drastically the capability of the ATMS to monitor such non cooperative aircraft, using a **breakthrough low cost sensor technology**, the MultiStatic PCL (Passive Coherent Location),
- to support controllers by providing them with an Active Hazard Assessment (AHA) capability, allowing them in case of confirmed danger to quickly **alert the adequate authorities** and if needed to the **relevant airliners.**

The scientific objectives of SINBAD are:

- to develop and optimise on live data a mock-up of the MultiStatic PCL sensor, and of the AHA software component,
- to assess MultiStatic PCL improvement in detection and localization performances compared to currently available sensors,
- to assess AHA's performance in terms of probability to anticipate collision risks between relevant aircraft and airliners, with a controlled false alarm rate.

To achieve these objectives, a consortium of 9 partners from 6 countries with all the required skills has been established as follows: 3 industrial partners, 1 SME, 1 academic institute, 2 research centres, and 2 government end-users institutions.

The project organized in 6 work-packages will allow:

- WP100: to refine the operational concept and system requirements,
- WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed,
- WP300: to validate the concept through live trials at Brno and Frankfurt airports,
- WP400: to assess the benefits in terms of safety, security and business efficiency, according to the Eurocontrol-Operational Concept Validation Methodology.
- WP500: to disseminate SINBAD results throughout the community of interested stakeholders, as potential end-users, industrial partners …
- WP600 standing for project management.

1.3 DOCUMENT OVERVIEW

The purpose of this document is to describe the execution of the SINBAD project. It includes a summary description of project objectives, contractors involved, work performed and end results, elaborating on the degree to which the objectives were reached. In particular it provides a description of the implemented system as well as the trials campaigns that were run. It briefly describes the methodologies and approaches employed and relate the achievements of the project to the state-of-the-art. It also explains the impact of the project on its industry or research sector. In the following chapter the complete list of the final documents produced in the project course is provided. These documents are available for downloading on SINBAD website sinbad.edufly.net.

2. REFERENCED DOCUMENTS

2.1 CONTRACTUAL DOCUMENTS

Index	Reference	Title
[C1]	TREN07/FP6AE/S07.69019/037164	SINBAD Contract
[C2]	TREN07/FP6AE/S07.69019/037164 Annex 1	SINBAD Contract : Description of Work

Table 1. Contractual documents

2.2 CONSORTIUM DOCUMENTS

Index	Reference	Title
[S1]	DJ/PC/204.2006	17 11 2006 Final version SINBAD Consortium Agreement

Table 2. Consortium documents

2.3 PROGRAM RELATED DOCUMENTS

Index	Partners #	CDRL #	Title
[P1]	ADV issue	D1.1	Baseline description of current system WP synthesis
[P2]	BUTE issue	D1.2	Threat/Danger identification and Scenarios report
[P3]	ADV issue	D1.3	SINBAD OCD report
[P4]	ADV issue	D1.4	SINBAD system requirements report
[P5]	TATM/Gmbh/SINBAD-02/09 -	D2.2	Interface Requirement Specification / Interface Control Document final version
[P6]	TATM/Gmbh/SINBAD-03/09 A	D2.3	Global Architecture Design
[P7]	NLR issue	Di.2.3.1	AHA Functional Design
[P8]	TR6/SR/PST-105/08	D2.4	Report describing the targeted performances of the sensor
[P9]	TR6/SR/PST-329/10	D2.5	High level description of the mock-up
[P10]	TR6/SR/PST-419/10	D2.6	Industrial tests report (sensor)
[P11]	TATM Ltd & Gmbh issue	D2.7	Report on the industrial test of the Sub System
[P12]	ANS CR issue	D3.2	Validation management (E-OCVM) final version
[P13]	ANS CR issue	D3.4	Test plan for trials in Brno final version
[P14]	ANS CR issue	D3.5	Report of the experiments and 1st validation synthesis
[P15]	NLR issue	Di.3.5	Report of the experiments and 1st validation synthesis
[P16]	DFS/SINBAD-01/09	D3.6	Test plan for trials in Frankfurt draft version
[P17]	NLR issue	D4.1	Safety Assessment (FHA)
[P18]	NLR issue	D4.2	Safety Assessment (PSSA)
[P19]	NLR issue	D4.3	Safety Case report
[P20]	NLR issue	D4.4	Threat Assessment report

Index	Partners #	CDRL #	Title
[P21]	NLR issue	D4.5	Initial Security Case report
[P22]	ECORYS/SINBAD-01/09	D4.6	Report on methodological issues and cost & benefit taxonomy; user decision criteria
[P23]	ECORYS issue	D4.7	Comprehensive cost-benefit analysis on the introduction of SINBAD system
[P24]	TR6/SR/PST-200/08	D5.2	Final version of Final Plan for using and Disseminating knowledge and Report on raising public participation and awareness
[P25]	TR6/SR/PST-420/10	D5.4	TIP report
[P26]	TR6/SR/PST-249/07	D6.1	Program Management Plan
[P27]	TR6/SR/PST-418/10	D6.2	Final report
[P28]	TR6/SR/PST-421/10	D6.3	18-month activity and management report n°2
[P29]	TR6/SR/PST-422/10	D6.4	Publishable final activity report

Table 3. Program related documents

2.4 OTHER REFERENCED DOCUMENTS

Eurocontrol Standard Document for Surveillance Data Exchange:

Index	Reference #	CDRL #	Title
[O1]	SUR.ET1.ST05.2000-STD-02b-01, Part 2b	Edition 1.27 Nov. 2000	Transmission of Monoradar Service Messages Category 034
[O2]	SUR.ET1.ST05.2000-STD-04-01, Part 4	Edition 1.15 Nov. 2000	Transmission of Monoradar DataTarget Reports Category 048

Table 4. Other referenced documents

2.5 ABBREVIATIONS

Abbreviation	Plain Text
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AHA	Active Hazard Assessment
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic COntroller
ATM (ATMS)	Air Traffic Management (System)
BSA	Baseline Security Assessment
CAT	CATegory
CBA	Costs and Benefits Analysis
CT	Cooperative Target
CTR	Control Terminal Region
CWP	Controller Working Position
DAB	Digital Audio Broadcast
DBF	Digital Beam-Forming
DMS	Display and Monitoring Sub-system
DVB-T	Digital Video Broadcasting – Terrestrial
EDDF	Frankfurt [Rhein-Main] airport indicative
E-OCVM	Eurocontrol-Operational Concept Validation Methodology
ESARR	Eurocontrol SAfety Regulatory Requirements
FHA	Functional Hazard Analysis
FPL	Flight PLan
GA	General Aviation
GSM	Global System for Mobile communications
IFR	Instrument Flight Rules
IP	Internet Protocol
IRR	Internal Rate of Return
ISA	Initial Security Assessment

LKTB	Brno airport indicative
MATLAB	Software, used in the SINBAD program for algorithm development
Mlat	Multilateration system
MSL	above Mean See Level
MTOW	Maximum TakeOff Weight
NCT	Non-Cooperative Target
NCTR	Non-Cooperative Target Recognition
NPV	Net Present Value
NTP	Network Time Protocol
OCD	Operational Concept Document
PCL	Passive Coherent Location
PISA	Pre-Implementation Security Assessment
PMS	Primary Multilateration Surveillance
PoD	Probability of Detection
PSR	Primary Surveillance Radar
RC	Radio Controlled
RCS	Radar Cross Section
RRS	Recording and Replay Station
Rx	Receiver
SFN	Single Frequency Network
SID	Standard Instrument Departure
SSR	Secondary Surveillance Radar
STAR	STandard instrument Arrival Route
STCA	Short Term Conflict Alert
TIP	Technology Implementation Plan
TMA	Terminal Manoeuvring Area
TR6	THALES Air Systems
TS	Threat Scenario
TV	Television
Tx	Transmitter
UAV	Unmanned Aerial Vehicle

UDP	User Datagram Protocol
UHF	Ultra High Frequencies (300 MHz – 1 GHz)
ULM	Ultra-Light Motorized aircraft
UMTS	Universal Mobile Telecommunications System
VDF	Very high frequency Direction Finding
VFR	Visual Flight Rules
VHF	Very High Frequencies (30 – 300 MHz)
VRML	Vector R Model L
WAM	Wide Area Multilateration
WP	Work Package
XNTP	eXtended Network Time Protocol

Table 5. Abbreviations

3. Description of work

3.1 Project organisation and workshare

The SINBAD project was organised in 6 Work Packages (WP):

- WP100 System requirement and OCD,
- WP200 System design and development,
- WP300 System validation,
- WP400 Safety, Security and business cases,
- WP500 Dissemination and TIP,
- and WP600 Consortium management.

SINBAD was a consortium of 9 partners from six European countries:

- **ADV Systems (ADV) United Kingdom**, was leader of WP100 System requirement and OCD and participated to the reviews of the WP200, 300 and 400.
- **Budapest University of Technology and Economics (BUTE) Hungary**, ran the analysis on the Threat/Danger identification and wrote D1.2 of WP100. They also developed a software module for real time classification of Non Cooperative Targets (NCT) in WP200. They provide valuable inputs for the cost benefit analysis of WP400 in the form of a European market analysis. Lastly they were responsible for the development and maintenance of SINBAD website.
- **Thales Air Systems (TR6) France**, mostly involved in the design and operation of a new passive Radar sensor a MultiStatic PCL, leader of WP200 System design and development. TR6 was also responsible for the dissemination activities and project coordinator, leader of WP500 and WP600.
- **Thales ATM Ltd (TATM Ltd) United Kingdom**, contributed to WP200 with the development of a dedicated EUROCAT-C system and also participated to WP100 reviews and WP300 integration activities.
- **Thales ATM Gmbh (TATM Gmbh) Germany**, contributed to WP200 with the definition of the system architecture and interfaces. They were also responsible with the system integration during WP300.
- **DFS air navigation service of Germany**, was an important contributor of WP300 but also participated to WP100, WP200 and WP500 activities.
- **Air Navigation Service of the Czech Republic (ANS CR)**, was leader of the WP300 System validation, in particular in charge of the trials campaign in Brno CR.
- **NLR the Netherlands**, contributed to WP100 documents and was leader of WP400 Safety, Security and business cases and in charge of the Safety and Security analysis. They also developed the Active Hazard Assessment (AHA) real time tool in WP200 and participate to the validation scenarios definition and execution in WP300.
- **ECORYS the Netherlands**, was in charge of the business case for SINBAD in WP400.

3.2 System description

The main functions of the SINBAD system are:

- To improve drastically the capability of the ATMS to monitor non cooperative aircraft, using a breakthrough low cost sensor technology, the PCL system,
- To support controllers by providing them with an Active Hazard Assessment (AHA) capability, allowing them in case of confirmed danger to quickly alert the adequate authorities and if needed to the relevant airliners.

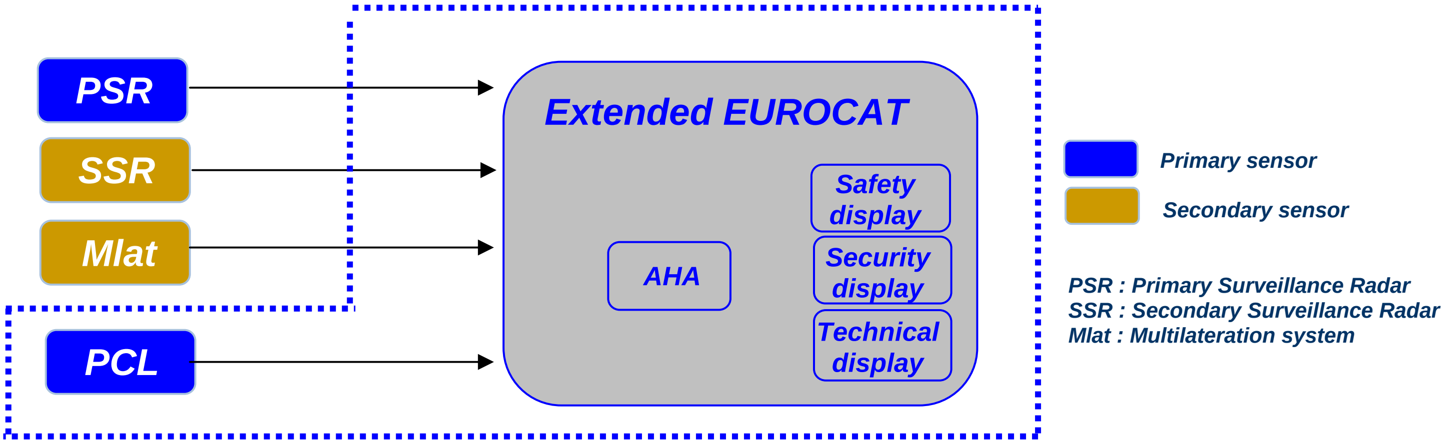


Figure 1. SINBAD system overview

The coverage objective is the Class B and C control zone (TerMinal Area TMA and ConTrol Region CTR), in which infringements are the most disruptive for air traffic and potentially the most dangerous for ATM installation.

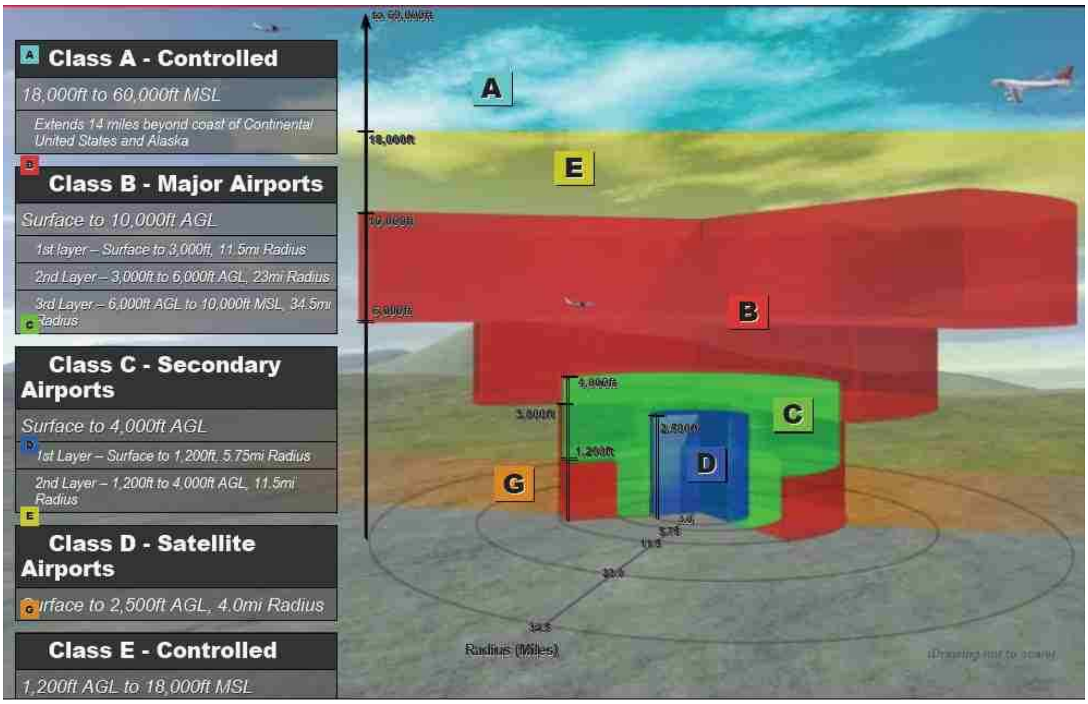


Figure 2. Airspace surveillance zones

3.3 Sensor description

SINBAD's sensor is in fact a Primary Multilateration System (PMS), in many ways similar to Wide Area Multilateration (WAM) system. Where the WAM uses the secondary Radars and transponders transmission, PMS uses several transmitters and receivers to operate as primary Radar. It enables primary detection based on the signal reflected by the target without the need of any cooperation from it.

A specific implementation of this global concept is the Passive Coherent Location sensor (PCL). One or several receiver stations exploit the signal of a target illuminated with transmissions of opportunity, which here were civilian broadcast of DVB-T signals.

The objective of coverage extension in which the sensor will detect flying targets is a circular area of between 20 and 40 NM in radius. Thanks to the simultaneous exploitation of multiple transmitters, on which is applied a triangulation processing; the sensor is able to give 3D estimation on the target position.

Note that as it is a purely passive concept, the sensor installation does not need transmission authorization.

3.3.1 Performance objectives:

- Coverage:
  - ≥ 20 NM at low altitude on small size aircraft (ULM),
  - 360° bearing detection capacity,
- Accuracy on the aircraft positioning:
  - 15m in the horizontal plane and 150 m in altitude.

3.3.2 Operational characteristics:

- Low energy consuming: ≤ 5kW (for a system composed of 4 receivers and 1 central unit),
- No disturbance on the already deployed equipments,
- Low acquisition cost,
- Standard Interface on ASTERIX format (CAT 38/42) for integration in ATC centre,
- Personnel safety thanks to the purely passive exploitation of surrounding signal,

3.4 SINBAD system overview

While SINBAD mock-up is based on DVB-T transmissions, the architecture of the mock-up is however fully compatible with opportunity transmitters using other signal types at other frequencies. Only the receiver central frequency, the bandwidth and some algorithms are different.

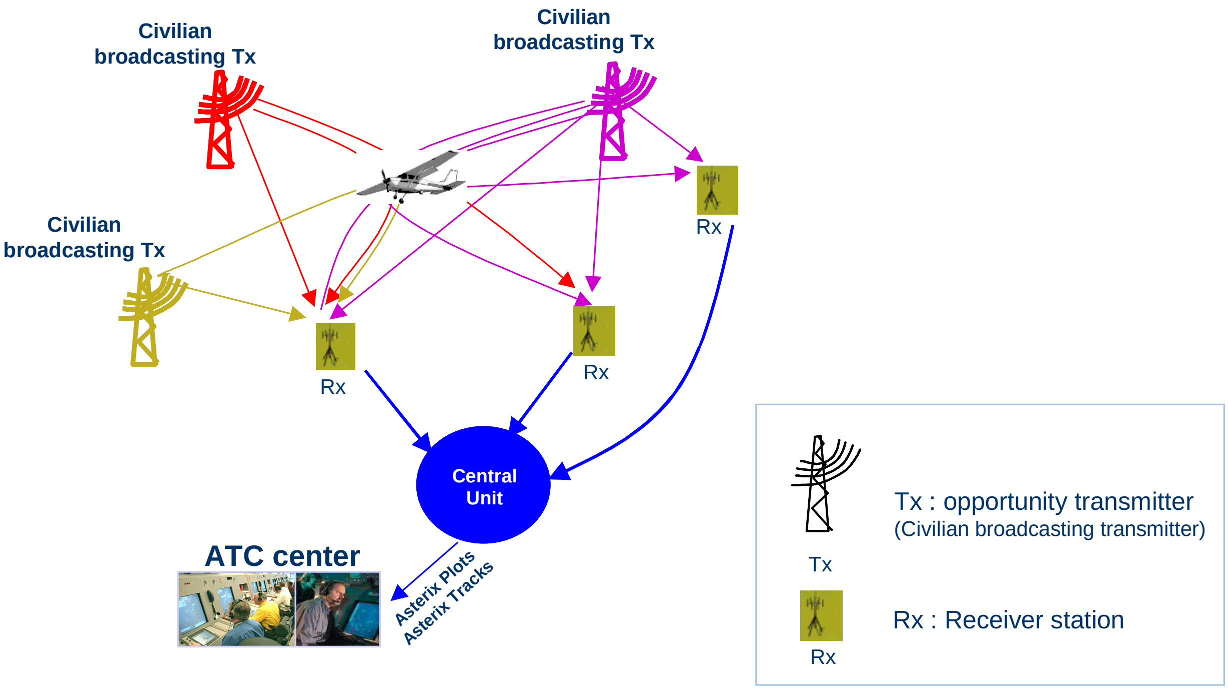


Figure 3. SINBAD's sensor concept view

Examples of opportunity transmitters that can be used in theory by PCL are:

- Radio transmitters (FM, DAB…),
- TV transmitters (analogue TV, DVB-T…),
- Radio communications transmitters (GSM, UMTS…),
- Satellites (GPS…).

In comparison with conventional PSR, advantages of PCL systems are:

- Easy coverage extension (by adding transmitters and/or receivers);
- 3D detection in position and velocity ([1]);
- Higher renewable rate (~1 s instead of 4 to 5 s for classical radars);
- Reduced cost;
- Aircraft recognition (using long time integration and high accuracy Doppler measurement),
- High level of resilience (the system sustains the loss of one or two elements).

PCL implementation requires at least 4 bistatic bases (Tx/Rx couples) to correctly track targets. Figure 1 above shows 3 transmitters and 3 receivers which are noted as: Txi and Rxj where $(i,j) \in \{1;2;3\}^2$. In that case 9 Txi/Rxj couples so 9 bistatic bases are available.

For the SINBAD trials the system uses DVB-T opportunity transmitters as they have the greatest bandwidth, so the best localisation accuracies. To provide robustness the deployment shall present a minimum of 6 bistatic bases, 2 more than the minimum.

[1] If at least 3 Tx/Rx pairs measurements can be merged.

3 transmitters were fully available in Brnö, 9 bistatic bases were then available.

SINBAD sensor mock-up is then a system constituted of several receivers and one central unit.

3.4.1 Sensor's Unit architecture, receivers and central unit

The global architecture of a receiver unit is described in the following figure:

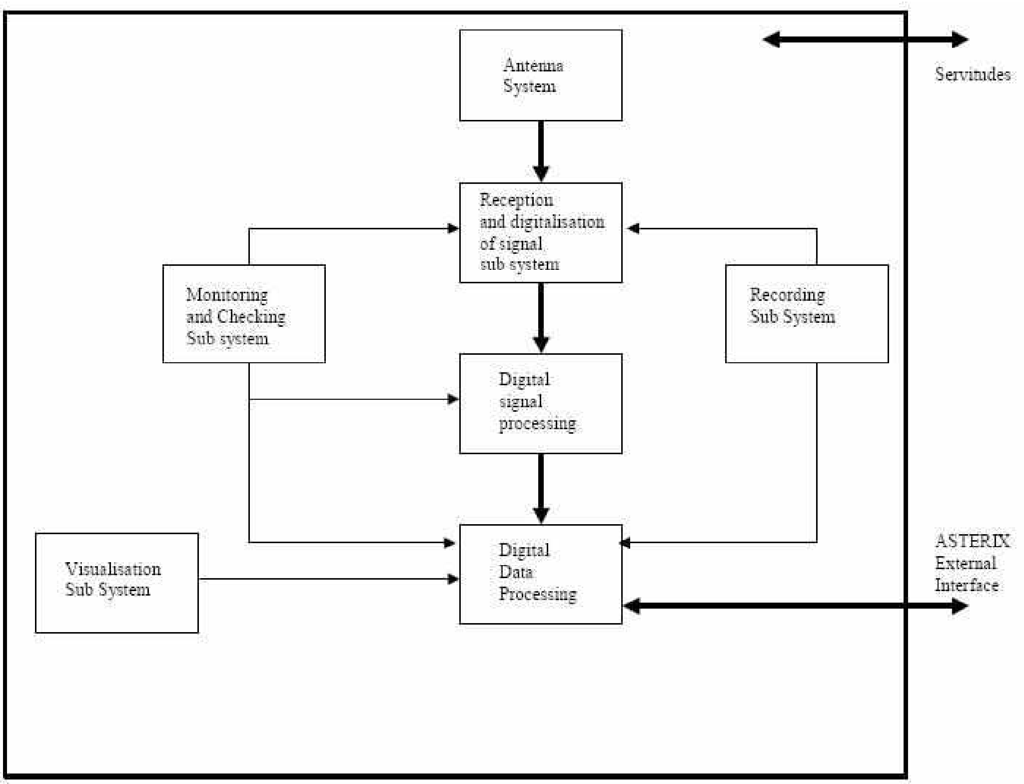


Figure 4. Receiver's architecture

The mock-up is made of 4 receivers with the following sub parts:

- Antenna sub system
- Reception and Digitalisation of the signals sub system,
- Digital Signal Processing sub system,
- Monitoring and Checking sub system,
- Visualisation sub system.

A GPS antenna and receiver is also part of the receiver's system.

A central unit complete the system with an architecture similar to the receivers plus a Digital Data processing sub system and without the first 3 functions:

- Digital Data Processing sub system,
- Monitoring and Checking sub system,
- Visualisation sub system.

The central unit mock-up provides an external interface on ASTERIX format.

3.4.2 Sensor's Sub Systems description

3.4.2.1 Antenna sub system

The antenna sub system is made of a multiple receivers' antenna, which will be fixed to a mast. It exploits signal in the DVB-T band: from 470 MHz to 870 MHz.

Antennas are 4 dipoles omnidirectional or directional antennas, to improve detection capability by DBF. Antenna type omnidirectional or directional is chosen according to each receiver's site configuration.

3.4.2.2 Signal Reception and Digitalisation

The Signal Reception and Digitalisation can operate both analogical and digital processing on different frequency channels (bandwidth ~8 MHz).

Thanks to the Checking and Monitoring Sub System, the operator can select the channels.

After filtering, digitalisation and demodulation, the signal is transmitted to the Digital Signal processing.

3.4.2.3 Digital Signal Processing

The output of the Signal Reception and Digitalisation sub system feed this function. On each channel, elementary detections are computed before transmission to the Digital Data Sub System. The same processing is applied simultaneously to all the channels independently.

From one receiver station, aircraft detection leads to three primary measurements ([2]) for each bistatic bases associated to the station:

- Bistatic range which corresponds to time difference of arrival between the aircraft path (transmitter-aircraft-receiver) and the direct path (transmitter-receiver). The aircraft is located on the ellipsoid defined by the transmitter and receiver (focal points) and an eccentricity depending on the bistatic range;
- Bistatic Doppler which is relative to the velocity of the aircraft and the (transmitter, aircraft, receiver) configuration (it mathematically corresponds to the time derivative of the bistatic range);
- Angle of arrival of the aircraft path, which is relative to the azimuth of the aircraft from the multi-elements antenna.

Principle of the processing done in each receiver station is described in Figure 5. Main steps are:

- Transmitted signal estimation: transmitted waveform being not known in advance by the receiver, this step reconstructs the transmitted signal;
- Direct path rejection: cancels interfering signals (direct path and zero Doppler clutter) to create signal which contains only Doppler echoes from aircrafts and noise (called "aircrafts signal");
- Cross correlation: performs coherent integration of the signals to get the processing gain (product of the signal bandwidth by the processing integration time);
- Detection: extracts bistatic measurements from cross correlation functions.

[2] Relative to the bistatic geometry, i.e. geometry defined by the positions of a transmitter and the receiver.

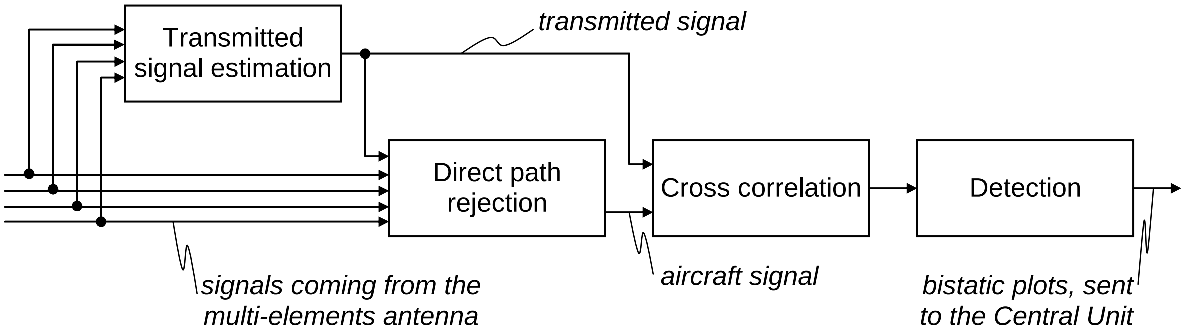


Figure 5. Principle of one receiver station processing

3.4.2.4 Digital Data Processing

The Doppler speed/range plots out of the Signal Reception and Digitalisation sub system feed this function. Data fusion and second level tracking are processed before transmission of radar plots and tracks to the visualisation.

The Central Unit then collects bistatic plots coming from the different receiver stations and performs Cartesian multiple aircraft tracking to retrieve the real-time air picture. Aircraft locations are obtained by estimating the interception of the ellipsoids created by the different bistatic geometries and range measurements.

Finally aircraft tracks are send to user systems through an ASTERIX categories 34 and 48 data link.

These algorithms shall be developed up to real time implementation, with both latency and update rate below 5s. This value of 5s is the absolute maximum value for integration in an ATC system. However and thanks to its principle of operation the system should be able to operate in a much shorter time. At product level the system should have both latency and update rate of about 1s. This improvement simply derived from the fact that there is no rotating antenna in the system, hence latency and update rates are purely an issue of computing power/software optimization.

3.4.2.5 Monitoring and Checking sub system

The Monitoring and Checking sub system enables the operator to access to a certain amount of parameters such as:

- Number of the channels and the central frequency of them,
- Signal Processing parameters,
- Data Processing parameters.

3.4.2.6 Visualisation Sub System

The visualisation sub system provides the operator with the visualisation of the radar plots and tracks on a Digital Terrain Map.

3.4.2.7 External interfaces

The mock-up provides data on ASTERIX format (with IP protocol), which enables the connection to the ATC centre.

3.4.3 AHA sub-system description

The SINBAD operational concept builds on the current Air Traffic Management (ATM) operation by adding a new type of surveillance sensor, the Primary Multilateration System (PMS), and by introducing an Active Hazard Assessment (AHA) system to the ground ATM system. The purpose of adding these systems is to improve the detection of Non-Cooperative Targets (NCTs) close to or inside the Control Zone (CTR). NCTs are aircraft that are not equipped with a transponder or aircraft of which the transponder has failed or has been switched off (either accidentally or intentionally). Nowadays, these NCTs are partially detected by primary radar or visually by the air traffic controller (ATCO) or by a pilot. The additional services provided by SINBAD to the ATCO are the generation of an alert when an NCT is about to infringe the CTR and an alert when a security threat is detected. With these new systems and services, ATC is able to improve the provision of separation between NCTs and other aircraft and to improve the provision of information by the ATCO to other aircraft about these NCTs.

The main objective of the AHA system is to assist the controller in charge of terminal-control, by providing alarms, with graduated levels of danger, in case the safety or security of the controlled airspace is to be jeopardized by a non-co-operative target. The assessment of the level of danger will be established to criteria such as:

- the “threatening aircraft” is non-cooperative (detected by PMS or PSR only),
- its track denotes a non-standard behaviour (e.g. not conforming to expected traffic flow, not conforming to flight plan, and potential airspace infringement),
- the “time before potential airspace infringement”,
- the class of the non-cooperative aircraft (e.g. conventional airliner, small aircraft, helicopter, UAV).

A Bayesian framework is used to calculate a measure of evidence for the intention of a target based on its observed track state. It must be noted that the aim of the AHA module is not to replace existing ATM safety nets, but rather to complement the existing ATM safety nets by using their information in combination with additional surveillance information to detect non-standard aircraft behaviour and to assess the threat posed by such aircraft.

3.4.3.1 AHA Architecture

An overview of the architecture of the AHA system is presented in the below figure:

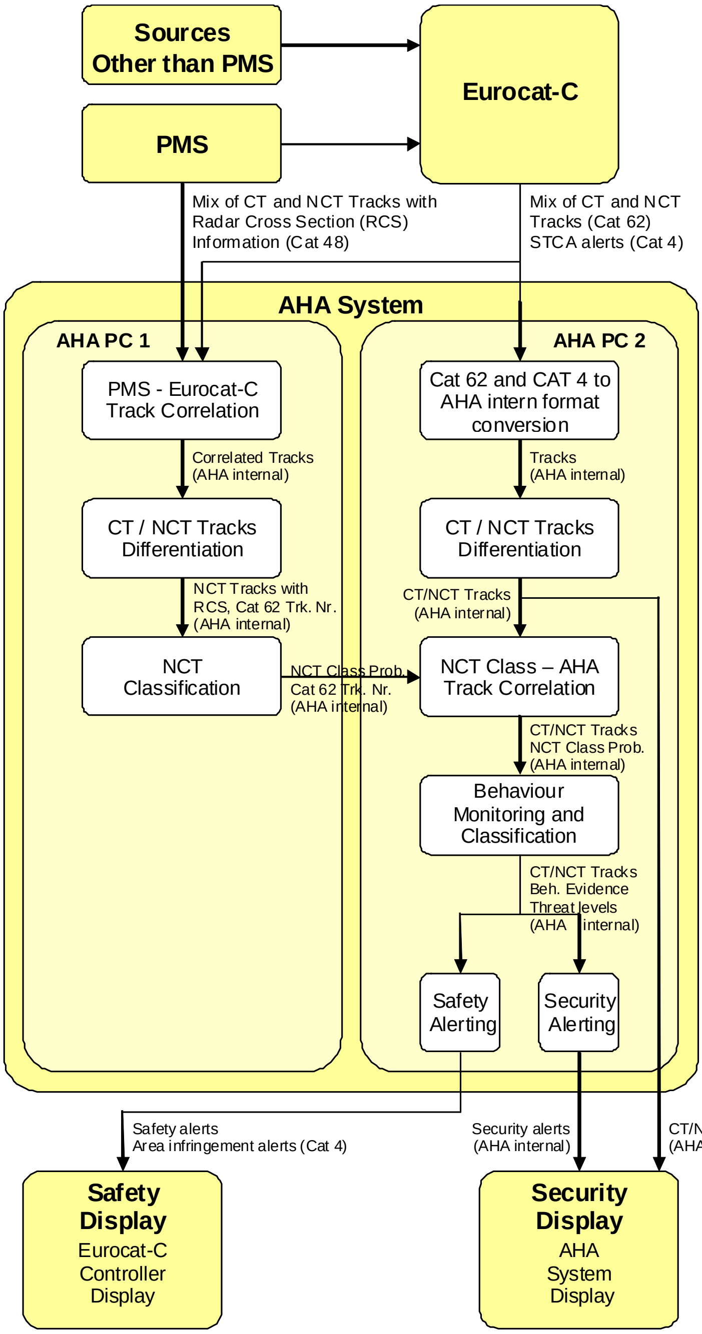


Figure 6. AHA global architecture

The AHA system comprises of two PC's, AHA PC 1 and AHA PC 2. AHA PC 1 performs NCT target type classification and AHA PC 2 performs CT and NCT target monitoring and alerting.

The AHA system comprises the following functions:

- PMS - Eurocat-C track correlation (on AHA PC 1)
- CT / NCT tracks differentiation (on AHA PC 1 and AHA PC 2)
- NCT Classification (on AHA PC 1)
- Cat 62 to AHA internal format conversion (on AHA PC 2)
- NCT Class – AHA track correlation (on AHA PC 2)
- Behaviour monitoring and classification (on AHA PC 2)
- Alerting (on AHA PC 2)

3.4.3.1.1 PMS - Eurocat-C Track Correlation

The PMS - Eurocat-C Track Correlation function correlates PMS local tracks to Eurocat-C tracks in order to be able to perform CT/NCT tracks differentiation for PMS tracks. Based on PMS data only, the AHA cannot differentiate between CT and NCT tracks because the PMS is a passive sensor which does not interrogate aircraft transponders so it needs the Eurocat-C tracks to differentiate between CT/NCT tracks. To be able to determine which PMS local tracks correspond to NCT tracks and which correspond to CT tracks, the AHA needs to correlate the Eurocat-C tracks, for which CT/NCT track differentiation can be performed, to the PMS local tracks. Furthermore, internally the corresponding Cat 62 track number is stored to be able to send it together with the classification probabilities to AHA PC 2 so that AHA PC 2 can perform NCT Class to AHA track correlation based on Cat 62 track number comparison.

3.4.3.1.2 CT / NCT Tracks differentiation

The CT / NCT Tracks differentiation function classifies Eurocat-C tracks either as “CT”, “NCT”, or “Undecided”. The “Undecided” classification is only tentative as long as no SSR update has been performed for a period of time since the corresponding track has been initiated. The reason for this is that a CT track may be initiated on PMS data only before it is updated with an SSR report. The CT/NCT tracks differentiation function uses the PSR age and the SSR age fields of Cat 62 to discriminate between CT and NCT tracks.

Note that CT / NCT Tracks differentiation is performed both on AHA PC 1 as well as on AHA PC 2 (see Figure 6). In this way, AHA PC 1 becomes independent of AHA PCA 2, which is convenient for development and testing. However, this dual implementation may lead to NCT tracks on PC 1 that differ from the NCT tracks on PC 2. It is expected that if this happens, it will only happen for a relatively short period of time since both PC’s use the same information to perform CT / NCT Tracks differentiation. In that case, either an NCT track in PC 1 may not have a classification and classification probability from PC 1 for a short period or for a CT track in PC 1 may receive a classification and classification probability from PC 1 is available for a short period. Both cases pose no problems for operational use of the AHA.

3.4.3.1.3 NCT Classification

The NCT Classification function classifies NCT target types (e.g. conventional airliner, small aircraft, helicopter, UAV) based on PMS data, in particular PMS local tracks and cross section information.

The operational principle of the developed AHA System’s NCT classification function was based on:

- use of primary surveillance system data measured by radar or other (optical, infra red, laser) sensors, for detection of the moving (flying) objects,
- correction made from secondary surveillance information,
- integrated use of direct sense data and databanks (RCS data) filled up by theoretical and practical investigations for NCT classification,
- hazard and conflict detection determined from the motion prediction of the identified and classified non-cooperative (NCT) and cooperative (CT) targets with taking into account the flight kinematics and flight dynamic characteristics of the detected CTs and NCTs,

- deconflicting procedures (conflict resolution) support by real-time simulation of the possible solutions (partly based on the rules, standard procedures developed for avoiding the conflicts.

The SINBAD concept then introduced new methods of NCT classification (using the measured trajectory kinematics in classification) and develops new and better situation awareness for supporting the ATCOs decision and introduces the automatic hazard and emergency situation avoidances.

Generally, the term target or patterns recognition describes a wide area of research, which includes topics from the fields of surveillance (radar) technology, signal processing, computer science, and statistics. The problem of deciding from which aircraft or flying object a particular measurement originates is an important problems for making decision about the targets and supporting the decision for managing with the situations might be initiated by the recognised targets.

A large consultation with the civil ATCOs has reached this conclusion: ATCOs do not need information about the real NCTs, they do not require real recognition and identification of the targets. What they need is to have some information about the type or class of NCTs and much more interesting for them a prediction of possible motion of the given class of targets. So, the SINBAD has focused its activities on NCT classification.

At first, the non-cooperative target categories were defined. Especially, the aircraft can be categorized in many ways but there are aircrafts with similar flight properties in the groups:

- mini and midi aircrafts: RC (radio control) models, smaller UAVs, and because of its speed, the paraglide.
- small aircrafts: gliders, ultra light aircrafts, up to 9 seated, single engine aircrafts.
- medium and large aircrafts: aircrafts over MTOW of 5670kg, multi engine turbo propeller aircrafts and large turbine airplanes.
- special targets: helicopters, static aircrafts,
- and other flying objects (like birds).

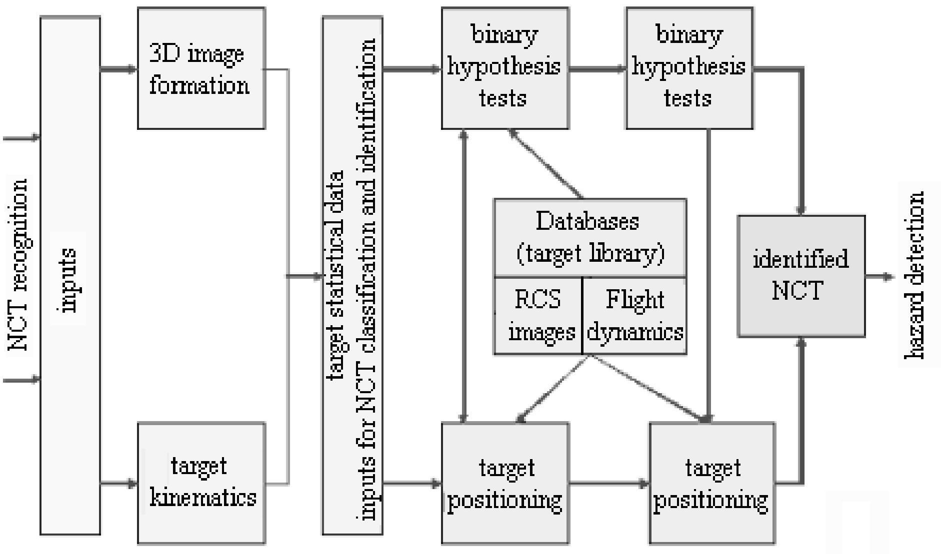


Figure 7. Non-cooperative target classification and identification procedure

The SINBAD system uses a low cost, easy to use passive radar system that detects and tracks objects by processing reflections from non-cooperative sources of illumination in the environment, such as commercial broadcast and communications signals. This radar provides raw data for the classification system. The architecture of the classification system can be seen in the above figure.

At first, the estimated motion characteristics can be used in binary hypothesis test for classification of the recognized target. During this procedure, the AHA system defines to which group the target can belong. Then the target classification function classifies targets based on the flight kinematics and the performance data. After that, the classified target can be identified only in optimal case, when the initial information, measurement accuracy are enough for target identification. This identification is based on the target positioning. That means the possible target echo database will be used for finding which echo images is closer to the measured and processed target image. Therefore the database has to contain the series of the radar echo images of each possible target depending on its position in space to get the nearest radar echo image as it was found from measurement.

3.4.3.1.4 Cat 62 and Cat 4 to AHA internal format conversion

The Cat 62 and Cat 4 to AHA internal format conversion function converts the Cat 62 and Cat 4 reports obtained from Eurocat-C to an AHA internal track structure.

3.4.3.1.5 NCT Class – AHA track correlation

The NCT Class – AHA track correlation function correlates the NCT Class probabilities obtained form AHA PC 1 to the corresponding AHA internal track structure in AHA PC 2 based on Cat 62 track number comparison. To this end AHA PC 1 sends the NCT Class probabilities together with the corresponding Cat 62 track number to AHA PC 2.

3.4.3.1.6 Behaviour monitoring and classification

For intention monitoring and alerting a Bayesian framework is used to calculate a measure of evidence between zero and one for the intention of a target based on its observed track state. It must be noted that the aim of the AHA methodology is not to be able to accurately determine intention probabilities, but rather to provide simple models that can be used to provide evidence for intentions that can be tuned to meet the expectations of the user.

The following target intentions are monitored by the AHA:

- Flow conformance
- Route conformance
- Flight plan conformance
- Area conformance
- Area escape
- Area infringement
- Separation
- STCA

The idea behind flow conformance monitoring is to determine the evidence that an aircraft is not flying in conformance with the general air traffic flow. The underlying assumption to flow monitoring is that it is possible to capture the general air traffic flow in a model by using a finite set of air traffic data to train the model.

The idea behind route conformance monitoring is to determine the evidence that an aircraft is not flying in conformance with a predefined standard route, such as a SID (Standard Instrument Departure) or a STAR (Standard Instrument Arrival Route) and other air routes.

The idea behind flight plan conformance monitoring is to determine the evidence that an aircraft is not flying in conformance with their flight plan. Within the AHA only the route points in the flight plan are used.

The idea behind area conformance monitoring is to determine the evidence that an aircraft is not flying in conformance with flight characteristics that are defined for that area. For instance a “glider area” may be defined where it is not expected to have aircraft flying at high speed. Or vice versa, an area may be defined where it is not expected to find low speed objects.

The idea behind area escape monitoring is to determine the evidence that an aircraft is leaving an area where it is expected to stay in. For instance a “glider area” may be defined where gliders are expected to stay in.

The idea behind area infringement monitoring is to determine the evidence that an aircraft is potentially entering an area it is not allowed to travel in. For instance, for non-co-operative targets it may be not allowed to travel in the CTR.

The idea behind separation monitoring is to determine the evidence that an aircraft is potentially violating minimum separation criteria. Since non-co-operative targets will usually not provide any intent information, the separation monitoring function is a very basic one that only uses state vector information and no intent information.

The idea behind STCA monitoring is to determine the evidence that a pair of aircraft is potentially violating minimum separation criteria based on an incoming STCA alert.

Based on the intention evidence a threat level is determined by multiplying the intention evidence with a predefined intention threat rate. The overall threat level is determined by the maximum threat level over all intentions.

3.4.3.1.7 Alerting

Alerting is based on the behaviour evidence in case of flow, route, flight plan and area conformance monitoring and on the time to occurrence of the event in case of area escape, infringement, separation and STCA monitoring. If the behaviour evidence exceeds a predefined threshold, or if the time to event occurrence gets below a predefined threshold, an alert is raised

Alerting function is composed of:

- Safety alerting (area infringement alerts through Cat 4 reports)
- Security alerting (behaviour monitoring alerts with threat level indication through AHA display)

3.4.3.2 Operational prototype

For real-time purposes the operational prototype has been written in the C programming language and runs on a standard PC (LINUX platform). To this end, the AHA functions that were developed and tested in MATLAB were automatically converted to C-functions after which manually some memory optimization adaptations have been performed.

The system sends ASTERIX messages of cat 004 and receives ASTERIX messages of Cat 062, cat 020 and Cat 004.

3.4.3.2.1 User Interface

Overviews of the operational prototype are presented in Figure 8 and Figure 9. Both figures show the traffic display on the left, the threat and alert information of the right and additional controls the below. Figure 9 shows a better overview of the threat and alert information

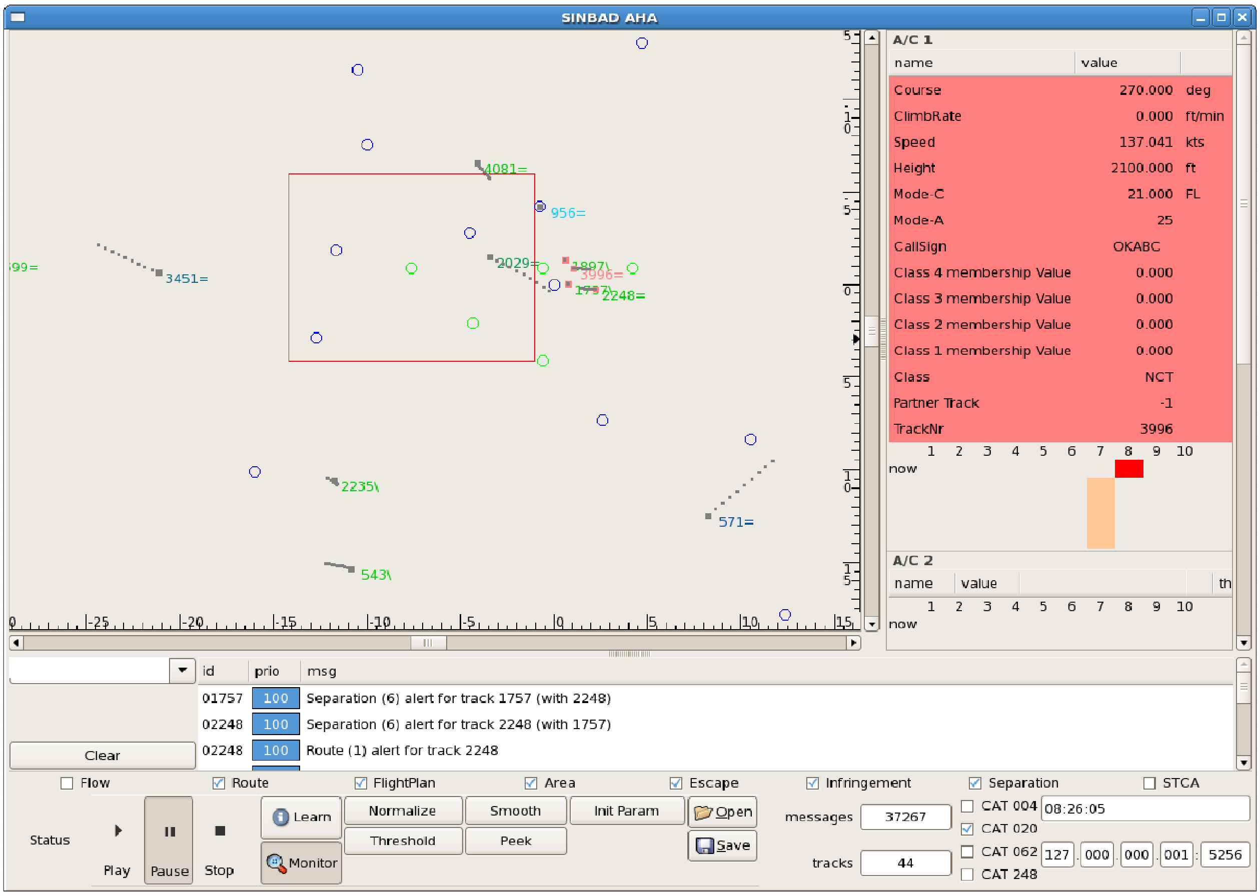


Figure 8. The AHA operational prototype (main view)

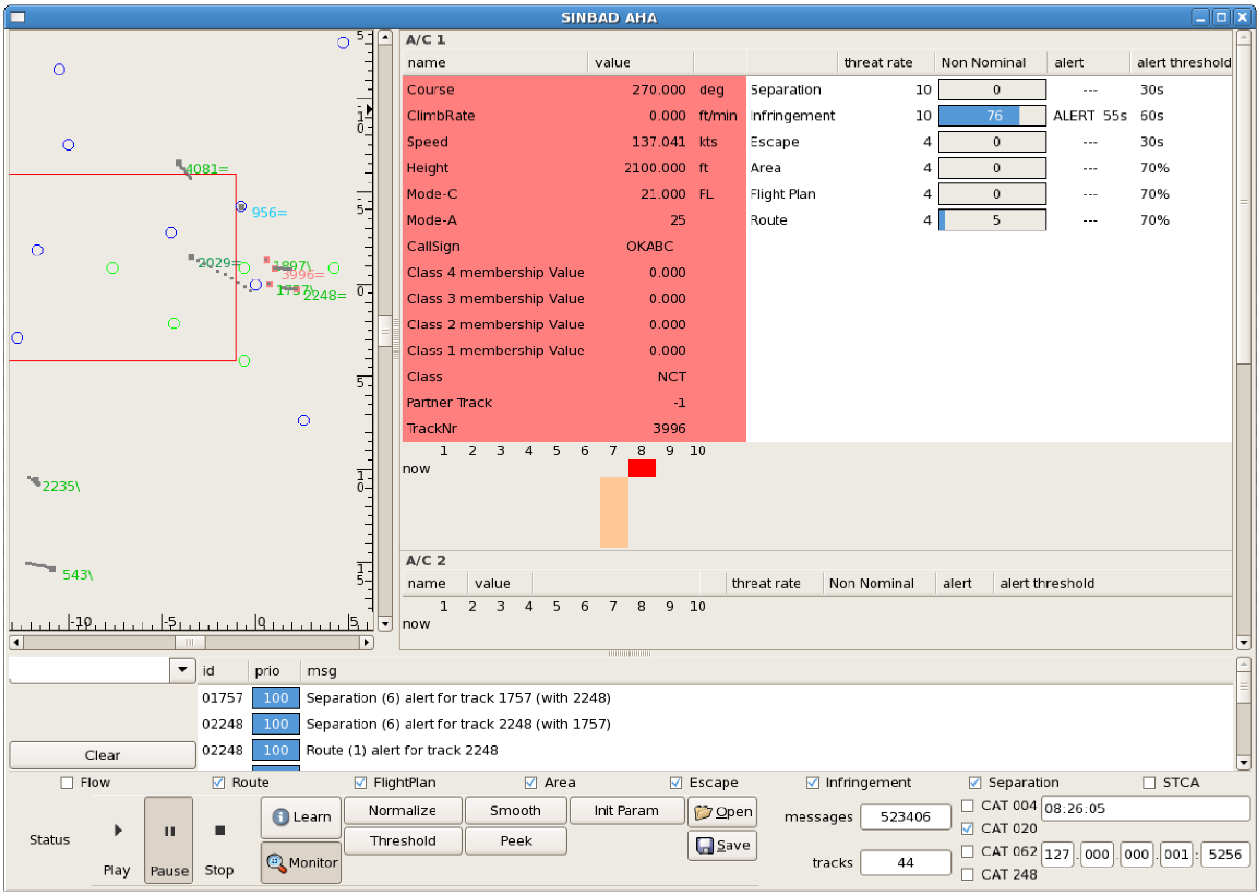


Figure 9. The AHA operational prototype (monitoring window)

In the display on the left the actual traffic is presented with corresponding “external track number”. This external track number corresponds to the track number that is found in the corresponding ASTERIX Cat 062 or Cat 020 message that is received by the AHA.

In case of an alert, the track symbol (square) turns red.

Tracks can be inspected by clicking on the corresponding track symbol in the traffic display.

Threat and alert details of the selected tracks are displayed on the right. At most 5 aircraft can be selected for inspection at the same time.

For each selected track general track information is displayed on the left, alert information on the right, and threat level information below.

Just below the traffic display and the threat and alert display, the individual alert massages are displayed, which can be cleared by pressing the “Clear” button on the left of it.

At the bottom of the AHA window, control buttons for starting, pausing, and stopping the AHA are displayed with next to it the control buttons for flow learning, flow normalizing, flow thresholding and flow smoothing. A learned flow can be saved and loaded, by respectively pressing the Save and Open button. Next to these buttons the number of messages and tracks is displayed, with on the far right the IP address and the port number used by the AHA, which are user-configurable.

Finally the AHA starts monitoring after pressing the Monitor button.

The operational prototype performs the following monitoring tasks:

- STCA monitoring
- Separation monitoring
- Area infringement monitoring
- Area escape monitoring
- Area conformance monitoring
- Flight plan conformance monitoring
- Route conformance monitoring
- Flow conformance monitoring

For each monitoring task, dedicated parameters, areas and routes are defined in separate monitoring constant files.

3.4.3.2.2 AHA functions

Safety Monitoring and Alerting:
AHA safety monitoring and alerting comprises the detection of NCT targets infringing the CTR and issuing the corresponding CTR infringement alert.

Security Monitoring and Alerting:
AHA security monitoring and alerting extends on AHA safety monitoring and alerting in the sense that it uses the area infringements from the AHA safety monitoring and alerting function as part of its input for NCT intention inferring.

Conformance monitoring:
The conformance monitoring function gives an indication of the probabilities that an NCT remains in an area or on a route it is allowed to travel in and that it is showing nominal behaviour for that area or route.

Advice generation:
The advice generation function determines which alert should be raised and determines potential advises for hazard / threat mitigation and resolution.
The management rules to determine potential advices are preliminarily defined for each predefined hazard. Note that these management rules need to be refined.
For the SINBAD mock-up only basic advice generation were implemented, for example:

- Perform security action *s*

Advising / Alerting
The advising / alerting function provides the generated advices and alerts to the users through the AHA system display.
For the SINBAD mock-up only basic advising and alerting were implemented, for example:
The colour of corresponding track marker and label will be changed and the following advice / alert will be displayed:

- NCT track *i* has been classified as class *c*
- NCT track i is potentially allowed area within t seconds with probability indication p
- Potential NCT track i intentions are flying into restricted area j with probability indication p_j
- Threat level is *L*
- Perform security action *s*

3.4.4 Detailed view of the complete SINBAD system

3.4.4.1 General Hardware Set-up

Figure 10 shows the hardware set-up and the data flow of the SINBAD system as it was used on Brno's test site.

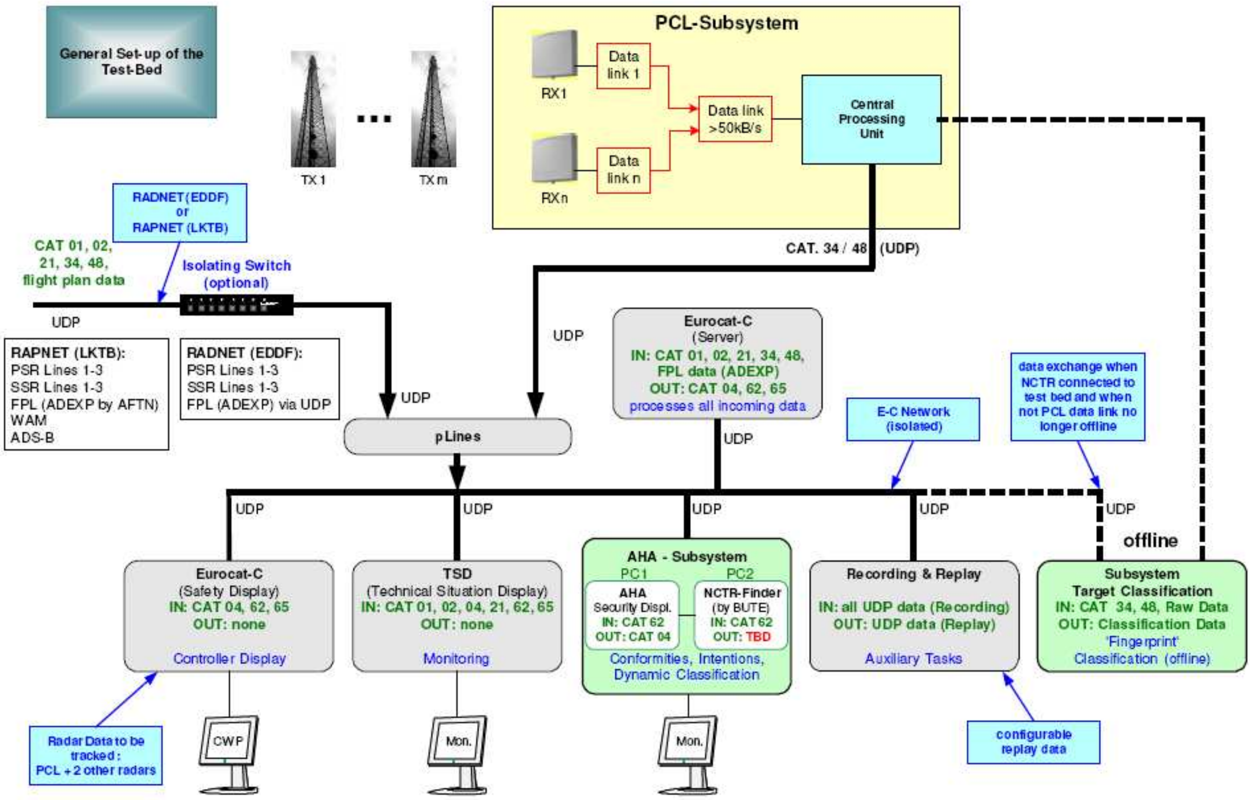


Figure 10. General Hardware Set-up and Data Flow

3.4.4.2 General Data Flow

The radar data at the local site comes from the RADNET (the EUROCONTROL radar network) by UDP. The flight plan data is also provided by UDP.
A switch forwards the data to the pLines-Hardware. The pLines isolates the local Eurocat-C network from the EUROCONTROL RadNet to ensure that no data flows back into the RadNet.

The PCL provides its data also to the pLines-Hardware.

The pLines provides the incoming data on the Eurocat-C network by broadcast. Whoever is interested in the data on the Eurocat-C network can read the data.

The Server PC is dedicated to take all the radar data and process them to track data. To optimise the tracker the data are filtered by mosaicing.
The Server PC also reads the flight plan information from the RadNet and performs the conformance monitoring as well. The processed information is provided by Asterix categories 4 (Safety Net Messages) and 62 (SDPS track messages) onto the Eurocat-C network.

The Technical Display and Controller display read this data from the Eurocat-C network and provide the means to monitor both the incoming data and the processed data provided by the Controller display.

The AHA component will read the processed information and the flight plan information and process the data to obtain hazard information about the airborne targets.

The Recording and Replay Station (RRS) – is responsible to record all UDP data as it is provided on the Eurocat-C network. It can also replay incoming data. The replay component shall be configurable, so it can be decided what recorded data shall be replayed.

The Target Classification component is carried out offline due to the huge amount of data to be processed. Due to this fact this computer needs to be a high-end device. It shall be a multiprocessor with enough memory to keep the data for all targets in the air at a time.

PCL - External Interfaces

The PCL interface provides data by TCP/IP or UDP/IP. This has to be set to UDP/IP. The data format in use for data interchange is ASTERIX CAT 34 and 48. The PCL provides the data according to the Standard User Application Profile of Edition 1.27 and 1.15 (see [O1] and [O2]).
The data exchange is one way from the PCL to the consumer (rest of test bed).

Display and Monitoring Sub System (DMS)

Eurocat-C is used for the Controller Display and the Technical Display. AHA is used for the Security Display.
It provides single and multiradar tracking functionality, combining data of all connected radars (PSR and SSR and PCL) and handles incoming flight plan information data (including Code/Callsign correlation data) received via AFTN (ADEXP format). It provides system tracks to the other displays.

AHA interfaces CT / NCT Tracks Differentiation

Eurocat-C provides a mix of CT and NCT tracks. By definition a non-cooperative target is an aircraft, which does not respond to the interrogations from ATC cooperative surveillance for one of the following reasons:

- Aircraft not equipped with a Mode A/C/S transponder;
- Transponder switched-off or in standby mode;
- Transponder failure (e.g. erroneous altitude report).

CT tracks can be distinguished from NCT tracks by inspecting the ASTERIX Cat 062 data items.
For NCT classification a distinction is made between “basic NCT classification” and “enhanced NCT classification”. Basic NCT Classification is based on processing target state vector information and enhanced NCT classification is based on processing the PCL raw signal. Since the enhanced NCT classification is very complex and there is a need of high bandwidth the enhanced NCT classification was rigged to be processed offline and/or in real time. The enhanced NCT classification based on PCL raw signal processing testing was just initiated as described in §3.5.2.

3.5 SINBAD trials campaigns

Two trials campaigns were run, both in Brno airport area in the Czech Republic.

The first installation and the initial tests were performed over October – November 2009. Based on the results thereof, it was decided and approved - at the progress meeting in December 2009 – that this experiment was to be repeated in Brno, after a partial redesign of the PCL's sensor.

At the same time, it was agreed that the suitability of the respective installation sites would be reassessed. The site survey in the surroundings of Brno was performed in May 2010 and the system's receivers were then installed and tested in Borkovany, Hradisko and Kadovská Hora. The data from these sites were transmitted to the ANS CR centre at Brno Airport.

The second campaign then started with June 2010 and was ended with August 2010.

The test plan for these campaigns is fully described in [P13]. To summarize its objectives were two-fold:

1. To test and measure the PCL's sensor performances,
2. To test the AHA functions.

Once the covered volume of the PCL's sensor was defined, through simulation, and tested by dedicated flight tests most constraints were in AHA requirements. As such the flights were mostly organized around AHA scenarios, with typically the beginning and end of the route used to further validate the covered volume. Detailed route description including the flight speed and altitude has been made for each flight day.

At the daily briefing with the aircraft crew and the air traffic control staff, the respective flights were discussed in the context of the surrounding air traffic and relevant flight conditions.

The method of presenting and recording the respective data was agreed at the daily technical briefing.
The progress of the flight was monitored on the display of the WAM system. All of the airplanes flying for the purpose of the experiment with the PCL system were fitted with SSR transponders for the sake of supervision of compliance with the scenario-set altitude requirements.

3.5.1 Installation and means

The below map shows the Brno area where the trials campaign were held:

Figure 11. Brno area with the DVB-T opportunity transmitters (blue labels), the receivers (yellow labels) and the airport (green label).

3.5.1.1 PCL's sensor Installation

a) DVB-T (digital TV) opportunity transmitters stations:

- Mikulov – Děvín 25 KW, horizontal polarisation, channel 29,40.
- Hády 10 KW, horizontal polarisation, channel 29,40 and 49.
- Barvičova 10 KW, vertical polarisation, channel 29, 40 and 49.
- Kojál 100 KW, horizontal polarisation, channel 29.

Note that as the results will show, the antenna's diagrams of the opportunity transmitters are very narrow in elevation (~3°). Furthermore due to its location in Brno city and the small size of its antenna mast, Barvičova transmitter was not really useful for the PCL. It did not provide a significant number of aircraft's detections and its detection range was very small. This was dutifully predicted by simulation and in anyway did not come as a surprise, in-city small transmitters main function is to provide TV to the surrounding district not more.

As such only the other three transmitters are considered in the rest of the document.

b) Receiver station sites:

- Borkovany
- Hradisko
- Kadovská Hora

These sites were selected according to the optimization of the expected performances of the PCL's sensor. However the system was also adapted to the affordable sites for this program. Quick simulations or simple geometrical considerations militate for equilateral triangles configuration between transmitters and receivers. This was not possible to achieve for the SINBAD program and it had a significant, but not disastrous, effect on the PCL's sensor accuracy and coverage zone.

Borkovany

Figure 12. Borkovany installation, microwave data-link antenna, PCL antennas and receivers.

Site location: 49° 01´28,502´´N – 016° 48´27,493´´E

- installation at Borkovany water plant site;
- data connection to the airport via a narrow-band microwave link leased from MIRAMO Company, line capacity over 2Mbit/sec;
- installation of two receiver stations, one directed to 045°, the other one to 300° with respect to t he North. Each receivers stations had a 120° aperture centred on these directions

Distance from the TV transmitters:

- Mikulov – Děvín 20,77 km
- Hády 23,96 km
- Barvičova 25,56 km
- Kojál 38,39 km

Distance from the neighbouring PCL receivers:

- Hradisko 30,29 km
- Kadovská Hora 37,40 km

Hradisko

Figure 13. Hradisko installation, PCL and GPS antennas.

Site location: 49^{o} 12´02,510´´N – 017^{o} 07´17,285´´E

- site of Radiokomunikace (a GSM provider)
- data connection via a leased circuit, directly to Brno Airport;
- line capacity 2Mbit/sec.
- installation of one receiver station directed to 240o (direction Brno Airport).

Distance from the TV transmitter:

- Mikulov – Děvín 50,39 km
- Hády 32,76 km
- Barvičova 39,47 km
- Kojál 29,14 km

Distance from the neighbouring PCL system site:

- Borkovany 30,29 km
- Kadovská Hora 65,13 km

Kadovská Hora

Figure 14. Kadovska Hora installation, PCL antenna.

Site location: 48^{o} 58´44,028´´ N – 016^{o} 18´01,214´´E

- site of Telefonica O2 (a GSM provider)
- data connection via a leased circuit, directly to Brno Airport
- line capacity 2Mbit/sec
- installation of one receiver station directed to 40°(direction Brno Airport).

Distance from the TV transmitter:

- Mikulov – Děvín 28,38 km
- Hády 38,45 km
- Barvičova 31,96 km
- Kojál 57,50 km

Distance from the neighbouring PCL system site:

- Borkovany 37,40 km
- Hradisko 65,13 km

Brno airport (central unit and Test bed with EUROCAT-C)

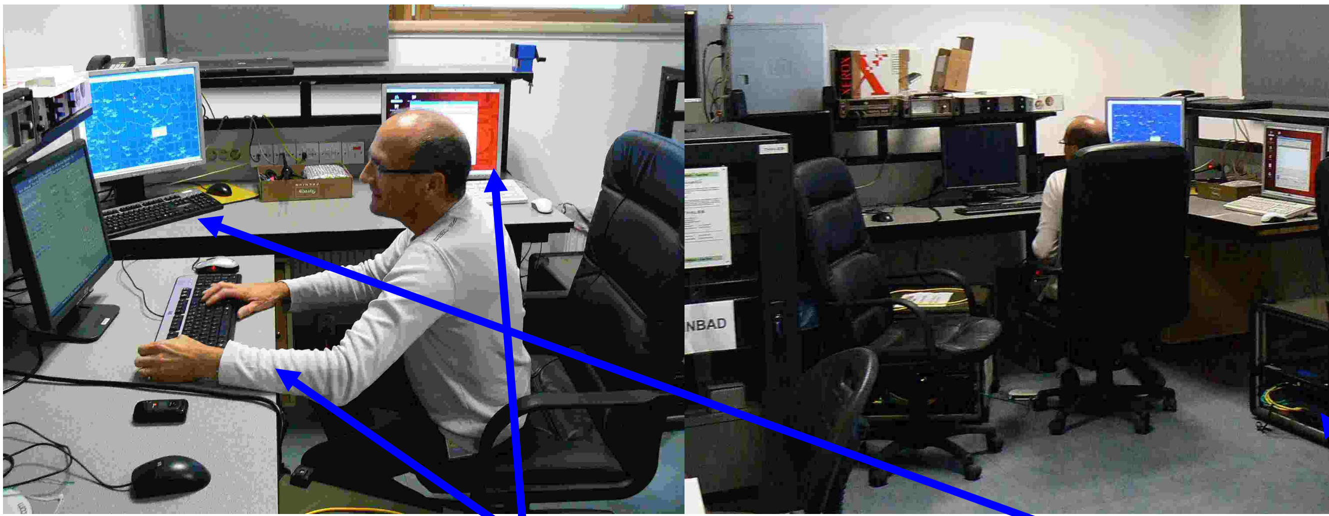


Figure 15. On the left two technical working position and the ATCO working position of the EUROCAT-C in the middle. On the right SINBAD Test bed, the three working position and the PCL central unit on the floor by the third working position.

At Brno airport both the PCL's sensor central unit and the SINBAD test bed with their relevant working position were regrouped. The system was installed at the ground floor of Brno airport control tower, in the ATC main technical room.

3.5.1.2 Aircrafts used during the dedicated flights

As the opportunity transmitters did not covers the volumes above 3° in elevation aircrafts were only d etected or tracked at low altitude. The normal traffic was then not sufficient or during too short time periods, to permit unambiguous performances evaluation.

Dedicated flights were then run with each airplane fitted with a GPS position recorder, these positions were then compared to the PCL tracks.

Four types of aircraft were used, a picture of each as well as their basic characteristics, are given below:

L200 Morava

- Full-metal construction
- wing span 13,31 m
- length 8,61 m
- gross weight 1950 kg
- engine 2x154 kW
- speed 360 km/h (max)
- Estimated RCS 4 m^2

CESSNA 172

- Full-metal construction
- wing span 10,92 m
- length 8,28 m
- gross weight 1113 kg
- engine 119 kW
- speed 288 km/h (max)
- Estimated RCS 3 m^2

JK05 JUNIOR

- Full-metal construction
- wing span 10 m
- length 5,95 m
- gross weight 480 kg
- engine 78 hp
- speed 160 km/hour (cruise)
- Estimated RCS 2 m²

KP 2U SOVA

- Full-metal construction
- wing span 9,90 m
- length 7,20 m
- gross weight 450 kg
- engine 58 kW
- speed 240 km/h (max)
- Estimated RCS between 1 and 2 m²

3.5.1.3 ATC means

Opportunity aircrafts and flight dedicated to the test were also tracked by a WAM system and SSR. During the dedicated flights aircrafts were equipped with Mode S or A transponder and their tracks were recorded.
PSR tracks were also recorded but as their quality level was poor they were not very useful at this stage, except maybe to confirm the lack of PSR coverage at low altitude around Brno airport.

WAM tracks record were the most useful and an example of such a record is given below:

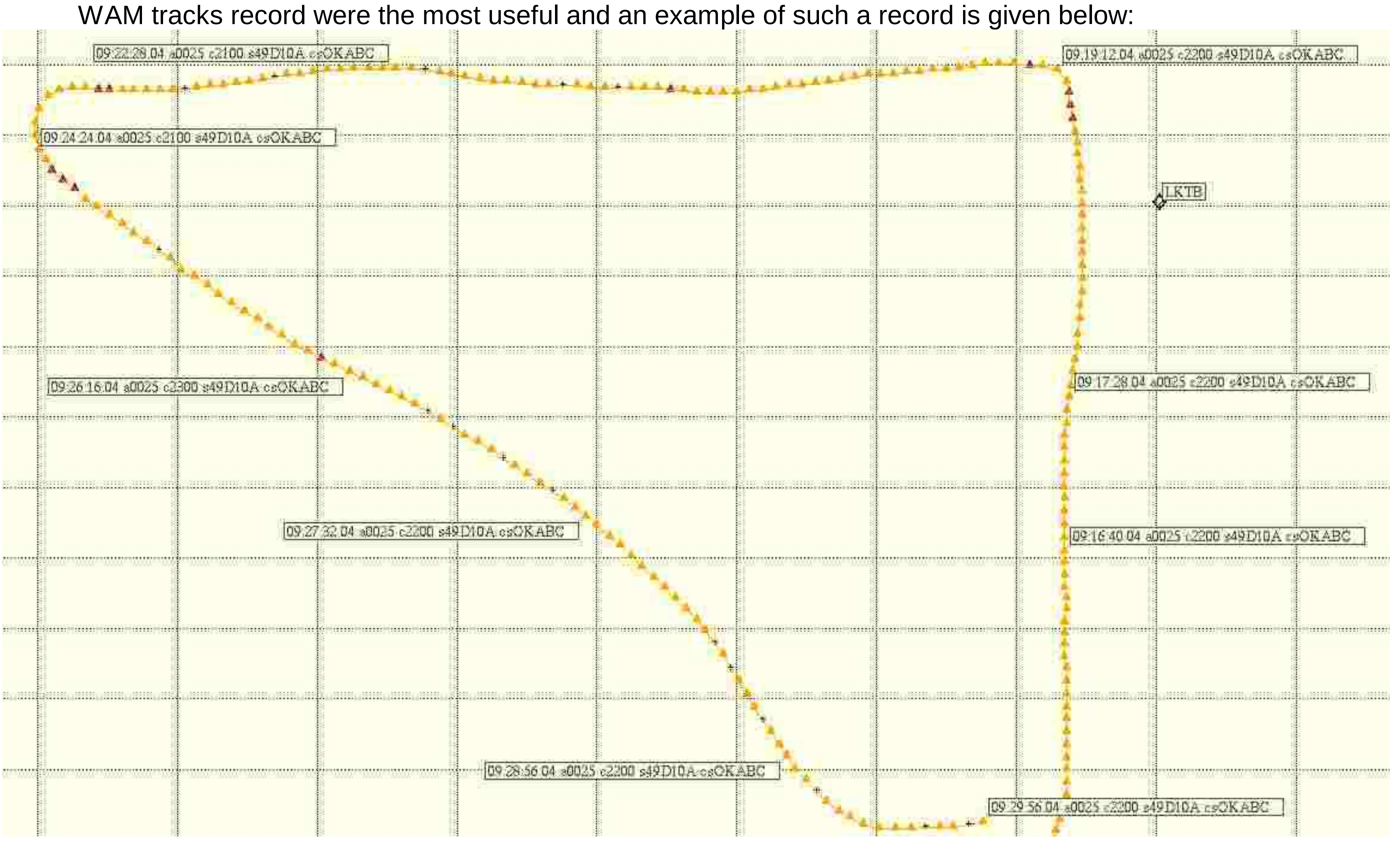


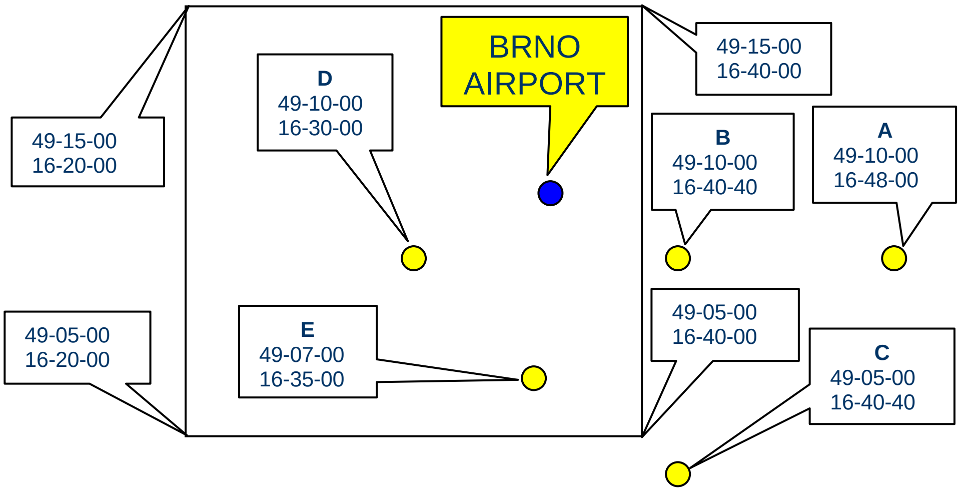
Figure 16. WAM Data Record – flight along the border of the fictive restricted area and entering restricted area – example 1 (scale in vertical ½ NM, horizontal 1 NM)– minimum speed 80kt - FL020

3.5.2 Results

3.5.2.1 Flight test scenarios

More than 15 dedicated flight tests with an average flight time of 2 hours each. 10 were conducted during the second test campaign and provided the most interesting results. Flight tests were designed to establish PCL coverage zone and validate AHA functions.

A fictive cube-shaped area was set for the tests, marked out by four points in an horizontal plane (8x6 NM²) and the lower-limit altitude of 1,500ft MSL and the upper-limit altitude of 3,000ft MSL in vertical direction.



The yellow points are turning points used in the scenarios definition: A, B, C, D and E.

Airport (blue point) is at 778ft MSL.

Figure 17. Definition of the fictive area

This fictive area is situated approximately in the middle of the area that is covered by signals from the respective TV transmitters and, at the same time, in the reception diagrams of the antennas situated on the receiver stations. The two reception antennas in Borkovany were added up to form a “wide” diagram receiver.

Test flights dates of the second test campaign

17.6.2010	the first informative flight, PCL system calibration,
23.6.2010	test for coverage area definition for next scenarios (2 flights),
25.6.2010	test for coverage area definition for next scenarios
29.6.2010	performances and AHA scenarios (2 flights),
2.7.2010	performances and AHA scenarios (2 flights),
8.7.2010	performances scenarios
19.7.2010	performances scenarios

An example of a flight test scenario is given below:

Scenario for 25.6.2010

Start at 07:02 UTC

Mode S address 49D10A, Mode A code 3320

Aircraft CESSNA 172

Altitude 3000ft above Brno airport reference point 49-09-05N=016-41-38E

1) Flight from A to B and fast turn back; 1500 and 3000ft (min/max speed)

2) Flight from A via B to E and back to A; 1500 and 3000ft (min/max speed)

3) Flight from C to B and turn to D; 1500 and 3000ft (min/max speed)

4) Flight from A via B to D in 1000ft, enter to D in climb to 2000ft (min/max speed)

5) From A to B to D in 4000ft, enter to D in descend to 2000ft (min/max speed)

Items 1, 2 and 3

a) Min speed, 1500ft

b) Max speed, 1500ft

c) Min speed, 3000ft

d) Max speed, 3000ft

Items 4 and 5

e) From bottom

f) From top

The first flights were performed for the sake of defining the area of reliable detection (dependent on the positions of the TV transmitters and the PCL receivers). These initialisation flights showed the following limitations:

- With the existing low number of transmitters, the area of reliable detection is dependent on the area of the triangle marked out by the three receiver stations;
- There is a remaining number of false targets in area with road traffic;
- The ground-directed radiation characteristics of the TV transmitters limits the possibility of detecting targets at levels above 5,000 – 6,000 ft.

The results of the initialisation flights were used for the final definition of the size and position of the fictive area to be used for the routes described in the respective scenarios.

3.5.2.2 PCL results

During the second test campaign up to 9 bistatic bases[3] were available. Each bistatic base is able to produce one detection for a given target at a given time. Detection is composed of

- a bistatic range, which corresponds to the distance transmitter-target-receiver
- a bistatic velocity, obtained from the Doppler frequency.
- an azimuth estimate made from the receiver

[3] A bistatic base is constituted of a transmitter and a receiver

Since the DVB-T transmitters are deployed in a SFN network[4], it is not possible to know which transmitter made the detection. The trickiest part in the development and tuning of the PCL sensor was then its tracker, which aim is to find targets' Cartesian locations. To do so, it needs to:

- Associate detections in the right transmitter,
- Associate detections together when they belong to the same target. A minimum of 3 simultaneous detections being required to initiate a new track.

The flight scenarios definition and purpose are shown in the table below:

Date	Target	Purpose
17/06/2010	Cessna C172	Calibration flight
23/06/2010, morning	Cessna C172	Coverage test
23/06/2010, afternoon	Ekolot JK 05 Junior (UL)	Coverage test
25/06/2010	Cessna C172	scenario
29/06/2010, morning	Cessna C172	scenario
29/06/2010, afternoon	Cessna C172	scenario
02/07/2010, morning	2 planes Cessna C172 & L200	Scenario Resolution flight
02/07/2010, afternoon	KP2U Sova (UL)	scenario
08/07/2010	Cessna C 172	Altitude coverage test
19/07/2010	2 planes Cessna C172 & Cessna C150	Scenario Resolution flight

Figure 18. Sum up of flights performed during the trial in Brnö

[4] In a SFN network, all transmitters are operating at the same frequency and broadcasting the same message

3.5.2.2.1 Coverage results compared to simulations

While all the tracks were obtained and shown in real time, one of the first post-processing activities was to compare the simulation made with the ADT tool to the observed coverage during the flights.

The figure below shows:

- on the left hand side, the superposition of the 10 test flights tracks of the second test campaign. The colours indicate the quality of the detection/track: dark blue no detection up to red 9 detections, i.e. detection of the aircraft by all the bistatic bases. Still on the left the black doted lines aim at reproducing the 90% probability of detection of the simulation to the right.
- On the right hand side, it is a simulation of the Probability of Detection (PoD) for a 1 m² RCS aircraft (UAV type) flying at 900 m above ground level. The scale is nearly the same than for the left hand side figure. The colours indicate the PoD in the sense of what is the probability to have at least 3 detections at the same time. The black level line is for a PoD of 90%, reproduced in doted lines on the left.

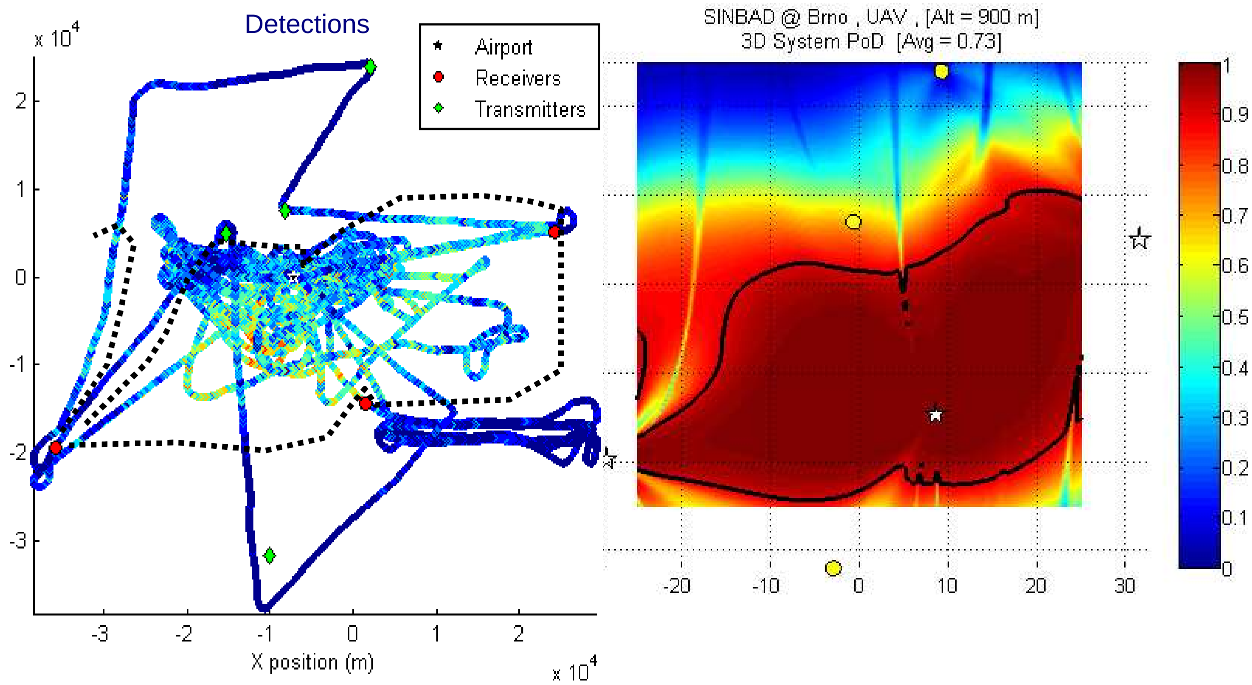


Figure 19. Comparison between a coverage simulation (on the right) performed by the ADT tool and the sum of detections (dark blue no-detections to red maximum) during all the test flights (on the left)

While the entire coverage zone could not be covered by a 2 month campaign its limits were tested. The correspondence between simulation and effective detections observed is impressive. Especially where there are unfavourable detection zones.

As such the first result of the campaign is the validation of the simulation tool ADT to such an extend that it can now be used in operation. This tool was calibrated by the results of the first test campaign and is now at a level of performances better than expected at the start of the project.

This is probably the only existing simulation tool, of MultiStatic passive radar, with this performance level.

3.5.2.2.2 Detailed results of one flight

Let's focus on one flight, the Cessna C172 flight of June 17th, 2010. It has been chosen as its pattern is rather simple. Results for other flights and the other sequences of this one can be found in [P14].

The below figure gives the number of simultaneous detections obtained along the aircraft trajectory. It shows that tracking should be at least possible between the airport and Hradisko, and in the vicinity of the airport.

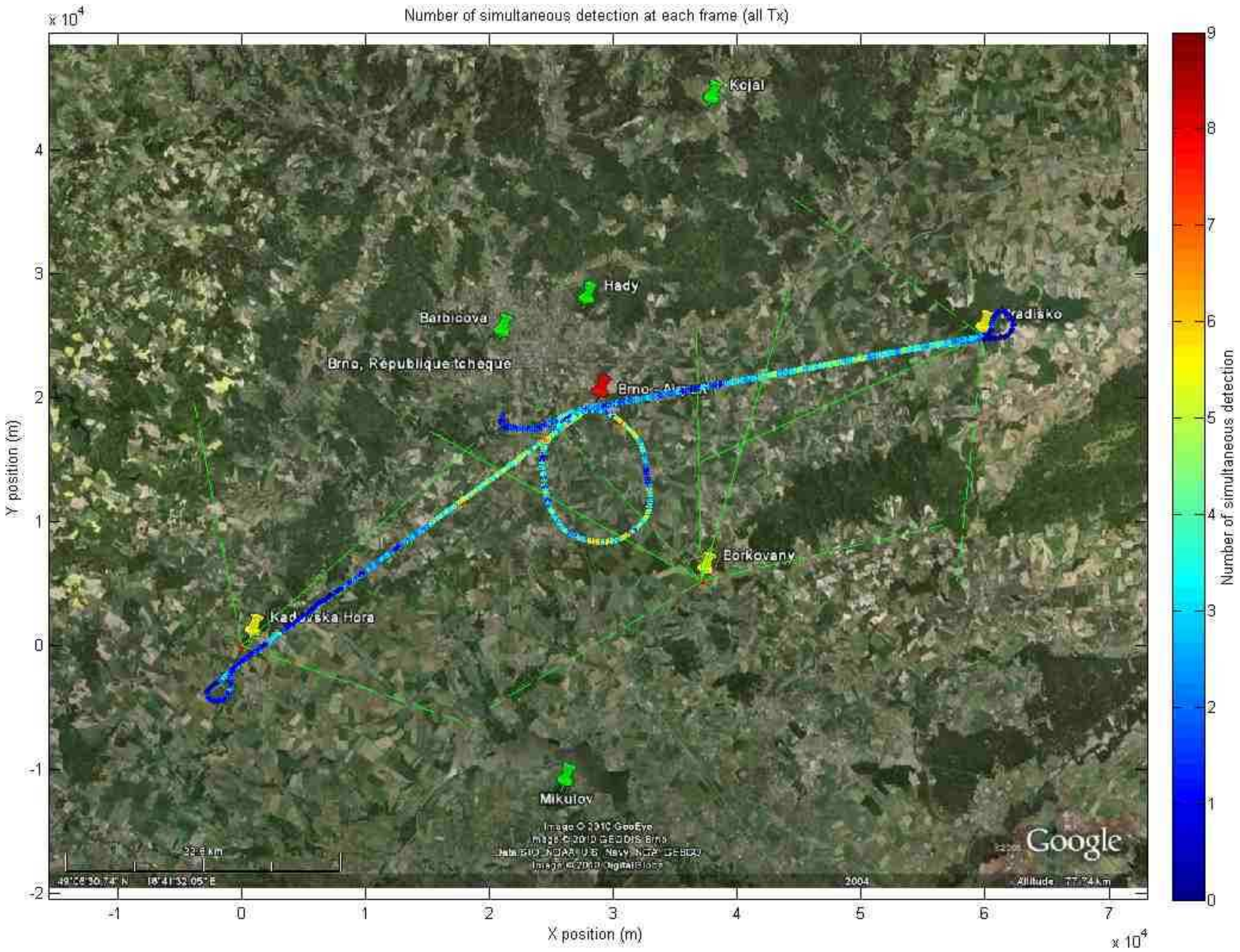


Figure 20. Number of detections filtered thanks to GPS data for Cessna C172 flight, 17 June 2010. The theoretical bistatic range, bistatic velocity and azimuth are obtained for each bistatic bases thanks to the GPS data. Those estimates are compared with the measurements to evaluate the PCL accuracy.

The above figure shows that the aircraft is detected in at least 2 bistatic bases (minimum for tracking, final track is shown in figure 21 on the next page) and on the average more than 4, while it is flying inside the coverage zone. This zone is roughly defined by the angular sectors of the receivers, shown by green segment on the figure.

Looking in more detail at these detections, one can see that they are linked to the transmitters characteristics and receivers location.

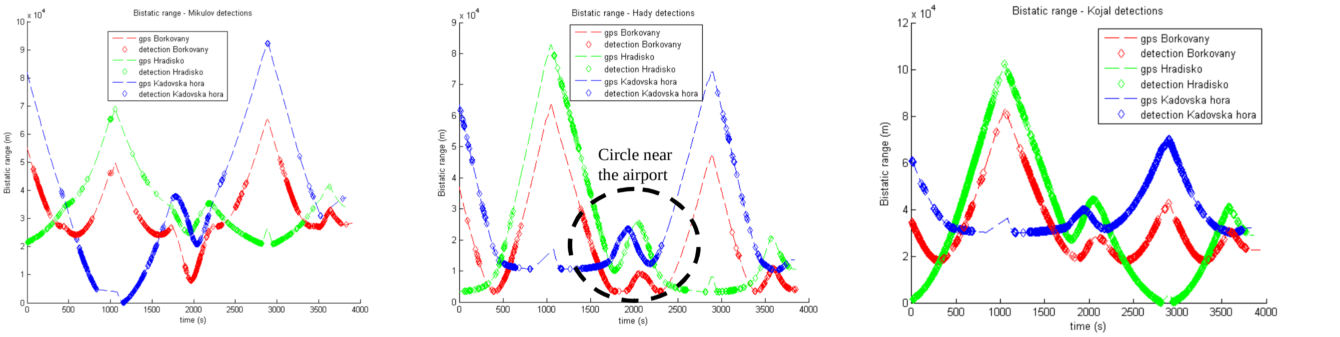


Figure 21. GPS data and measurements for all bistatic bases involving Mikulov, Hády and Kojàl. Dashed lines: GPS position on the aircraft projected in the relevant bistatic base providing the theoretical bistatic range of the target. Diamonds: bistatic ranges of measurement fitting with the GPS data.

While the concept of bistatic range and base is difficult to apprehend one can see clearly that the Kojàl transmitter is providing nearly continuous detection thanks to its high transmitted power. Even with the Kojàl transmitter the aircraft is not detected when it is behind the receivers.
The optimization of the transmitters/receivers geometry is then paramount to the system performance.

Also note that:

- Hády only gives detections when the target is in the vicinity of the airport (for example when the plane is performing a circle near the airport). Hády is a poor contributor for the tracker.
- Mikulov gives some detection for the entire pattern. It is an interesting contributor for the tracker.
- Kojàl is by far the best transmitter. It almost gives 3 detections for the entire pattern.

Now taking a look at the tracker performances the below figure shows an example of track:

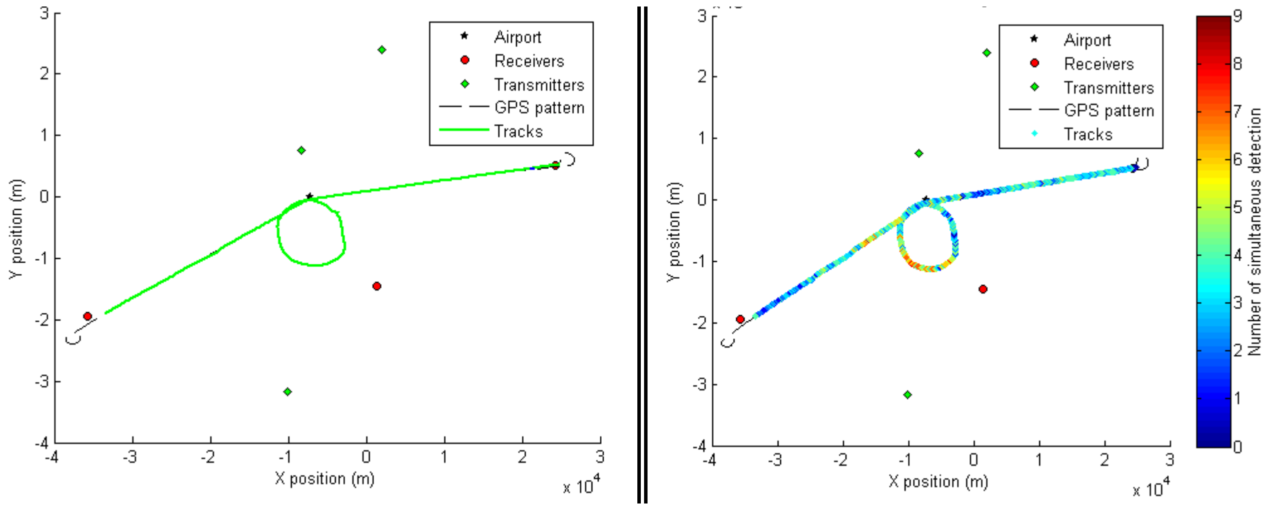


Figure 22. Tracking results for the Cessna C172 flight, 17 June 2010, time is from 1000 to 3000 s. On the left: track obtained with PCL radar for the Cessna C172; one colour corresponds to one track. On the right: number of simultaneous detection used by the tracker to locate the target. Note that X and Y position are in 10s of km.

The most interesting result is that there is only one colour for the track, which means that the aircraft was never lost during the pass. Another point of interest is that the tracker is able to select the relevant detections as well as the filter around the GPS data used to present the detections. The tracker was operating in real time.

Back to the detections considering that the GPS positions are perfect, the accuracy (defined by the standard deviation) of the measurements in bistatic space was on the average of:

- Range : 28-m,
- Speed : 2.4-m/s,

- Azimuth : 3.6°, note that this value, obtained in bistatic space, is greatly improved by tracking. In fact after tracking the angular accuracy is more or less given by the range accuracy. Azimuth measurements in bistatic space are only used to associate plots to Tx during the tracking process.

These average values were obtained across the various test flights run, different aircrafts, altitudes, trajectories ... This performance level is clearly in line with the ATC needs and especially good for a first mock-up. As a reminder typical range inaccuracy for a standard ATC PSR are in the order of 100-m, i.e. 4 times greater.

Development of a product level tracker was not in the scope of the SINBAD program. As such work was focussed on the robustness of SINBAD's tracker design to record as much pertinent data as possible. Results are then only those of a mock-up. In particular sharp turns were poorly handled by the tracker in terms of accuracy. Hence inaccuracy spikes can be seen each time therewas a sharp turn or track loss.

Based on the known performances of other trackers the accessible values for such a system in the same conditions are estimated at:

- Horizontal accuracy : 40-m,
- Vertical accuracy : 200-m.

During this particular flight the aircraft did not flew over ~1500-m or 5000-ft according to the planned scenario. One limitation of the SINBAD's sensor that was expected and observed on opportunity flight (commercial traffic of Brno's airport) lies in the volume covered in altitude by the opportunity DVB-T transmitters. As their main objective is to ensure correct transmission to ground user, their diagram limits transmission to ~5000-ft above the airport's runway. The highest altitude at which an aircraft (a liner) was detected was then around 7000-ft.

it has also been noted that the aircraft position relatively to the receivers/transmitters, had a strong impact on the accuracy, up to a factor 2. So an optimized geometry of the network can greatly improve these figures. For the Brno tests the number of accessible sites was limited. In a product level configuration the site number as well as the number of receivers should be greater.

3.5.2.2.3 Conclusion on the SINBAD's sensor results

With these two test campaigns SINBAD's consortium has conducted the planned work i.e. the system's sensor was evaluated in terms of sensitivity, covered zone, and accuracy, as set in the project objectives:

Sensitivity and Pod	Validated in the 0 to 5.000 ft. range in altitude for aircraft of 1 to 2 m² RCS.
Horizontal accuracy	In the order of 40 m, i.e. 2 times better than standard PSR.
Vertical accuracy	Non-uniform, value increase rapidly when altitude decrease, typically at 200 m for 400 m an altitude of 400 m.

In relation to the state of the art this sensor is clearly ahead of any other existing equipment, particularly in the DVB-T domain of signals. It was developed from scratch with the beginning of SINBAD project. With such a technological step three test campaigns were required instead of the planned two. However the duration of the SINBAD program did not permit to run a third test campaign in a high traffic area, namely Frankfurt.

Nonetheless the results are striking with an elementary accuracy similar to state of the art PSR, SINBAD's sensor has been field proven, in real time at a regional airport CTR, as a feasible alternative to PSR for non-cooperative ATC.

Furthermore SINBAD's sensor has also demonstrated its capacity to reliably tracked aircraft, even ones with an estimated RCS of 1 m², below 500 ft. of altitude and in particular down to touch down on the airport runway. This capacity is a clear improvement when compared to the PSR available on the market.

SINBAD's sensor performances were then verified in the Brno airport area. While the observed robustness was very good, no failure during the tests, more trials in different environment are required to fully assess the sensor's soundness. Furthermore additional studies are also required on the operational concepts: coverage of CTR or TMA zone or as gap filler for existing PSR …, before going to product level.

3.5.2.3 AHA results

The main objective of the AHA system is to assist the controller in charge of terminal-control, by providing alarms, with graduated levels of danger, in case the safety or security of the controlled airspace is to be jeopardized by a non-co-operative target. The assessment of the level of danger will be established to criteria such as:

- the "threatening aircraft" is non-cooperative (detected by SINBAD's sensor or PSR only),
- its track denotes a non-standard behaviour (e.g. not conforming to expected traffic flow, not conforming to air routes, and potential airspace infringement),
- the "time before potential airspace infringement",
- the class of the non-cooperative aircraft (e.g. conventional airliner, small aircraft, helicopter, UAV).

It must be noted that the aim of the AHA module is not to replace existing ATM safety nets, but rather to complement the existing ATM safety nets by using their information in combination with additional surveillance information to detect non-standard aircraft behaviour and to assess the threat posed by such aircraft.

The core of the AHA consists of an NCT classification function and a behaviour/intention monitoring function. To detect non-nominal aircraft behaviour/intentions, in some cases, for instance in case of flow conformance monitoring, it is convenient to model nominal behaviour (e.g. the nominal flow) and in other cases, for instance in case of area infringement monitoring, it is convenient to directly model non-nominal behaviour (e.g. the time to infringement). Based on these models, non-nominal behaviour/intention evidence is determined which is subsequently used to determine the corresponding threat level and whether an alert should be raised or not.

The purpose of this paragraph is to present the results of the validation of the AHA system based on expert judgment. Based on a set of test scenarios with dedicated flights the classification and monitoring functions of the AHA are evaluated by air traffic controllers and system experts. Due to a lack of reference data, a statistical analysis of AHA performance was not possible. As such the validation mainly relies on expert judgment of air traffic controllers and system experts. Furthermore, due to an insufficient number of SINBAD's sensor tracks for the dedicated flights, the AHA performance is mostly validated with Wide Area Multilateration (WAM) data.

3.5.2.3.1 AHA functions and detailed scenarios description

The AHA distinguishes between safety related monitoring functions dedicated to assist the Air Traffic Controllers (ATCO), and security related functions to assist ATM security units. Some of the security related functions are also useful as safety monitoring functions, but were left out of the operational concept with respect to the ATCO.

Only the functions "NCT type classification" in combination with "Area infringement monitoring" are considered safety related functions dedicated to assist the ATCO. The other functions are considered security related functions; however, some of these are also of interest for the ATCO.

Based on the definition of §3.5.2.1, an AHA oriented, complementary description of the scenarios sorted by functions, is presented below:

Scenarios for area infringement monitoring:

- Infringements
  - Flights from A via B to E
  - Flights from C to B and turn to D
  - Flights from A to B to D, entering the area from below after B
  - Flights from A to B to D, entering the area from above after B
- Near infringements
  - Flights from A to B and fast turn back to A

Scenarios for area escape monitoring:

- Flights from D via E to C
- Flights from D via E to B
- Flight from D to E and back to E while climbing to 4000ft

Scenarios for area conformance monitoring:

- Flight around D left and right 360 degrees, speed varying between 90 kts and 185 kts

Scenarios for route conformance monitoring:

- Flights from A to B and fast turn back
- Flights from A via B to E

Scenarios for flow conformance monitoring:

- Learn flow from track data recorded before the flights from C to B and turn to D and verify that these flights are detected as flying not conform the flow.

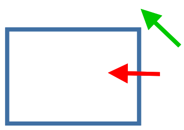
Scenarios for separation monitoring:

- Two flights from A to B and back to A.
  Two aircraft at an altitude around 2000 ft are flying from A to D and back. Above A the horizontal distance between the aircraft is around 2 km. After B the aircraft gradually move towards each other. Above D both aircraft turn back to A, one aircraft making a left turn and the other one making a right turn and gradually bringing aircraft closer together again.

3.5.2.3.2 AHA results and ATCOs' validation results

In this section the test results of the AHA monitoring functions are summarized. Due to a lack of reference data, a statistical analysis of AHA performance was not possible. The validation mainly relies on expert judgment.

It must be noted that the AHA expects decent track information as input and is not designed to accurately track aircraft. Due to a lack of rate of climb or descend information in the current data set, the AHA calculates this information based on the height information it receives, but since the AHA is not designed to accurately track aircraft, the resulting vertical rate is not very accurate. This has a major impact on some of the test results.

Figure 23. **Area infringement monitoring:**  (see figure 17 for box definition)

20 flights with different speeds and heights have been investigated with an average of 4 per scenario. In case the AHA alerting threshold is set to 60 seconds before infringement, for all flights the AHA starts alerting with a time to infringement indication between 50 and 60 seconds with a true alert 15 seconds before actual infringement.

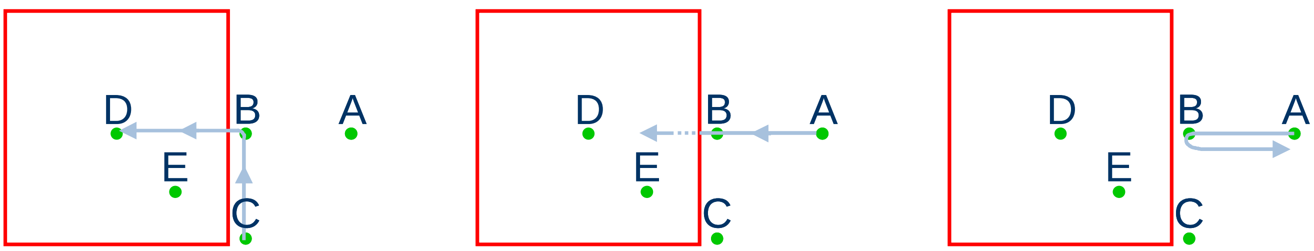
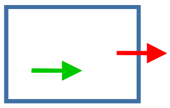


Figure 24. Three examples of flight pattern during the scenarios (see figure 17 for area definition - red boxes)

Due to the inaccuracy of the tracked course and in the case of the B to C trajectory was parallel to the zone for all flights the AHA produces false alerts. Still due to inaccuracy some missed detections occur between 60 and 20 seconds before infringement. In those cases the estimated vertical rate indicates that the intention of the target is to pass the area from above or below.

In case the alerting threshold is set to 0 seconds, the estimated vertical rate has no impact on the alerts anymore and for all flights the AHA starts alerting at the moment the corresponding track state indicates that the target is inside the area.

The main conclusion is that the area infringement monitoring function is most useful when the alert threshold is set to 0 seconds, that is, an alert is raised at the moment of infringement. This conclusion has been confirmed by air traffic controllers. In fact it may be useful in some cases to get an alert a certain time span before the actual infringement to allow the controller to prepare for a resolution action (this also is dependent on the speed of the target). The controllers understand that providing an early alert, e.g. 60 seconds ahead of an actual infringement, may result in false alerts in case aircraft turn away from the CTR at the last moment. The system should basically provide correct warnings 95% of the time and such the alert threshold is best set to 0 seconds.

Figure 25. **Area escape monitoring:**  (see figure 17 for box definition)

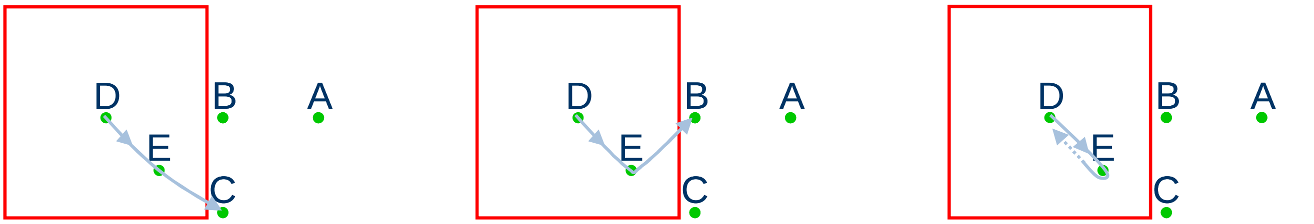
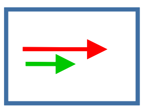


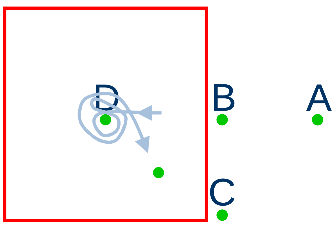
Figure 26. Flight patterns during the scenarios (see figure 17 for area definition - red boxes)

5 flights have been investigated. The AHA issues true alerts some 30 seconds before the tracks are leaving the area. However, due to the inaccurate vertical rate also some false alerts are raised. To reduce these false alerts the number of consecutive internal AHA alerts before sending the actual alert to the ATCO could be set to a value larger than one, e.g. 3. A disadvantage of this strategy is however that it introduces an additional delay to the final alert.

In case of alerting at the moment of escape, the vertical rate has no impact anymore. Since the current version of the area escape monitoring function only alerts *before* the actual escape occurs and not *after* the aircraft has escaped, it has to be modified such that it maintains the alert for a number of scans after a target has escaped the area.

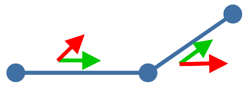
The main conclusion is that the area escape monitoring function is most useful when the alert threshold is set to 0 seconds, that is, an alert is raised at the moment of escape. This conclusion has been confirmed by air traffic controllers who have found the function useful.

Figure 27. **Area conformance monitoring:**  (see figure 17 for box definition)

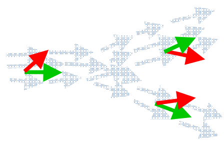


The area conformance monitoring function issues an alert if the speed gets above 175 kts (90m/s). In one occasion, due to an extreme vertical rate, the area conformance monitoring function also issues an alert. Even though the aircraft performed 360 degrees turns, no alert related to this was raised. This was due to the 12x360 degrees standard deviation for the course, which has been deliberately set to this value to allow every possible course in the area.

The area conformance monitoring function effectively detects the intention of an aircraft to deviate from a standard speed or standard vertical rate. The monitoring of speed conformance, especially low speed, can be interesting for ATC to help sequencing aircraft. This conclusion has been confirmed by air traffic controllers but they expressed low interest for the function.

Figure 28. **Route conformance monitoring:**  (see figure 17)

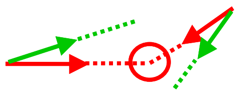
The route conformance monitoring function effectively detects the intention of an aircraft to leave a route. However, it must be noted that, if an aircraft leaves the route at the end of the route, it always issues a non-conformance alert. Since leaving the route at the end of the route is clearly nominal behaviour, these alerts are to be considered as false alerts. Additional logic should be implemented to avoid these false alerts. Furthermore, other aircraft in the vicinity of the route that are not expected to follow the route may cause some false alerts. As such this function is most useful to monitor Standard Instrument Departures (SID) and Standard Arrival Routes (STAR). This conclusion has been confirmed by air traffic controllers.

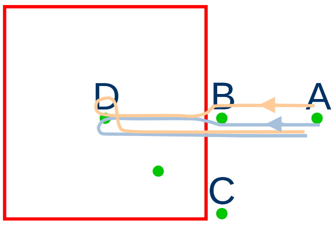
Figure 29. **Flow conformance monitoring**:  (see figure 17)

The flow conformance monitoring function effectively detects aircraft that are not flying according to the learned flow. It must be noted, however, that to reduce the number of false alerts, the flow should be learned from large amount of track data that is representative for the general flow of aircraft. Furthermore, to reduce the number of false alerts in case the operational mode of an airport changes, flows should preferably be learned for all possible types of operational modes.

Furthermore, in case of very flexible routes, the number of false alerts can be relatively high, making this function not useful to air traffic controllers. This conclusion has been confirmed by air traffic controllers.

This function may however be useful to help finding “suspicious flights” in large amounts of track data.

Figure 30. **Separation monitoring**: 



Two aircraft at an altitude around 2000 ft are flying from A to D and back. Above A the horizontal distance between the aircraft is around 2 km. After B the aircraft gradually move towards each other. Above D both aircraft turn back to A, one aircraft making a left turn and the other one making a right turn and gradually bringing aircraft closer together again.

Since the aircraft are flying at a distance to each other less than 2000 meters horizontally and 60 meters vertically, the horizontal minimum separation distance is set to 500 meters, and the vertical minimum separation distance is set to 100 meters.

The separation monitoring function effectively detects potential loss of separation situations. It must be noted however that the minimum separation distance parameters currently function cannot be set separately for different types of flights. Since the minimum separation criteria for IFR and VFR flights are different, this must be taken into account. Air traffic controllers have confirmed this conclusion.

3.5.2.3.3 Non-Cooperative Target Recognition results

3.5.2.3.3.1 Preliminary testing

The first tests of the possible use of the detected targets flight performance in NCT classification had been made at the beginning of the SINBAD projects with use of theoretical models. The simulated track records were applied in the NCT classification based on different identification methods. As the required RCS database development was at first very limited the neural network estimation technology was applied. Due to the complex and opaque structure of these networks further developments in this area were rejected. Choice fell on Fuzzy logic, as it is conceptually easy to understand, flexible, tolerant of imprecise data, it can model nonlinear functions and it is based on natural language.

In terms of RCS database development real measurements from the SINBAD's test campaign, always too few, and simulated RCS were used.

For the simulated RCS three-dimensional VRML models were created built-up with triangular facets. The calculation based on these models as perfectly conducting solid models. Then the flight path was analyzed the Euler, azimuth and elevation angles were determined. For each triangle, a ray-tracing algorithm was applied that was developed to reach simple and fast computation time with acceptable accuracy. Physical Optics integrals were formulated for each illuminated triangle, which were calculated analytically. The radar cross section was summed up to get bistatic RCS from all possible viewpoint.

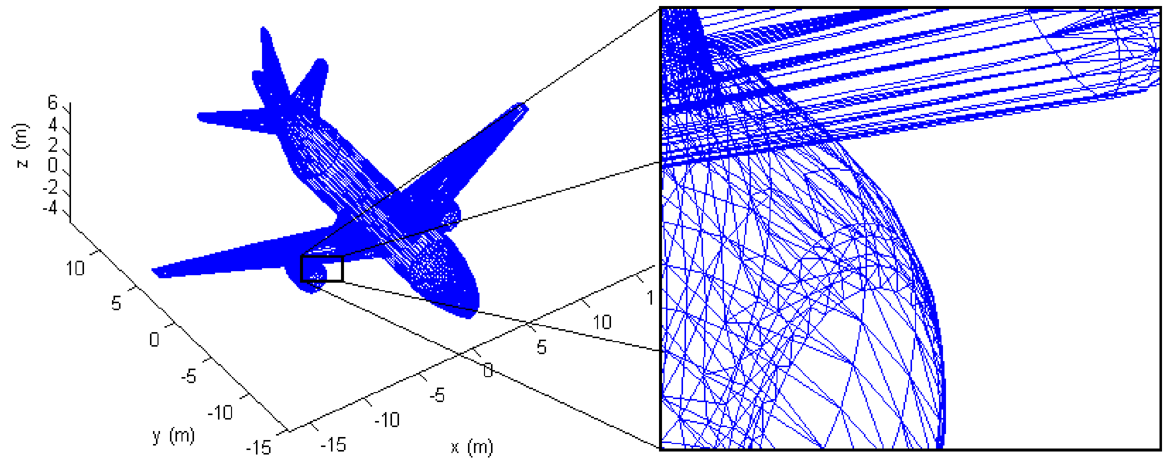


Figure 31. Generic airliner built-up by triangular facets

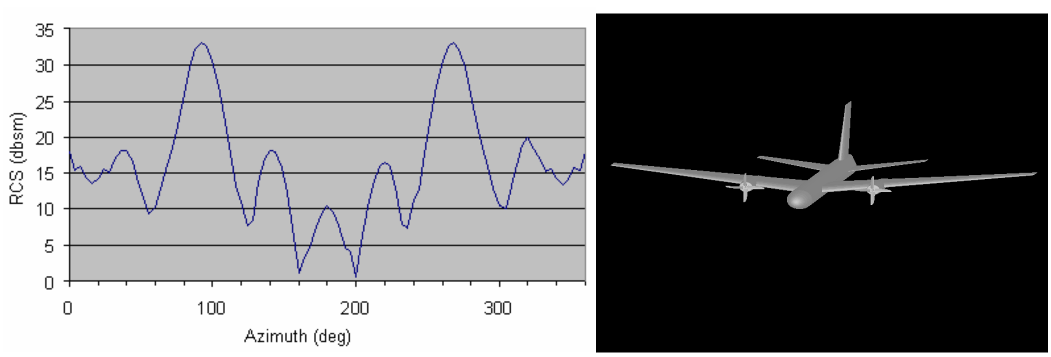


Figure 32. Example of a monostatic RCS from another aircraft type

3.5.2.3.3.2 *Practical tests*

The first practical tests run were dedicated to the tuning of the fuzzy logic classification methods applied to the surveillance data provided by the HungaroControl.

Fuzzy logic is tuned by the parameters for the membership functions, the rules (connection of inputs), and the rule weights. A pre-operational algorithm was made in MATLAB environment. The results of the classification process were the membership values, which are the degree of membership for each aircraft class between 0 and 1. This algorithm was used on a one-day raw data of air traffic over Hungary. Only outgoing air traffic from Budapest Airport was considered. The results are summarized in the below table. The algorithm could classify 99 aircrafts out of the total observed of 102; hence more than 97% reliability. The AvgOut row shows the average belonging probability, which is on the average of 99%. This value reflects the integrity of the classification.

	Small	Medium	Heavy	Sum
Quantity	2	13	87	102
OK	2	12	85	99
OK /%	100	92	98	97.1
AvgOut	1	0.96	1	0.99

Table 6. Results of the classification

An example of the practical test is shown in below figure:

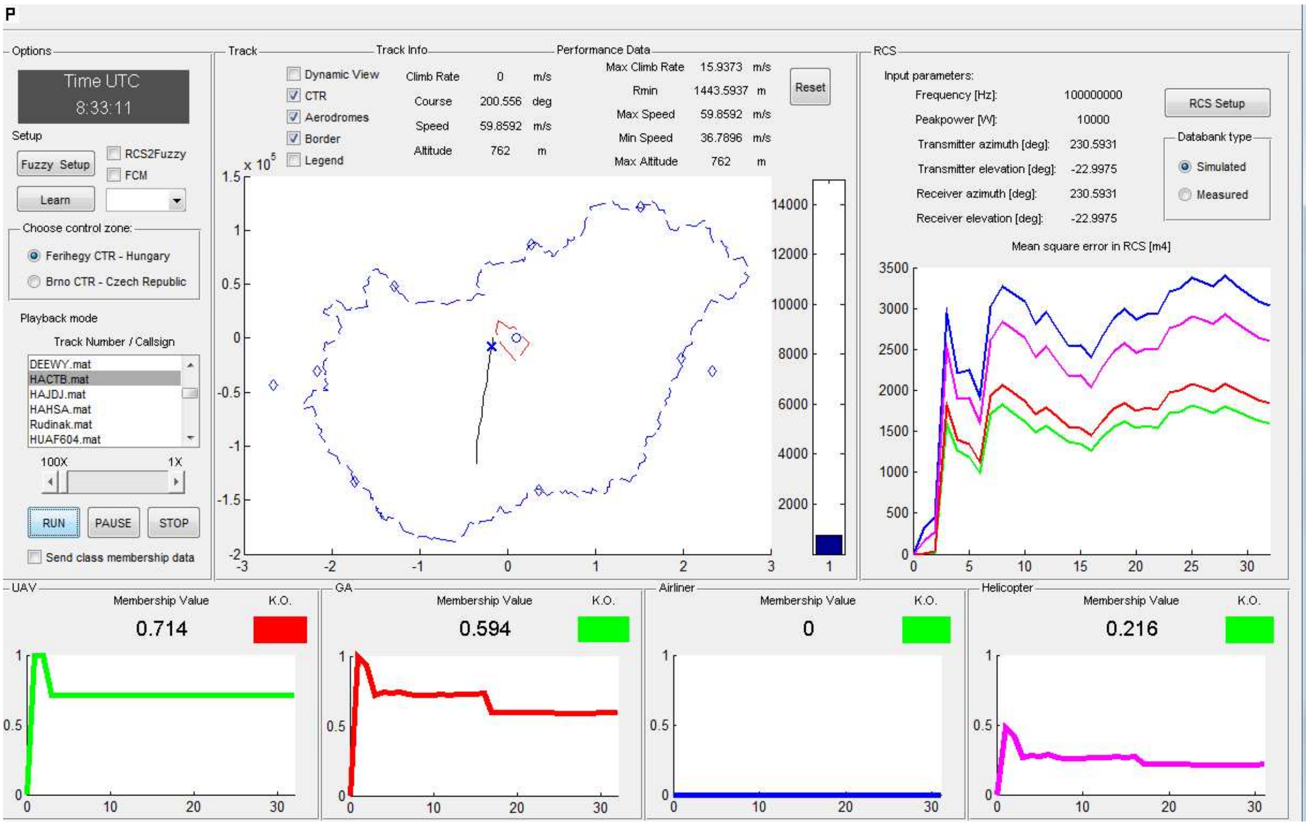


Figure 33. An example of the practical test with using the Hungarocontrol supported surveillance data

The above figure is a screen copy of the technical display/workstation developed for SINBAD. The commands are in the Upper left hand zone “Options” , then to the right the “Track” window with all the relevant data of the considered target including its trajectory above a local map here Hungary. Further right one can find the RCS classification window while at the bottom the evolution of the membership value through time for each of the four defined categories of aircraft: UAV, General Aviation (GA), Airliner and Helicopter, is shown.

The test results demonstrate the good applicability of the developed methods. Especially the classification with using the flight kinematics directly and the fuzzy logic gave the same results, however, the type of targets were limited to the airliners, only.

3.5.2.3.3.3 Specific tests with SINBAD's sensor

The SINBAD project developed a new type of sensor. Therefore the sensor and the developed classification technology were tested in a real environment organised at Brno airport.

The specific tests include some experimental flights realised by using different aircraft types.

Because of the significant errors in the altitude measured by the new sensor, the GPS positioning results were used for testing the developed classification method, as shown below:

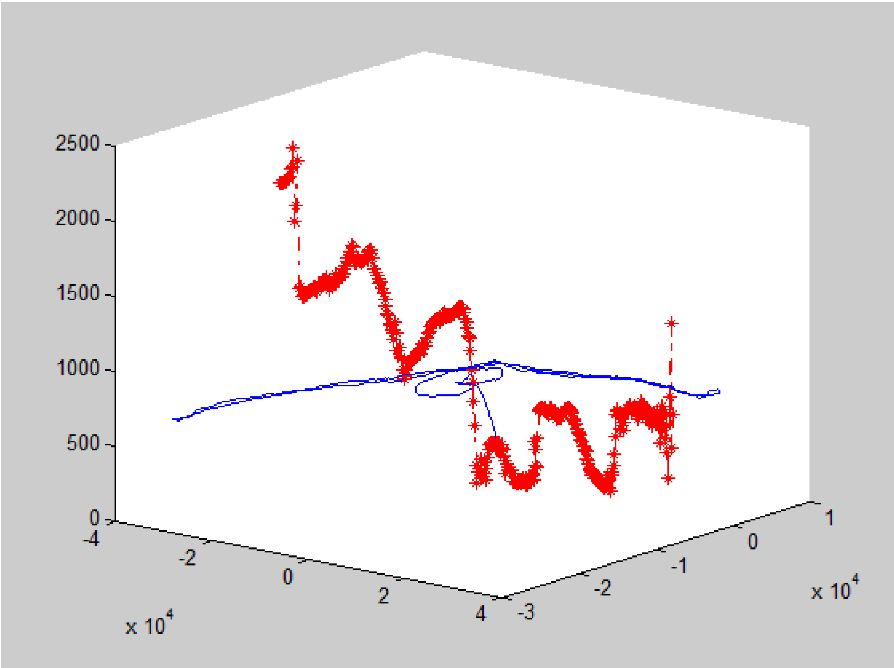


Figure 34. A test flight trajectory rebuilt from the new sensor measurements (red crosses) and GPS (blue points), altitude in ft and horizontal position XY in m.

The below figure presents a typical results of the first test of NCT classification. Unfortunately, the result of the fuzzy logic classification and the classification based on the simple measured kinematics of the targets gave very different results; they were mainly used on a small aircraft during the given test.

Generally, the least square error method calculating the sum of errors of different between the measured and simulated RCS gives good results. However, even in this case the different between the small aircraft and the UAV is not so good. This is why the classification of the big airline aircraft and helicopter are mixed.

The Fuzzy logic could not classify exactly the differences between the small and big aircraft. That can be explained by using the fuzzy logic technology that was not well tuned.

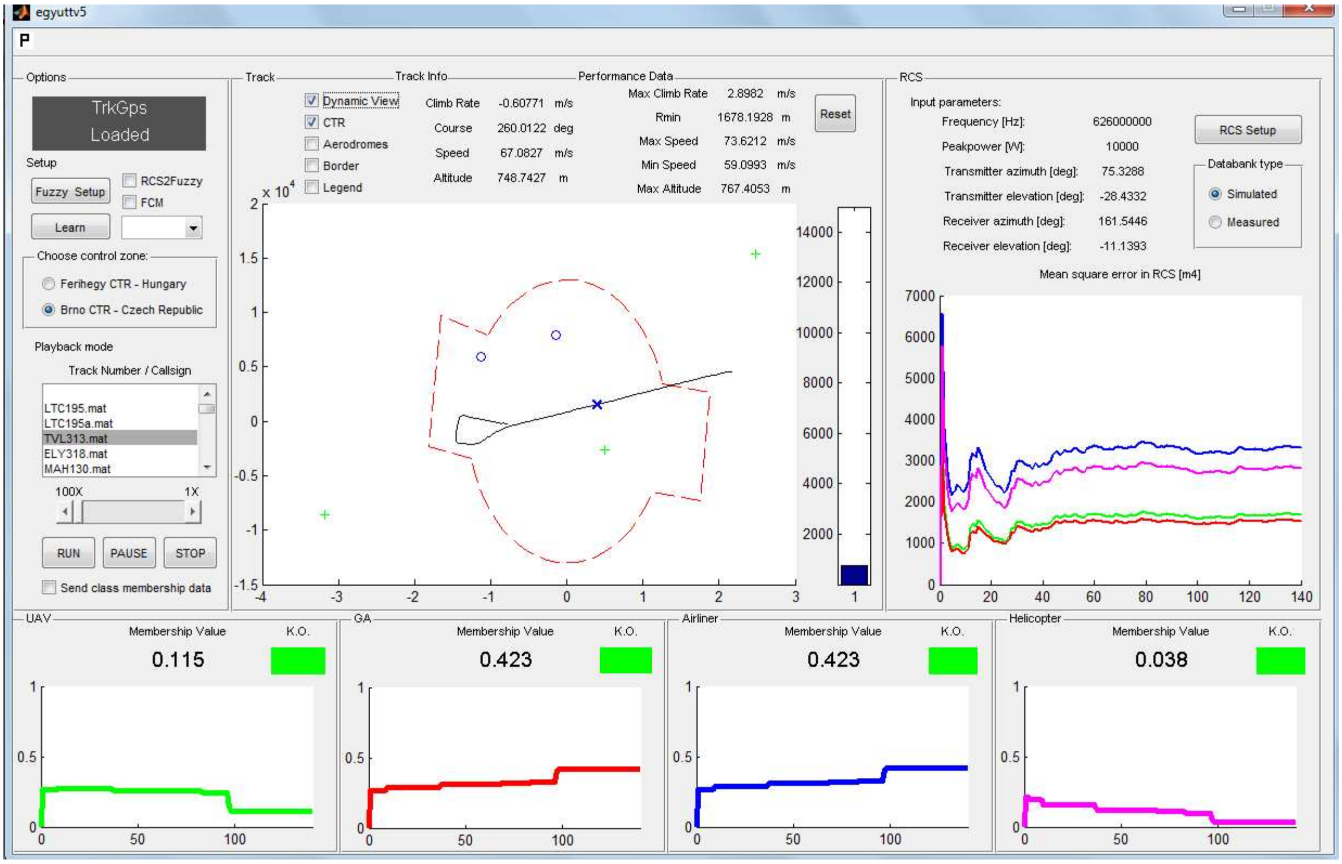


Figure 35. An example of the special test uses the results measured at the landing of the target

Fuzzy logic parameters were then tuned again and a special test flight was run to test it. As it can be seen below during this test the target specifically made a full turn in the horizontal plane. In this way the RCS was measured from every angles and it could be used as initial data for the further classification.

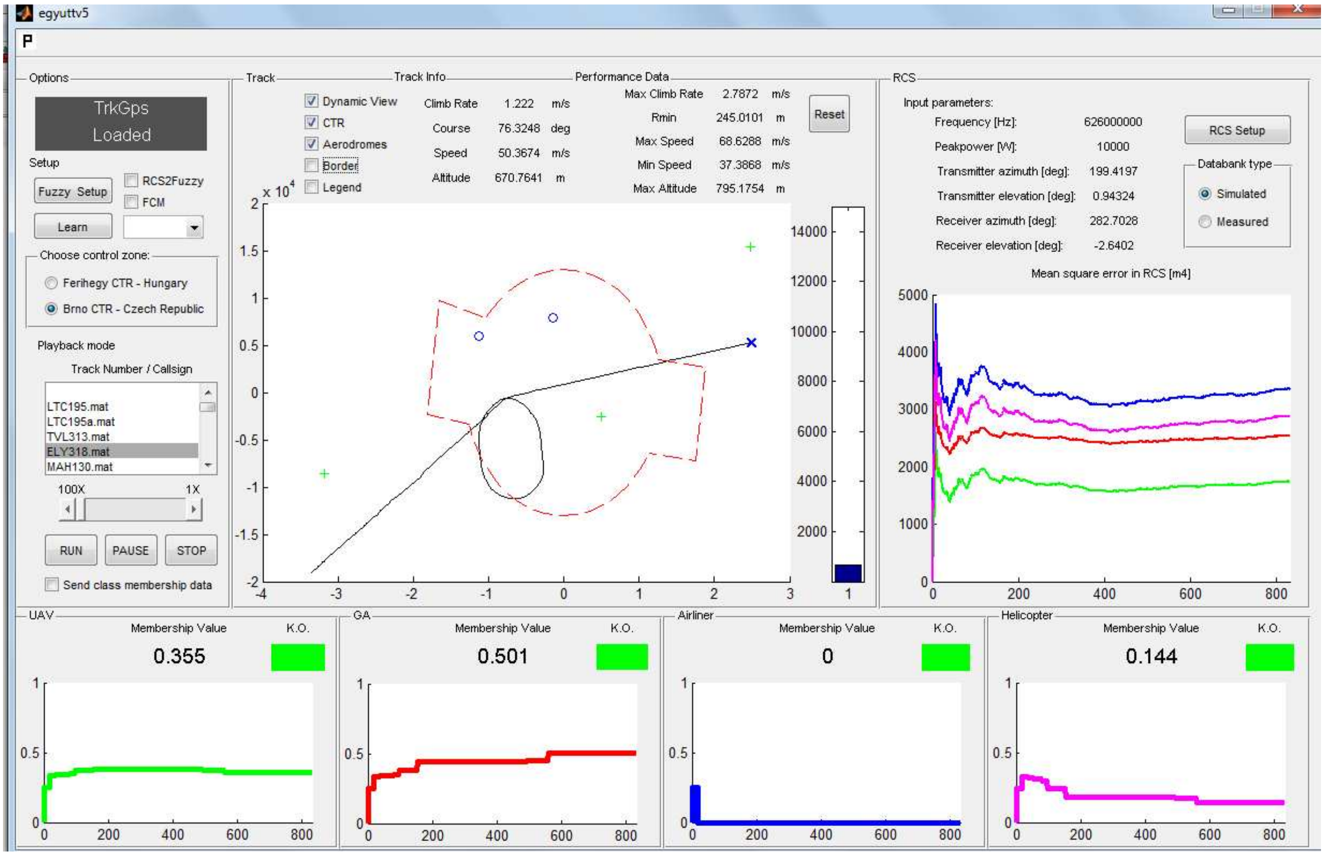


Figure 36. The display of the developed NCT classification tool

In the figure one can also see that the tuned fuzzy logic gave good classification results. The least square method still must be corrected but it is a need that should be covered by the enrichment of the RCS database. By using the measured RCS and the simulated one, too, then the least square method would also be improved.

3.5.2.3.3.4 Conclusions

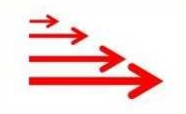
The objectives NCT classification work in the SINBAD project was to develop software to support the investigations on the feasibility of such a classification, and to establish the background for further relevant research. They were fully achieved.

The Active Hazard Assessment NCTR module used radar echo data from SINBAD's sensor to classify NCTs supplemented with the motion kinematics. The performance data were calculated from 4D flight paths, and a fuzzy logic function was created and tuned with statistics on several types of aircraft (28 including B747, A320, MD90, PZL101, C172, Falcon, Zlin142, Predator, etc). The belonging probability was given as a membership value by the fuzzy logic. The accuracy of the results was tested in Brno TMA (Terminal Control Area) with radar measurements in the summer of 2010 as planned.

The calculated data were reliable; the applied assumptions have imperceptible influence on results. However while kinematics provides around 80% accuracy in classification, RCS data were insufficient to complement it to an acceptable operational value.

The method needs further relevant development but the NCT classification is achievable with suitable 3D models and with availability of several different bistatic RCS from SINBAD's sensor independent Tx/Rx pairs. The capacity to classify should be improved by adding more the aircrafts in the database, preferably by measurement but also with additional simulation.

3.5.2.3.4 ATCO's validation of NCT classification

NCT type classification: 

The classification of the target is helpful because together with speed, course, and location it helps detection of the target by other pilots. It provides a kind of "search window" to the pilot to look out for the infringing NCT. Currently the classification consists of four classes, namely:

- UAV, RC model;
- Glider, ultra light aircraft, up to 9 seated, single engine general aviation aircraft;
- Multi engine turbo propeller aircraft, large turbine airplane;
- Helicopter

An additional class "Hot air balloon" would be appreciated by the ATCO's.

(Note that the 4 arrow symbol is here only to represent the NCT classification function and is not a reference to the fictive area of figure 17.)

3.5.2.3.5 Conclusion on AHA results

The AHA has been validated based on expert judgment. Based on a set of test scenarios with dedicated flights the classification and monitoring functions of the AHA were evaluated by air traffic controllers and system experts. Due to a lack of reference data, a statistical analysis of AHA performance was not possible. As such the validation mainly relies on expert judgment of air traffic controllers and system experts. Furthermore, as too few SINBAD's sensor tracks of the dedicated flights were available, the AHA performance was mostly validated with Wide Area Multilateration (WAM) data.

The AHA distinguishes between safety related monitoring functions dedicated to assist the Air Traffic Controllers (ATCO), and security related functions to assist ATM security units. Only the functions "NCT type classification" in combination with "Area infringement monitoring" are considered safety related functions dedicated to assist the ATCO. The other functions are considered security related functions; however, some of these are also of interest for the ATCO.

The test results show the effectiveness of the AHA monitoring functions and recommendations are presented to reduce the number of false alerts. The area infringement monitoring function is most useful when the alert threshold is set to 0 seconds, that is, an alert is raised at the moment of infringement. The area escape monitoring function is most useful when the alert threshold is set to 0 seconds, that is, an alert is raised at the moment of escape. The area conformance monitoring function can be useful to monitor speed conformance, especially low speed to help sequencing aircraft. Route conformance monitoring is most useful to monitor SID and STAR. Flow conformance monitoring may be useful to help finding "suspicious flights" in large amounts of track data. Separation monitoring is useful if it takes into account different separation rules for VFR and IFR flights to avoid false alerts.

The air traffic controllers indicated that besides NCT classification and area infringement monitoring also area escape monitoring, route monitoring and separation monitoring are of interest to them. Area conformance monitoring is of less interest to the controllers, and flow conformance monitoring of no interest to the controllers due to highly flexible routes.

Test results also show that the accuracy of the track state information had a significant impact on the performance of the monitoring functions. Depending on the situation, there is a clear need for accurate height and vertical rate information.

Since the accuracy of the track data has a significant impact on the AHA performance, it is recommended to pursue AHA performance validation on more tracks obtained from SINBAD's sensor data. Furthermore, it is recommended to perform a statistical analysis on missed detections and false alarm rates based on SINBAD's sensor data and the corresponding reference data.

To reduce the number of false alerts, the controllers want to be able to acknowledge alerts so that the alert can be suppressed.

To gain insight into proper alerting threshold times it is recommended to perform real time simulations with the controller in the loop.

Furthermore, it is recommended to study the operational and safety benefits of the introduction of SINBAD and the AHA functions specifically per airport of deployment. Many factors influence the potential impact and benefit, such as local operational procedures, traffic mix, CTR layout, airspace class, surveillance systems, environmental factors, route structure...

Then beyond the present project frame the following extensions should be subject of subsequent research:

- Extension of SINBAD airspace domain associated to a data acquisition campaign,
- Security monitoring of CT (besides NCT) with additional flight plan conformance monitoring,
- Incorporation of conflict monitoring function in AHA that effectively takes into account NCT intentions and manoeuvrability,
- Incorporation of SINBAD's sensor signal processing for improved NCT classification.

To conclude besides the above reported performances of the AHA demonstrator it has proven its capacity as a platform for Safety Nets functions verification and validation with a minimal effort in term of design and disturbances of the day to day ATC operations. At the end of the SINBAD project AHA can be easily plug in parallel to an existing ATC system, with or without Safety Nets functions.

3.6 SINBAD system analysis

3.6.1 Analysis on SINBAD Safety and impact on Safety of ATC

The SINBAD operational concept was validated following the European Operational Concept Validation Methodology (E-OCVM).

ATM safety performance needs have been identified and the safety validation approach has been defined for phase V2 of the E-OCVM operational concept development lifecycle (Feasibility). The safety performance needs for the SINBAD operational concept are based on European regulations ESARR 4 and EC Regulation No. 2096/2005, and on the SESAR project. The safety validation focuses on those elements of the ATM system that are affected by the introduction of the SINBAD operational concept, including SINBAD's sensor and AHA systems. In particular the addition of NCT 3D position, speed and classification information on the ATCO radar screen, the CTR infringement warning and their consequences for the situational awareness of the ATCO are of interest. The geographic scope of the safety validation is the CTR of an airport and the type of accidents and incidents that are in scope are mid-air collisions and airproxes. For this scope, the ATM safety performance needs have been tailored to a SINBAD safety target.

This analysis was conducted in four steps. The first two were dedicated to the Functional Hazard Assessment (FHA) which results are summarized in the following paragraph. The third was a Preliminary System Safety Assessment while the last is the SINBAD Safety case, which results are reported in §3.6.1.2.

3.6.1.1 Functional Hazard Assessment (FHA)

In these steps, the first part of the safety validation in phase V2, a Functional Hazard Assessment (FHA) has been performed. The objective of the FHA is to determine how safe the SINBAD operational concept including the SINBAD's sensor and AHA systems has to be to comply with the ATM safety performance needs. This is done by means of the identification of Functional Hazards for which Safety Objectives are derived.

Assumptions

During the preparation and execution of the FHA, various assumptions have been made. These assumptions are related to:

- the identification of ATM safety performance needs and the tailoring of the overall safety target to the SINBAD scope; and
- FHA parameters (e.g. estimated probabilities).

The results of the FHA are subject to these assumptions. During subsequent safety validation activities in the SINBAD project these assumptions were verified but additional verification are required prior any implementation.

Results

For the SINBAD scope, five Functional Hazards have been identified and for each one, one or more cases are identified. These cases are specific situations of a Functional Hazard that have a different effect on operations. For each of the cases, Safety Objectives are determined. The results of the FHA are summarised in the following table:

ID	Functional Hazard	ESARR 4 severity class	Safety Objective per flight
H1	**ATCO is not aware of CTR infringement by NCT while there is at least one**		
	Case 1: NCT not tracked by SINBAD system	2	5.0E-06
	Case 2: Failed infringement warning	2	5.0E-05
	Case 3: ATCO is not aware of the NCT	3	1.7E-04

H2	**ATCO is aware of CTR infringement by NCT(s) but there is none**		
	Case 1: NCT is shown while there is no NCT	4	1.0E-04
	Case 2: ATCO observes an NCT while there is no NCT	5	no SO
H3	**ATCO has wrong awareness of NCT position**		
	Case 1: NCT 3D position is wrong	2	5.0E-06
	Case 2: 3D position of NCT wrongly interpreted by ATCO	4	2.0E-04
H4	**ATCO has wrong awareness of additional NCT information**		
	Case 1: NCT with wrong information	4	2.0E-04
	Case 2: ATCO misinterprets additional NCT information	4	2.0E-04
H5	**ATCO has wrong awareness of a CT**		
	Case 1: The ATCO is not aware of a CT	4	1.7E-04

Table 7. Functional Hazard Assessment (FHA) results

3.6.1.2 Safety case

This step presents the safety case of the R&D project SINBAD. This R&D safety case has been developed for the SINBAD concept based on the safety analysis activities that were separately performed in the SINBAD project. The R&D safety case follows the guidance from the European Operational Concept Validation Methodology (E-OCVM), the applicable validation framework for safety analysis in European ATM R&D projects [E-OCVM, 2010]. As well explained by E-OCVM, concepts in R&D often need further development or redevelopment before being optimized with respect to all key performance areas of ATM. Therefore, the purpose of a safety case in R&D is to provide relevant information on safety aspects of the concept to decision makers, and operational feedback regarding the concept to concept developers.

Identified objective of the safety case

The objective of the R&D safety case has been determined, including identification of the stakeholders of the SINBAD concept, the stakeholders' ATM need with respect to safety, and the level of maturity of the SINBAD concept:

- Identified stakeholders involved in the SINBAD project are Regulators (Eurocontrol and the European Commission), the German and Czech ANSPs (DFS and ANS CR, work was focussed on these two ANSPs as representative entities as they were partners in the SINBAD consortium), human operators (air traffic controllers and pilots) and manufacturers (ATM and surveillance systems).
- For these stakeholders, an appropriate ATM need has been derived in line with the safety targets in current regulations and in SESAR, and their main rationale that absolute numbers of accidents and risk bearing incidents should not increase, despite traffic growth. The identified ATM need for safety is that where the SINBAD concept is introduced, it should lead to a reduction in risks of incidents and accidents related to NCT infringement that is sufficient to account for traffic growth until 2020.
- It has been determined to develop a safety case for the SINBAD concept in E-OCVM phase V2 (Feasibility). According to E-OCVM, the objective of safety analysis in phase V2 is to determine the feasibility of the concept and to provide safety feedback to the concept development process. Here, feasibility is interpreted as the feasibility of developing the SINBAD concept further to reach the identified ATM need for safety.

Adopted approach in determining safety case results

As a first step in determining the safety case results, the safety analysis activities performed in the SINBAD project were summarized. To this end, the scope and approach adopted in those activities were described, with specific attention for how evidence has been derived that support the results of these activities. Also, a summary was provided of the arguments resulting from these safety analysis activities. Since these activities were performed without the availability of specific E-OCVM guidance on safety case development, a comparison was made of the scope and approach adopted in those activities with the guidance provided by [E-OCVM, 2010], resulting in a number of observations. Then the safety case results were determined by using identified arguments from the safety analysis activities and from analysis of the consequences of identified assumptions and observations.

Safety case results

SINBAD is estimated to deliver a significant positive effect on safety, sufficient for ensuring that the absolute numbers of accidents and risk bearing incidents that are related to NCT infringements do not increase, even when accounting for traffic growth as expected in the 2020 timeframe. This estimate is based on direct expert judgement from a small group of controllers and on operational experience with the NATS' airspace infringement warning system.

For illustration purposes, the below tables present quantitative and qualitative results regarding the safety benefit of SINBAD, which also serves as input to the business case. Care should be taken in the use of the quantitative results, since they are based on estimations by a small group of experts without operational experience with SINBAD. However this restriction is solely due to the fact that the SINBAD product only exists at a mock-up stage, as per the project scope. Then to conduct the safety case assumptions were made that the product in its final form will be state of the art in terms of Man to Machine Interface and with at least standard PSR level of performances.

CTR infringements by NCTs			*CTR infringements by CTs*		
Severity	*Without SINBAD*	*With SINBAD*	*Severity*	*Without SINBAD*	*With SINBAD*
Accident	0%	0%	Accident	0%	0%
Serious incident	10%	1%	Serious incident	3%	0%
Major incident	10%	2%	Major incident	4%	1%
Significant incident	25%	17%	Significant incident	22%	15%
No safety effect	55%	80%	No safety effect	71%	84%
Total	*100%*	*100%*	*Total*	*100%*	*100%*

Table 8. Estimated percentage of CTR infringements per severity class for NCTs and CTs

With SINBAD	**Summarized comments**
NCT detection	SINBAD gives the ATCO information about the direction, speed and classification data of the NCT such that ATCOs are more aware of possible traffic before they enter the CTR.
Infringement detection	SINBAD could be really helpful in detecting CTR infringements by NCTs, but at an airport with many a/c unequipped with a transponder this tool might be disturbing.
Conflict detection and resolution	It will be easier to detect an NCT and once there is an infringement and a potential conflict, the resolution will be better coordinated with the other aircraft as the exact location, speed and altitude of the NCT are known. It could be hard to find a solution for a conflict if the airspace is confined. The resolution of the airspace infringement or conflict will be easier when reliable altitude information is available. But even if the altitude accuracy is low, it could still be helpful to know in which altitude band an NCT is moving.
Workload	In normal operations the SINBAD system will introduce a little bit more workload to monitor the additional NCT targets, but this is not a great concern. In non-normal operations, workload will be reduced and it will be easier to solve the airspace infringements and potential conflicts.
Capacity	The controllers estimate that the impact on the capacity in the CTR is minimal. The TMA capacity may increase according to the controllers, but it is not possible to quantitatively estimate the improvement as so many factors play a role.
Potential	For CTs the benefit of SINBAD is less than for NCTs, because CTs are already

benefit for CTs	detected, tracked, and monitored through SSR. An airspace infringement alert is useful for both NCTs and CTs. However, the main improvement achieved with SINBAD, and therefore the main benefit, lies in the detection and tracking of NCTs.
What is the operational benefit?	SINBAD and AHA will definitely help in detection and monitoring of NCTs. It would be a major improvement when ATC would be able to see NCTs on the radar. Another major benefit is the availability of altitude information from the SINBAD system for such targets. The classification of the target is helpful because it supports detection of the target by other pilots. Also, service can be continued if a CT becomes an NCT. All together SINBAD can give controllers better tools to detect infringements and conflicts, so the additional confidence will add some comfort to working environment.
What is the safety benefit?	The safety benefit is in the reduction of the number of separation infringements in which an NCT is involved. Other traffic can be arranged around the infringing NCT and information about it can be provided. Increasing comfort in the working environment and reduction in workload can increase the overall safety assurance. Deployment of CAIT in the UK has demonstrated that it strengthens the safety delivery of the Air Traffic Service within controlled airspace.

Table 9. Qualitative safety and operational benefit of SINBAD

The main safety case results are then summarized as follows:

- There is reasonable confidence that the SINBAD concept is feasible from a safety perspective. Accordingly, the expectation is that the SINBAD concept can meet the identified ATM need of contributing proportionally to the absolute number of NCT infringement related accidents and risk bearing incidents not increasing or even decreasing. The confidence is based primarily on analysis using two different approaches (FHA/PSSA and a relative safety analysis) and on judgements of operational experts and safety experts.
- While there is reasonable confidence that the SINBAD concept is feasible from a safety perspective, there is still a significant level of uncertainty. The main factor in this remaining uncertainty is that complex interactions between various elements of the concept could only to a limited extent be taken into account, while such interactions feature human performance and the possibility of emergent risk. Another important element that has received limited attention is the analysis of situations in which no ground-based hazard occurs. Less significant factors in the remaining uncertainty are limited availability of evidence for the feasibility of identified safety requirements, limited availability of experience with SINBAD and confirmation of ATM needs by stakeholders.
- Since a significant level of uncertainty remains about the feasibility of the concept, the magnitude of the safety benefit that can be delivered by SINBAD cannot yet be further specified. A SINBAD system nearer to product level is needed to proceed. Nevertheless, with the sole assumption that the concept is feasible some detailed information from the safety case has been fed to the SINBAD business case. In the business case the feasibility of the SINBAD concept with respect to cost-efficiency is investigated with an evaluation of the magnitude of the safety benefit.

Recommendation

It is recommended to have the further development of the SINBAD concept (e.g. in E-OCVM phase V3) be accompanied by further safety case development activities, in such a way that uncertainties about the safety of the SINBAD concept are further reduced. Then, it is suggested to focus more on analyzing well the interactions between concept elements, on human performance, and on situations in which no ground-based hazard has occurred. Furthermore, more attention could be given to generating more evidence for the feasibility of the identified safety requirements, confirming the stakeholders' ATM needs, and detailing the expected safety benefit of the SINBAD concept.

3.6.2 Security case

During this project a preliminary version of the Security Case for SINBAD was run in the context of the European Operational Concept Validation Methodology (E-OCVM). Guidance material for building a safety case was used, due to the lack of guidance on building a security case in the E-OCVM.

3.6.2.1 Security case methodology

Security analyses in the SINBAD project were performed with a new methodology designed from the safety case one. The security case methodology that is used prescribes, within the scope of the SINBAD project, three consecutive security assessments:

- The Baseline Security Assessment (BSA), which determines the baseline - the security risk of the current operation - against which the SINBAD system later will be analyzed by providing.
- The Initial Security Assessment (ISA), based on the SINBAD operational concept description, investigates the risk of the relevant threats to the aviation system based on the protection provided as described in the SINBAD operational concept description. Moreover, the effect of the integration of the SINBAD concept on the current operation is analyzed, using the results of the BSA as a reference. The initial security assessment provides the security objectives, which the SINBAD functional design should be able to meet.
- The Pre-Implementation Security Assessment (PISA), which is based on the actual SINBAD architecture description. This can include possible countermeasures based on the results from the ISA. The risk of threats to the SINBAD architecture is assessed, as well as the effect of the integration of the SINBAD concept on the current operation is analyzed, using the results of the baseline security assessment as a reference. The aim of the PISA is to provide security requirements that have to be met by the system design for the security objectives to be reached; this can include mitigation achieved through system configuration e.g. redundancy, or possible countermeasures introduced into the system design.

Each of the security assessments follows the same methodology. After having set the scope of the assessment, the assets that are within the scope are identified. Threats to and vulnerabilities of the system are then identified using brainstorm sessions. Based on expert judgement, the risk level associated with each threat is finally derived, using the impact and potentiality of the threat.

But first, the stakeholders, the validation objective and the validation scope were identified as prescribed in the European Operational Concept Validation Methodology.

The stakeholders involved in SINBAD are regulators, ANSPs and in particular the ones of Germany and the Czech Republic that were partners of the SINBAD's consortium, human operators such as air traffic controllers and pilots, and system manufacturers (ATM and surveillance systems).

The objective of security analysis is to determine the feasibility of the concept and to provide feedback on security to the concept development process. Here, feasibility is interpreted as the feasibility of detailing the SINBAD concept further to reach the ATM need for security. The SINBAD program intends to improve aircraft safety and security. The main focus of the SINBAD system and operation is on the detection and monitoring of Non-Cooperative Targets (NCTs) and the detection of airspace infringements. An investigation of the actual needs of relevant stakeholders with respect to security and other key performance areas, or of ATM barriers that need to be alleviated, was not part of the scope of work of the SINBAD project.

The SINBAD concept should improve security by improving situational awareness about NCTs, detection of infringements of (restricted) airspace, and a threat assessment function. Currently, there is no guidance or standard available representing a Target Level of Security or expressing what level of security risk would be acceptable to stakeholders. Therefore the SINBAD project adopted the criterion that the introduction of the SINBAD system shall not increase current level of security risk and that the SINBAD system must be specified such that the risk related to threats introduced by the system compare favourable to the risk of threats caused by other types of surveillance/monitoring systems in the current operation.

The security case provides results and feedback that are required for concept developers to develop a secure system and provide stakeholders with information to make a decision on further development or redevelopment.

The scope of the Security Case is limited in geographic sense to the Control Zone of an airport. The focus is operationally on non-cooperative targets, and functionally on those elements of the ATM system that are affected by the introduction of the SINBAD operational concept. The triggering of protection measures is not within the scope of this assessment. The core of the Security Case is the Security Argument for SINBAD.

3.6.2.2 Security Argument for SINBAD

The argument rests on two pillars. Firstly, the risk of current security threats to the operation should not increase as a result of the introduction of SINBAD. Furthermore, the risk associated with new threats that can be targeted to the SINBAD system should compare favourably to similar types of threats to current operations.

The Security Argument is presented here using Goal Structured Notation.

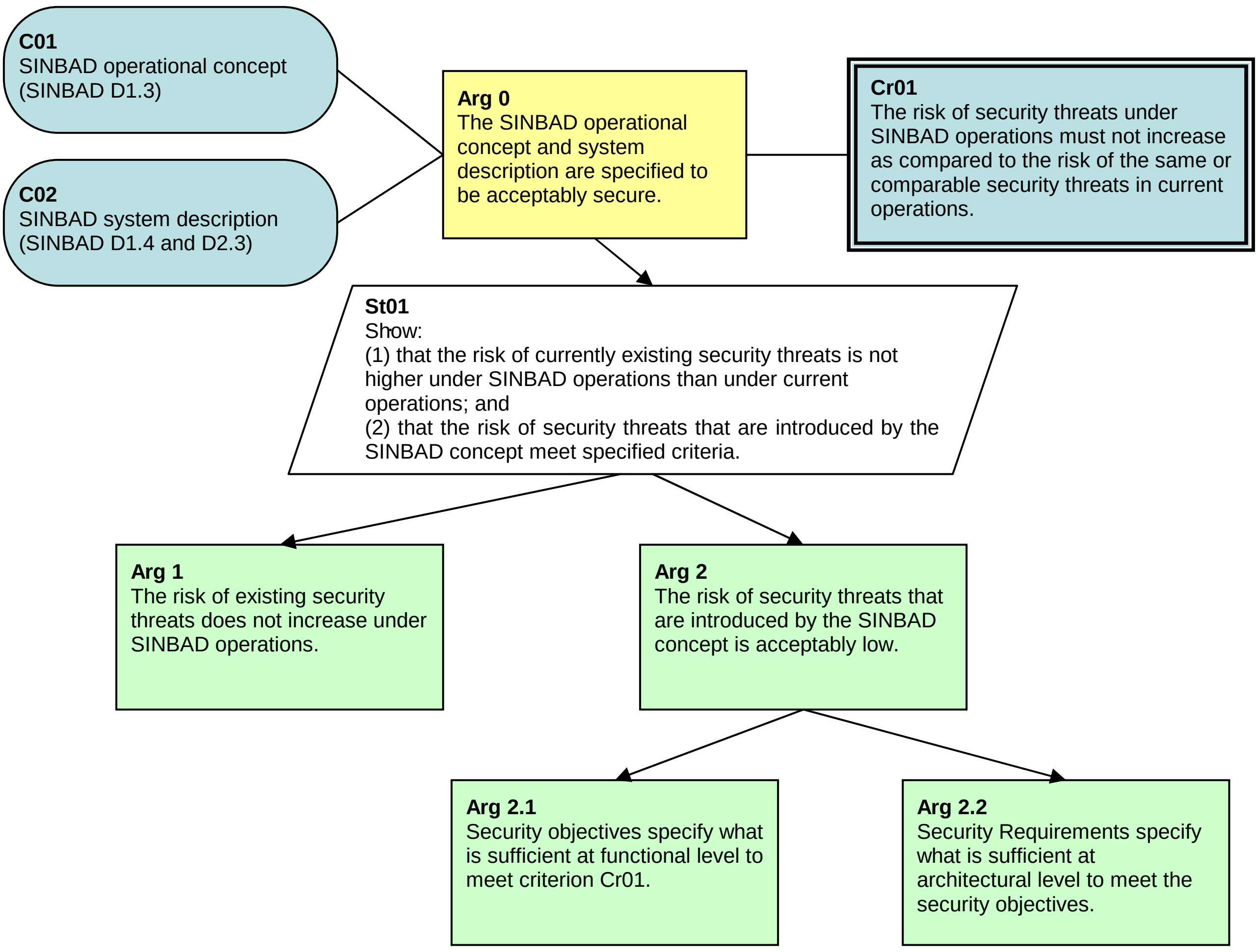


Figure 37. Security Argument for the validation of the SINBAD Operational Concept

The proof that supports the first argument (Arg 1 above) was found in a comparison of the results of the baseline security assessment (BSA) of the SINBAD system with those of the initial security assessment (ISA). The security risks of 15 threat scenarios, representing the currently known security threats, are equal or – in one case – lower when SINBAD is implemented, than in the current situation where SINBAD is not implemented. This result is valid for large and medium-sized airports; no effect was found for small airports.

Supporting evidence for the second argument (Arg 2 above) is provided in two steps. First, the ISA formulated 3 Security Objectives that specify the level of security that is sufficient at a functional level so that security risk does not increase due to the operation of SINBAD. Subsequently, a pre-implementation security assessment (PISA) identified the security vulnerabilities on an architectural level, and defined 17 Security Requirements that, if met, ensure that SINBAD will achieve the specified level of security.

3.6.2.3 Security requirements

A Pre-Implementation Security Assessment (PISA) was performed to identify security vulnerabilities in the SINBAD system architecture and to assess their resilience to intentional interferences. The PISA assures that the SINBAD system architecture meets the security objectives, defining security requirements on SINBAD system components where necessary. Security requirements are stated as measures to reduce the likelihood and, in some cases, the impact of a threat. They are not to be confused with the threat scenarios, representing the currently known security threats, from which they are in fact derived.

The PISA followed a three-step approach. First, the relevant SINBAD data components and system components needed to be identified that play a role in each of the three SINBAD specific threat scenarios.

The identification was based on the SINBAD System Requirements and on the SINBAD Global Architecture Design. Next, the possible attack methods within a threat scenario had to be identified. Finally, the risk of an attack on a system component was assessed.

This assessment involved classifying the impact of attacks on a particular system component, and classifying the potentiality of choosing a specific attack. The resulting risk levels as derived for each data or system component were summed over the components and the result was subsequently compared to the Security Objectives formulated above.

Wherever the cumulative risk of the data/system components exceeded the risk allowed by the Security Objectives, security bottlenecks needed to be identified and countermeasures reducing either the impact or the potentiality of an attack method on a system component were determined. These countermeasures form the security requirements for the SINBAD system.

Number	Security Requirement
SecR1	The PCL-subsystem shall be equipped with a firewall.
SecR2	The PCL-subsystem’s sensitive ports shall be protected.
SecR3	The PCL-subsystem’s unused ports shall be closed.
SecR4	Lockout policies shall be applied to end-user accounts on the PCL subsystem to limit the number of retry attempts that can be used to guess passwords.
SecR5	Default account names shall not be used on the PCL subsystem.
SecR6	Failed logins on the PCL subsystem shall be audited to identify password cracking attempts.
SecR7	The data on the PCL subsystem shall be encrypted.
SecR8	Accessing software in the PCL subsystem shall require additional authentication.
SecR9	Changes in the PCL subsystem software shall be logged.
SecR10	The PCL-subsystem shall be equipped with anti-virus and anti-Trojan software.
SecR11	Personnel authorized to access the PCL subsystem shall be screened.
SecR12	Access to the PCL subsystem shall be logged.

SecR13	Measures to detect and trace IP-spoofing shall be installed on the Ethernet data link from the PCL subsystem to the pLines.
SecR14	Measures to detect and trace IP-spoofing shall be installed on the EUROCAT-C Network.
SecR15	Accessing software in the AHA PC's shall require additional authentication.
SecR16	Personnel authorized to access the AHA PC's shall be screened.
SecR17	Access to the AHA PC's shall be logged.

Table 10. Security Requirements for the SINBAD system architecture

The PISA delivered Security Requirements as was demanded by security argument 2.2. However, the validity of the results remains uncertain for the following reasons:

- The methodology used to derive Security Requirements is new and should be reviewed by independent security analysts. Especially the impact and potentiality tables employed in the methodology need to be reviewed.
- The impact and potentiality classifications in the PISA were performed by analysts and should be reviewed by ATM and security experts.

3.6.2.4 Security case conclusions

The following main conclusions are drawn from this study:

- There is reasonable confidence that the SINBAD concept is feasible from a security perspective;
- The extent to which the SINBAD system can contribute to a higher level of security remains to be evaluated;
- The security methodology applied in this study can deliver the type of results that are required to develop a secure system.

The following is recommended to:

- To determine explicitly the stakeholder's ATM needs with respect to the security of the SINBAD concept and the security related function of SINBAD;
- To perform additional validation exercises to assess the extent of the security benefit of the SINBAD concept;
- To gather more evidence for the feasibility of the security requirements to improve confidence in the feasibility of the SINBAD concept from a security perspective.
- To perform an independent review of the methodology that was used in the security assessment activities within the SINBAD project;
- To review the impact and potentiality classification for all identified threat scenarios more carefully;
- When the SINBAD system is to be implemented genuinely in an operational environment, an additional security assessment will be required to take into account the specific conditions in which the SINBAD system is to be operational.

3.6.3 Business case

For the SINBAD project the business case tasks were the description of a Cost Benefit Analysis (CBA) methodology and the analysis itself. The objective is to quantify the impact in terms of economic benefits arising from the implementation of the new Sinbad system. The assumptions were retrieved from other tasks of the project and particularly from Safety and Security cases. The impact is calculated for three European airports Frankfurt, Brno and Egelsbach. These are the airports on which trials were planned or have taken place in the project. This economic analysis has compared the new scenario with the Sinbad system to a 'business as usual' situation without the Sinbad system.

3.6.3.1 Methodological framework for the Costs & Benefit Analysis

A thorough set-up of a framework for project appraisal avoids double-counting costs and benefits. It comprises the following steps:

- Defining the problem area is a first step in conducting a CBA. The scope of the assessment needs to be determined. It should clarify what the objectives of the CBA are.
- Extensive stakeholder analysis, identifying all stakeholders that are affected by implementing SINBAD.
- Identification of costs categories for each stakeholder.
- Identification of benefit categories for each stakeholder.
- Specification of transfers between stakeholders, as it is important to be aware of double-counting in this respect. Elements that could be defined as a cost for one stakeholder might be a revenue for another stakeholder, for example ATC charges.
- Definition of CBA characteristics: what has to be evaluated for the project? E.g. base case, project case(s), geography, time horizon, discount rates, decision rules and other practical issues.
- Specification of sensitivity analysis: identifying (and justifying) alternative assumptions on costs, benefits and timing.

The actual CBA assessment mainly consists of a series of steps:

- Development of the baseline as a basis for comparison with the SINBAD approach. An assessment is made of the effects that will take place in a scenario with SINBAD compared to the baseline. This may concern operational improvements, security improvements and safety enhancements.
- Calculation of the costs of the project for each stakeholder: R&D-costs, implementation costs, operation- and maintenance costs, termination costs.
- Quantification and monetarisation of effects for all stakeholders: this step will translate the effects derived in the step before into monetary terms, based on test results on two airports. E.g., the value of extra capacity will be assessed, and the safety and security effects will be expressed in euros as much as is possible. Those effects that will not be taken into account will be included as pro memory items.
- Trade-off: finally the costs and benefits will be balanced, and these will be expressed in indicators such as net present value (NPV), Internal rate of return (IRR) and payback period. In addition, the analysis will be broken down to (groups of) stakeholders (E.g. public (EU, governments) and private (individual airports, airlines))
- Sensitivity analysis: The outcomes of CBA in terms of NPV or related indicators, however, are meaningless if the underlying *assumptions* are not soundly based. Assumptions regarding the physical size of costs and benefits, as well as prices and timing should be reviewed systematically. This is done by determining the NPVs (the output) for different assumptions regarding costs and benefits (including prices and timing) while the other variables are set to their base values.
- The CBA outcomes are based on the test results of SINBAD on two airports: Frankfurt and Brno. The results from these cases will provide a basis for analysis of the effect of SINBAD implementation in the wider European area.

3.6.3.2 Definition of CBA characteristics

Investment appraisal in general, and cost-benefit analysis (CBA) in specific, is the formal process that provides and formulates a framework within which investment decisions can be made.
Measures are assessed according to criteria such as costs, revenues, socio-economic benefits and risk.

Evaluations have to distinguish public vs. private, collective vs. particular (or individual) interests. In CBA, it is important to bear in mind that different sectors/stakeholders will often have different objectives.
Since the analysis necessarily should reflect the appraiser's objectives, the impacts included in the analysis, the importance given to the various impacts as well as the discount factor used is determined by the interest of the appraiser.
It follows that the outcome of an analysis may differ depending upon the stakeholders' viewpoint is taken. For instance, the outcome of a CBA may be different for an airline than for an airport.
Furthermore, benefits of a certain measure could fall very unbalanced compared to cost for a stakeholder: it may be possible that an airline bears the cost of an alternative, but that other stakeholders largely benefit from the alternative.

A CBA from a societal perspective is often called a socio-economic cost-benefit analysis. A socio-economic CBA involves the identification of all effects of a project[5] on the welfare of all members of society.
In welfare economic theory this is expressed in utility, which is a rather intangible measure. A common unit of measurement is required to establish whether aggregate benefits outweigh aggregate costs given a certain discount rate during the lifetime of the project.
Generally, the common unit is money reflecting the amount of money that would make an individual indifferent with or without the project.
Impacts are evaluated if possible on the basis of prices observed in the market, with certain necessary adjustments.
Where impacts lack an appropriate market price or cannot be directly measured in monetary units, it is sometimes possible to estimate unit money values indirectly through some form of shadow pricing.
Nonetheless, some impacts that cannot be valued in money (intangibles) remain in principle outside the quantitative analysis[6].
From a society point of view a CBA is conducted in terms of resource costs, i.e., the real net costs to society of the impacts it has.
Taxes and transfer payments are excluded. Also excluded in many national CBA applications is valuation of impacts outside the country concerned. For appraisal from a Europe-wide perspective the geographical impact area must be agreed upon.

In SINBAD the most important actors that are distinguished are society and the airports/aviation sector.
It is proposed to use a CBA approach for the economic evaluation of operational scenarios for society as a whole (in casu Europe), but that also allows a clear assessment of effects on airports/aviation community.
A socio-economic CBA (i.e. a CBA from the perspective of society) supports the decision on the SINBAD implementation, which are desirable for Europe.
The investment decision from an airport perspective is much narrower and focuses on the impacts for the airport (or aviation sector) itself.

Regarding the CBA approach and toolset, there is material available at different levels: EUROCONTROL and other organisations have a well defined CBA method supported by models, tools, standard values and guidance material. Current practice in CBA, like EMOSIA, ATOBIA and MEDINA, has been reviewed and consolidated in SESAR[7].
The models best suited for this kind of appraisal are referred to as: general models. It is opted to use the EMOSIA approach as a basis for the CBA method to evaluate the SINBAD operational concept.

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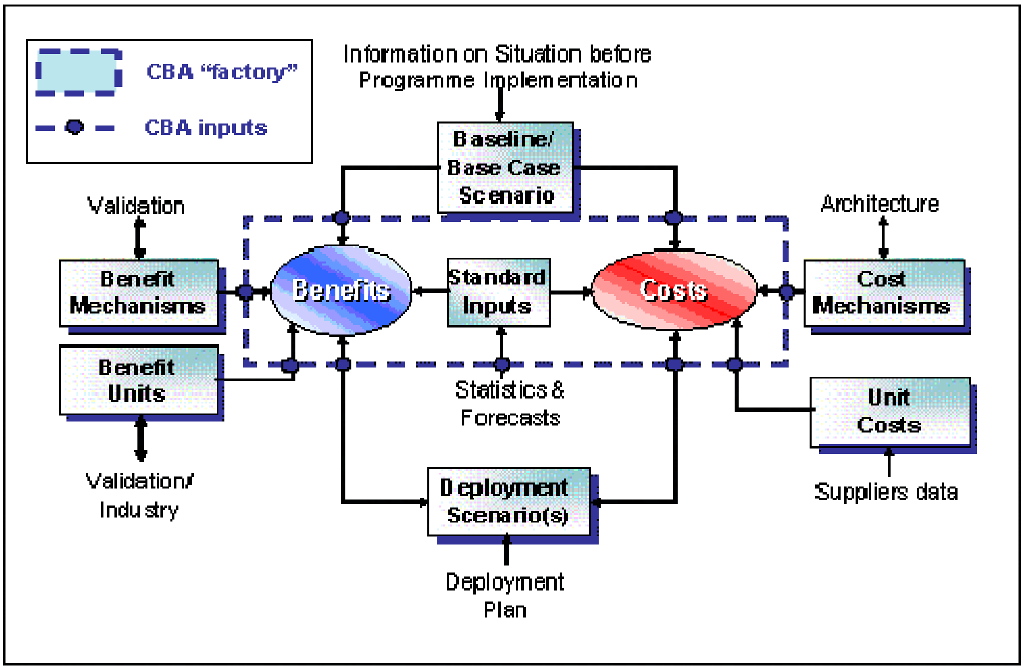
[5] In CBA terminology the term 'project' has a different meaning than traditionally. In this case, a project represents the topic of the CBA, which can be the introduction of one single measure, or of a set of measures. Hence if one carries out a CBA of a Threat Assessment Response Management System TARMS, the introduction of TARMS (under a certain scenario) is the project.

[6] In fact, the effects that cannot be monetarised will be taken up as pro memory items in the CBA, and should be described in the best possible way qualitatively. This enables decision-makers to attach their own value to these non-quantified effects.

D [7] SESAR (2006)

In the below figure a generic model of a CBA is summarised:

- The “Deployment Scenario” (the situation with SINBAD) is compared to the “Baseline Scenario” (the situation without SINBAD).
- The deployment of SINBAD will generate both costs and benefits for the stakeholders.
- The cost and benefit mechanisms are the way a SINBAD improvement translates into a monetary benefits or costs for stakeholders.
- The Cost and Benefit Elements are elementary values that are used to compute the final costs and benefits.
- Standard Inputs are these components and values that can be re-used from previous CBAs.



Source: SESAR (2006).

Figure 38. The CBA Building Blocks

3.6.3.3 CBA results

By principle the CBA assumes that the SINBAD system is at product level. As such it uses the safety and security cases outputs assuming this level of development. However the SINBAD program objectives and achievements were to produce a prototype or mock-up level system. Then the two following assumptions were made to conduct these analyses and should be kept in mind while considering the results:

1. At product level SINBAD Man to Machine Interface shall be at the state of the art,
2. At product level SINBAD level of performances in its area of operation shall be better or equal to the current PSR.

While the SINBAD program results partially confirms the validity of these assumptions their complete validation cannot be performed without a product development and test phases.

3.6.3.3.1 Safety benefits

In order to monetize the identified benefits and costs, the general inputs have been updated. These general inputs refer to information such as the average number of seats per flight, average occupancy rate and average number of passengers, average number of crew on board, average costs of an aircraft replacement and repair, average insurance value, etc. These costs differ per airport and as a result the costs of incidents may differ per airport.

Nevertheless, in order to conduct the CBA it was necessary to make assumptions on the level of costs. Therefore, average costs levels recommended by Eurocontrol as standard inputs for CBA as well as data from other sources (Eurocontrol, Standard inputs for CBA, 2009, Airclaims database, AEA Summary of Traffic and Airline results 2005, ASICBA team estimation, etc), were applied. All the general inputs have been expressed in EUR 2009 prices.

Due to the large operational differences between commercial aviation and general aviation, different estimates and assumptions have been applied for the Egelsbach airport compared to those for the airports at Frankfurt and Brno. In order to translate the specific costs to different severity levels of impacts, certain percentage of the costs were assumed to be applicable to each severity class. These have been different for various cost categories and have been dependant on the expected impacts.

In a next step, various costs of airspace infringements per Sinbad severity level have been calculated, based on the probabilities of occurrences proposed by NLR, and the severity of airspace infringements within the defined categories. The costs have been allocated and calculated per stakeholder group.

By multiplying the calculated costs per stakeholder group by airspace infringement severity level distribution (Safety Case input for the Business Case, NLR, July 2010), it was possible to calculate the costs of NCTs and CTs infringements in the scenario without and scenario with Sinbad system.

The next table presents the severity of infringements distribution applied.

	Scenarios	Accident (class 1)	Serious incident (class 2)	Major incident (class 3)	Significant incident (class 4)	No safety effect (class 5)
1	CTs Scenario without Sinbad	0,00%	3,00%	4,00%	22,00%	71,00%
2	CTS Scenario with Sinbad	0,00%	0,20%	0,80%	15,00%	84,00%
3	NCTs Scenario without Sinbad	0,00%	10,00%	10,00%	25,00%	55,00%
4	NCTS Scenario with Sinbad	0,00%	1,00%	2,00%	17,00%	80,00%

Table 11. Severity of infringements by NCTs and CTs, Safety Case input for the Business Case, NLR July 2010.

The proposed probabilities have been multiplied by the previously calculated costs of NCTs and CTs infringements in the baseline scenario and scenario with Sinbad system. As a result, the difference between the baseline scenario and the scenario with the Sinbad system has been calculated. This difference provides the information on the level of benefits both for NCTs and CTs infringements (per stakeholder group) per flight.

In order to calculate the overall benefits for the period of 20 years, traffic forecasts have been used for Frankfurt, Brno and Egelsbach for the period 2010-2029, as described in section 5.1. By multiplying the calculated safety benefits per flight by the number of flights in the respective year, it calculations have been made of the yearly benefits of SINBAD detecting NCTs and CTs infringements for Frankfurt, Brno and Egelsbach airports over the period 2010-2029. These benefits have been discounted using the 8% discount rate, as recommended by Eurocontrol. As a result the Net Present Value (NPV) of the total (sum for all stakeholders) safety benefits has been calculated:

Safety benefits (all stakeholders)	FRANKFURT	BRNO	EGELSBACH	TOTAL
CTs	4,06	0,24	0,15	4,45
NCTs	6,12	0,37	0,19	6,68
Subtotal safety benefits	**10,18**	**0,61**	**0,34**	**11,13**

Table 12. Overview of overall safety benefits (million EUR)

As presented in the above table the expected safety benefits from the implementation of the Sinbad system are valued at 11,1 million EUR for all three airports analyzed together. The total safety benefits calculated are positive for all three airports taken into account. The safety benefits are expected to be at the level of approximately 10,2 million EUR for Frankfurt airport. The expected benefits for Brno and Egelsbach are smaller, reaching 0,6 million EUR and 0,3 million EUR respectively. The NPV for Egelsbach is almost two times smaller than in case of Brno airport. The majority of safety benefits on all three airports come from the safety benefits result from better detection of NCTs.

It can be concluded that the Sinbad system has large impact on the improvement of safety especially at large airports like Frankfurt.

3.6.3.3.2 Security benefits

On the basis of the Security Case, fifteen security scenarios have been taken into account as relevant to the Sinbad system. It was concluded that the expected impact level would change with the introduction of the Sinbad system only for four scenarios. These scenarios and their changes are applicable in the assessment of the expected security benefits. It is concluded that expected level or potentiality level will not change for the remaining threat scenarios with the introduction of the Sinbad system. Therefore the expected benefits from the remaining threat scenarios are equal to zero.

The below table presents the four relevant security Threat Scenarios (TS) for which the impact level will differ between the situation without Sinbad and with the Sinbad system.

TS No	Description
7	Aircraft used to disrupt the airport operations
13	False security warnings
14a	Disruption of the SINBAD system - Physical damage to surveillance infrastructure and information
14b	Disruption of the SINBAD system - Cyber attack

Table 13. Security Threat Scenarios (TS) from which the security benefits are expected with Sinbad system

Each of the four threats scenarios reacts differently to the introduction of SINBAD. One threat scenario may have different possible severity levels, each with a particular probability of occurrence. An estimate of the impact level change and its conditional probability change was proposed by NLR in the Security Case is presented in the next table.

	Baseline (BSA)		Introduction SINBAD	
TS No	Updated impact	Impact probability	Impact of SINBAD	Impact probability
7	medium	50%	weak	100%
	weak	50%		
13	-	-	weak	100%
14 a	-	-	very strong	1%
			strong	33%
			medium	33%
			weak	33%
14 b	-	-	weak	100%

Table 14. Updated security impact assessment, Security case, NLR, 2010

Out of these four threat scenarios the only threat scenario that exists in the situation without the Sinbad system is the threat of the aircraft being used to disrupt the airport operations (TS7).

The impact of the occurrence of this threat decreases with the introduction of the Sinbad system from Medium / Weak (50:50) to Weak (100%). The Security Case (NLR, 2010) shows that the risk level for TS7 will decrease accordingly from High to Medium. As a result of the reduction in the impact level, the introduction of Sinbad system will bring positive security benefits from this threat scenario. With the introduction of Sinbad system, new security threats occur which do not exist in the situation without the new system. These refer to the threat scenarios 13, 14a and 14b. Therefore, the introduction of the SINBAD system will result in negative security effects related to these three threat scenarios.

In order to calculate the security benefits the general inputs and assessed the costs of accidents and incidents per different severity class were updated. These costs have been expressed in Euro. The calculated costs have been allocated to various stakeholder groups such as Airline, Occupants, Airport operator, Authorities, Society, Other airlines, Insurer and Manufacturer. The probabilities per potentiality class proposed by NLR in the Security Case, have been applied on the calculated costs from security incidents.

The situation with Sinbad was compared to the situation without the system and the security impacts have been calculated per flight. The difference of the impacts provides the information on the average security benefits per flight. The security benefits per flight have been calculated per stakeholder group. Their sum builds up to the total security benefit per flight.

Finally, in order to calculate the total benefits for Frankfurt, Brno and Egelsbach airport, the forecasts on the air traffic have been done for the period 2010-2029. The security benefits per flight calculated previously have been multiplied by the number of flights per airport. As a result the total security benefits from the introduction of Sinbad system at these airports have been calculated.

The balance between the positive benefits from TS 7 on the one hand and negative benefits from TS 13, TS 14a and TS 14b on the other hand, determines the overall security benefits from the introduction of Sinbad system:

Security benefits (all stakeholders)	FRANKFURT	BRNO	EGELSBACH	TOTAL
Threat Scenario 7	870,37	52,22	10,86	933,45
Threat Scenario 13	-117,15	-7,03	-0,90	-125,09
Threat Scenario 14a	-287,91	-17,27	-4,91	-310,09
Threat Scenario 14b	-117,15	-7,03	-0,90	-125,09
Total security benefits	**348,15**	**20,89**	**4,15**	**373,19**

Table 15. Overview of overall security benefits (million EUR)

The overall security benefits are positive. The benefits from TS 7 are higher than the sum of the negative benefits resulting from the new threat scenarios TS 13, TS14a and TS14b. The total security benefits for Frankfurt airport are valued at 348,15 million EUR. The NPV for Brno is much smaller but still positive and equals almost 21 million EUR. The net security benefits for Egelsbach airport are approximately 5 times lower than at Brno, but are still positive.

3.6.3.3.3 Other potential benefits

Workload

During the workshop organized by NLR with the representatives of the ANSP of the Czech Republic, an initial assessment of the changes in the workload of ATCOs was done. In case of introduction of the Sinbad system, the workload of the air traffic controller slightly increases as the controllers expect that they will have to monitor a few more tracks than today, i.e. the non-cooperative, and this will require extra attention, task sharing etc. On the other hand, the information on these additional flights will make other operations more efficient.

Therefore, it is assumed that the overall workload will remain at the same level as in the situation without Sinbad. Since NCTs are limited in numbers per day, it is fair to say that the extra workload is manageable for a certain ATC unit. Therefore, it is not expected that the introduction of SINBAD requires extra manpower. As a result the introduction of Sinbad system is not expected to bring any additional benefits or costs in the area of workload.

Capacity

During the same workshop, an initial assessment of the changes in the capacity of the airports was done. Referring to the capacity, the Sinbad system will enable the controllers to manage the airspace more efficiently.

The issue whether it will enable more flights to be managed will depend on many factors including the conditions present at a particular airport. Nonetheless, the increased capacity in the air and more reliable information about the position of NCTs, might result in more efficient flight handling (e.g. direct flights) of the CTs. The controllers will be able to use the existing airspace more efficiently.

However, at this stage of the project, it is not possible to quantify these potential benefits. Further analysis, simulations and modelling taking into account the specific local conditions at the airport (traffic mix, number of NCTs, traffic patterns, route structure, etc) is required to confirm this and to enable assessing capacity benefits for the airspace, i.e. more efficient use of airspace may save flight time/distance. Therefore, it is recommended to further analyze this issue at the implementation phase of the project.

3.6.3.3.4 Costs analysis

Details of the costs analysis are Consortium confidential, however the methodology and hypothesis are not.

Costs were calculated considering:

- Investment costs to move from demonstrator level to product level,
- Production costs based on a yearly production of 8 systems, one system being a network of receiver station able to cover a CTR.
- Installation costs and controller/personnel training costs,
- Operational costs covering maintenance, receiver sites rental and data link costs. Spectrum charges were also considered at the level of 30 K€ per year per country for 2.5 MHz.

3.6.3.4 CBA conclusions

The CBA is calculated for the period of 20 years (2010-2029). The yearly discount rate applied is 8%. The scope of the CBA is geographically limited to three airports. The benefits are found mainly in safety and security. The safety benefits focus on the differences in the non-cooperative targets and cooperative targets infringements of the airport control zone between the situation without and with the Sinbad system. The security benefits focus on the changes in the impacts and potentiality of security threat scenarios between the situation without and with the Sinbad system. The costs include investment costs and operating costs. The assumption is made that first costs are borne in 2012 while the first expected benefits would be visible in 2013.

The overall outcome of the CBA is positive for all three analyzed airports. The net present value (NPV) is highest for Frankfurt airport. Small airport such as Egelsbach will benefit from the implementation of the Sinbad system but the benefits will be much smaller. The safety benefits outweigh the costs only in case of Frankfurt while for Brno and Egelsbach the safety benefits are smaller than overall costs of the system implementation. The overall security benefits outweigh the overall costs for all three airports.

The following main conclusions are drawn from this study:

- The safety benefits outweigh the costs only at Frankfurt airport. For Brno and Egelsbach the balance of the safety benefits and all investment and operating costs is negative.
- The overall security benefits outweigh the overall costs of the Sinbad system implementation at all three airports analyzed. There are, however, uncertainties around the security benefits as the sensitivity analysis showed that the changes of selected assumptions, i.e. the probability held by potentiality class or five year delay in the system implementation may significantly influence the overall NPV results.
- The benefits from the Sinbad system implementation will be allocated primarily to airlines and society while most of the costs will be borne by ATC.
- The outcomes of the CBA analysis show that implementation of the Sinbad system will be most beneficial for large airports with many commercial flights. Smaller airports with many general aviation flights will also benefit from the system implementation but the benefits will be less visible in economic terms.
- Applying the concept at different airports could well influence the CBA results.

The following is recommended:

- As the outcomes of the preliminary CBA are positive for Frankfurt, Brno and Egelsbach airports, it is therefore recommended to further analyze the possibility of the Sinbad system implementation at these airports as it looks promising.
- It is recommended to the decision makers to take into account that changes in the concept further on in the development stage will influence the CBA result accordingly.
- It is recommended to review the results with caution as they are based on certain assumptions, i.e. assumptions underlying the security assessment that, when changed, will influence the final results.
- In order to confirm the validity and robustness of the results for a specific airport, a further analysis of costs associated with airspace infringements at that airport is recommended.
- It is recommended to obtain the information on the market structure and translate the obtained CBA results for three airports to all European airports.
- It is recommended to run further sensitivity testes on the critical assumptions to check how the results would change.
- It is recommended to further analyse the potential benefit for workload and capacity for specific airport.

3.7 Dissemination

3.7.1 Dissemination Activities

The objectives of the dissemination activities were both to give information to stakeholder groups on the SINBAD concept and to collect their feedback. This feedback was mostly achieved by workShop or interviews organized in the scope of the AHA development as reported in section 3.5.2.3.

Apart from confidential documents all SINBAD's materials can be downloaded from its website available at: sinbad.edufly.net.

The below table lists all dissemination activities to give information to the public:

Activity	Planned Date Actual Date	Type	Type of Audience	Countries addressed	Size of Audience	Partner responsible Partner involved
European R&D coordination	NA	ARDEP data base	all public (website)	World wide	NA	**TR6**
European R&D coordination	NA	FP6 Synopses Book	all public (website)	World wide	NA	**TR6**
SESAR coordination	09/01/2007 09/01/2007	Conference	European Commission and organisations involved in FP6 projects	Europe	70 people	**TR6** ANS CR
SESAR coordination	14/11/2007 14/11/2007	Conference	European Commission and organisations involved in FP6 projects	Europe	70 people	**TR6** ADV
SESAR coordination	NA	Inputs to the WP3.1	all public (website)	Europe	NA	**TR6**
EUROCONTROL "Emerging Alternatives to Primary Surveillance Radar"	29/09/2008	Workshop	ANSPs, Research, Industry	World wide	30-40 persons	**TR6**
ICAO Aeronautical Surveillance Panel	08-12/12/2008 08-12/12/2008	Information Paper	Regulators, ANSPs, Research, Industry	World wide	50-70 people representing about 20 states & international organisations	**DFS**
ICAO Manual on surveillance technologies and applications	07-12/2008 07-12/2008	Support for ICAO Aeronautical Surveillance Manual	States, Regulators, Internat. Organisations, ANSPs, Research, Industry	World wide	129 ICAO contracting states	**DFS**
ICAO ASP WorkingGroup	10/2008	Working Paper	Regulators, ANSPs, Research, Industry	World wide	30-40 persons	**DFS**
ESAV'08	03-05/09/2008 03-05/09/2008	Coordination meeting	Research Industry	World wide		**TR6**
ICNPAA'08	25-27/06/2008 25-27/06/2008	Conference	½ mathematicians ½ aeronautical industrials	World wide		**BUTE** NLR, TATM GmbH

PSCA EU 18 review	Oct. - 2009	Article	European Commission and organisations, States, Regulators, Internat. Organisations, ANSPs, Research, Industry	Europe	NA	**TR6**
SESAR JU WP15	2009-2013	European research and following implementation	ANSPs, Industry	Europe	SESAR JU partners	**TR6** DFS
ICRAT Budapest	June - 2010	Conference	Research Industry	World wide		**BUTE**
SINBAD Demo in Brno	July - 2010	Field demonstration	ANSP UK (NATS)	UK	3 persons from NATS	**TR6** ANS CR
ESAV'10	Sept. - 2010	Coordination meeting	Research Industry	World wide		**TR6**
ISSST China	Oct. - 2010	Conference	Research Industry	World wide	Several hundreds	**BUTE**
3rd FHR Focus Days on PCL	May - 2011	Conference	ANSPs, Industry	Europe	30-40 persons	**TR6**
IRS 2011	Sept. - 2011	Conference	Research Industry	World wide	Several hundreds	**TR6**
Transport Research Arena	April - 2012	Conference	European Commission and organisations, States, Regulators, Internat. Organisations, ANSPs, Research, Industry	Europe	Event to come.	**ECORYS**

Table 16. SINBAD's dissemination activities

Exploitable results in terms of functionality, purpose, innovation and so on were multiple at the end of the SINBAD project:

Exploitable Knowledge Description	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial user	Patents or other IPR protection	Owner & Other Partner(s) involved
Multi Static Detection and Tracking with a Primary Radar	Passive MSPSR	Air Surveillance	2013 - 2015	FR2949567, FR2933775, FR2927423, FR2910131 and several other pending.	TR6
New methodology for security case analysis	Methodology	Security case studies	NA	NA	NLR
AHA: o Safety net like functions, o Demonstration and test platform for other similar functions.	AHA system	ATC	Available now	NA	NLR & BUTE

Table 17. SINBAD's exploitable results

3.7.2 Exploitation of the Passive MSPSR

The Passive MSPSR sensor enables for detection and tracking thanks to a multi static configuration based on several receiver stations. As for the transmitters, it takes benefit from civilian broadcasting. It is Primary radar in the sense that it does not rely on the transponder of the aircraft (as secondary radars do). This is why the Passive MSPSR system is a sensor concept that integrates the following:

- the benefits of Primary Surveillance radar, e.g. it is independent from aircraft equipment (no transponder or transponder failure), or aircraft misuse (shutdown transponder);
- the benefits of Wide Area Co-operative Multilateration Systems, with its 3D localization capability, high data update rate, reduced acquisition and maintenance cost, while overcoming their major limitations, such as their inability to detect non co-operative small Radar Cross Section (RCS) or low flying aircraft.

Its operating principle is based on:

- making use of the illumination of the surveillance volume (using the transmit stations) by a continuous waveform operating at low frequency band, just as an extrapolation of the principle of Primary Surveillance radar;
- analysing the echoes of this waveform reflected by any aircraft present in the illuminated volume (using the receive station(s)), and retrieving the localisation of aircraft using Time Difference of Arrival algorithms, just as an extrapolation of the principle of Mode S Cooperative Multilateration systems.

TR6 will be involved in the exploitation of this result. For the need of the SINBAD project, a mock-up has been developed but for a mature product there is a need to consolidate the design. TR6 is in charge of it as well as future developments, industrialisation and commercialisation of the product.

For the two years too come TR6 efforts are focussed on:

- Reduction of the latency time below 2s to improve sensor interoperability,
- Increasing the coverage in altitude,
- Adding a multi-frequency capability too increase the detection range and availability,
- Commercialisation of the test campaigns and of the mock-up as it is for evaluation/research activities.

In terms of commercial impact two research and demonstration contracts were obtained by TR6 in France as follow-up to SINBAD. Furthermore SINBAD has achieved to reinforce European cooperation on passive Radar.

Four further contracts are under consideration with France, Swiss, Spain and the United Kingdom.

3.7.3 Exploitation of the new methodology for security case analysis

While safety cases studies are well covered by widely approved and stable methodologies, security cases studies are a pretty new subject in the ATM world. As such there was a need to develop a new methodology and applied it to SINBAD.

NLR developed this methodology on the basis of the European Operational Concept Validation Methodology (E-OCVM) by analogy to the safety case. It is presented in SINBAD security documents (cf. §2.2 [20] and [21]) with its results for SINBAD's case.

This methodology is now public and NLR eager to see it used as widely as possible. Returns from users are welcome to improve the methodology as needed.

3.7.4 Exploitation of the AHA

Apart from its functions in the SINBAD system the AHA developed by NLR, with its NCTR functions developed by BUTE, is also a non-intrusive and easy to use verification and validation platform for safety nets or related functions.

The platform SW is available at NLR who are willing too share it freely, provided that they have some returns and/or description of use.

4. Conclusion

To conclude lets go back to the program overview, the main SINBAD initial objective was to perform the proof of application of a new functionality => Passive Radar for ATC enhanced by an alerter the AHA. It has been successfully completed at prototype level, as required in the contract.
In more details Scientific and Technological objectives were:

- S&T1: to refine ATC and security management operational concepts. Achieved by:
  - System analysis, live demonstrations and discussion with ATCO.
  - Main conclusions are that for ATC, Passive Radar and AHA introduction should be smooth and easy with a Benefit/Costs ratio evaluated at 3 for large airports.
  - For security, the subject is newer in the ATC world. As such the consortium had to create the methods of analysis in SINBAD.
  - These techniques need now to be tried on other related subjects involving security analysis, both for validation and improvement.
  - The results are however outstanding with an estimated Benefits/Costs ratio of greater than 10. This value should be used with care as the security benefits considered are currently not paid for by stakeholders. Given the current trends, where safety improvement and reduction of the costs of PSR coverage leads to an easy business plan, the consortium consider that the security improvements or functions provided by SINBAD shall be difficult to valorised at first.
  - Recommendation for a product is to refine the safety cases linked to the management of the small uncooperative aircraft, major aim of the all PSR-like system. Considering that the security cases are for now a side bonus to be investigated in more details once in place. For now even if the security business case has the best ratio the users are not ready to buy full functions.

- S&T2: to develop Primary Multilateration Surveillance (PMS). Achieved as:
  - SINBAD has produced a very reliable set of: 4 receivers, a central unit and a test bed (incorporating EUROCAT-C) all fully operational and field-tested!
  - Accuracy performances are at least at the level of current PSR coverage and it is not even a product.
  - As such in its demonstrator stage SINBAD's sensor can be deployed and used operationally for low altitude NCT detection and also as a gap filler for PSR.
  - Recommendation for a product is to improve the sensitivity of the Rx and deploy more Rxs.
  - This prototype is already looking forward at a coastal application, ATC in Capital city area, ATC in connection with WAM.

- S&T3: to develop Active Hazard Assessment (AHA). Achieved as:
  - SINBAD has developed a complement to the current safety nets the AHA (real time SW), which core consists of an NCT classification function and a behaviour/intention monitoring function.
  - This new function was tested on the air traffic of Amsterdam and Brno (while the SINBAD's sensor was active but as the tracks were fragmented WAM data was mostly used).
  - Application of the AHA was then shown to ATCOs during a WS and received very favourably, especially: NCT classification, area infringement/escape monitoring function, route monitoring and separation monitoring.
  - AHA validation mainly relies on expert judgment of air traffic controllers and system experts => real time deployment and then statistical analysis needed.
  - AHA has a clear need for accurate height information => it requires a WAM+PMS system.

- S&T3: to perform AHA/PMS proof of concept in Brno & Frankfurt. Achieved as:
  - SINBAD PMS development faced, as any new concept, unexpected difficulties.
  - As such the 36-month of this project while the consortium was able to fully test the system in Brno, through 2 tests campaigns, it was not possible to move to Frankfurt.
  - Deployment for the test was easy ½ day per Rx or site.
  - No HW failure in the system for nearly 10 month of mostly continuous operation.

Apart from the scientific there was also a Potential Impact objective (PI1): to give Europeans a leading position in ATC safety and security management.

- With SINBAD PMS based on DVB-T transmissions the consortium has provided the first operational passive radar capable of PSR level performances and more with its 2D+ capacity.
- SINBAD has initiated methods to handle security requirements and functions that are also a first.
- SINBAD AHA has opened the way for an easy validation assessment of complementary functions to safety nets.
- SINBAD PMS put Europe at the leading edge of passive Radar and **M**ulti**S**tatic **P**rimary **S**urveillance **R**adar (MSPSR).
- SINBAD security studies give the lead to Europe on these new analysis methods.

In short SINBAD successfully fulfilled its objectives and a new kind of Radar is now on its tracks for product development. In this development phase and beyond the present project frame the following recommendations or extensions should be subject of subsequent research:

- Operational concepts: coverage of CTR or TMA zone or as gap filler for existing PSR … Can one type of product be defined to cover all the identified needs?
- Extension of SINBAD airspace domain associated to data acquisition campaigns, with a particular focus on how deployment and vertical accuracy can be optimized,
- Security monitoring of CT (besides NCT) with additional flight plan conformance monitoring,
- Incorporation of conflict monitoring function in AHA that effectively takes into account NCT intentions and manoeuvrability,
- Incorporation of SINBAD's sensor signal processing for improved NCT classification.
- Safety and Security case development activities to further reduced uncertainties about the concept by confirming the stakeholders' ATM needs, and detailing the expected benefits of the SINBAD concept.
- To perform independent review of the Security case methodology defined within the SINBAD project;
- To systematically rerun additional safety, security and CBA assessment for new airports to take into account the specific conditions in which the SINBAD system is to be operational.

Once at product level SINBAD type of Radar should complement, at first, PSR as WAM is complementing SSR, with Europe in leading position. Safety cases are to be refined and transition from standard PSR to MSPSR is still to be defined but with SINBAD the consortium and several interviewed ATM stakeholders consider that the future of PSR functions lays with MSPSR technology.

New analysis methods and SW functions to support safety and security, with Europe in leading position.

SINBAD PMS and AHA have a clear near and far future, with coastal applications of PMS that started in 2010.

Lastly despite various problems SINBAD consortium kept a real team spirit, showing that Europe is a reality to a grateful coordinator.

SINBAD and MSPSR will be back in SESAR.

5. Appendix A: Project Performances and Management

5.1.1 Project objectives and Major achievements

The global objectives of the SINBAD project are detailed in [C2], Annex I – Description of Work:

Objectives	*Progress towards achieving objectives*
❑ To refine an enhanced traffic monitoring and collision avoidance Concept of Operations. This new ConOps will be derived from the current one using the ground based Air Traffic Management system, by taking into account the benefits of both PMS and AHA new technologies; its main features will be based on: ❑ A more complete and more accurate "Air- (and to some extend Surface-) Traffic Situation", including low altitude flying aircraft, and low RCS aircraft, updated at a higher data update rate, ❑ A "decision aid" tool dedicated to support the controller or the security officer in making better decisions within shorter time scales, in case a collision risk has been identified or is being anticipated, ❑ A ground-to-air communication concept based on specific procedures, using the existing equipments on board the aircraft, so as to ensure a "zero" impact on the aircraft hardware equipment.	The new Con Ops is described in the D1.3 Operational Concept Document (OCD) which defines the contribution of the SINBAD automated system for the detection and the notification (AHA) of safety or security hazardous situations caused by the intrusion of Non-Cooperative Targets (NCT) within the controlled airspace of European airports. Detection of NCT is essentially PMS based but PSR inputs and all data on the aircraft kinematics are also used for classification. The document covers the description of the operational services provided to Air Traffic Controllers (ATCO) and ATM Security Units, the relationships with existing ones available currently at Air Traffic Service units. Such description encompasses operational scenarios for ATCO as well as the definition of the required Quality of Service characteristics. The 3 new services provided by SINBAD may be summarised as follows: – Automated support for the detection of airspace infringements by NCT through appropriate notification of concerned ATCO; – Improvement to ATCO situational awareness about NCT (altitude and classification); – Automated support for the notification of Security Units about NCT creating a potential threat to ATM security. Several improvements to existing ATC services such as traffic conflict prediction have also been analysed by considering their known limitations. The main operational improvements targeted by the SINBAD OCD have been identified as follows: – Improved detection capability for NCT and potential airspace infringements and support for ATC actions, including low altitude flying aircraft, and low RCS aircraft, updated at a higher data update rate; – Reduction of false detections of airspace infringements; – Reduction of false or nuisance safety

	alerts associated to NCT presence in controlled airspace; – Automated classification of intruders (light aircraft, balloon, UAV…). A generic description of the operational environment in which SINBAD services are to be deployed for trials is provided; the 3 test airports (Frankfurt, Brno, Egelsbach) chosen for the project being use cases.
❑ To provide the "proof of concept" and cost-benefit analysis of the new PMS system, by designing, developing and testing within real environments a full-scale mock-up. Research efforts will be placed especially: ❑ On the processing algorithms that will ensure in real time for each target an accurate 3D position and velocity estimation, together with satisfactory detection and false alarm control performances	SINBAD's sensor the PMS system is manufactured and has been verified in real time at Brno airport (Czech Republic) and Limours (France) near Paris – Orly airport. It is a full-scale mock-up verified in real environments. It is a multi-static system with four receivers for the SINBAD program. This mock-up operates in real time with a reduced latency compared to standard PSR. Tests results indicate that the horizontal accuracy is in line with the requirements, while probability of detection and false alarm exceeds the expectation. Vertical accuracy is still a research area. With SINBAD provided an accurate indication of altitude above 15 000 ft. but very few detection. The today sensor is then capable of 2D+ indication, like is the aircraft below or above 3 000 ft.
❑ To provide the "proof of concept" and cost-benefit analysis of the new PMS system, by designing, developing and testing within real environments a full-scale mock-up. Research efforts will be placed especially: ❑ On the detailed analysis of each relevant performances (detection, false alarm, track accuracy…) and to their sensitivity to external parameters (terrain and meteorological environment, target velocity, target RCS). These performances will be assessed primarily on the CTR volume segment (i.e. for air targets); they will be completed by an assessment of their validity domain on the surface segment (i.e. for ground targets).	"Proof of concept" was provided by the test campaigns run in Brno, over the full airport CTR. Results were in line with the requirements except for vertical accuracy, which is significantly below them as expected. Sensitivity to external parameters is similar to a standard PSR. However a specific sensitivity to the opportunity transmitters antenna diagram and position have been characterized. For ground targets the range was significantly reduced (a tenth of the air targets). This was however a secondary objective and the project focussed on air target detection. Nonetheless, while the system was not deployed to survey the airport's ground, too few receivers were available; the system was able to detect the ground traffic on nearby roads with several receivers. In this first stage of the mock-up it was mostly seen as a nuisance and algorithm measures were taken to suppress these detections. Ground surveillance capability was nevertheless verified at an elementary level.

❑ To develop a functional prototype of the Active Hazard Assessment (AHA) module, focussing research activities mainly: ❑ On the "target classification" procedures, based on the exploitation of high data rate, high accuracy trajectories delivered by PMS, together with a priori knowledge on kinematics features gathered on each target class.	A functional prototype of the Active Hazard Assessment (AHA) module has been developed with a "target classification" sub-function. Its algorithm is based on the exploitation of data delivered by PMS but PSR inputs and all data on the aircraft kinematics are also used for classification. A priori knowledge on kinematics and RCS features gathered on each target class where also used.
❑ To develop a functional prototype of the Active Hazard Assessment (AHA) module, focussing research activities mainly: ❑ On the "hazard level assessment" procedures, derived from the aggregation of various information on the concerned target.	A functional prototype of the Active Hazard Assessment (AHA) module has been developed with a "hazard level assessment" sub-function. A real time prototype, programmed in C language, was used for trials. It also includes a target simulator and a Graphical User Interface. It takes into account: • NCT type classification, • Flow conformance, • Route conformance, • Flight plan conformance, • Area conformance, • Area escape, • Area infringement, • Separation, • STCA, • Threat level classification, • Flow learning/monitoring.
❑ To develop a real time test-bed, implementing the part of the Operational Concept related to the on ground equipment devoted to CTR. This test-bed will incorporate: ❑ A PMS mock-up, able to detect and localize in position (3D) and velocity (3D) the targets present in the covered volume, and to deliver tracks on a standardized ASTERIX protocol	SINBAD's sensor the PMS system is manufactured and has been verified in real time at Brno airport (Czech Republic) and Limours (France) near Paris – Orly airport. It is fully capable of measuring 3D positions and velocities and has an ASTERIX output.
❑ To develop a real time test-bed, implementing the part of the Operational Concept related to the on ground equipment devoted to CTR. This test-bed will incorporate: ❑ An Air Traffic Management test-bed, able to record, analyse or fuse tracks from the PMS mock-up, with tracks from a set of existing radar sensors (SSR, PSR, WA-CMLAT…), to apply the Active Hazard Assessment module, and to display the situation either for operational purposes, or for technical purposes.	The test-bed is defined in D2.3 "Global architecture design" document, which has been delivered. It has been developed and connected to the available sensors at Brno airport (SSR, PSR, WA-CMLAT…). It was able to record, analyse, fuse tracks and send all data to AHA.

❑ To assess and quantify the performances of the concept, using the test-bed against various operational situations, demonstrated in the Controlled Terminal Region (CTR), or on a part of the Airport surface, of two relevant commercial airports in Europe: Brno and Frankfurt	In Brnö the performances of the concept have been assessed and quantified via dedicated flight tests. The flight tests were performed with aircraft equipped with a GPS and a recording mean. Test in Frankfurt were run in Brno as the first test campaign ask for a redesign of the SINBAD's sensor and the same environment was preferable for the correct execution of the verification activities.
❑ To identify and analyse some possible additional benefits that could be obtained in using PMS for other purposes than collision avoidance (e.g. monitoring the traffic around a VFR airfield, supporting the acoustic noise monitoring of departure traffic around a commercial airport…).	These additional benefits were identified and analysed during AHA validation by ATCOs and by the CBA. Area infringement monitoring, area escape monitoring, route monitoring and separation monitoring are of interest to ATCOs. However the value of such functions were evaluated to be minor by the CBA. As these functions do not exist the CBA was maybe slightly pessimistic on this point. Anyway these functions are clearly secondary or bonus functions.
❑ An assessment of the safety and security improvements with respect to collision avoidance, provided by the introduction of the new PMS and AHA technologies in currently existing ATM systems. This assessment will be made according to the Eurocontrol Operational Concept Validation Method (E-OCVM)	Both Safety and Security cases analysis were conducted according to the Eurocontrol Operational Concept Validation Method (E-OCVM). For the Security case analysis a new methodology was developed by analogy to E-OVCM, as none existed.
❑ A Cost-Benefit Analysis, showing in a parameterized approach which costs would be generated and which benefits would be extracted from the insertion of SINBAD technology into the European Air transportation system, according to various deployment hypotheses.	The first elements of the cost-benefit analysis were delivered with document D4.6 Starting with a "Report on methodological issues and cost & benefit taxonomy; user decision criteria" that clearly defines the Cost-Benefit Analysis (CBA) scope; a full CBA was conducted over three typical European airport.
❑ A technology analysis and the related Technology Implementation Plan, showing the future steps to be taken, in order to provide the market with a certified operational product.	A Technology Implementation Plan (TIP) was delivered with all the future steps defined. In particular active MSPSR is presented in it as the best way to provide the market with a certified operational product.

5.1.2 Work done in comparison to the 'Description of Work'/problems encountered

For each partner the work done has been summarized here with the main problems encountered.

5.1.2.1 Thales Air Systems (TR6)

WP100: to refine the operational concept and system requirements.

Review of the WP's documents.

WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed.

TR6 was in charge of the development of the MultiStatic PCL new sensor, including system definition, specification and development. 1 FM receiver was manufactured and tested. 4 DVB-T receivers and a central unit were manufactured and tested. All the deliverables were provided.

Participation to the AHA functional design workshops.

Review of the WP's documents.

The sole issue encountered during this WP, standard development issue aside, was the too high number of deliverables. A lot of effort was spend on document that in the end nobody shall use. This problem was however alleviate by a comprehensive Project Officer, who grants the consortium additional time to write them. Two documents should have been enough for this WP namely an architecture (complete system) and a specification of the SINBAD's sensor (with rationales from simulations) documents.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

Participation to site surveys around Brnö in October 2007, May 2009, April 2010 and around Frankfurt in May 2008.

Review of the WP's documents.

Participation to the validation workshop held in Prague on October the 30th 2008.

Installation of the SINBAD's sensor in Limours and Brno (two test campaigns).

Participation to tests campaign in Brno and delivery of the associated documents.

As for WP200 there was too much deliverables. A sole test plan/procedure and report should have been sufficient.

WP400: to assess the benefits in terms of safety, security and business efficiency, according to the Eurocontrol-Operational Concept Validation Methodology.

Review of the WP's documents and participation to safety workshops in Amsterdam.

WP500: to disseminate SINBAD results throughout the community of interested stakeholders, as potential end-users, industrial partners …

TR6 has written documents D5.1 and D5.2 "Plan for using and Disseminating knowledge".

With the help of BUTE, TR6 have create and are maintaining a SINBAD website that is both used as a mean of dissemination and a document storage facility accessible to the consortium, EC and Eurocontrol.

TR6 has also followed and/or performed the dissemination activities described in §3.7.

WP600: consortium and project management

TR6 management activities are presented in §**Erreur ! Source du renvoi introuvable.**.

In terms of problems TR6 had a hard time with the costs reports retrieval from several partners in the consortium. It has provided some insights for the writing of a future consortium agreement.

5.1.2.2 Thales ATM Ltd (TATM Ltd)

WP100: to refine the operational concept and system requirements.

Review of the WP's documents.

WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed.

TATM Ltd was in charge of the development of the EUROCAT part of the test bed. It has been manufactured and tested. All the deliverables were provided.

Review of the WP's other documents.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

Review of the WP's documents.

Participation to the second test campaign in Brno.

WP400: to assess the benefits in terms of safety, security and business efficiency, according to the Eurocontrol-Operational Concept Validation Methodology.

Review of the WP's documents.

WP500: to disseminate SINBAD results throughout the community of interested stakeholders, as potential end-users, industrial partners …

Review of the WP's documents.

5.1.2.3 National Aerospace Laboratory (NLR)

Preparation and attendance of SINBAD consortium meetings.

WP100: to refine the operational concept and system requirements.

Review of documents D1.1, D1.2, D1.3 and D1.4.

WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed.

Together with BUTE, NLR is responsible for WP 233 and have contributed to WP 210 and WP 235. Within this workpackage NLR focused on the development of a support module for flight path monitoring based on the available surveillance information and on a support module for non-nominal aircraft behaviour detection, classification and alerting.

The following subtasks had been performed by NLR:

Task 0 Management of NLR and BUTE contribution

Task 1 AHA Functional Design (WP 210 contribution)

Task 2.1 Literature research performed on flight path monitoring and non-nominal aircraft behaviour detection, classification and alerting. (WP 233 contribution)

Task 2.2 Algorithms development (WP 233 contribution)

Task 2.3 MATLAB algorithms implementation (WP 233 contribution)

Task 2.4 MATLAB algorithms testing and conversion to C language for real time operation (WP 233 contribution). Additionally a Graphical User Interface was developed.

Task 3.1 AHA Operational System setup (C language) on a Linux machine with ASTERIX Cat 62 interface and a basic display: tracks, alerts … (WP 233 contribution). Delivery of a design description document.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

Preparation and attendance of the SINBAD validation workshop in Prague. Review of the test documents. Preparation and attendance of the AHA validation workshops with ATCOs in Amsterdam and Prague.

Performed off-line tests of the AHA functions on data recorded from the second Brno test campaign and from Amsterdam airport. Delivery of a test report.

WP400: to assess the benefits in terms of safety, security and business efficiency, according to the Eurocontrol-Operational Concept Validation Methodology.

General WP410 Safety Case and WP420 Security Case
Project plans for WP410 and 420, with detailed scope, approach, methodology, time schedule etc.
WP410 Safety Case
Approach, safety assessment methodology and scope of the safety case had been defined. Functional Hazard Assessment (FHA), Preliminary System Safety Assessment (PSSA) and Safety Case Report documents written.
WP420 Security Case
Threat Assessment report and Initial Security Case Report had been finalized, reviewed by consortium partners and Eurocontrol and updated.

5.1.2.4 ECORYS

Preparation and attendance of SINBAD consortium meetings.

WP430 Economic analysis: to assess the benefits in terms of business efficiency.

Project plan, detailing the scope, approach, methodology, detailed time schedule etc.

Delivery of D4.6 Methodological issues and cost & benefit taxonomy and D4.7 Comprehensive cost-benefit analysis on the introduction of SINBAD system.

5.1.2.5 German Air Navigation Services (DFS)

DFS project team participated to all WPs meetings, providing important technical information and explained the feasibility of proposed technical solutions. DFS has also run the preparations for the test bed trials (laboratory location / tools /data acquisition), so that an optimum work with Thales GmbH was fulfilled.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

The validation/test plan Frankfurt draft version (D3.6) has been delivered and reviewed. As no test campaign was run in Frankfurt, no final issue of the document was needed.

WP500: Dissemination: to disseminate SINBAD results throughout the community of interested stakeholders, as potential end-users, industrial partners …

The DFS played an active role in dissemination work by participating at the Aeronautical Surveillance Panel meeting in Montreal (December 2008) where a paper has been presented which stressed the advantages of the SINBAD project in future multilateration programmes.

In several meetings with international participation for the project PAMELA (**P**assiveCoherentLocation **A**dvanced **M**ultistatic **E**valuation and **L**imitation **A**nalysis), where aspects upon Passive Covert Radar (PCR) have been discussed, DFS presented the project SINBAD and the actual work status as well as its impact to multilateration.

5.1.2.6 Air Navigation Services of the Czech Republic (ANS CR)

Preparation and attendance of SINBAD consortium meetings.

WP100: to refine the operational concept and system requirements.

Review of documents D1.1 (with contribution), D1.2 (with contribution), D1.3 and D1.4.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

The D3.1 and D3.2 Validation Management (E-OCVM), D3.3 and D3.4 Test Plan for Trials in Brno, D3.6 validation/test plan draft version have been delivered and reviewed.

TR6 site Surveys and SINBAD's sensor installation in Brno were supported.
A workshop was organised to prepare Documents D3.3 and D3.6; it was held in October 2008.
SINBAD's sensor tests were conducted in Brno area, including organisation of test flights.

5.1.2.7 Thales ATM GmbH (TATM GmbH)

WP100: to refine the operational concept and system requirements.

Review of documents D1.1, D1.2, D1.3 and D1.4.

WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed.

Delivery of D2.1 and D2.2: "Interface Requirement Specification / Interface Control Document".
TR6 site Surveys in Frankfurt were supported.
Delivery of D2.3 "Global Architecture Design".
Development of Subsystem "Record & Replay" as well as "Technical Situation Display" (TSD) for the test bed.
Sensor configuration at Brno airport was analysed, PSR, SSR, WAM and ADS-B. Test bed was integrated with these sensors and the SINBAD's PCL for record and display.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

Review of the WP's documents.

Participation and running of the test bed during the test campaign in Brno.

5.1.2.8 ADV Systems (ADV)

Preparation and attendance of SINBAD consortium meetings.

WP110: Baseline of Current Systems

Prepared a questionnaire for the analysis of current operational and system issues with respect to non-cooperative targets (NCT).
Based on the consolidated contributions received from DFS, ANS CR, BUTE and reviews with European Commission (EC) delivery of the D1.1 document.

WP120: Threat Identification and Scenarios

Investigated potential estimates on non-cooperative targets in ECAC airspace.
Reviewed D1.2 prepared by NLR and BUTE as part of D1.2.

WP130: SINBAD Operational Concept Description

Developed the main elements constituting the SINBAD operational concept.
Organised workshop with operational experts from DFS and ANS CR to develop the key operational scenarios for SINBAD system (Prague 04/12/2007).
Delivery of D1.3 Operational Concept Document, after taking into account comments from EC and EUROCONTROL.

WP140: SINBAD System Requirements

Delivery of D1.4 System Requirements document after review and validation. Additionally this document was updated on the basis of the results obtained in WP200 and 300 (System design and validation).

WP200, 300,and 400:

Review of the WPs' documents.

5.1.2.9 Budapest University of Technology and Economics (BUTE)

Preparation and attendance of SINBAD consortium meetings.

WP100: to refine the operational concept and system requirements.

- Preparation of the D1.2 ‘Threat identification and scenarios’ was organized by the BUTE. The report describes the identification of possible safety and security related threats and scenarios of non-cooperative targets (NCTs) for airports on the basis of incident/accident and security data.
- BUTE delivered information on the technical environment characteristics required for the AHA System.

WP200: to develop MultiStatic PCL new sensor and AHA new algorithms, and implement them into a real-time test bed.

BUTE participated in WP212 and WP233. The main activity focuses on the development of the NCT classification based on flight path and Radar Cross Section analysis.

WP212: BUTE participated in the definition of the internal end external interfaces of the AHA system.
WP233: BUTE was responsible for the development of the NCT classification algorithm and system.

- Method was developed to extract information from flight path and to convert into performance specifications (speed, acceleration, climb, bank angle, load factor).
- The time series of the RCS (measured by each bistatic base) is compared to the simulated time series of the RCS. The different is evaluated and supports the decision on the class of the NCT.
- Fuzzy algorithm was chosen and developed to perform the support of the classification, and the determination of the fidelity of the classification
- Database of present airborne devices (aircraft, helicopters, UAVs) was set up to support the decision algorithm.
- Off-line AHA NCTR module was developed, including a technical display unit.

WP300: to validate the concept through live trials at Brno and Frankfurt airports.

Review of the WP’s documents.

Participation during the test campaign in Brno.

Performed off-line tests of the AHA NCTR module on data recorded from the second Brno test campaign and from Budapest airport. Delivery of a test report.

WP500: to disseminate SINBAD results throughout the community of interested stakeholders, as potential end-users, industrial partners …

- BUTE participated at the ICNPAA 25-27 June 2008 and disseminated the structure and goals of the project.
- The website of the SINBAD project was developed and is maintained by the BUTE to disseminate the results and to provide a proper file and information repository for the partners.

5.1.3 Consortium management

In terms of initial management tasks TR6 have written document D6.1 “Management plan”, defined, sent to the partners, filled and consolidated templates for:

- Slides,
- Documents,
- Effort reporting;
- Cost budget follow-up,
- Quarterly Progress report

TR6 has also organized and chaired the meeting listed below:

Title	*Date and Place*	*Main conclusions*
Steering committee 1	05/06/2007 - Brussels (TR6)	Meeting held to prepare the next day with EC, conclusions as below.
EC Kick-off meeting 1	06/06/2007 - Brussels (TR6)	Some points of the contract needs clarification or simply definition on the how to fulfil it.
EC Progress meeting	06/09/2007 - Brussels (EC)	RCS are defined per type of target; WP120 is to be more detailed in terms of output and impact on the rest of the study.
EC Progress meeting	25/10/2007 - Brussels (EC)	Hazard scenarios are the central element to ensure the consolidation of the different work streams. It has been proposed to organize a workshop with SINBAD partners and several air traffic controllers to develop several hazard scenarios and to initiate the work of ‘mapping’ data gathered by WP110 and WP120 to these scenarios.
AHA WS functional design	10/01/2008 - Amsterdam (NLR)	Operational Concept extended to the TMA as the expected range coverage of the PMS sensor permits it. AHA system shall perform “Classification” only not “Identification”. PMS signal signature information, such as the bistatic Doppler response, transmission requires too much bandwidth to be successfully deployed in the SINBAD operational test system.
Steering committee 2	17/01/2008 - Budapest (BUTE)	Meeting held to prepare the next day with EC, conclusions as below.
EC contractual meeting 2	18/01/2008 - Budapest (BUTE)	WP100 is delayed and consequently WP400 deliverables also (2 months).
EC Progress meeting	30/01/2008 - Brussels (EC)	The sensor solution will be based on the use of DVB-T transmitters. Initially it was planned to deploy a collocated sensor (i.e. Receiver) functioning with DVB-T and/or FM transmitters. After analysis it appears much more relevant in terms of performance to deploy several Rx stations (only one initially) functioning with DVB-T transmitters. EC agreed that the definition of countermeasures is not in the scope of security case.
Steering committee 3	18/06/2008 - Amsterdam (NLR)	Meeting held to prepare the next day with EC, conclusions as below.

EC contractual meeting 3	19/06/2008 - Amsterdam (NLR)	SINBAD will operate as a PSR alongside SSR. While PSR maybe replaced by PCL this is not taken into account in the safety case. Ground-air data link considered not feasible. Classification shall focus on NCT but should be active on all targets. PMS mock-up detection range should be typically of 40NM, 20NM in the worst case. Based on this result an informal GO is pronounced, formal GO shall be effective with the approval of D2.4. Current WPs' deliverables are delayed but the schedule of the mock-up trials is unaffected.
EC Progress meeting	Oct. 2008 - Brussels (EC) cancelled	NA
Steering committee 4	14/01/2009 - Limours (TR6)	Meeting held to prepare the next day with EC, conclusions as below.
EC contractual meeting 4	15/01/2009 - Limours (TR6)	Mr. Hoang Vu-Duc replaces Elizabeth Martin as EC project officer for SINBAD. User feedbacks shall be used to refine D1.3 and D1.4. Data link rate from the receivers to the central unit of 40 kbytes/s maybe difficult to accommodate on some trial sites. TR6 and NLR to write a more global D2.5 document including a description of the AHA function. The SINBAD concept introduces a "Security officer" that does not currently exist; his role and responsibilities are must be defined in the OCD to cover all the new-functions covered by the SINBAD system. CBA to take into account the data links costs and the spectrum charging schemes. SINBAD consortium is trying to initiate cooperation with NATS UK as they have developed an infringement tool and experimented it for a bit more than a year.
EC Progress meeting	April 2009 - Brussels (EC)	Documents official delivery.
PSSA WS	15/09/2009 - Amsterdam (NLR)	Initial assessment of safety requirements feasibility. Review validation of the fault trees.
Validation WS	29/10/2009 - Prague (ANS-CR)	SINBAD system is fully operating but PCL performances are not sufficient to retrieve tracks from its Asterix output. An extension of the program end date to the end of 2010 is needed.
Steering committee 5	December 2009 - Brno (ANS CR)	Meeting held to prepare the next day with EC, conclusions as below.
EC contractual meeting 5	December 2009 - Brno (ANS CR)	The consortium has encountered much more difficulties than expected to deploy and track with SINBAD's sensor. Nonetheless SINBAD's system (including the Sensor) is working fine in terms of robustness and SW stability. TR6 preliminary analysis shows that at some locations the receivers are behaving as foreseen and remains optimistic in their capability to adapt their sensor. This additional work cannot fit in the original schedule and a 6-month extension is requested. Status of the deliverables and proposal of schedule and are in the slides of the meeting. A management meeting TR6+EC is planned in Brussels February 2010. The aim of this meeting is to establish how the consortium and EC should proceed with the extension.
EC Progress meeting	February 2010 - Brussels (EC)	During this meeting the consortium and EC conclude that the details of the extension shall only be defined after the additional site survey in Brno planned in March 2010.
EC Progress meeting	June 2010 - Brussels (EC)	Extension process is so complex that the consortium and EC

		were to consider it carefully. In the end extension is not requested and the consortium and EC opted for the delay process (+45 days during which only working hours are eligible and an additional 45 days to finish the reports).
Steering committee 6	July 2010 - Frankfurt (DFS)	Technical difficulties to deploy and track with SINBAD's sensor are overcome but approximately 1 year late. The SINBAD's system is fully operating in Brno area, but has to be dismantled on July the 21st at the latest. As the extension process is too complicated the consortium shall use the delay process +90 days to produce the last report.
EC contractual meeting 7	October 2010 - Brussels (EC)	Final meeting: SINBAD successfully fulfilled its objectives. A new kind of Radar product is now on its tracks to complement PSR as WAM is complementing SSR, with Europe in leading position. New analysis methods and SW functions to support safety and security, with Europe in leading position.

As coordinator of the consortium TR6 has operated as official channel between the Consortium and the European Commission ensuring that everyone were aware of the progress of global project. TR6 hasmaintained the timescale plan and action database, writing minutes of the meetings as well as performing Quality Assurance activities as described in the management plan.

An additional activity, not foreseen at this effort level, was that as coordinator TR6 had to act as “editor-in-chief” for all the deliverables paper form, electronic and Web. With more than 30 documents and considering only the edition tasks it has been a 2-man.month effort.

On the financial side TR6 has duly and timely distributed the funds provided by the European Community.

Now considering management issues TR6 has experienced difficulties with timely delivery and approval of documents.

Several causes are identified:

- Intrinsic research nature of the project. As the results were new and unforeseen some documents were significantly different from their initial description and/or had to be re-issued several times.
- High number of deliverables and length of the comments, modification and approval process.
- Consortium agreement was not binding enough to provide the coordinator with the necessary means and authority to motivate all the partners on timely delivery. It was especially difficult for financial documents as most of the partners were from a technical/research background and poorly receptive to these issues.

In terms of possible cooperation with other projects, contacts were initiated with:

- NATS UK as they have experimented an infringement tool for one year now and were interested with the AHA. They are also interested in SINBAD's sensor, particularly for surveillance of events and discussion is open for a demonstration during the 2012 Olympics games in London.
- SESAR P15.04.01 as one of the way to circumvent the limitation of coverage in altitude is to use dedicated transmitters, so to go to full MSPSR. Cooperation with SESAR P15.01.06 is also underway as dedicated transmitter leads to a discussion on the available frequency ranges.
- PROPAGATION a French project monitored and funded by ANR (National Research Agency) to evaluate new surveillance techniques is coastal area for boats and ships.