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North European CNS/ATM Applications Project

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DOCUMENT PURPOSE AND SCOPE

This document is Volume 3 of the Final Summary and Conclusion Report submitted after the completion of the North European CNS/ATM Application Project (NEAP). It provides a detailed overview of the objectives, assumptions, methodology, testing, results, and conclusions of the Project.

The Final Summary and Conclusion Report is divided into three Volumes:

1. Executive Summary,
2. Final Consolidated Progress Report with an Appendix and several Annexes,
3. Final Report for Publication (this volume).

Each of these Volumes is a separate and standalone document with its own intended audience.

Together with the Executive Summary in Volume 1, Volume 2 comprises the full report, including all contracted documentation for all applications evaluated in the Project, and is primarily intended for the European Commission, the Project's Steering Committee and the participating organisations.

Volume 3 provides a fairly detailed overview of the Project and its conclusions and recommendations, and is intended to enable the results to be brought to a wider audience within the aviation industry. It includes an Executive Summary intended as a broad overview of the Project. It should be noted that the structure of the Executive Summary differs slightly from that of the main report in this volume.

The emphasis in the main report in this volume is on the testing and evaluation of the individual applications and services. Care has been taken to explain the operational context of the respective application, i.e. a comparison between the currently used technique and that offered in the future by employing a data link. Each application description also includes the hypotheses, or assumptions, on operational benefits and technical characteristics and properties established prior to commencement of the testing and evaluation activities, the results, and recommendations for future improvements.

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ABBREVIATIONS AND ACRONYMS

a/c	aircraft
ACARS	Aircraft Communication and Reporting System
ACAS	Aircraft Collision Avoidance System
ACD	Alert Condition Definition
ADS	Automatic Dependent Surveillance
ADS-B	ADS-Broadcast
AEEC	Aeronautical Electrical Engineering Committee
AFTN	Aeronautical Fixed Telecommunications Network
AGH	Ängelholm Airport
AIRLINK	Product name of CWP developed by DASA NFS
AOM	Aircraft Operation Manual
ARCO	AIRINC CODER (ARINC 429 converter tool)
ARN	Stockholm-Arlanda Airport
ASTERIX	All purpose Structured Eurocontrol Radar Information eXchange
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATIS	Automatic Terminal Information Service
ATIS-B	ATIS-Broadcast
AWOP	All Weather Operations Panel
B-RNAV	Basic RNAV
CAT	*[approach]* Category (I, II,III)
CATCAS	Copenhagen Air Traffic Control Automated System
CCC	Cellular CNS Concept
CDTI	Cockpit Display of Traffic Information
CDU	Control and Display Unit
CFIT	Controlled Flight Into Terrain
CM1	Crew Member #1 (Captain)
CM2	Crew Member #2 (First officer)
CNS	Communications, Navigation, Surveillance
CPDLC	Controller-Pilot Data Link Communications
CWP	Controller Working Position
DAP	Downlink of aircraft parameters
DCAA	Danish Civil Aviation Administration (SLV)
DFS	Deutsche Flugsicherung GmbH
DGNSS	Differential GNSS
DGPS	Differential GPS
DIAS-3100	Product name for Raytheon SCAT-I system
DLH	Deutsche Lufthansa
DLR	Deutsche Institut für Luft und Raumfahrt
D-RIMS	Distributed RIMS
EASA	European Aviation Safety Authority
EHS	Extended Helicopter Surveillance
EFIS	Electronic Flight Instrument System
EFR	Extended Flight Rules (extension to IFR and VFR)
ENH	Enhanced Surveillance for ATC
ETSI	European Telecommunications Standardisation Institute
EUROCAE	EURopean Organisation for Civil Aviation Equipment
FAT	Factory Acceptance Test
FIS	Flight Information Services
FIS-B	FIS-Broadcast
FL	Flight Level
FMC	Flight Management Computer
FMS	Flight Management System
FREER	FREE Route experiment
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRAS	GNSS Regional Augmentation System
GRPU	GNSS and Radar Processing Unit
HMI	Human-Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IPV	Instrument Approach with Vertical Guidance
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements

JTSO	Joint Technical Standards Order
LINCS	Product name for SAAB STDMA/VDL Mode 4 transponder
LFV	Luftfartsverket (SCAA)
MMI5000	Product name for cockpit display manufactured by Carmenta
NAAN	North Atlantic ADS-B Network
ND	Navigation Display
NDB	Non-Directional Beacon
NEAN	North European AD-B Network (project)
NEAP	North European CNS/ATM Applications Project
NUP	NEAN Update Programme
NM	Nautical Mile
NPA	Non-Precision Approach
NUP	NEAN Update Programme
OBT	Operational Benefit Test
PA	precision Approach
PETAL	Preliminary Eurocontrol Test of Air/ground data Link
PFD	Primary Flight Display
RIMS	Runway Incursion Monitoring System
RAIM	Receiver Autonomous Integrity Monitoring
RMCDE	Radar Message Conversion and Distribution Equipment
RTCA	Requirements and Technical Concepts for Aviation
RNAV	Area Navigation
RNP	Required Navigation Performance
SAR	Search and Rescue
SAS	Scandinavian Airlines
SAT	Site Acceptance Test
SCAA	Swedish Civil Aviation Administration (SCAA)
SCAT-I	Special Category I
SCT	System Characteristics Test
SLV	Statens Luftfartsvaesen (DCAA)
SMR	Surface Movement Radar
STAR	Standard instrument Arrival Route
STDMA	Self-organising Time Division Multiple Access
SUPRA	Support for the Use of PResently unserved Airspace
TA	Traffic Advisory
TCAS	Traffic Collision Avoidance System
TDI	Track Deviation Indicator
TEN-T	Trans-European Network
TIS	Traffic Information Services
TIS-B	TIS-Broadcast
TSO	Technical Service Order
TWR	Control Tower
VDL	VHF Digital Link
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
WAN	Wide Area Network
WIAS	Weather Information Automated Systems

EXCUTIVE SUMMARY

1 SPONSORSHIP AND PARTNERS

The North European CNS/ATM Applications Project (NEAP) was sponsored by the Directorate General VII of the Commission of the European Union within the framework of the Trans-European Transport Network (TEN-T).

The following organisations participated in the project:

- Deutsche Lufthansa (DLH)
- Scandinavian Airlines (SAS)
- Deutsche Flugsicherung GmbH (DFS)
- Statens Luftfartsvaesen; the Danish Civil Aviation Organisation (DCAA)
- Luftfartsverket; the Swedish Civil Aviation Organisation (SCAA).

Each of the project partners was responsible for activities within a specific segment of the project, but activities were closely co-ordinated across segment boundaries.

2 OBJECTIVES

The overall project objectives of NEAP were to investigate, specify, develop, test and evaluate civil aviation user applications and services within an integrated communications, navigation and surveillance (CNS) concept. Activities focused on the following domains:

- Enhanced surveillance for Air Traffic Control (ATC)
- Pilot situation awareness
- GNSS (Global Navigation Satellite System) Precision navigation capability for all phases of flight.

Each of these domains includes one or more applications that cover aspects of all phases of flight in a gate-to-gate concept. Therefore, the testing and evaluation activities included the verification of the suitability of a single technical system solution to support ATC and aircrew from pushback to docking at the arrival gate.

The NEAP project objectives must be viewed on two levels. *Overall project objectives* relate to the suitability of a single integrated CNS system to support a range of operational services and multiple phases of flight. *Specific objectives* relate to the capability and suitability of that system to support individual applications and services. Evaluation of individual applications and services also addressed the potential benefits to be gained by their use in a future CNS/ATM concept. Application-specific objectives were also defined.

The project designation NEAP implies an applications oriented project, which means that emphasis was on operational suitability rather than technical performance. However, applications and technical performance are closely linked - poor system technical performance inevitably leads to poor operational performance and therefore low rating by operators. International standardisation organisations also place formal technical requirements on applications, such as update rate, accuracy and reliability. The testing and evaluation of applications in NEAP therefore in effect also applied to the capability of the technical system to support those applications. Therefore, testing

and evaluation of the system characteristics and performance formed an important part of NEAP activities.

3 PROJECT LIFE CYCLE

NEAP started on 1 September 1997 and ended on 31 December 1998.

4 TECHNOLOGY BACKGROUND

The International Civil Aviation Organisation (ICAO) has adopted the *CNS/ATM concept*. This concept envisages the use of data link communications, satellite navigation systems and automatic dependent surveillance (ADS) in the future provision of air traffic management (ATM). When implemented, this new global system will provide the aviation community with cost-effective replacement of current systems and technology.

A number of projects are ongoing world-wide to determine how to implement the mix of satellite, air and ground technologies in the most optimal way. To achieve the greatest benefits from the introduction of the new technology all airspace users must be appropriately equipped. The required equipment has to be affordable and suitable for all user groups. This implies that future systems will have to be based on multi-purpose, low cost equipment. The applications using this equipment must be user friendly.

The Self-organising Time Division Multiple Access (STDMA) technology was developed to meet the requirements for a low-cost data link to support a range of CNS domains. Several national and international projects have focused on the demonstration of the basic technology and its application in support of ground and airborne users, and work on international standardisation is ongoing. ICAO has adopted *VDL* (VHF Digital Link) *Mode 4* as the designation for the STDMA technology when standardised for civil aviation.

STDMA was the enabling technology in NEAP, providing the necessary platform for the testing and evaluation.

Operating in the VHF band, STDMA/VDL Mode 4 is capable of handling time-critical information in well-defined time slots for air-to-air, air-to-ground and ground-to-ground data communications. Messages can be broadcast to all users or addressed to specific users (end-to-end). The primary application of the technology is ADS-Broadcast (ADS-B), which provides not only controllers, but pilots too, with a highly accurate display of nearby traffic. The North European ADS Broadcast Network (NEAN) project, another project sponsored by the European Commission and a sister project of NEAP, provides the ground and air infrastructure to allow the extensive testing of specific CNS/ATM applications conducted within NEAP to take place. The NEAN ground infrastructure consists of a number of ground stations that provide consistent VHF coverage across a large part of northern Europe. A ground station exchanges data through the STDMA/VDL Mode 4 data link with “transponder” equipment onboard aircraft and ground vehicles, and with other ground stations through the ground network.

User display equipment were key to the testing conducted in NEAP. Six DLH B747s, two SAS F28s and two DC9s, one MAERSK helicopter, one DLR Do-228 and several ground vehicles formed the backbone of mobile platforms used in the testing.

5 THE GATE-TO-GATE CONCEPT

Today, a range of dissimilar and segregated communication, navigation and surveillance systems supports pilots and controllers in different phases of flight and airspace types. The emergence of data link services creates an opportunity to establish integrated, “seamless” gate-to-gate services to pilots and ATC alike. In NEAP, several examples of data link applications and services, based on a single technical platform, were tested and evaluated.

6 NEAP APPLICATIONS

The data link applications tested and evaluated in NEAP are essential for meeting the requirements of the future CNS/ATM system. The following applications were included in the test program (the responsible organisation is given within brackets):

- GNSS precision navigation capability for en-route and approach (SAS)
- On ground situation awareness/ taxi guidance (DLH)
- In-flight situation awareness (DLH)
- Enhanced ATC surveillance – downlink of aircraft parameters (DFS)
- Automatic Terminal Information Service broadcast; ATIS-B (DFS)
- Extended helicopter surveillance (DCAA)
- Runway incursion (SCAA).

Hence at least one application, or service, of each component of the CNS/ATM concept was included in NEAP. Combined, they demonstrate a single system solution for seamless gate-to-gate operations, i.e. a system that supports pilot and controllers in all phases of flight from the departure gate, through pushback, taxiing, take-off, climb, en-route, descent, approach, landing and taxiing to docking at the arrival gate.

Following is a brief, generic, description of the fundamental techniques on which these applications and services are based. A more detailed description of each particular application/service is given later in this summary.

6.1 Automatic Dependent Surveillance - Broadcast

Automatic Dependent Surveillance - Broadcast (ADS-B) is a new aviation surveillance concept whereby aircraft transmit their positions (usually derived from a GNSS receiver on-board the aircraft) over a radio data link. In a fully implemented system, position information is transmitted and received by every aircraft in the vicinity so that all users have knowledge of their own location and the locations of all other aircraft. The position information may be displayed in the cockpit of suitably equipped aircraft to give new situation awareness capabilities. Also, ground vehicles and fixed ground stations can be equipped to transmit and receive position data, allowing surveillance of all types of traffic and a two-way data link capability.

ADS-B is an enabling technology that can help to deliver the free flight concept to airspace users. ADS-B will provide new surveillance capabilities to ATC at reduced cost compared to conventional radar.

STDMA/VDL Mode 4 supports ADS-B for all phases of flight. For ground operations, it allows taxiing aircraft and airport vehicles to be monitored from the control tower. This could provide a safety net against unintentional runway incursion.

6.2 Pilot situation awareness

Data link communications will remove the “party line”, i. e. the possibility for pilots to monitor the voice communications between ATC and other aircraft. Pilots will therefore lose their present situation awareness. ADS-B, with an appropriate cockpit display (commonly known as a Cockpit Display of Traffic Information (CDTI)), gives a much better situation awareness to help overcome this concern. ADS-B and a CDTI will provide the pilot with full situation awareness of all surrounding traffic, including intent as appropriate, and will also show the own aircraft position superimposed on a moving map in all phases of flight. As ADS-B also works on the ground, a CDTI may be used to support taxiing and detect other aircraft and airport vehicles in low visibility conditions.

6.3 Enhanced ATC surveillance

ADS-B data transmitted will provide accurate and reliable surveillance information for ground ATC. This information can be used to enhance the quality of surveillance. For example, position data can be supplemented with aircraft parameter data from the FMS or airborne computers. Such data can also be used by the airline technical support.

6.4 GNSS augmentation

When using GNSS data for navigation or surveillance, a GNSS augmentation system can be used to improve the quality of the position data. GNSS augmentation signals transmitted by data link from satellites or ground stations provide information on the quality of the GNSS signals and correction data to overcome intentional and unintentional errors in the signals from the satellites. There are several possible approaches to augmentation and one is the GNSS Regional Augmentation System (GRAS). With GRAS, a network of STDMA/VDL Mode 4 ground stations gathers data on GNSS satellite integrity and calculates augmentation information. The augmentation information is transmitted from the ground to the aircraft, possibly using the same data link as that used to support ADS-B and other applications.

Using the STDMA/VDL Mode 4 data link to augment satellite navigation signals can give very high accuracy of position information, for example, 1-2 m in the horizontal plane. This allows aircraft and ground vehicles to navigate in the air and on the ground using the augmented position information. The service provided by GRAS will be appropriate for most navigation applications including approach operations down to Instrument Approach with Vertical Guidance (IPV).

6.5 Communications

A data link can be used to transmit data in a point-to-point or broadcast fashion. Point-to-point, or addressed, transmissions can be used for controller-pilot data link communications (CPDLC) for exchange of mainly routine messages.

Broadcast transmissions from the ground to many aircraft simultaneously can be used to provide broadcast uplink of, for instance, meteorological data, flight information services (FIS) and traffic information services (TIS). TIS-B provides broadcast uplink of radar derived position data, and is suitable as a complement to ADS-B during transition when all aircraft have not yet been equipped. Automatic Terminal Information Service-Broadcast (ATIS-B) is used to transmit airport information and weather data to aircraft for display on the CDTI.

7 TEST ENVIRONMENT

Testing was carried out in Germany, Denmark and Sweden. Ground testing activities were located in Frankfurt, Langen, Esbjerg/Tyra oil rig, Ängelholm and Stockholm-Arlanda. Except for a limited number of dedicated test flights, in-flight testing was conducted on scheduled revenue flights, including North Sea helicopter operations.

The project designation NEAP implies an applications oriented project. The achievement of the overall and specific requirements assumed the availability of a properly functioning ground and airborne infrastructure and basic services offered by that infrastructure. The basic ground and airborne infrastructure was provided by NEAN, which provided the following data and services within its coverage area:

- ADS-B information,
- differential GPS data (DGPS),
- rudimentary end-to-end message delivery,
- CDTI functionality onboard participating aircraft,
- network management and maintenance functions,
- data broadcast capability.

In addition to the dependency on the NEAN technical platform, NEAP included the development of NEAP-specific equipment and functionality. For instance, the testing of GNSS approach required the development of a new ground station at Ängelholm, an upgrade of the CDTI developed within NEAN, and integration of an additional flight instrument.

8 RELATIONSHIP WITH OTHER PROJECTS

- ***NEAN.*** As noted above, NEAN provided the ground and airborne infrastructure necessary for the testing and evaluation carried out in NEAP.
- ***PETAL II.*** Managed by Eurocontrol Brussels, PETAL II focuses on the use of data links for real-time CPDLC, that is, point-to-point communications between ATC and aircraft. One of the data links used by PETAL II is STDMA/VDL Mode 4, and the project is using some of the aircraft also used by NEAP for its trials.
- ***FREER III.*** The FREER projects aim to lay the foundation for a future “free flight” concept in which more autonomy and authority in the ATM system are placed on the aircraft. In FREER III, experiments are carried out on the use of an air-to-air data link to detect and resolve conflicts. Experiments include the use of the STDMA/VDL Mode 4 data link technology and CDTI as a means for displaying ADS-B derived traffic and traffic advisories.

Other projects using the same technology or sharing project objectives, such as FARAWAY, DEFAMME, FAA SAFEFLIGHT 2000 and MagnetB.

9 METHODOLOGY

This section outlines the test methodology applied in NEAP.

The objective of NEAP was to evaluate the operational benefits of services associated with different applications of data link techniques. In addition, the ability of the

data link technology (STDMA/VDL Mode 4) employed to support those applications and services was to be evaluated.

The evaluation of the suitability of a certain service must be based on judgements and opinions expressed by experienced users, i.e. pilots and controllers, who were to base their judgements on a comparison between their experience from the current (non-data link) service and the service being tested in NEAP. Moreover, certain functional requirements, such as Required Navigation Performance (RNP) parameters for en-route navigation and approach, must be met by the technical systems, and data to support technical evaluation must be collected and analysed.

Questionnaires were used to gather opinions and comments from the users and the answers were analysed statistically. In addition to gathering "subjective" data through questionnaires, data from various technical sources, such as the NEAN network, onboard MMI and ATC systems was collected and used in the evaluation of the technical systems. Emphasis in testing and evaluation was placed on common "key" factors such as safety, impact on workload, technical limitations and required improvements.

Evaluations made for individual services were used to arrive at conclusions regarding the overall capability and suitability of a single system solution to support CNS/ATM applications and services in all phases of flight, i.e. "a seamless gate-to-gate CNS/ATM system".

10 APPLICATIONS

10.1 Precision Navigation

This application was developed in co-operation between SAS and the SCAA.

10.1.1 Operational context

Modern aircraft are capable of navigating without overflying fixed navigation aids on the ground. Area navigation can be supported, for instance, by use of satellite navigation. Basic GNSS accuracy and integrity can be augmented by differential GNSS (DGNSS) signals. The presence of DGNSS is needed for more demanding approach and landing operations.

Non-Precision Approach (NPA) is a major contributor to controlled flight into terrain (CFIT) accidents. Lack of vertical guidance and poor situation awareness is a main reason.

10.1.2 NEAP application

The precision navigation service tested in NEAP was supported by the STDMA/VDL Mode 4 data link. Differential corrections were broadcast from ground stations and ADS-B reports were received from equipped aircraft and ground vehicles.

En-route navigation and approach testing was conducted using two SAS Fokker 28s on scheduled service between Stockholm-Arlanda (ARN) and Ängelholm (AGH). The approach into AGH was made as an Instrument Approach with Vertical guidance (IPV). Two separate Track Deviation Instruments (TDI) were installed to provide lateral and vertical guidance to the pilots during final approach. The TDI was used together with the CDTI, which provided situation overview throughout en-route navigation and approach phases of flight.

A new ground station was developed and installed at AGH. It used a combination of a commercial SCAT-I system for generating differential corrections and an STDMA/VDL Mode 4 system for providing the two-way data link capability to support DGNSS broadcast and reception of ADS-B reports. New display equipment was installed in the AGH control tower (TWR). The availability of NEAN data allowed the controller to view, in a seamless fashion, aircraft positions from the departure gate at ARN through the en-route, approach, landing and taxiing phases into the parking position at AGH.

10.1.3 Testing and evaluation

Testing included the collection and evaluation of both operational and technical data. The main testing platform was the two specially equipped SAS Fokker F28s, but testing also focused on the AGH ground station and equipment in the TWR. System characteristics were tested to assess the system's performance and potential to support seamless CNS/ATM gate-to-gate operations. The operational aspects and benefits were assessed through questionnaires and interviews.

10.1.4 Results and conclusions

The following bullet points summarise principal findings.

- All application-specific objectives were met, and the assumptions on expected benefits and system characteristics were accepted.
- The evaluated service provided potential operational benefits in terms of improved situation awareness for pilots and controllers.
- The system delivers support for approach and landing and potentially for seamless gate-to-gate operations.
- The combination of ADS-B and GNSS augmentation using a single data link provides an efficient solution for all phases of flight.
- The workload on the pilots with a future system is expected to be equal or reduced compared to ILS.
- Collaborative procedures could be developed between pilots and controllers to enhance capacity in the terminal area.

A number of ATC benefits enabled by ADS-B was identified.

10.2 On-ground situation awareness and taxi guidance

This application was developed by DLH.

10.2.1 Operational context

One of the bottlenecks in today's growing air traffic is the ground traffic at busy airports. The efficiency of aircraft movements on ground, although skilfully managed by ground controllers, still very much depends on the weather conditions and is far away from being optimised.

Previous trials have demonstrated that ADS-B based on STDMA/VDL Mode 4 works equally well on the ground as in the air. Own position and the positions of other aircraft can be shown on a cockpit display, superimposed on a moving map of the airport. As ADS-B reports include the identity of the transmitting aircraft or vehicles, this information is included in the information presented. This leads to a much-improved pilot awareness of nearby traffic in poor visibility.

By combining a cockpit display with a suitable HMI, it is possible to create a taxi guidance system that leads to more efficient, safer and weather-independent ground movements.

10.2.2 NEAP application

The on-ground situation awareness and taxi guidance service evaluated in NEAP is based on ADS-B reports transmitted and received by six DLH Boeing 747-200 aircraft, other STDMA/VDL Mode 4 equipped aircraft and airport vehicles at the Frankfurt International Airport. The ADS-B reports were based on very accurate DGNSS position data. High-precision airport maps were used in the B747 cockpit displays.

The test program included revenue ground operations of the DLH B747s at Frankfurt during the test period.

10.2.3 Testing and evaluation

Testing included collection and evaluation of operational data using questionnaires. A set of hypotheses was established before testing as the basis for the questionnaires.

10.2.4 Results and conclusions

The tests lead to different results depending on whether the application is viewed from a short or longer perspective. The degree of development and deployment in the field is a crucial factor.

- Small benefits were achieved already with the trial equipment.
- Visual reference is required for collision avoidance during ground operations, requiring restrictions to be applied in low visibility conditions. Therefore a suitable taxi guidance display is required in order to make use of the ADS-B features on ground.
- Taxi guidance increases safety and may reduce taxi time on unfamiliar airports.
- Taxi guidance down to CAT III conditions is possible, allowing a significantly higher flow of ground traffic under low visibility conditions, provided that a suitable taxi guidance display is available and operational procedures are in place.
- On-ground situation awareness allows aircraft to maintain separation independent of weather.

10.3 In-flight situation awareness

This application was developed by DLH.

10.3.1 Operational context

Today, most major international airports face severe problems in accommodating the increasing air traffic, especially at peak hours. The problems are even more severe in poor weather conditions. The identification of new methods to maximise the flow of outbound and inbound traffic is therefore a major challenge.

To allow a weather independent constant flow of traffic, application of visual procedures in instrument weather conditions should be a possible option, provided that suitable means for providing pilots with information on surrounding traffic are in place. This would put the pilot in the ATC information loop and enables him to take an active role in the air traffic management process.

If relevant surveillance information is presented in the cockpit, new operational procedures could be implemented that would allow, under certain circumstances, the delegation of separation responsibility from ATC to the cockpit. One possible “visual” procedure would be “station keeping”, where the aircrew maintains own separation to a preceding aircraft.

10.3.2 NEAP application

The in-flight situation awareness service tested in NEAP was based on ADS-B position reports and radar data uplinked from the ground being received by an STDMA/VDL Mode 4 transponder in six DLH Boeing 747-200 aircraft. This information was presented on a dedicated display in the cockpit, the MMI 5000. The display provided precise area and airport maps on which the positions of ADS-B equipped aircraft and uplinked radar data were superimposed.

Traffic representation on the cockpit display included a label showing the aircraft’s identity(usually the flight number), relative altitude and a prediction vector.

10.3.3 Testing and evaluation

Testing included collection and evaluation of operational data using questionnaires. All tests were based on the NEAP test methodology. Hypotheses were established before testing as a basis for the development of the questionnaires. A clear distinction was made between existing trial equipment and an assumed certified system, and between single flight experience and extended experience from the service being evaluated.

10.3.4 Results and conclusions

The tests lead to different results depending on whether the application is viewed from a short or longer perspective. The degree of development and deployment in the field is a crucial factor.

- TIS-B (uplink of radar data) enables in-flight situation awareness in high traffic density airspace with few ADS-B equipped aircraft.
- ADS-B based in-flight situation awareness forms the basis for an additional safety net with pre-warning times much longer than for TCAS, and therefore allows for early tactical flight path coordination rather than last minute conflict avoidance, resulting in increased safety margin and redundancy.
- In-flight situation awareness including the display of the flight number of other aircraft allows aircrews to optimize their flight profile according to the traffic situation (e.g. change of flight levels between company aircraft).
- Weather independent constant throughput and increased capacity is possible through adaptation of VMC procedures to IMC (e.g. follow visually, climb through level of selected aircraft).
- Airborne station keeping with increased capacity is possible provided that separation responsibility is clearly defined and operational procedures are in place.
- In-flight situation awareness closes the information loop between ATC and the aircraft allowing delegation of responsibilities to the cockpit. As a result, ADS-B based free flight scenarios in low density airspace are possible in the long term.
- Potential to apply reduced separation minima due to enhanced surveillance accuracy.

Finally, uplink of radar data via TIS-B is a key factor in a transition phase.

10.4 Enhanced surveillance for ATC

This application was developed by DFS

10.4.1 Operational context

Today's ATC surveillance is primarily based on radar data. With secondary radar (SSR), identity and altitude is added to the basic position data, and the tracking function in modern ATC systems automatically calculates the speed, vertical attitude and track. The controller's forward planning is based on current radar data combined with information in the flight plan. Information on a flight's actual intentions must be communicated by means of voice.

Increasing load on voice channels and capacity problems in high-density areas require that the controller be provided with improved planning data. The onboard flight management system (FMS) knows exactly the flight path of the entire flight. Access to such precise FMS data for ATC could increase efficiency, reduce delays and costs for airlines and provide an additional safety net.

The DFS Project JANE (Joint Air Navigation Experiments) has determined that with improved strategic and tactical planning the potential number of conflicts (delays, sector load etc.) may be reduced significantly.

10.4.2 NEAP application

The Enhanced Surveillance for ATC application evaluated in NEAP was based on enhanced surveillance (ENH) data, broadcast by an appropriately equipped experimental aircraft and received by the NEAN ground network. Data was presented on the controller working position (AIRLINK). The specification of DAP (Download of Aircraft Parameter) was used to select the information flags. The experimental aircraft supported the following ARINC 429 labels (information):

- Aircraft address
- SSR Mode 3A
- Magnetic Heading
- Roll angle (bank)
- Flight Level (barometric)
- Rate of Turn
- Ground Speed
- Wind Speed/Wind Direction

The DAP data delivered by the ARINC 429 bus system was accepted and converted into the STDMA/VDL Mode 4 format and subsequently broadcast every second on the data link. Each report contained the aircraft data listed above.

10.4.3 Testing and evaluation

The flight tests were performed by the DLR experimental aircraft DO-228. The aircraft was equipped with a ARINC 429 interface card and a STDMA GNSS transponder. The conversion of the aircraft data was performed by a software application.

10.4.4 Results and conclusions

The results provided a perception of how ground system functions such as radar tracking could be improved by using downlinked aircraft parameters. Aircraft intentions and manoeuvres could be detected faster than when using common radar systems.

The following points summarise the principal results and conclusions.

- The evaluated STDMA/VDL Mode 4 system is capable of supporting the downlink of aircraft parameters.
- The format used for the downlink has to be improved and adjusted to operational requirements

There is a unified synchronised time required for all users and systems. The STDMA/VDL Mode 4 system uses the GPS UTC time and could provide this time to other systems.

10.5 Automatic Terminal Information Service - Broadcast

This application was developed by DFS.

10.5.1 Operational context

One of the standard operating procedures in today's operational environment is for pilots to obtain weather and airport information from the Terminal Information Service prior to departure and arrival. The Air Traffic Service Providers are providing the information on the Automatic Terminal Information Service (ATIS) frequency as voice information. The pilot selects the appropriate ATIS frequency and listens to the information. For a written copy of the ATIS information the pilot has to write down the information manually.

The ATIS-B service evaluated in NEAP provided a data link broadcast service to deliver the ATIS information into the cockpit. The pilot used the ATIS function on the cockpit display to access the information.

10.5.2 NEAP application

The ATIS-B service was based on the data link functionality of the NEAN STDMA/VDL Mode 4 system. The ATIS information received from the German weather information systems (WIAS) was automatically broadcast by all German NEAN ground stations. Appropriately equipped aircraft within the coverage of a German ground station would receive ATIS messages from all participating airports. The pilot had the possibility to display the current, as well as previously received ATIS messages from different German airports using the MMI 5000 cockpit display system.

10.5.3 Testing and evaluation

The system tests were divided into a system characteristics test and an operational benefits test.

The system characteristics test was based on monitoring of the message flow through the system. Different steps were defined to;

- verify the applicability of the ATIS conversion tool,
- demonstrate the ATIS reception at a selected flight, and

- evaluate an ATIS coverage map.

The operational benefits test was based on questionnaires developed in co-operation with DLH. A statistical evaluation of the questions concerning the ATIS service was done.

10.5.4 Results and conclusions

A significant percentage of the ATIS messages were not delivered to airborne users. The main bottleneck related to the conversion process. 9 % of all ATIS messages obtained from the AFTN could not be used for the ATIS data link service because of an error message from the conversion module. The major problems were;

- the use of a free text AFTN ATIS format, and
- the use of a not exactly defined phraseology in the AFTN ATIS format.

The ATIS coverage had nearly the same characteristics and range as the ADS-B coverage. From a technical perspective, if applying the results from the Frankfurt ground station to all NEAN ground stations, aircraft within the overall NEAN coverage volume would be able to utilize the ATIS-B service.

Pilots prefer the use of an ATIS broadcast service to using the currently offered ´ATIS on-request´ service. To improve the ATIS presentation on the cockpit display pilots strongly requested a cockpit printer and the use of standard abbreviations rather than plain text.

10.6 Extended Helicopter Surveillance

Thi*s application was developed by SLV.*

10.6.1 Operational Context

For helicopter operations in an uncontrolled airspace without radar coverage, situation awareness for the Air Traffic Control (ATC) relies entirely upon flight plans and position reports from the pilots using voice radio communication during the flight.

Continuously updated visual information on aircraft position will improve situation awareness and reduce the tension for ATC should a position-over-voice arrive later than expected. Reliable and accurate information regarding the last known position would improve the probability for a successful Search and Rescue (SAR) operation, especially when weather conditions are rough and visibility low.

10.6.2 NEAP application

The purpose of the Extended Helicopter Surveillance (EHS) service is to provide extended situation awareness for air traffic controllers by providing enhanced visual capabilities for a designated area of the North Sea, which is only partly covered by radar. The EHS service was extended with a CDTI in a helicopter and an ADS-B-only display system on ground to obtain feedback from the helicopter pilots and operator.

The EHS service depends on ADS-B position reports broadcast by an STDMA/VDL Mode 4 equipped helicopter and received by ground stations installed in Esbjerg and Børsmose - both located at the west coast of Jutland - and on the Tyra East platform. The Tyra East platform is located in the North Sea, approximately 125 nautical miles from the coast, outside radar coverage. The ADS-B position reports were distributed through the NEAN ground infrastructure and displayed together with conventional radar data - when within radar coverage - on a dedicated Controller Working Position

(CWP). The CWP was situated in the Copenhagen ATC centre close to the controllers providing flight information and alerting services for the area.

10.6.3 Testing and Evaluation

No special test flights were conducted for the evaluation. All tests relied on data from regular commercial flights between Esbjerg and offshore installations in the North Sea with a Super Puma from MAERSK HELICOPTERS.

The service evaluation included collection of both operational and technical data. Detailed technical data from all NEAN sensors used by the service were collected and analysed and questionnaires were developed for collecting operational feedback from controllers and helicopter pilots.

10.6.4 Results and Conclusions

The Extended Helicopter Surveillance service enabled ATC to monitor a helicopter, down to flight level 10, from Esbjerg Airport to offshore installations in the North Sea, beyond radar coverage.

According to the helicopter operator, the system provides correct position to the ADS-B-only Display Station almost continuously, despite several problems encountered in the current test implementation.

The test results indicate that a future extended surveillance solution for the examined area can be established using the STDMA/VDL Mode 4 technology.

10.7 Runway incursion monitoring

This application was developed by the SCAA.

10.7.1 Operational context

Unauthorised or unintentional entry onto runways and taxiways by aircraft and vehicles constitutes a serious threat to aviation safety. Hazardous conflict situations may develop between aircraft and airport ground vehicles in, for instance, snow clearing situations when several vehicles operate on, or close to an active runway. The threat is more critical when poor visibility conditions prevent the controllers in the control tower (TWR) to visually monitor ground movements and aircraft on final approach.

10.7.2 NEAP application

The runway incursion (prevention) service tested in NEAP was based on ADS-B reports from appropriately equipped aircraft and airport vehicles being presented on a dedicated display in the TWR. The *Runway Incursion Monitoring System (RIMS)*, developed for the NEAP test programme, included functions that enabled TWR controllers and vehicle drivers to be automatically alerted when a hazardous situation developed.

The test scenarios were designed to replicate potential airport conflict situations such as;

- vehicle too close to active runway as aircraft is landing,
- aircraft still on runway as next aircraft is landing.

Alert conditions that applied to these and similar situations were developed. Alert conditions included *warning* when a conflict risk was present, and *alarm* when there was an actual conflict. Alerts generated visual and audible indications.

10.7.3 Testing and evaluation

Testing included collection and evaluation of both operational and technical data. Scenario testing involved the TWR, specially equipped airport vehicles and a BE200 flight inspection aircraft. Other STDMA/VDL Mode 4 equipped aircraft and vehicles served as "background traffic" that only played a passive role in the tests. Most scenarios were designed to replicate conflicts between aircraft and ground vehicles and between two aircraft, both airborne and on ground. One set of scenarios was specifically designed to serve as the basis for assessment by controllers and addressed many different conflict situations. Such assessment was made through *questionnaires*, which addressed operational aspects of individual RIMS functions and the usefulness of the system. The completed questionnaires used to draw conclusions regarding operational benefits.

10.7.4 Results and conclusions

The following bullet points summarise the principal results and conclusions.

- The evaluated system provided significant operational benefits in terms of safety, reduced controller workload, improved situation awareness, and improved capacity in low visibility conditions.
- The evaluated system was technically viable. However, it was not possible, during the course of the trials, to implement algorithms that covered all possible conflict situations.
- It is possible to realise, through relatively limited technical and economic means, a powerful RIMS based on ADS-B and the STDMA/VDL Mode 4 technical platform.

11 CERTIFICATION ROAD MAP

11.1 Certification Activities

The following NEAP Applications are addressed below:

- Station keeping using Airborne Situation Awareness – CDTI.
- ATIS Broadcast at European Airports.
- IPV approach using a combined ADS-B/DGNSS ground-station.

The Certification process has been analysed from a European perspective, assuming that these applications will be certified in Europe before the US. The study outlines:

- the content of a certification application,
- potential certification owners,
- identification of required certification bodies,
- possible road map for certification of applications,
- potential problems,
- required time for certification, EC activities to support European certification of applications.

A legal survey was carried out of European legislation to support the certification activities.

11.2 NEAP Certification Analysis

As the NEAP shows, significant benefits could be gained through the introduction of new CNS/ATM applications and services. However, NEAP illustrates several fundamental problems currently preventing EU airlines and airports capitalising on the potential benefits. These problems and their effects are common to European CNS/ATM initiatives and include the;

- fragmented European regulatory framework,
- lack of enforcement and confusion over the status of EU legislation,
- critical dependence of European Regulation on the FAA and on US Industry bodies,
- dominant US influence at ICAO,
- dominant position of US manufacturing interests.

Individual NEAP Application projects show that cost/effective technical solutions exist for European and world-wide capacity and safety issues. These solutions are constrained by the lack of a coherent European regulatory framework that is needed to bring them to the market. Individual European regulatory authorities are reluctant to issue approvals on their own initiative unless based on a 'transatlantic dialogue' i.e. the support of the US regulatory infrastructure (including FAA, RTCA, AEEC etc.) Limited progress is only made after the most intense and careful negotiation between a major airline and its regulatory authority – often initially resulting in "company only procedures". This limits the availability of these solutions to the market and greatly reduces the rate of introduction.

11.3 Recommendations

The following key recommendations are made:

- Development of European Standards - to support VDL Mode 4 and its exploitation.
- These European Standards (ENs) should include:
  - radio performance (for TA),
  - data link performance,
  - communication services and applications,
  - network standards and performance requirements.
- Incorporate European standards for VDL Mode 4 into JAA JTSOs for certification/installation in aircraft.
- Development of JAA Operational Standards for ADS-B airborne applications.
- Rationalisation of regulatory framework and enforcement of legislation.
- Development of a certification strategy for VDL Mode 4

12 CONSOLIDATED CONCLUSIONS AND RECOMMENDATIONS

12.1 General

Like the project objectives, the results and conclusions from NEAP should be viewed on two levels:

- The results and conclusions from the individual applications. These also included evaluation of new operational methods. These results and conclusions are stated in the application descriptions earlier in this document.
- The results and conclusions on a "system" level based on the results and conclusions from the applications level. These overall results and conclusions relate to the capability of a common technical platform, i.e. the STDMA/VDL Mode 4 technology, to support applications and services through-out all phases of flight ("gate-to-gate") and across CNS domains. They also relate to conclusions drawn with regard to operations in a wider context.

12.2 Conclusions

The following bullet points summarise the main findings on the system level. They are based on results from all applications evaluated within NEAP.

Operations:

- ADS-B for surveillance and as a basis for several other CNS services is feasible in all phases of flight, including surface operations. It works equally well on different types of aircraft, helicopters and ground vehicles
- Operational use of ADS-B in airborne and ATC installations requires careful analysis of Human Machine Interface (HMI) issues.
- Organised broadcast services of DGNSS, TIS-B and FIS-B (e.g. ATIS) is feasible and potentially very spectrum efficient. Coverage is the same as for ADS-B.
- Capacity and safety can be improved in unserved airspace by using ADS-B.
- The operational concept of ADS-B is not complete, e.g. it lacks requirements for efficient aircraft and ATC implementation.
- Operational implementation of STDMA/ VDL Mode 4 requires close co-ordination between ground service providers (CAA's).
- The aviation community currently lacks sufficient guidance on emerging CNS/ATM concepts.

Technical

- The combination of CNS services using a common technical platform is feasible. STDMA/VDL Mode 4 provides a suitable system solution.
- STDMA/VDL Mode 4 is a feasible system solution for a ground-based regional augmentation system (GRAS). From a technical viewpoint, uplinked GNSS augmentation messages can be combined with ADS-B downlink on the same data link and channel. The combination of a SCAT-I ground station with an STDMA/VDL Mode 4 data link is potentially a viable technical solution for GRAS.
- STDMA/ VDL Mode 4 message throughput is not fully satisfactory under all conditions.

12.3 Recommendations

- Introduction of ADS-B in Europe should be accelerated, especially in unserved airspace.
- Further development of ADS-B and associated applications requires close co-operation with airframe and ATC airport system manufacturers. Discussions to that end should be initiated.
- Develop operational procedures related to the use of ADS-B in Europe
- Initiate research on human factors regarding cockpit layout of traffic information (CDTI).
- Initiate extensive cost/benefit analyses with respect to ADS-B and other broad-cast applications.
- Analyse certification issues for ADS-B and other broadcast services. Promote the development of European Standards (e.g. ETSI), JAA Joint Technical Standards Orders (JTSOs) and JAA Operational Standards.
- Analyse safety, certification and operational approval aspects of using a common data link standard and a mix of CNS applications.

FINAL REPORT

1 OVERVIEW

1.1 General

The North European CNS/ATM Applications Project (NEAP) was sponsored by the Directorate General VII of the European Union within the framework of Trans-European Transport Network (TEN-T).

The project was a follow-on project to the North European ADS Broadcast Network (NEAN). Whereas the NEAN project focused on technical issues and the creation of a working ground and airborne infrastructure, NEAP used that infrastructure as a platform for testing real-life Communications, Navigation and Surveillance (CNS) applications and services in support of a future air traffic management (ATM) system.

1.2 Partnership

The following organisations participated as Partners in the project:

- Luftfartsverket; the Swedish Civil Aviation Organisation (SCAA).
- Deutsche Flugsicherung GmbH (DFS)
- Deutsche Lufthansa (DLH)
- Scandinavian Airlines (SAS)
- Statens Luftfartsvaesen; the Danish Civil Aviation Organisation (DCAA)

Each of the Project Partners was responsible for activities within a specific segment of the project, but activities were closely co-ordinated across segment boundaries.

The SCAA was the Project Co-ordinator. As such, the SCAA was responsible for project management and the interface with the CEC. As a Partner, the SCAA contributed with test environment that included the national airspace, two airports with control towers, an air traffic control centre, airport vehicles and a technical test centre. Manpower resources provided to the project included engineers, technicians, controllers and administrative staff. The SCAA was responsible for developing the “Runway incursion monitoring” application.

DFS contributed with the national airspace, airports and airport vehicles. Manpower resources included engineers, technicians and ATC staff. DFS was responsible for developing the “Enhanced Surveillance for ATC” and “Automatic Terminal Information Service Broadcast (ATIS-B)” applications, and for co-ordinating flight-testing for those applications conducted by DLH and DLR (Deutsche Institut für Luft und Raumfahrt).

DLH contributed with six Boeing 747-200 aircraft, pilots and engineers and was responsible for developing the “On-ground situation awareness and taxi guidance” and “In-flight situation awareness” applications including in-flight and ground testing on scheduled revenue operations in Germany and adjacent airspace.

SAS contributed with two Fokker 28 aircraft, pilots and engineers, and was responsible for developing the “Precision navigation” application that included in-flight testing on scheduled revenue operations in Sweden.

The DCAA contributed with the national airspace, airports and a North Sea helipad. Manpower resources included engineers, technicians and controllers. The DCAA was responsible for developing the “Extended helicopter surveillance” application and for co-ordinating flight-testing conducted onboard a helicopter operated by MAERSK Helicopters.

1.3 Project life cycle

NEAP started on 1 September 1997 and ended on 31 December 1998.

2 SETTING THE SCENE

2.1 Scope

NEAP testing and evaluation activities focused on “real-world” civil aviation user applications and services within an integrated CNS (Communications, Navigation, Surveillance) concept within the following domains

- Enhanced surveillance for ATC.
- Pilot situation awareness.
- GNSS precision navigation capabilities for all phases of flight, i.e. surface movements, departure, en-route, and approach and landing operations.

One or more applications within each of these domains were developed by the NEAP partners for the purpose of addressing ATC and aircrew aspects of different phases of flight in a gate-to-gate concept, i.e. from pushback at the departure airport to docking at the arrival gate.

2.2 The CNS/ATM concept

The International Civil Aviation Organisation (ICAO) has adopted the *CNS/ATM concept*. This concept envisages the use of data link communications, satellite navigation systems and automatic dependent surveillance (ADS) in the future provision of air traffic management (ATM). When implemented, this new global system will provide the aviation community with cost-effective replacement of current systems and technology.

The use of the high-capacity Self-organising Time Division Multiple Access (STDMA) data link was key to all applications and services evaluated in NEAP. Standardisation of the STDMA data link is ongoing in the International Civil Aviation Organization (ICAO). The acronym *VDL Mode 4* (VHF Digital Link Mode 4) is used by ICAO to designate the STDMA technology. To indicate the close relationship between the technology used in NEAP and the future standardised technology, the acronym *STDMA/VDL Mode 4* has been used throughout this document.

A high-capacity data link is an enabler for a range of applications and services in a future ATM system. Following is a brief, generic, description of the fundamental techniques on which these applications and services are based. A more detailed description of each particular application/service is given later in the document.

2.2.1 Automatic Dependent Surveillance - Broadcast

Automatic Dependent Surveillance - Broadcast (ADS-B) is a new aviation surveillance concept whereby aircraft transmit their positions (usually derived from a GNSS receiver on-board the aircraft) over a radio data link. In a fully implemented system, position information is transmitted and received by every aircraft in the vicinity so that

all users have knowledge of their own location and the locations of all other aircraft. The position information may be displayed in the cockpit of suitably equipped aircraft to give new situation awareness capabilities. Also, ground vehicles and fixed ground stations can be equipped to transmit and receive position data, allowing surveillance of all types of traffic and a two-way data link capability.

ADS-B is an enabling technique that can help to deliver the free flight concept to airspace users. ADS-B will provide new surveillance capabilities to ATC at reduced cost compared to conventional radar. An ADS-B ground station is a transmitting/receiving station without the expensive and complex rotating antennas of radar systems. Also, an ADS-B ground station is not required to make high precision measurements of aircraft position unlike radar systems, so the cost of ground electronics is much less.

STDMA/VDL Mode 4 supports ADS-B for all phases of flight. When used to support ground operations it enables aircraft and airport vehicles to be monitored from the control tower and provides a basis for much improved pilot situation awareness in low visibility conditions. This could provide a safety net against unintentional runway incursion.

2.2.2 Pilot situation awareness

Data link communications will remove the “party line”, i. e. the possibility for pilots to monitor the voice communications between ATC and other aircraft. Pilots will therefore lose their present situation awareness. ADS-B, with an appropriate cockpit display (commonly known as a Cockpit Display of Traffic Information (CDTI)), gives a much better situation awareness to help overcome this concern. ADS-B and a CDTI will provide the pilot with full situation awareness of all surrounding traffic, including intent as appropriate, and will also show the own aircraft position superimposed on a moving map in all phases of flight. As ADS-B also works on the ground, a CDTI may be used to support taxiing and detect other aircraft and airport vehicles in low visibility conditions.

2.2.3 Enhanced ATC surveillance

ADS-B data transmitted will provide accurate and reliable surveillance information for ground ATC. This information can be used to enhance the quality of surveillance. For example, position data can be supplemented with aircraft parameter data from the FMS or airborne computers. Such data can also be used by the airline technical support.

2.2.4 GNSS augmentation

When using GNSS data for navigation or surveillance, a GNSS augmentation system can be used to improve the quality of the position data. GNSS augmentation signals transmitted by data link from satellites or ground stations provide information on the quality of the GNSS signals and correction data to overcome intentional and unintentional errors in the signals from the satellites. There are several possible approaches to augmentation and one is the GNSS Regional Augmentation System (GRAS). With GRAS, a network of STDMA/VDL Mode 4 ground stations gathers data on GNSS satellite integrity and calculates augmentation information. The augmentation information is transmitted from the ground to the aircraft, possibly using the same data link as that used to support ADS-B and other applications.

Using the STDMA/VDL Mode 4 data link to augment satellite navigation signals can give very high accuracy of position information, for example, 1-2 m in the horizontal plane. This allows aircraft and ground vehicles to navigate in the air and on the ground using the augmented position information. The service provided by GRAS will

be appropriate for most navigation applications including approach operations down to Instrument Approach with Vertical Guidance (IPV).

2.2.5 Communications

A data link can be used to transmit data in a point-to-point or broadcast fashion. Point-to-point, or addressed, transmissions can be used for controller-pilot data link communications (CPDLC) for exchange of mainly routine messages.

Broadcast transmissions from the ground to many aircraft simultaneously can be used to provide broadcast uplink of, for instance, meteorological data, flight information services (FIS) and traffic information services (TIS). TIS-B provides broadcast uplink of radar derived position data, and is suitable as a complement to ADS-B during transition when all aircraft have not yet been equipped. Automatic Terminal Information Service-Broadcast (ATIS-B) is used to transmit airport information and weather data to aircraft for display on the CDTI.

2.3 The gate-to-gate concept

Today, a range of dissimilar and segregated communication, navigation and surveillance systems supports pilots and controllers in different phases of flight and airspace types. The emergence of data link services creates an opportunity to establish integrated, “seamless” gate-to-gate services to pilots and ATC alike. In NEAP, several examples of data link applications and services, based on a single technical platform, were tested and evaluated.

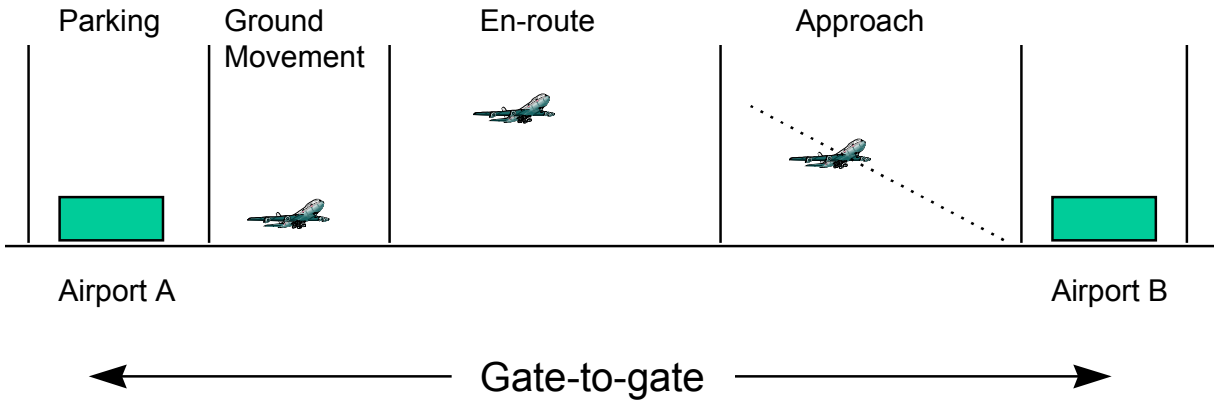


Figure 2.2 - Gate-to-gate-concept

2.4 Relationship with other projects

- ***NEAN***. As noted above, NEAN provides the ground and airborne infrastructure necessary for the testing and evaluation carried out in NEAP. Co-ordination between the two projects has been close on both management and working levels.
- ***PETAL II.*** Managed by Eurocontrol Brussels, PETAL II focuses on the use of data links for real-time CPDLC, that is, point-to-point communications between ATC and aircraft. One of the data links used by PETAL II is STDMA/VDL Mode 4, and the project is using some of the aircraft also used by NEAP for its trials. To develop and optimise human-machine interface (HMI) of the CDTI for both

point-to-point and broadcast operations, co-ordination between the two projects has taken place on a regular basis.

- ***FREER III.*** The FREER projects aim to lay the foundation for a future "free flight" concept in which more autonomy and authority in the ATM system are placed on the aircraft. In FREER III, experiments are carried out on the use of an air-to-air data link to detect and resolve conflicts. Experiments include the use of the STDMA/VDL Mode 4 data link technology and CDTI as a means for displaying ADS-B derived traffic and traffic advisories.
- Other projects using the same technology or sharing project objectives, such as FARAWAY, DEFAMME, FAA SAFEFLIGHT 2000 and Magnet B.

3 APPROACH

3.1 Objectives

The NEAP project objectives must be viewed on two levels. *Overall project objectives* relate to the suitability of a single integrated CNS system to support a range of operational services and multiple phases of flight. *Specific objectives* relate to the potential benefits to be gained by the individual applications and their use in a future CNS/ATM concept. The specific objectives also relate to the capability and suitability of the CNS system to support these applications and services.

3.1.1 Overall objectives

The overall project objectives of NEAP were to investigate, specify, develop, test and evaluate civil aviation user applications and services within an integrated CNS concept. Emphasis was to be placed on gaining "real-world" experience.

Testing and evaluation activities would focus on the following domains of applications and services:

- Enhanced surveillance for ATC.
- Pilot situation awareness.
- GNSS precision navigation capabilities for all phases of flight, i.e. surface movements, departure, en-route, and approach and landing operations.

Each of these domains includes one or more applications that address aspects of all phases of flight in a gate-to-gate concept. Therefore, testing and evaluation activities included the verification of the suitability of a single technical system solution to support ATC and aircrew from pushback at the departure airport to docking at the arrival gate. However, the applications and services were developed as stand-alone products, and no attempt was made, or planned, to create a fully integrated gate-to-gate system. Nor was any attempt made, or planned, to integrate hardware and software used for the testing with existing operational equipment.

3.1.2 Specific objectives

Throughout the testing and evaluation conducted within each application, feedback from aircrews and ATC was to be gathered for analysis. Such data would be useful for improvement of equipment and services and refinement of HMI. Experience from the testing would be used for future concept development and safety analyses.

The following specific objectives relating to one or more applications were adopted:

- Gathering of operational feedback on human-machine interface (HMI) aspects with regard to the cockpit display (CDTI), including digital maps of European airspace and airports.
- Gathering of technical and operational feedback on broadcast of flight information services.
- Gathering of technical and operational feedback on a combined ADS-B and DGNSS concept for approach and landing.
- Gathering of technical and operational feedback on surveillance in previously unserved airspace, such as surveillance of low-altitude operations in the North Sea.
- Preliminary analysis of safety implications of combining different CNS applications in a single technical system.
- Development of preliminary operational requirements for a CNS system supporting gate-to-gate operations.
- Refinement of the cellular CNS concept (CCC).

In addition, application-specific objectives were defined.

The project designation NEAP implies an applications oriented project, which in turn means that emphasis was on operational suitability rather than technical performance. However, applications and technical performance are closely linked - poor system technical performance inevitably leads to poor operational performance and therefore low rating by users. International standardisation organisations also place formal technical requirements on applications, such as update rate, accuracy and reliability. The testing and evaluation of applications in NEAP therefore in effect also applied to the capability of the technical system to support those applications. Therefore, testing and evaluation of the system characteristics and performance formed an important part of NEAP activities.

3.2 Test environment

Testing was carried out in Germany, Denmark and Sweden. Ground testing activities were located in Frankfurt, Langen, Esbjerg/Tyra East oilrig, Ängelholm and Stockholm-Arlanda. Except for a limited number of dedicated test flights, in-flight testing was conducted on scheduled revenue flights, including North Sea helicopter operations.

The achievement of the overall and specific requirements assumed the availability of a properly functioning ground and airborne infrastructure and basic services offered by that infrastructure.

The basic ground and airborne infrastructure was provided by NEAN, which provided the following data and services within its coverage area:

- ADS-B information,
- differential GPS data (DGPS),
- rudimentary end-to-end message delivery,
- CDTI functionality onboard participating aircraft,
- network management and maintenance functions,
- data broadcast capability.

In addition to the dependency on the NEAN technical platform, NEAP included development of NEAP-specific equipment and functionality. For instance, the testing of GNSS approach required the development of a new ground station at Ängelholm, an upgrade of the CDTI developed within NEAN, and integration of an additional flight instrument.

Six DLH B747s, two SAS F28-4000 and two DC-9-41, one MAERSK Super Puma helicopter, one DLR Do-228 and several ground vehicles formed the backbone of mobile platforms used in the testing activities.

3.3 Methodology

This section outlines the test methodology applied in NEAP.

The evaluation of the suitability of a certain service must be based on judgements and opinions expressed by experienced users, i.e. pilots and controllers, who were to base their judgements on a comparison between their experience from the current (non-data link) service and the service being tested in NEAP. Moreover, certain functional requirements, such as Required Navigation Performance (RNP) parameters for en-route navigation and approach, must be met by the technical systems, and data to support technical evaluation must be collected and analysed.

Each of the services tested in NEAP, as well as the scenario in which the testing was to be conducted, was clearly specified in a S*ervice description, a Realisation plan* and a *Test plan* for each service to be tested. However, since testing of certain services took place in a live operational environment onboard commercial aircraft and helicopters and at ATC units, the scenarios could not always be fully controlled.

The benefits expected to be gained from a particular application or service were used as hypotheses that were to be accepted or rejected through the testing activities. Questionnaires were used to gather opinions and comments from the users, and the answers were analysed statistically. Care was taken to ensure objectivity by not influencing the answers by leading questions.

In addition to gathering “subjective” data through questionnaires, technical data from various sources, such as the NEAN network, onboard MMI and ATC systems was collected and used in the evaluation of the technical systems. Emphasis in testing and evaluation was placed on common “key” factors such as safety, impact on workload, technical limitations and required improvements.

Evaluations made for individual services were used to arrive at conclusions regarding the overall capability and suitability of a single system solution to support CNS/ATM applications and services in all phases of flight, i.e. “a seamless gate-to-gate CNS/ATM system”.

4 SCIENTIFIC AND TECHNICAL DESCRIPTION

4.1 Technology background

All applications and services evaluated in NEAP require the use of a data link for communications between airborne and ground users. The STDMA/VDL Mode 4 technology and the NEAN ground and air infrastructure constituted the common technical platform for the trials and evaluations. A brief description is given below of the enabling technology and infrastructure.

4.1.1 STDMA/VDL Mode 4

A number of projects are ongoing world-wide to determine how to implement the mix of satellite, air and ground technologies in the most optimal way. To achieve the greatest benefits from the introduction of the new technology all airspace users must be appropriately equipped. The required equipment has to be affordable and suitable for all user groups. This implies that future systems will have to be based on multi-purpose, low cost equipment. The applications using this equipment must be user friendly.

The STDMA data link technology has been developed to meet the requirements for a high-capacity data link to support a range of CNS domains. Several national and international projects have focused on the demonstration of the basic technology and its application in support of ground and airborne users, and work on international standardisation is ongoing. ICAO has adopted *VDL* (VHF Digital Link) *Mode 4* as the designation for the STDMA technology when standardised for civil aviation. Recognising the close relationship between the equipment used in NEAP and future, standardised equipment, the designation “STDMA/VDL Mode 4” has been used throughout this document.

STDMA was the enabling technology in NEAP. Together with the ground and air infrastructure created in NEAN it provided the necessary technical platform for the testing and evaluation.

4.1.1.1 Technical overview

STDMA/VDL Mode 4 is a time-critical VHF data link, providing digital communications between aircraft and other aircraft and ground stations, designed for CNS/ATM aviation applications, including broadcast applications (e.g. ADS-B) and air-to-air and ground-to-air communications.

STDMAVDL Mode 4 supports the Cellular CNS Concept, a vision of future CNS/ATM technology in which there is one CNS system solution for all user groups in all phases of flight. STDMA/VDL Mode 4 is part of the system solution as it is seen as an efficient, affordable gate-to-gate data link. In the CCC, each aircraft, ground station, or other user is surrounded by a communications volume (a ‘cell’). Each user can communicate directly with any other user in the cell, and indirectly (through appropriate routing networks) with users outside of the cell.

VDL Mode 4 transmits digital data in a standard 25 kHz VHF communications channel. The unique feature of VDL Mode 4 is the way that the available transmission time is divided into a large number of short time-slots, each of which may be used by a radio transponder (mounted on aircraft, ground vehicles or at fixed ground stations) for transmission of data. The exact timing of the slots and planned use of them for transmissions are known to all users in range of each other, so that efficient use of the data link can be made and users do not transmit simultaneously. As a result of this ‘self-organising’ protocol, VDL Mode 4 does not require any ground infrastructure to operate and can therefore support air-air as well as ground-air communications and applications. The concept is illustrated in Figure 4.1.1.1.

The STDMA/VDL Mode 4 system consists of ground and mobile components. Basic user equipment includes a GNSS receiver for establishing precise time and position, a communications processor for managing the communications on the data link and a VHF transceiver for reception and broadcast of data. More sophisticated installations include interface with other aircraft systems and a display, which also provides a graphical user interface for input and selection of data. The ground station has ba-

sically the same architecture, but usually also incorporates a GNSS reference receiver for establishing pseudorange correction data for transmission to users.

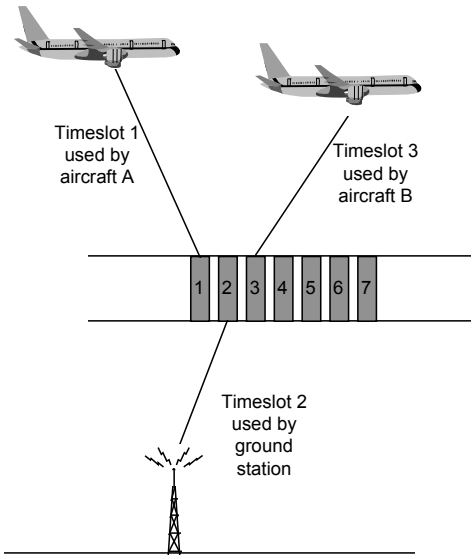


Figure 4.1.1.1 – Time slots in STDMA/VDL Mode 4

4.1.1.2 STDMA/VDL Mode 4 applications

STDMA/VDL Mode 4 provides a range of digital communications services that support many applications. However, STDMA/VDL Mode 4 also incorporates a surveillance function in which all users regularly transmit their position, making it possible for all aircraft, ground stations and other users to know the exact location of all other users in the vicinity. This information is used to manage the data link but also makes possible a host of communication, navigation and surveillance (CNS) applications. The fundamental application of the technology is ADS-Broadcast (ADS-B), which provides not only controllers, but pilots too, with a highly accurate display of nearby traffic. ADS-B and other primary data link techniques are described in Section 2.2.

STDMA/VDL Mode 4 provides a platform on which to develop new applications. Such applications operate in a wide range of operational scenarios from worldwide civil aviation to the local airport environment. Examples of applications intended to evaluate the ability of the system to support gate-to-gate services were tested in NEAP.

4.1.2 Display equipment

A prerequisite for several of the NEAP applications was the presence of cockpit display equipment. The cockpit display type installed in the participating DLH B747-200, SAS F28 and MAERSK Super Puma was the MMI5000 made by Carmenta/Hectronic of Sweden. It has the following characteristics:

- TFT screen showing moving map and air surveillance picture (using the data provided via the STDMA/VDL Mode 4 data link).
- Graphical user interface.
- Interface to some on-board avionics buses, for the extraction of data.
- Flight planning functions.
- Display of ATIS and other data link messages to pilot with controller-pilot data link communications (CPDLC) functionality.
- Display of IPV approach data (F28 only)

A mobile display system manufactured by Carmenta was used in airport vehicles in runway incursion tests. This robust single unit interfaces directly to a GNSS transponder and presents moving map and surveillance pictures on a touch screen display.

In addition to mobile displays, fixed ground displays were used for display and evaluation of surveillance and alphanumerical data. Some of these displays have been specifically adapted for use with STDMA/VDL Mode4. Controller displays included the RIMS and GRPU display systems, both made by Pixus of Sweden. RIMS at Stockholm-Arlanda is fitted with runway incursion monitoring software. The GRPU at Angelholm is used for displaying ADS-B and radar data simultaneously. Combined ADS-B and radar input was also supported in the controller working position used for monitoring helicopter operations at the Copenhagen air traffic control centre. The AIRLINK controller working position was used in the DFS trials.

4.1.3 NEAN infrastructure

The NEAN project, another project sponsored by the European Commission and a sister project of NEAP, provided the ground and air infrastructure for the extensive testing of specific CNS/ATM applications conducted within NEAP. The NEAN ground infrastructure consists of a number of ground stations that provide consistent VHF coverage across a large part of northern Europe. A ground station exchanges data through the STDMA/VDL Mode 4 data link with the STDMA/VDL Mode 4 transponder equipment onboard aircraft and ground vehicles, and with other ground stations through the ground network. The Cellular CNS Concept (CCC) applied in NEAN replicates the handling of communications in the ground infrastructure of a mobile telephone system.

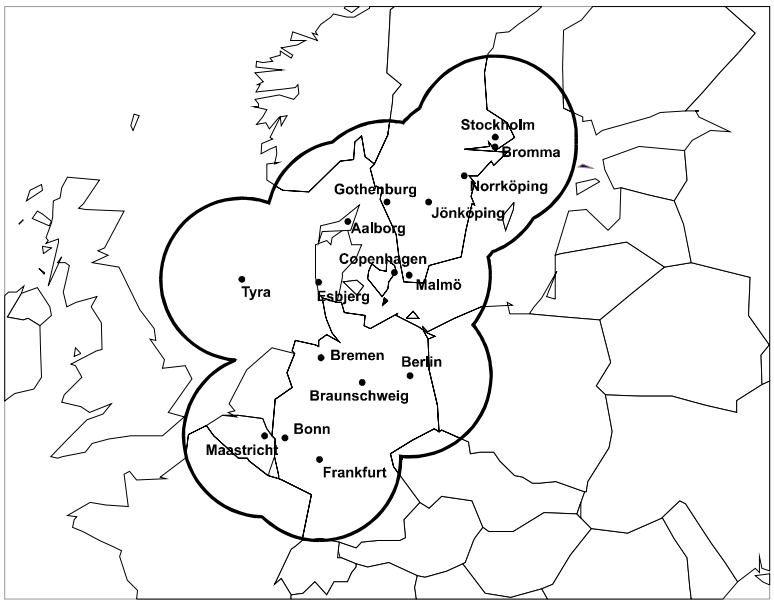


Figure 2.1 b) - NEAN coverage at 30,000 ft

NEAN also included the fitting of a number of aircraft with airborne components for exchange and display of data with the ground and other users. A significant number of airborne and ground users have been equipped to date with an STDMA/VDL Mode 4 transponder allowing broadcast of position reports to the ground and to other airborne users as well as reception of position reports, GNSS augmentation and other data.

4.1.4 Applications and services evaluated

The data link applications and services tested and evaluated in NEAP are essential for meeting the requirements of the future CNS/ATM system. The following applications were included in the test program (the responsible organisation is given within brackets):

- GNSS precision navigation capability for en-route and approach (SAS)
- On ground situation awareness/ taxi guidance (DLH)
- In-flight situation awareness (DLH)
- Enhanced ATC surveillance – downlink of aircraft parameters (DFS)
- Automatic Terminal Information Service broadcast; ATIS-B (DFS)
- Extended helicopter surveillance (DCAA)
- Runway incursion (SCAA).

Hence at least one application, or service, of each component of the CNS/ATM concept was included in NEAP. Combined, they provide the basis for evaluating a single system solution for seamless gate-to-gate operations, i.e. a system that supports pilot and controllers in all phases of flight from the departure gate, through pushback, taxiing, take-off, climb, en-route, descent, approach, landing and taxiing to docking at the arrival gate.

4.1.5 Expected benefits

As explained in section 3.3, the expected benefits from a particular application or service were used as hypotheses that were to be accepted or rejected through the testing activities. Emphasis in testing and evaluation was placed on common “key” factors such as safety, impact on workload, technical limitations and required improvements. Hypotheses, or assumptions, were also used as a basis for the testing of technical system characteristics and properties, and were used to evaluate the capability of the technical platform to support the respective application.

The hypotheses established for each application is given in the following sections.

4.2 Application Reports

4.2.1 GNSS precision navigation capability for en-route and approach

This application was developed in co-operation between SAS and the SCAA.

4.2.1.1 Service description

4.2.1.1.1 Operational context

Satellite navigation allows aircraft to navigate with great accuracy and to fly direct routes rather than navigate between fixed navigation aids on the ground. The basic accuracy provided by GNSS can be greatly improved by differential GNSS (DGNSS) signals transmitted by satellites or stations on the ground. The improved accuracy, as

well as the integrity information also provided, is needed for more demanding types of approach and landing operations. DGNSS signals are broadcast by all NEAN ground stations and used to provide GNSS augmentation over a wide area.

In the NEAP tests, the aircraft position was displayed on a Cockpit Display of Traffic Information (CDTI) whose basic functionality to support en-route navigation was developed within NEAN. The current aircraft position was superimposed on a moving map showing aeronautical airspace and airport information. ADS-B reports were continuously broadcast by the aircraft, and received by ground stations and other aircraft. The position of nearby STDMA/VDL Mode 4 equipped traffic was also displayed on the CDTI. In the en-route phase, the GNSS receiver would receive augmentation signals from all STDMA/VDL Mode 4 ground stations in view, but only process and use those originating from the strongest, and hence most adjacent, station. During approach, augmentation signals were received from the ground station located at the destination airport.

4.2.1.1.2 NEAP applications

The precision navigation tests in NEAP focused on two different applications of GNSS:

- GNSS used for en-route navigation
- DGNSS used for approach.

In addition, the possible safety implications of the STDMA/VDL Mode 4 data link being used in a two-way fashion, i.e. for simultaneous uplink of DGNSS signals and downlink of ADS-B data was to be evaluated. Such a service mix could be implemented in a future ground-based regional (or wide-area) augmentation system (GRAS) concept, and the certification aspects would therefore be addressed. Improved monitoring in the control tower (TWR) of aircraft making approach was also evaluated, and new display equipment was installed for that purpose. Activities also included evaluation of the new ground station at Ängelholm, which incorporates a commercial SCAT-I system for generation of differential corrections and an STDMA/VDL Mode 4 station for managing the data link.

The tests were conducted using two SAS Fokker 28s on scheduled revenue service between Stockholm-Arlanda (ARN) and Ängelholm in southern Sweden. The approach conducted at Ängelholm was an Instrument Approach with Vertical guidance (IPV), a new type of approach procedure made possible by the introduction of satellite navigation. IPV is formally a non-precision approach (NPA) based on the ICAO All Weather Operational Panel (AWOP) standards, but the improved accuracy and use of vertical guidance from GNSS enable lower minima to be used than for conventional NPA based on NDB or VOR. The IPV approach procedure was selected for evaluation because it enabled a comparison to be made with the regular NDB approach to runway 32 at AGH. Even though VDL Mode 4 supports RNP lateral and vertical accuracy requirements for precision approach (PA), it is not intended for support of those procedures. A dedicated ground-based augmentation system (GBAS) is being developed and standardised by ICAO to support approach categories I, II and III.

Two separate Track Deviation Instruments (TDI) were installed to provide ILS look-alike lateral and vertical guidance to the pilot during final approach. The TDI was used in conjunction with the CDTI, which continued to provide situation overview throughout the approach. Flying en-route, the pilot used the information provided on the CDTI to fly a direct RNAV route. The deviations from the nominal flight planned track were continuously displayed on the CDTI and TDI´s. When approaching Ängel-

holm, DGNSS signals from the ground station located at the airport were received and processed. The pilot was prompted to select the approach mode at a specified distance from the airport. Rather than navigating to pass overhead the approach beacon, followed by a procedure turn to line up for final approach, the pilot would fly a straight-in approach using stored “fly-by” and “fly-over” waypoints, hence saving distance and time.

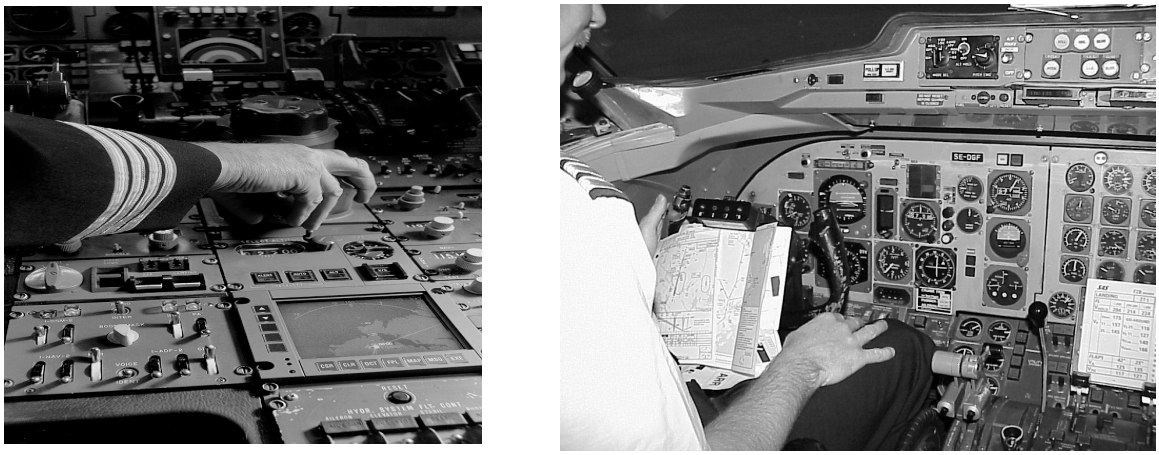


Figure 4.2.1.1.2 - The CDTI (MMI5000) and TDI installations in the SAS Fokker F28.

Minima for IPV in these tests were the same as for the corresponding NPA procedure, on which the IPV was overlaid. The new approach procedures were developed in co-operation with the Swedish Flight Safety Department. Approval was also obtained for using the system for sole means Basic RNAV (B-RNAV).

The TWR controller was able to monitor, on the TWR display, the aircraft movement from the en-route phase, through approach and landing to taxiing into the parking position. A display window showed a vertical view of the final approach section, allowing the controller to also monitor the aircraft position relative to the virtual glide slope. The status of the ground station was also monitored in the TWR. Specific phraseology to be used between controllers and pilots was developed.

4.2.1.1.3 Relevance to the gate-to-gate concept

The services provided by the evaluated system concept support both airborne and ground users.

For pilots, a single system, with onboard and ground components, supports en-route and approach navigation, and situation awareness in a seamless fashion. Other flight phases can be supported by the same system concept. Since the AGH ground station and TWR display were connected to NEAN, all test flights were able to be displayed and monitored from ARN to AGH from the departure gate to the arrival gate. Although gate-to-gate surveillance coverage was not the focus of these tests, it shows that gate-to-gate coverage can be achieved through ADS-B and networked ground stations. Other flight phases were tested in other NEAP applications.

For ATC, the same system provides seamless surveillance capabilities for aircraft from en-route to approach and landing, including a capability to monitor the aircraft position with regard to the glide-slope. It can be assumed that the system concept can provide surveillance from gate-to-gate. Other surveillance aspects are being tested in other NEAP applications.

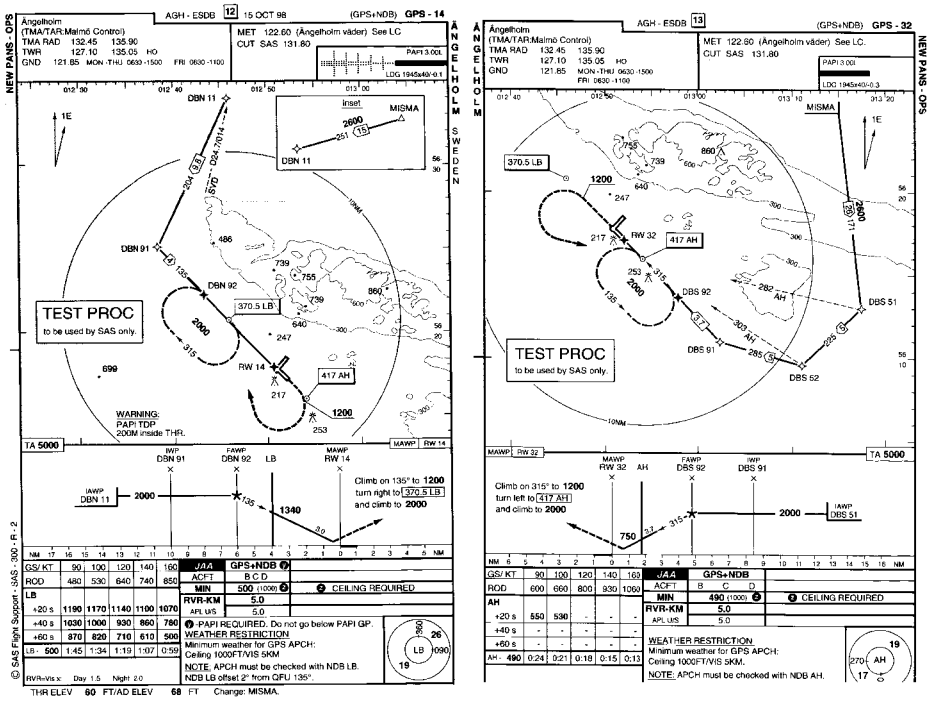


Figure 4.2.1.1.3 - IPV approach charts to AGH RWY 14/32.

4.2.1.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate the use of GNSS on direct routes from Stockholm-Arlanda (ARN) to Ängelholm (AGH).
- Evaluate the use of DGNSS approaches to AGH.
- Evaluate a combination of ADS-B downlink and uplinked GNSS augmentation messages using a single datalink, i.e. a possible future GRAS concept based on STDMA/VDL Mode 4.

4.2.1.2 Assumptions

4.2.1.2.1 General

The expected benefits to be achieved from the services described above were defined as:

- The evaluated aircraft and ground installations constitute a single seamless system supporting both the en-route and approach phases.
- GNSS in conjunction with display of position, track deviation and map information on a CDTI provides improved situation awareness for the pilot.
- DGNSS combined with CDTI for situation awareness and TDI for ILS look-alike guidance on final approach enables the pilot to make a straight-in IPV approach.
- ADS-B position data presented on a suitable TWR display allows the controller to continuously monitor the entire approach and landing phases without the need for radar data.

These expected benefits served as the basis for detailed *hypotheses*, or assumptions on expected results, which were to be accepted or rejected by the tests. The hypotheses were divided into system characteristics and operational benefits.

4.2.1.2.2 System characteristic hypotheses

Characteristic/Hypothesis	**Tested through**
A single seamless CNS/ATM system supporting gate-to-gate operations	
The IPV system supports the concept of a single seamless CNS/ATM system; • *the ground system supports both en-route and approach operation* • *the airborne system supports multiple flight phases and applications* • *the ground system supports multiple applications (in particular a combination of GRAS and ADS-B functionality was to be tested).*	*Analytical discussion*
RNP requirements	
The IPV system meets the IPV RNP requirements (RNP 0.3/125); • *lateral/vertical accuracy* • *containment levels* • *integrity* • *continuity* • *availability*	*Technical data* *Analytical discussion*
Coverage	
The IPV system meets relevant requirements for approach and landing systems; • *coverage exceeds the minimum requirements for approach, runway, missed approach and departure regions specified for approach guidance systems* • *coverage exceeds by far the coverage of SCAT-I in the approach and landing regions* • *coverage at FL 300 exceeds 200 nautical miles (NM).* • *Coverage at low altitude is good enough to potentially support approaches to more than one airport from one ground station.*	*Technical data*

4.2.1.2.3 Operational benefit hypotheses

Characteristic/Hypothesis	**Tested through**
Pilot operations	
• *The service does not increase the pilot workload.* • *The service increases the pilot's situation awareness both with regard to aircraft position during approach manoeuvres and to other traffic.*	*Questionnaires*
ATC operations	
• *The service reduces ATC workload through elimination of the need for radar vectoring except for traffic reasons.* • *The service improves ATC situation awareness*	*Questionnaires*

through better (including ground) coverage offered by ADS-B and the possibility to view the aircraft position relative to the virtual glide slope during final approach	
Capacity and flexibility	
• *DGNSS approaches potentially improve capacity* • *DGNSS approaches potentially improve flexibility through adaptation of procedures to traffic situations, environmental considerations and noise abatement.*	*Questionnaires*
Airline operational cost savings	
• *The service will reduce operational costs for the airline by reducing airborne time through direct routings and straight-in approaches*	*Analytical discussion*
Ground infrastructure cost savings	
The service will reduce costs for the ground infrastructure • *a single STDMA/VDL Mode 4 ground station supports IPV operations to all runways at the airport where it is located, and potentially other airports as well, thus saving costs for multiple installations,* • *the cost of a ground station installation is less than, or equal to the cost an ILS installation serving a single runway.*	*Analytical discussion*
Environment	
DGNSS approaches and a seamless CNS/ATM system potentially decrease harmful environmental effects by; • *reducing flying time and fuel consumption, thereby reducing pollution,* • *avoiding noise over sensitive areas by flexible approach patterns.*	*Analytical discussion*
Safety	
Potential benefits for approach operations include: • *IPV improves safety compared to NDB approaches.* • *Improved situation awareness for the pilot with the combination of TDI and moving map*. • Improved situation awareness for ATC through the capability to monitor the aircraft position relative to the glide path during approach.	*Questionnaires*

4.2.1.2.4 System characteristics tests (SCT)

The following test items relating to one or more of the above hypotheses were specified:

- Accuracy,
- Integrity,
- Continuity,
- Availability,
- DGNSS/ADS-B coverage.

In addition, data throughput and failure modes were to be analysed.

4.2.1.3 Test set-up

4.2.1.3.1 General

The realisation of the tests required the development and installation of new equipment both onboard the participating aircraft and on the ground. Implementation of new functions and human-machine interface (HMI) in the CDTI to support terminal navigation and approach was also required. The equipment, functions and procedures implemented were developed as an experimental system tailored for these tests.

4.2.1.3.2 Airborne equipment

The airborne STDMA/VDL Mode 4 transponders installed in NEAN were replaced by third generation SAAB LINCS T3L/M transponders certified to JAA Form 1 non-hazardous level and designed to meet applicable ETSI, RTCA and MIL-STD requirements. The CDTI (the Carmenta MMI 5000, developed for NEAN) HMI was adapted to provide approach functionality, such as alerts, prompts and messages, approach mode selection with appropriate scale settings, and a STAR (standard instrument arrival route) database. Installation of a TDI was required to serve as the primary instrument for IPV approaches. Lateral and vertical guidance was provided in an ILS look-alike fashion with lateral scale deflection being in accordance with the TSO-C129a, and with a vertical full deflection of 125 ft at all times.

Because of the limited space available in the F28 cockpit, the CDTI was installed in the cockpit centre pedestal, and therefore outside the pilots´ primary field of vision. The two TDI was placed in front of each pilot on the centre panel. The additional instrumentation was approved on a “non-interference” basis, meaning that it had no physical connection or impact to other flight instruments.

4.2.1.3.3 Ground equipment

A ground station was installed in Ängelholm to support IPV operations. This station incorporates as one component a commercial Raytheon DIAS-3100 SCAT-I ground station for generation of differential GNSS corrections and integrity data. The data is output to a SAAB LINCS T3L/F STDMA/VDL Mode 4 ground station, which provides the two-way data link capability for DGNSS broadcast and reception of ADS-B reports. The DIAS-3100 is designed to meet RTCA/DO-217 Change 2 standard and the T3L/F to the same standards as the T3L/M described in the previous section. The combined station is connected to NEAN through a local server, and to a display in the TWR. The connection to NEAN enables data to be exchanged with the network of ground stations as well as remote monitoring and logging of the local station to take place. NEAN uses the Swedish National Aeronautical Telecommunication Network (NATN) for ground communications. The ground architecture is illustrated in Figure 4.2.1.3.3.

4.2.1.4 Testing and evaluation

4.2.1.4.1 Test environment

Ängelholm airport is used for both military and civil air traffic. SAS operates some 60 flights per week into Ängelholm. Approximately half of these flights use F28 aircraft. The airport has one instrument runway, RWY 14/32. RWY 14 is equipped with a Category I ILS, whereas RWY 32 only has a single NDB to support instrument approach. Special IPV approach procedures based on DGNSS, and overlaid on the respective ILS and NDB approaches, were developed and used in the NEAP tests.

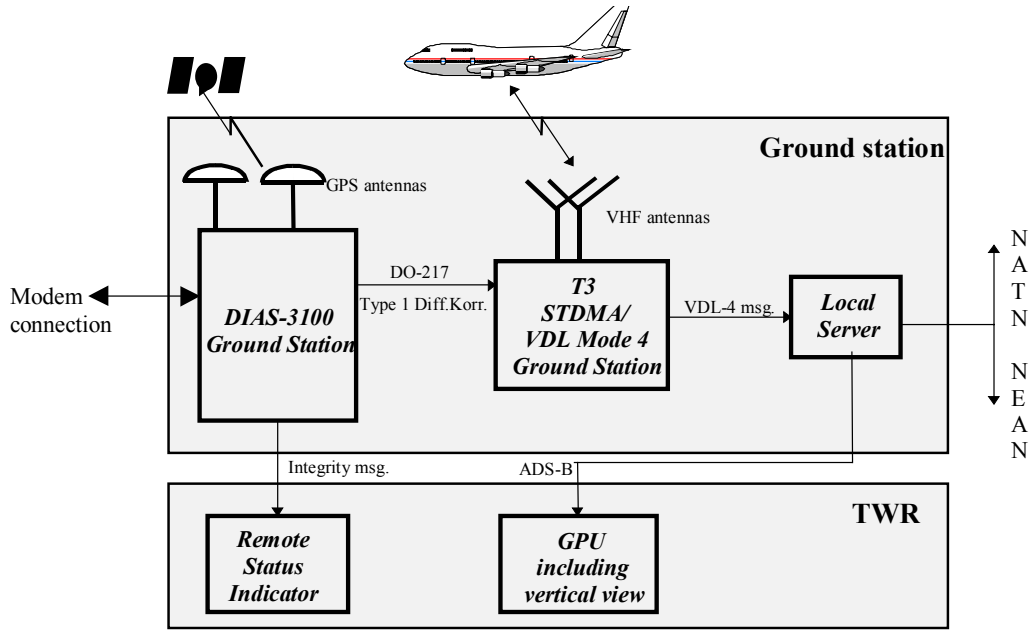


Figure 4.2.1.3.3 - IPV ground system architecture

Two SAS Fokker 28s on scheduled revenue service were used as platforms for the airborne testing. An SCAA Beech 200 was used for flight inspection purposes prior to the SCAA Flight Safety Department approving the final test programme. A limited number of SAS aircrew was trained prior to commencement of the tests. TWR controllers on normal duty monitored the IPV approaches on the display provided, as well as the proper function of the ground station. Radar monitoring was also available in the TWR. In addition, controllers at the Malmö Air Traffic Control Centre (ATCC), responsible for approach control in the Ängelholm terminal area, monitored the approaches on their regular radar display.

As the tests were conducted during scheduled operations, details of the scenarios could not be controlled.

4.2.1.4.2 Scientific approach

The test methodology included the collection and evaluation of both *objective data*, such as recording of ADS-B reports and technical quality of service (QoS) parameters, and *subjective data*, i.e. opinions expressed by participating pilots and controllers in answers to questionnaires. Some hypotheses, for instance those relating to cost benefits, had to be verified by *analytical discussion*, often by comparison with other systems and procedures.

Recording of data was made in the MMI5000 onboard the aircraft. All data transmitted and received by the onboard STDMA/VDL Mode 4 transponder was recorded during the approach and landing phase. On the ground, data recording took place in the ground station.

A questionnaire was produced both for pilots and controllers based on the assumptions established earlier in the project. In addition to check boxes there was room for detailed comments. Most questions focused on the application as implemented, but some were of the type “what if”. The latter type intended to obtain opinions about a future operational system lacking the limitations imposed on the tested system.

4.2.1.4.3 Test realisation

Validation and verification of the ground and airborne installations preceded operational testing. These factory and site acceptance test (FAT and SAT) activities were conducted between February 1997 and June 1998.

The acceptance tests of the Ängelholm ground station included FAT and SAT of the T3L/F transponder (as the core component of the STDMA/VDL Mode 4 ground station) and the DIAS-3100 SCAT-I ground station. Finally, acceptance tests were conducted of the combined, integrated system, and flight tests verified its proper function. FAT and SAT of the ground system also included the TWR display sub-system.

Validation and verification of the airborne installations on the two participating SAS F28s were carried out in parallel with ground system testing activities, and were followed by appropriate approval by the Swedish Flight Safety Department in May 1998.

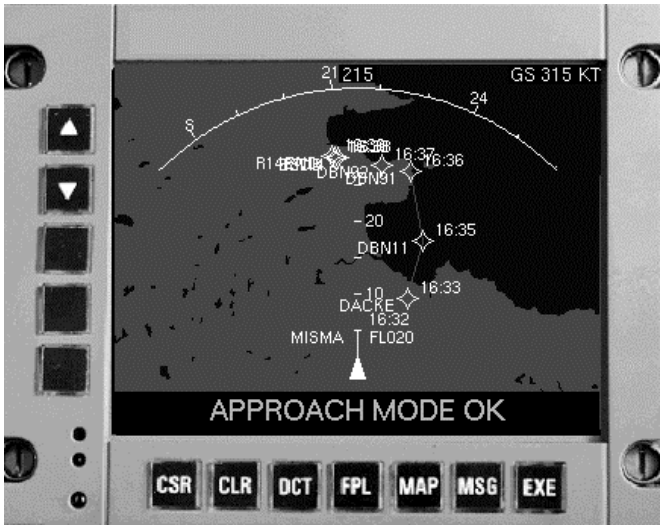


Figure 4.2.1.4.3 - Screenshot of the CDTI during IPV approach to AGH RWY 14.

Final validation and verification of the total IPV system, including the ground and airborne components and associated approach procedures, were completed through flight-testing using one of the F28s in May 1998.

Operational testing took place between May 1998 and February 1999. Owing to aircraft and crew availability, the number of test flights was lower than originally planned. At the completion of the test programme some 30 fully documented test flights had been conducted.

4.2.1.5 Results and conclusions

Results and conclusions are divided into operational and technical aspects. Objective and subjective data is used together to form the conclusions.

4.2.1.5.1 Principal results and conclusions

The following is a summary of the results and conclusions.

1. Application-specific objectives

All application-specific objectives listed in section 4.2.1.2.2 were met, i.e.:

- Evaluate direct routes from Stockholm/Arlanda to Ängelholm.

- Evaluate DGNSS approaches to Ängelholm.
- Evaluate a combination of ADS-B and GNSS augmentation in an integrated system using a single data link.

These three applications were found to be successfully supported by the evaluated system, i.e. a combination of ADS-B, DGNSS, STDMA/VDL Mode 4 and the NEAN infrastructure.

2. Expected benefits

All assumptions on expected benefits listed in section 4.1.1.2.1 were met, i.e.:

- Single seamless system for en-route and approach.
- Improved situational awareness for the pilot.
- System enables the pilot to make straight-in approaches.
- Continuous monitoring in TWR without radar.

3. System characteristics

All assumptions on system characteristics listed section 4.2.1.2.2 were accepted with one exception concerning RNP requirements. This aspect is addressed in section 4.2.1.5.2.

4. Operational Benefits.

All assumptions on expected operational benefits listed in section 4.2.1.2.3 were accepted, with the exception of the hypothesis that the IPV approach will decrease the pilot workload. This assumption is addressed in the section 4.2.1.5.2.

Operational conclusions and results

5. Seamless system.

The system provides seamless support for approach and landing and forms a seamless part in the gate-to-gate concept.

6. Safety and situation awareness.

The evaluated service provided operational benefits in term of safety and improved situation awareness.

7. *En-route navigation and direct routes*

Since 8 October 1998, the airspace in Scandinavia is based on B-RNAV, and ATS routes are no longer based on “fly-over” terrestrial navigation aids. Approved by the Swedish Flight Safety Department, the two Fokker 28s are currently flying with the evaluated system in support of sole-means B-RNAV. Aircrews have not experienced any navigation problems when using the system.

8. Combination of ADS-B and GNSS augmentation

The combination of ADS-B and GNSS augmentation in an integrated system using a single two-way data link works well and provides an efficient solution. The services evaluated in this application can be expanded to include more navigation and surveillance services covering all phases of flight.

9. *Pilot workload*

The workload on the pilots when using a future satellite-based system is expected to be the same as, or less than for a conventional ILS system.

10. Collaborative procedures

As both pilots and controllers use ADS-B derived data for situation awareness, a potential exists to develop new collaborative procedures between controllers and pilots. Such procedures could enhance capacity in terminal area operations.

11. ATC benefits.

The acceptance of the evaluated system by controllers was very high. Benefits identified by controllers included:

- ground surveillance capability
- potential enhancements to capacity and flexibility
- gate-gate surveillance.

12. ATC view on CDTI/ADS-B in cockpit.

The majority of the controllers were positive to pilots obtaining a detailed picture of the traffic situation through the CDTI and to the possible implications of that improved situation awareness, such as:

- possibility to transfer separation responsibility to pilots during approach (station keeping), including more efficient visual approaches
- better understanding of the traffic flow.

Technical conclusions and results.

13. Equipment, general

After some initial technical problems, all equipment worked well.

14. VDL Mode 4 data link for approach and landing

The STDMA/VDL Mode 4 data link works well in support of approach and landing systems.

15. Ground station

The combination of a commercial SCAT-I system and an STDMA/VDL Mode 4 ground station provided higher integrity, availability, continuity and accuracy than the current generation of STDMA-only ground stations.

4.2.1.5.2 Comments and observations

Operational comments and observations.

1. Pilot Workload

Early in the project, there were some concerns in the project group that the pilot workload would increase during these trials, as the pilots also had to monitor the conventional instruments during the approach, and the fact that the IPV represented a new procedure. To some extent the answers from the pilots confirmed this. However, with a future integrated system the workload is expected to be the same as, or less than for an ordinary ILS approach.

2. Collaborative procedures

As pilots and controllers use the same ADS-B data for navigation, surveillance and situation awareness, a closed-loop situation is achieved, allowing better collaboration between air and ground. Despite some concern expressed among controllers on how the improved pilot situation awareness would impact on their work, a large majority expressed the opinion that there was a number of benefits. One benefit is that the co-operation between controllers and pilots will improve since pilots acquire a

view of the flow of traffic and an understanding of the ATC way of working. Furthermore, it was anticipated that holding situations and delays would be more acceptable if pilots could see that the delays were due to high traffic load. The CDTI also provides a tool for obtaining visual contact with the airport and preceding aircraft, and hence for enabling visual approach to be conducted and own separation to be maintained to other traffic. TMA controllers in particular expressed the opinion that station keeping would decrease both workload and stress and a majority also thought that efficiency would increase.

3. Intercept angle for GPS approaches

Before the trials started there was a debate amongst the pilots about the preferred intercept angle to the final approach centreline. The ICAO standard GPS intercept angle is 70°. As the evaluated IPV system is not coupled to the autopilot, some pilots suggested that the same angle be used as for radar vectoring, i.e. 30°. To investigate the best option, approach procedures using the two different intercept angles were developed. Only a limited number of pilots has flown both approach procedures. Therefore no firm conclusions can be drawn.

4. Controlled Flight Into Terrain (CFIT) during NDB approaches

50% of all Controlled Flight Into Terrain (CFIT) accidents happen during NPA procedures. The lack of vertical situation awareness is one of the major risk factors. Operational feedback from the pilots indicates that major safety benefits could be gained by replacing current NPA procedures with IPV due to better situation awareness and operational procedures.

5. Airline cost reduction

Potential cost savings for the airlines could be achieved from not having to train pilots for different types of approaches. Basically the same techniques are applied when flying IPV and ILS. The IPV approach was approximately 5 minutes shorter in time compared to the normal racetrack NDB procedure to RWY 32.

6. *Multi-runway and multi-airport coverage*

The tests proved that the single ground station supported both runway ends at Ängelholm. One test flight performed an approach to Ljungbyhed airport 30 km from Ängelholm. Continuous reception of differential corrections was maintained throughout the approach down to 50 ft, at which point the approach was aborted.

7. *ATC: ADS-B benefits*

The controllers considered ADS-B to have a number of benefits over radar for surveillance purposes. Most controllers expressed the opinion that the precise information that DGNSS/ADS-B provides could be used to increase efficiency. Methodology may also change due to the usually better resolution and update rate offered by ADS-B. A great majority of the tower controllers believed that ADS-B based surveillance of ground traffic would increase efficiency, capacity and safety.

<u>Technical comments and observations.</u>

8. RNP requirements hypothesis.

Evaluation of Required Navigation Performance (RNP) was simplified compared to what is suggested by AWOP and what would be required for certification.

9. Initial technical problems

The NEAP IPV project represents a major investment in the development of new equipment, operational procedures and evaluation tools as well as aircraft and aircrew scheduling and training. Even though the fundamental concept and equipment, such as the STDMA technology and the NEAN infrastructure, were already in place, the airborne, ground and ATC equipment needed further development to support the IPV. Completely new operational procedures were developed for the purpose of these trials. All this was completed successfully in a very short time frame. However, the project suffered some delay due to the complexity of the task and early technical problems. These problems were resolved, and no remaining fundamental problems with the concept or the equipment have been identified.

4.2.1.6 Recommendations for system improvements

General aspects and overall concept.

1. Applicability to other aircraft

These trials have been tailored for the SAS F28, and therefore the system and IPV concept will have to be evaluated for use with other aircraft types. Moreover, evaluation must take into account that different aircraft have different equipment installed and use varying levels of automation.

2. TDI deflection, parallel approaches

In these trials the lateral TDI deflection depended on the distance to the ground station in three steps. En-route, the full scale deflection was 5 NM, within 30 NM of AGH it was 1 NM, and from the final approach fix 0.3 NM. Vertical deflection was 125 ft at all times. The pilot reactions to the non-angular lateral deflection and the sensitivity of the glide slope being unchanged throughout the approach were positive, and the principles were easy to adopt. This concept should be studied further and taken into consideration as a possible factor in parallel approaches where a potential can be identified for closer spacing between runways.

3. Environmental impacts

Due to time constraints, the evaluation of the environmental impact has not been fully addressed. This important area should be addressed in future projects. However, one important environmental aspect is the fact that the IPV approach to RWY 32 saves approximately 5 minutes of flying time compared to the normal NDB racetrack procedures. Reduced flight times means less pollution from exhaust gases.

4. Combination of ADS-B and GNSS augmentation

The combination of ADS-B and GNSS augmentation could form the basis for a system supporting a future dual-function GRAS concept. To fully explore this concept, further tests need to be performed, for instance for investigating network management and the possibility of distributed integrity monitoring.

Operational – ATC.

5. Pilot-ATC co-operation.

The potential benefits with regard to new procedures that could be achieved through improved airborne situation awareness should be further analysed.

Technical - Aircraft installation.

6. Airborne equipment certification

These trials were based on an experimental installation in a classic F28 cockpit. The system was a stand-alone system and certified as not to interfere with other onboard systems. In future, the system has to be certified and integrated into existing aircraft system architecture or installed as an add-on certified component for less complex aircraft.

Technical - Ground installation.

7. Ground station architecture

The combined SCAT-I/STDMA/VDL Mode 4 ground proved to work very well. The architecture is promising and the station provides high integrity together with wide area coverage and support for multiple services. It could be the basis for a certifiable system supporting the GRAS concept as well as NPA operations. This, however, would require:

- Full integration of the differential (DIAS-3100) and data link (T3L/F) components. This will provide an integrated system with integrated control and monitoring. The tested system was not completely consistent in this respect.
- The DIAS-3100 SCAT-I system incorporates a “listen-back” function, which verifies each transmitted message to assure the integrity of transmissions. Since the SCAT-I data link was not used, this function was not used either. The T3L/F has no “listen-back” function. To improve overall integrity, such a function should be included in the architecture.

Technical - TWR equipment.

8. TWR display.

The TWR display used in the trials was a radar display used operationally in many Swedish control towers. The vertical view provided was however a prototype. The unit can receive and display radar data as well as ADS-B data. During the trials it was used for ADS-B only.

The vertical view needs to be further developed in accordance with the controller suggestions. The display has to be better integrated into the TWR control panels. During the trials, the position of the display unit was not optimal.

4.2.1.7 Future plans

The operational and technical results from the IPV trials will serve as very valuable inputs to further work, in particular in the NEAN Update Program, NUP, in which both SAS and the SCAA will participate. One of the work packages in NUP will focus on GRAS. Within the work package, a GRAS station will be specified and developed. The experience from the IPV trials will be very valuable in this work. The architecture of the AGH ground station will be used as input for the definition of GRAS station architecture.

SAS will keep the installation on the two Fokker F28s after the completion of the NEAP project. IPV approaches into AGH will continue to be conducted. Log data and experience will continue to be collected until the summer of 1999, at which time the aircraft type will be phased out from the SAS fleet.

The SCAA is investigating possibilities to retain the infrastructure installed at AGH, and also has a work programme for use of GPS at small airports. This program will

initially focus on NPA based on GPS without ground based augmentation, but a second phase will likely include ground augmentation and ADS-B. The experience from IPV trials and GRAS will be accommodated in this work. The SCAA and SAS will take an active role in the development of new collaborative procedures between pilots and controllers.

4.2.2 On-ground situation awareness & taxi guidance

This application was developed by DLH.

4.2.2.1 Service description

4.2.2.1.1 Operational context

One of the bottlenecks in today's growing air traffic is the ground traffic at busy airports. The efficiency of aircraft movements on ground, although skilfully managed by ground controllers, still very much depends on the weather conditions and is far away from being optimised.

Busy airports are usually equipped with surface movement radar (SMR) allowing controllers to view and guide the traffic on radar display in the tower (TWR). Unlike modern radar systems, most SMR displays do not display the identity of aircraft targets, and there are no means for identifying vehicles. Therefore an increased separation is required between ground traffic during low visibility ground operation.

Previous trials have demonstrated that ADS-B based on STDMA works equally well on the ground as in the air. The position accuracy offered by DGNSS is better than that of an SMR and the display is clean and not cluttered by echoes from buildings and other structures on the airport as is often the case with SMR. As ADS-B reports include the identity of the transmitting aircraft or vehicle, this information is included in the target representation on the cockpit display. Whilst SMR only provides data to the controller, ADS-B reports are also received by aircraft and ground vehicles. These reports are displayed to pilots to provide a much-improved awareness of nearby traffic.

Based on this information the pilot acquires situation awareness with regard to other aircraft and ground vehicles. By combining a cockpit display with a suitable human-machine interface (HMI), it is possible to create a taxi a taxi guidance system that leads to more efficient, safer and weather independent ground operations.

The high-level assumption for this NEAP application was that ADS-B based on STDMA/VDL Mode 4, with appropriate functionality, could support an on-ground situation awareness and taxi guidance system.

4.2.2.1.2 NEAP application

The on-ground situation awareness and taxi guidance service tested in NEAP is based on ADS-B reports from appropriately equipped aircraft and airport vehicles being received by an STDMA/VDL Mode 4 transponder in six Boeing 747-200 aircraft and presented on a dedicated display in the cockpit. The ADS-B reports were based on very accurate DGNSS position data. High-precision maps for Frankfurt international airport were used in the B747 cockpit displays.

The test program included all revenue ground operation of the equipped aircraft at the Frankfurt international airport. Other STDMA/VDL Mode 4 equipped aircraft and vehicles served as "background traffic" that only played a passive role in the tests.

4.2.2.1.3 Relevance to the gate-to-gate concept

On-ground situation awareness and taxi guidance facilitate aircraft movements on aprons and taxiways when taxiing to and from the runway in use in low visibility conditions. The functions support the first and last phases in a gate-to-gate ATM system. One objective of NEAP is to show that this and other components of a gate-to-gate concept can be provided in a seamless fashion by the STDMA/VDL Mode 4 technical platform.

4.2.2.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate the suitability of STDMA/VDL Mode 4 as the basis for on-ground situation awareness and taxi guidance.
- Evaluate the concept of on-ground situation awareness and taxi guidance.
- Develop and evaluate a common cockpit platform for supporting implementation and evaluation of future on-ground situation awareness and taxi guidance functions.
- Demonstrate on-ground situation awareness and taxi guidance as vital components of a gate-to-gate concept.

4.2.2.2 Assumptions

4.2.2.2.1 General

To allow testing of an ADS-B system in a real life environment within the limits of the pre-certification equipment, some results are based on assumptions in order to assess possible long-term benefits. The assumptions on a future environment were;

- a fully integrated and certified system is used,
- a large number of aircraft are equipped with STDMA/VDL Mode 4 based ADS-B system,
- suitable human machine interfaces are available,
- procedures have been modified and/or added to make use of the STDMA/VDL Mode 4 based CNS/ATM system capabilities.

Throughout the evaluation it was clearly distinguished between results based on the currently used system and environment in which it operates, and those based on assumptions on a future system and environment.

4.2.2.2.2 System characteristic hypotheses

All system characteristics were evaluated by the DFS in the Enhanced surveillance application.

Picture 4.2.2.2.1 MMI 5000 in the DLH B747-200 cockpit with taxi display

4.2.2.2.3 Operational benefit hypotheses

Several benefits were anticipated to be gained with the STDMA/VDL Mode 4 supported services provided in this NEAP application. Operational benefit tests (OBTs) were designed to verify or reject assumptions on these benefits.

	Taxi Guidance
Safety	STDMA/VDL Mode 4 based CNS/ATM system increases the safety of taxi
Profitability	STDMA/VDL Mode 4 based CNS/ATM system reduces costs
Punctuality	STDMA/VDL Mode 4 based CNS/ATM system reduces taxi time

	On-Ground Situation Awareness
Safety	STDMA/VDL Mode 4 based CNS/ATM system increases the safety of the ground operation
Profitability	STDMA/VDL Mode 4 based CNS/ATM system reduces costs
Punctuality	STDMA/VDL Mode 4 based CNS/ATM system saves time

All trials were tested through questionnaires distributed to each crewmember with the flight documents.

4.2.2.2.4 Test parameters

The following parameters were observed throughout the testing:

	Parameter	Comment
Safety	General safety items	General overview Traffic identification Position identification
	Human factors (cockpit)	Close the loop pilot - controller Big picture Distraction
	Pilot workload	Additional duties Restrictions
Profitability	Cost reductions	Faster, optimized ground operations
	Capacity	Seamless gate-to-gate concept
Punctuality	Delay	Pilot information Pre-planning
	Operational issues	

These parameters were addressed through closed questions with standardized answers, enabling the comparison of all questionnaire results. A “short-term” questionnaire was used.

Other issues addressed were:

	Parameter	Comment
Technical	Integration, limitations	
	Experiences made	Pilots experience
	Required improvements	Pilots view
Environmental	Environment protection	
	Noise abatement	

These parameters were addressed by open questions with non-standardized answers in order to trace pilots’ experience with the onboard system. A “long-term” questionnaire was used.

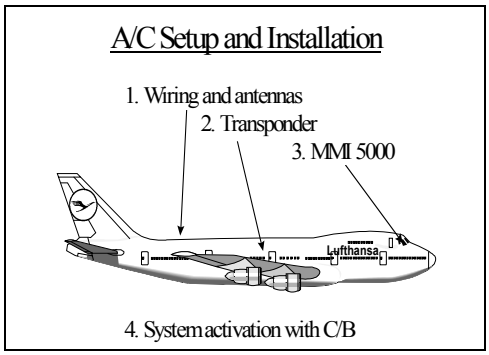
4.2.2.3 Test set-up

4.2.2.3.1 General

Using trial equipment on revenue flights limited testing to a certain amount. The equipment and trials were mainly restricted by:

- pre-operational status of the equipment, certified only on a non-interference basis,

- stand-alone installation not integrated in today's state of the art EFIS,
- location of the MMI (cockpit display) outside the crew's main field of vision,
- only revenue flights used for trials, no special scenarios used,
- no special procedures established,
- no special taxi guidance features implemented,
- low number of ADS-B equipped aircraft,
- most MMI features available in Frankfurt only,
- trials during summer time, therefore no low visibility conditions present.



Picture 4.2.2.3.1 Aircraft setup and installation

4.2.2.3.2 Airborne equipment

For the trials the MMI 5000 cockpit display was used in the Boeing 747-200s. Special software adaptations had been made by the Swedish software manufacturer Carmenta in order to meet special pilots needs such as a suitable display brightness control.

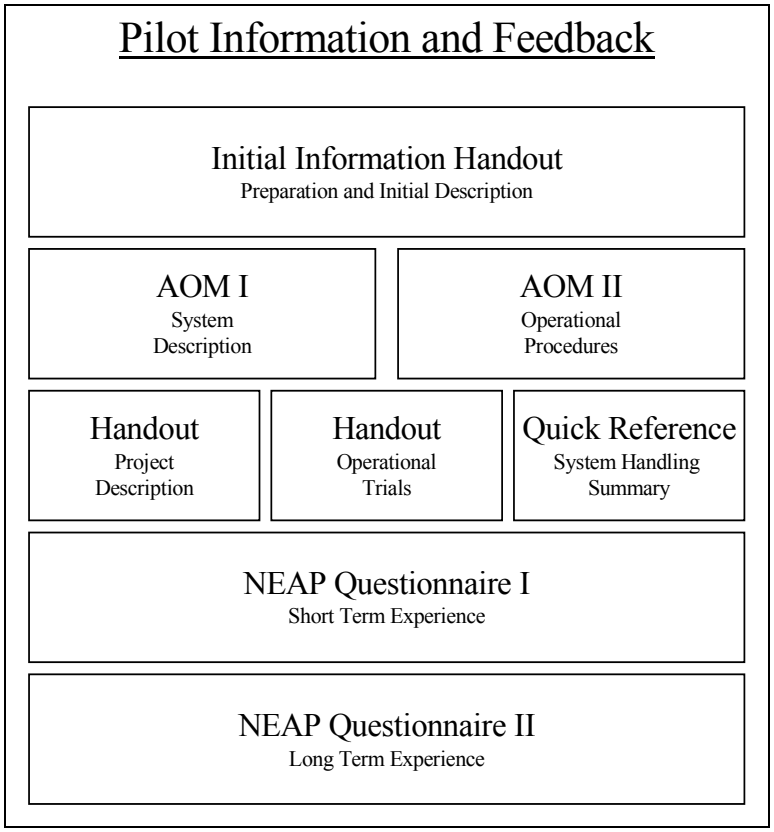
4.2.2.3.3 Ground equipment

A base station providing DGNSS corrections is required for the on-ground situation awareness and taxi guidance trials in order to achieve the required position accuracy. During the trials, the Frankfurt base station was operating and used.

4.2.2.3.4 Pilot information and questionnaires

At the beginning, intensive pilot information was required to prepare for the trials. The method used to collect data was the distribution of questionnaires to the aircrews.

Short-term questionnaire
In order to gather information about the individual experience made on a particular flight, a short-term questionnaire was developed and distributed to the pilot. The questionnaire was relatively short and addressed the operation of that flight only. It highlighted possible special problems and constraints, but also the benefits of the system



Picture 4.2.2.3.4 - Pilot information and feedback.

Long-term questionnaire

After a period of practical experience with the MMI 5000 and the CNS/ATM system a second, long-term questionnaire was developed and distributed to each participating pilot. It addressed the overall experience with the system in regards to the contributing projects. Thus a general assessment of the advantages and benefits achievable with a STDMA/VDL Mode 4 based CNS/ATM system was possible. After the evaluation phase suggestions were encouraged in order to improve the system in line with the pilots needs.

4.2.2.4 Testing and evaluation

4.2.2.4.1 Test environment

All tests took place on revenue flights. Hence the tests were always based on a real life situation where no pre-planned scenario was possible. As all flights were inbound to or outbound from Frankfurt international airport, tests focused on operations at that airport.

4.2.2.4.2 Scientific approach

All tests were based on the NEAP test methodology. Hypotheses were established prior to testing. The questionnaires were based on these hypotheses, assessing special parameters in different areas. It was always clearly distinguished between;

- phases of flight (on-ground and in-flight),
- existing trial equipment and potential certified system, and
- individual flights and long term experience.

Development of questionnaires was made in the following order:

1. Specification, clarification, precise meaning of hypotheses.
2. Formulation of questions with regard to hypotheses.
3. Order of questions.
4. Checking of questionnaire
5. Main survey.

4.2.2.4.3 Test realization

After start of preparations in September 1997, testing of the NEAP application in-flight situation awareness began in July 1998. Until the end of October 1998, six Lufthansa Boeing 747-200 Classic participated in the NEAP trials each fully equipped with an STDMA/VDL Mode 4 ADS-B transponder and the associated cockpit display unit (CDU). During the trial period of about 10,000 revenue flight hours, crew experience and system capacity was assessed.

Picture 4.2.2.4.3 Screenshot MMI 5000 with taxi display at Stockholm-Arlanda

4.2.2.5 Results and conclusions

4.2.2.5.1 Principal results and conclusions

The trials with the ADS-B system in regards to in-flight situation awareness lead to different results depending on the degree of development and deployment in the field, i.e. whether the current or an assumed future situation was addressed.

4.2.2.5.2 Pre-certification STDMA/VDL Mode 4 based ADS-B equipment

The pre-certification trial equipment may only be used as an additional information source without any operational application, but;

- there are already small benefits achieved with the trial equipment, e.g. map display with detailed airport maps provide orientation for taxiing,
- overall feedback from the aircrew was positive.

4.2.2.5.3 Taxi guidance display

In flight, electronic flight instrument system (EFIS) and ATC may be the only source of information in IMC, but during taxiing visual reference is required for collision avoidance as far as weather permits. Therefore a suitable taxi guidance display is required in order to make use of the ADS-B features on ground. Possible solutions are;

- CM1 (captain) uses the primary flight display (PFD) for taxi guidance plus navigation display (ND) for airport chart and collision avoidance, CM2 (first officer) maintains visual contact, *or*
- windshield display.

4.2.2.5.4 Few STDMA based ADS-B equipped aircraft

As long as there is only a low number of ADS-B equipped aircraft present, as is anticipated during a transition phase, the following initial benefits are expected;

- taxi guidance increases safety and may reduce taxi time on unfamiliar airports,
- taxi guidance down to CAT III conditions is possible, allowing a significantly higher flow of on ground traffic under low visibility conditions, provided that;
  - suitable taxi guidance display is available, and
  - operational procedures are established,
- on-ground situation awareness reduces the possibility of runway incursions.

4.2.2.5.5 Large number of STDMA/VDL Mode 4 based ADS-B equipped aircraft

After an initial transition phase with an increased number of ADS-B equipped aircraft additional benefits are expected, based on the above mentioned assumptions:

- on-ground situation awareness allows the crew to maintain separation to other aircraft weather independently,
- potential of reduced on-ground separation minima due to enhanced surveillance accuracy,
- potential for building up ADS-B based surveillance infrastructure at comparably low costs.

Due to the mentioned limitations it is impossible to exactly quantify the amount of achievable savings. Nevertheless remarkable benefits are expected in regards to safety, punctuality and costs when introducing a fully developed and certified STDMA/VDL Mode 4 ADS-B based CNS/ATM system.

4.2.2.5.6 Comments and observations

To overcome today's problems with increasing air traffic a seamless gate to gate concept is required. The CNS/ATM system presented in this project should be able to become the backbone of this concept. The next important step is, as the trials show, integration of such a system into the glass cockpit of a modern passenger aircraft and certification of the required system components.

The trials showed that the introduction of an onboard taxi guidance system, including cockpit displays with improved HMI and new operational procedures, could potentially contribute to more efficient ground operations. The shared responsibility between ATC and aircrew supported by the increased aircrew situation awareness provides higher capacity and weather independent ground operations at lower costs, while today’s safety standards are maintained or even exceeded. A first step was

taken by establishing pre-certification data link networks and trial equipment. Now the next step should be towards system integration and operational concepts.

4.2.2.6 Recommendations for system improvements

In order to gain benefits from using a fully developed ADS-B based CNS/ATM system the following steps are recommended:

- research in regards to human factors including selection and layout of traffic information to avoid information overload in the cockpit,
- development of suitable man machine interface for taxi guidance,
- partnership with airframe manufacturers,
- integration of VHF based ADS-B equipment in a modern transportation aircraft,
- development of operational procedures to make use of achievable benefits.

Finally a transition phase should be developed and implemented which would allow early benefits to be achieved without all aircraft being equipped with an STDMA/VDL Mode 4 based ADS-B system.

4.2.2.7 Future plans

After completion of the evaluation of on-ground situation awareness DLH will continue to use the aircraft trial equipment in other projects like the FREER (free flight scenarios) and the PETAL II (controller-to-pilot data link communication) trials.

The next step following the NEAP activities is only possible based on a cooperation with a major airframe manufacturer and should result in the integration of a CNS/ATM system in a modern aircraft cockpit. Main focus of DLH future plans is achievement of immediate benefits, which means that all investments will be planned according to cost benefit analysis.

4.2.3 In-flight situation awareness

This application was developed by DLH.

4.2.3.1 Service description

4.2.3.1.1 Operational context

Today, most major international airports face severe problems in accommodating the increasing air traffic, especially at peak hours. The problems are even more severe in poor weather conditions. Today's principal surveillance source is secondary surveillance radar (SSR). SSR data is used by ATC only, and is not received and displayed on aircraft. As a result, the pilot is not in the loop and has no means for acquiring information on the positions of other nearby aircraft. Visual monitoring through the cockpit window is severely limited by visibility conditions and monitoring of the radio traffic only provides a very broad conception of the traffic situation. TCAS/ACAS is for last minute conflict avoidance only. The identification of new methods to maximise the flow of outbound and inbound traffic is therefore a major challenge.

A possibility to overcome the limitations of currently used SSR techniques is expand the use of the procedures used in visual meteorological conditions (VMC) to also include instrument conditions. Such procedures would require that pilots be provided with a suitable surveillance picture, which in turn requires the introduction of new technologies. Moreover, new operational procedures, like maintaining own separation (station keeping) are required.

Key to this new technology is appropriate presentation of all required information in the cockpit. In-flight situation awareness puts the pilot in the ATC information loop and enables him to take an active role in air traffic management. As a result, traffic flow is optimized and safety enhanced.

Picture 4.2.3.1.1. Overview of MMI 5000 (lower right) in the DLH B747-200 cockpit

The high-level assumption for this application is that ADS-B based on STDMA/VDL Mode 4, with appropriate functionality, could support an in-flight situation awareness system.

4.2.3.1.2 NEAP application

The in-flight situation awareness service tested in NEAP was based on ADS-B reports from appropriately equipped aircraft being received by an STDMA/VDL Mode 4 transponder in six Boeing 747-200 aircraft. Information was presented on a dedicated display in the cockpit, the MMI 5000, capable of displaying precise area maps, ground and airborne traffic equipped with a STDMA/VDL Mode 4 ADS-B transponder, and traffic information service broadcast (TIS-B) traffic (uplinked radar data). Features also included display of ATIS-B data. This function is addressed in another section of this document.

Display of aircraft position was combined with its identification tag (usually flight number), relative altitude and prediction vector. The result was a surveillance picture that provided an excellent visual view of the current traffic situation and a potential means for applying visual procedures.

4.2.3.1.3 Relevance to the gate-to-gate concept

In-flight situation awareness potentially facilitates operations in the terminal and en-route phases of flight. The service provided therefore represents the major airport-to-airport link in gate-to-gate operations. One high-level NEAP objective was to show that this and other components in a gate-to-gate concept can be provided in a seamless fashion by the STDMA/VDL Mode 4 technical platform.

4.2.3.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate the concept of in-flight situation awareness.
- Demonstrate in-flight situation awareness as a component of a gate-to-gate concept.
- Evaluate the suitability of STDMA/VDL Mode 4 as the basis for in-flight situation awareness.
- Develop and evaluate a common cockpit platform for supporting implementation and evaluation of future if-flight situation awareness.

4.2.3.2 Assumptions

4.2.3.2.1 General

To allow testing of an ADS-B system in a real life environment within the limits of the pre-certification equipment, some results are based on assumptions in order to assess possible long term benefits. The assumptions on a future environment were;

- a fully integrated and certified system is used,
- a large number of aircraft are equipped with STDMA/VDL Mode 4 based ADS-B system,
- suitable human machine interfaces are available,
- procedures have been modified and/or added to make use of the STDMA/VDL Mode 4 based CNS/ATM system capabilities.

Throughout the evaluation it was clearly distinguished between results based on the currently used system and environment in which it operates, and those based on assumptions on a future system and environment.

4.2.3.2.2 System characteristic hypotheses

All system characteristics were evaluated by the DFS in the enhanced surveillance application.

4.2.3.2.3 Operational benefit hypotheses

Several benefits were anticipated to be gained with the STDMA/VDL Mode 4 supported services provided in this NEAP application. Operational benefit tests (OBTs) were designed to verify or reject assumptions on these benefits.

In flight	In-Flight Situation Awareness
Safety	CNS/ATM system increases the safety in flight
Profitability	CNS/ATM system reduces costs
Punctuality	CNS/ATM system reduces delays

All trials were tested through questionnaires distributed to each crewmember with the flight documents.

4.2.3.2.4 Test parameters

The following parameters were observed throughout the testing:

	Parameter	Comment
Safety	General safety items	General overview Traffic identification Position identification
	Human factors (cockpit)	Close the loop pilot - controller Big picture Distraction
	Pilot workload	Additional duties Restrictions
Profitability	Cost reductions	Faster
	Capacity	Seamless gate-to-gate concept
Punctuality	Delay	Pilot information Pre-planning
	Operational issues	

These parameters were addressed through closed questions with standardized answers, enabling the comparison of all questionnaire results. A “short-term” questionnaire was used.

Other issues addressed were:

	Parameter	Comment
Technical	Integration, limitations	
	Experiences made	Pilots experience
	Required improvements	Pilots view
Environmental	Environment protection	
	Noise abatement	

These parameters were addressed by open questions with non-standardized answers in order to trace pilots’ experience with the onboard system. A “long-term” questionnaire was used.

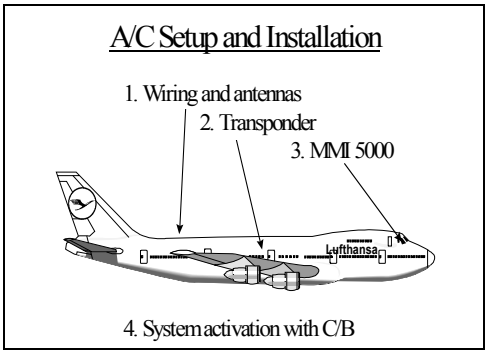
4.2.3.3 Test set-up

4.2.3.3.1 General

Using trial equipment on revenue flights limited testing to a certain amount. The equipment and trials were mainly restricted by:

- pre-operational status of the equipment, certified only on a non-interference basis,

- stand-alone installation not integrated in today's state of the art EFIS,
- location of the MMI (cockpit display) outside the crew's main field of vision,
- only revenue flights used for trials, no special scenarios used,
- no special procedures established,
- no special taxi guidance features implemented,
- low number of ADS-B equipped aircraft,
- most MMI features available in Frankfurt only,
- trials during summer time, therefore no low visibility conditions present,
- late activation of the TIS-B functuality.



Picture 4.2.3.3.1 Aircraft setup and installation

4.2.3.3.2 Airborne equipment

For the trials the MMI 5000 cockpit display was used in the Boeing 747-200s. Several software adaptations had been made by the Swedish software manufacturer Carmenta in order to meet special pilots needs such as a suitable display brightness control.

Picture 4.2.3.3.2 Detailed MMI 5000 with enroute display

4.2.3.3.3 Ground equipment

No special ground equipment is required for in-flight situation awareness. To enable an initial transition phase, traffic information TIS-B service was established by the DFS around the Frankfurt international airport.

4.2.3.3.4 Questionnaires

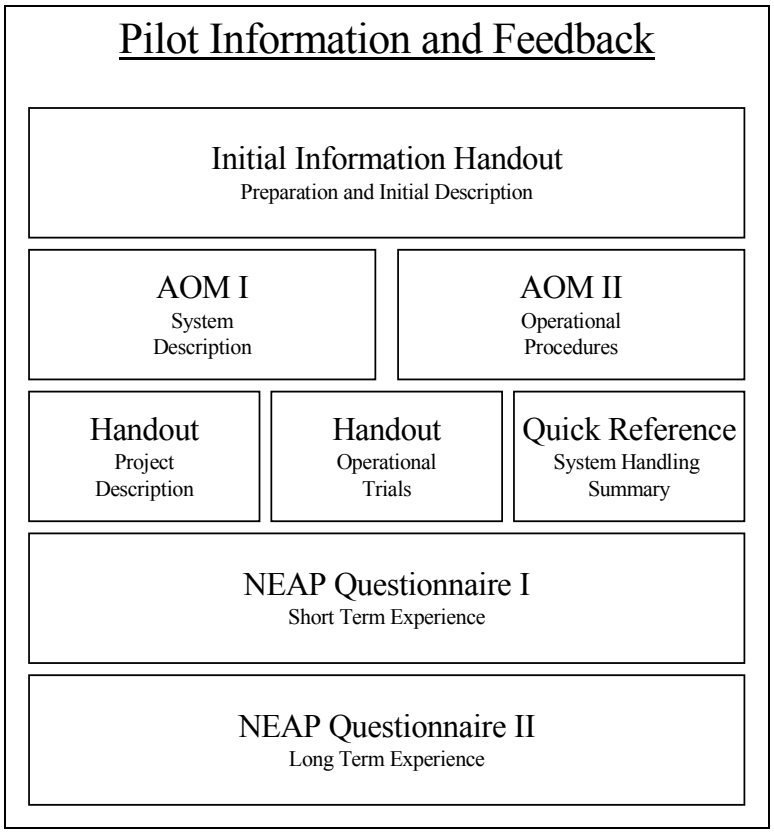
At the beginning, intensive pilot information was required to prepare for the trials. The method used to collect data was the distribution of questionnaires to the aircrews.

Short-term questionnaire

In order to gather information about the individual experience made on a particular flight, a short-term questionnaire was developed and distributed to the pilot. The questionnaire was relatively short and addressed the operation of that flight only. It highlighted possible special problems and constraints, but also the benefits of the system.

Long-term questionnaire

After a period of practical experience with the MMI 5000 and the CNS/ATM system a second, long-term questionnaire was developed and distributed to each participating pilot. It addressed the overall experience with the system in regards to the contributing projects. Thus a general assessment of the advantages and benefits achievable with a STDMA/VDL Mode 4 based CNS/ATM system was possible. After the evaluation phase suggestions were encouraged in order to improve the system in line with the pilots needs.



Picture 4.2.2.3.4 Pilot information and feedback

4.2.3.4 Testing and evaluation

4.2.3.4.1 Test environment

All tests took place on revenue flights. Hence the tests were always based on a real life situation where no pre-planned scenario was possible. As all flights were inbound to, or outbound from Frankfurt international airport, tests focused on operations at that airport.

4.2.3.4.2 Scientific approach

All tests were based on the NEAP test methodology. Hypotheses were established prior to testing. The questionnaires were based on these hypotheses, assessing special parameters in different areas. It was always clearly distinguished between;

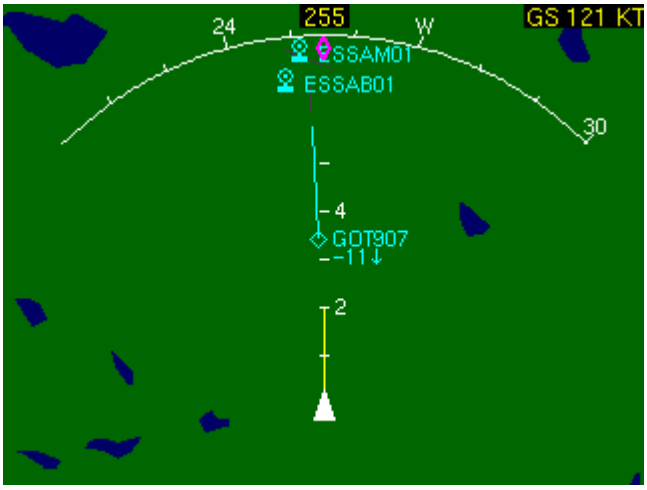
- phases of flight (on-ground and in-flight),
- existing trial equipment and potential certified system, and
- individual flights and long term experience.

Development of questionnaires was made in the following order:

1. Specification, clarification, precise meaning of hypotheses.
2. Formulation of questions with regard to hypotheses.
3. Order of questions.
4. Checking of questionnaire
5. Main survey.

4.2.3.4.3 Test realization

After start of preparations in September 1997, testing of the NEAP application in-flight situation awareness began in July 1998. Until the end of October 1998, six Lufthansa Boeing 747-200 Classic participated in the NEAP trials each fully equipped with an STDMA/VDL Mode 4 ADS-B transponder and the associated cockpit display unit (CDU). During the trial period of about 10,000 revenue flight hours, crew experience and system capacity was assessed.



Picture 4.2.2.4.3 Screenshot MMI 5000 with enroute display including preceding traffic and ground stations

4.2.3.5 Results and conclusions

4.2.3.5.1 Principal results and conclusions

The trials with the ADS-B system in regards to in-flight situation awareness lead to different results depending on the degree of development and deployment in the field, i.e. whether the current or an assumed future situation was addressed.

4.2.3.5.2 Pre-certification STDMA based ADS-B equipment

The pre-certification trial equipment may only be used as an additional information source without any operational application, but;

- there are already small benefits achieved with the trial equipment, e.g. map display with detailed airport maps provide orientation for taxiing,
- overall feedback from the aircrew was positive.

4.2.3.5.3 Few STDMA based ADS-B equipped aircraft

- As long as there is only a low number of ADS-B equipped aircraft present, as anticipated during a transition phase, it is expected that situation awareness can initially be supported by TIS-B (uplink of radar data).

4.2.3.5.4 Large number of STDMA/VDL Mode 4 based ADS-B equipped aircraft

After an initial transition phase with an increased number of ADS-B equipped aircraft additional benefits are expected, based on the above mentioned assumptions:

- ADS-B based in-flight situation awareness provides an additional safety net with pre-warning times much longer than for TCAS, and therefore allows for early tactical flight path coordination rather than last minute conflict avoidance, resulting in increased safety margin and redundancy.
- In-flight situation awareness, including the display of other aircraft's flight number, allows crews to optimize their flight profile according to the traffic situation (e.g. change of flight levels between company aircraft).
- Weather independent constant throughput and increased capacity is possible through adaptation of VMC procedures to IMC (e.g. follow visually, climb through level of selected aircraft).
- Airborne station keeping resulting in increased capacity is possible provided:
  - separation responsibility is clearly defined,
  - operational procedures are established.
- In-flight situation awareness closes the information loop between ATC and the aircraft, allowing delegation of responsibilities into the cockpit. As a result, ADS-B based free flight scenarios in low density airspace are possible in the long term.
- Potential to reduce separation minima due to enhanced surveillance accuracy.
- Potential to establish an ADS-B based surveillance infrastructure at comparably low costs.
- Possible airspace charging structure according to required airspace capacity.
- potential to create dedicated ADS-B EFR (extended flight rules) zones between high density destinations.

Due to the mentioned limitations it is impossible to exactly quantify the amount of achievable savings. Nevertheless remarkable benefits are expected in regards to

safety, punctuality and costs when introducing a fully developed and certified STDMA/VDL Mode 4 ADS-B based CNS/ATM system.

4.2.3.5.5 Comments and observations

To overcome today's problems with increasing air traffic a seamless gate-to-gate concept is required. The CNS/ATM system presented in this project should be able to become the backbone of this concept. The next important step is, as the trials show, integration of such a system into the glass cockpit of a modern passenger aircraft and certification of the required system components.

The trials showed that the introduction of a new onboard system, including cockpit displays with improved HMI, new operational procedures and electronic flight rules (EFR), could potentially contribute to more efficient flight operations. The shared responsibility between ATC and aircrew supported by the increased aircrew situation awareness provides higher capacity and weather independent operations at lower costs, while today's safety standards are maintained or even exceeded. A first step was taken by establishing pre-certification data link networks and trial equipment. Now the next step should be towards system integration and operational concepts.

4.2.3.6 Recommendations for system improvements

In order to gain benefits using a fully developed ADS-B based CNS/ATM system the following steps are recommended:

- Research in regards to human factors including selection and layout of traffic information to avoid information overload in the cockpit.
- Partnership with airframe manufacturers.
- Integration of VHF based ADS-B equipment in a modern transport aircraft.
- Development of operational procedures to accommodate achievable benefits.
- Study on extended delegation of responsibility to the cockpit.
- Promote the implementation of ADS-B capability in aircraft. In the longer term the number of ADS-B equipped aircraft should reach 95% or more to achieve maximum benefits.

Finally a transition plan should be developed and implemented which would allow users to achieve early benefits even with a limited number of aircraft being equipped with an ADS-B system. Uplink of radar data via TIS-B is a key factor in this transition phase.

4.2.3.7 Future plans

After completion of the evaluation of on-ground situation awareness DLH will continue to use the aircraft trial equipment in other projects like the FREER (free flight scenarios) and the PETAL II (controller-to-pilot data link communication) trials.

The next step following the NEAP activities is only possible based on a cooperation with a major airframe manufacturer and should result in the integration of a CNS/ATM system in a modern aircraft cockpit. Main focus of DLH future plans is achievement of immediate benefits, which means that all investments will be planned according to cost benefit analysis.

4.2.4 Enhanced Surveillance for ATC

This application was developed by DFS

4.2.4.1 Service description

4.2.4.1.1 Operational context

Today's ATC surveillance is primarily based on radar data. With secondary radar (SSR), identity and altitude is added to the basic position data, and the tracking function in modern ATC systems automatically calculates the speed, vertical attitude and track. The controller's forward planning is based on current radar data combined with information in the flight plan. Information on a flight's actual intentions must be communicated by means of voice.

Increasing load on voice channels and capacity problems in high-density areas demand a solution for providing the controller with improved planning data. The onboard flight management system (FMS) knows exactly the flight path of the entire flight. Access to such precise FMS data for ATC could increase efficiency, reduce delays and costs for airlines and provide an additional safety net.

4.2.4.1.2 NEAP application

The Enhanced Surveillance for ATC application evaluated in NEAP was based on enhanced surveillance (ENH) data broadcast by an appropriately equipped experimental aircraft and received by the NEAN ground network. Data was presented on the controller working position AIRLINK. The specification of DAP (Download of Aircraft Parameter) was used to select the information flags. The experimental aircraft supported the following ARINC 429 labels (information):

- Aircraft address
- SSR Mode 3A
- Magnetic Heading
- Roll angle (bank)
- Flight Level (barometric)
- Rate of Turn
- Ground Speed
- Wind Speed (Velocity)
- Wind Direction

The DAP data delivered by the ARINC 429 bus system was accepted and converted into the STDMA/VDL Mode 4 format and then broadcast every second on the STDMA/VDL Mode 4 radio channel. Each report contained the aircraft data mentioned above.

4.2.4.1.3 Relevance to the gate-to-gate concept

The service provided by the evaluated system concept support ATM in airborne operations.

For planning purposes, particularly in the context of Airspace Management (ASM) and Air Traffic Flow Management (ATFM), access to dynamically updated information about flight intentions in a certain timeframe within the geographical area of responsibility is required as comprehensively and accurately as possible (e.g. downlink

of FMS-derived aircraft parameters). Depending upon the timeframe considered for ASM/ATFM planning, data would be derived from the following sources:

- Long-term flight intentions from flight plans in the pre-flight phase.
- Actual intentions from airborne aircraft.
- Surveillance data correlated with flight plan data.
- A combination of these data sources (e.g. considering the mixture of short-haul and long-haul traffic).

4.2.4.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate how the service could enhance the ATC surveillance function by providing additional information to the ground ATC system.
- Evaluate the possible improvement of ATC surveillance (tracking) and planning process by the service.
- Evaluate the impact of the service on safety net functions.
- Evaluate the possible reduction of the load on voice channels by the service.

4.2.4.2 Assumptions

4.2.4.2.1 General

The expected benefits to be achieved from the ENH service were defined as:

- Enhanced information transfer by aircraft in all phases of flight.
- Reduced radio traffic and controllers workload.
- Improved tracker functionality concerning aircraft intention and manoeuvres.
- Example of processing of transferred weather data on ground.

4.2.4.2.2 System characteristic hypotheses

The main objective was to determine the reliability of the “downlink of aircraft parameter” functionality of the system during normal operations in different areas of interest.

The test focused on the following reliability and application issues:

Test function or property	Tested mainly by
Conversion reliability	**System characteristic test** The “ARCO” software will be tested on several aspects regarding reliability and conversion capability.
Completeness	**System characteristic test** The recordings will be analysed to obtain the values of lost packets transmitted via the wireless link. By using the ADS – B data produced coverage maps will support the results.
Evaluation of weather data	**Theoretical discussion** The possibility for the transmission of weather data using the enhanced surveillance application and the NEAN datalink will be demonstrated.

4.2.4.2.3 Operational benefit hypotheses

Due to time and costs the development of a multisensor-tracker had to be excluded from the project. Therefore operational tests with, for instance, controllers were not executable. These issues are addressed by the DFS project JANE (Joint Air Navigation Experiments) which investigates the further on development of possibilities to downlink the on-board flight management system (FMS) data.

4.2.4.3 Test set-up

4.2.4.3.1 General

The following equipment was used for the demonstration of this NEAP application:

- Experimental aircraft DO-228 equipped with GNSS-transponder.
- Industrial PC onboard running ARCO, developed by DFS.
- ARINC 429 interface card onboard.
- Controller working position (AIRLINK) running analysing tool ARINC-view.
- NEAN ground network.

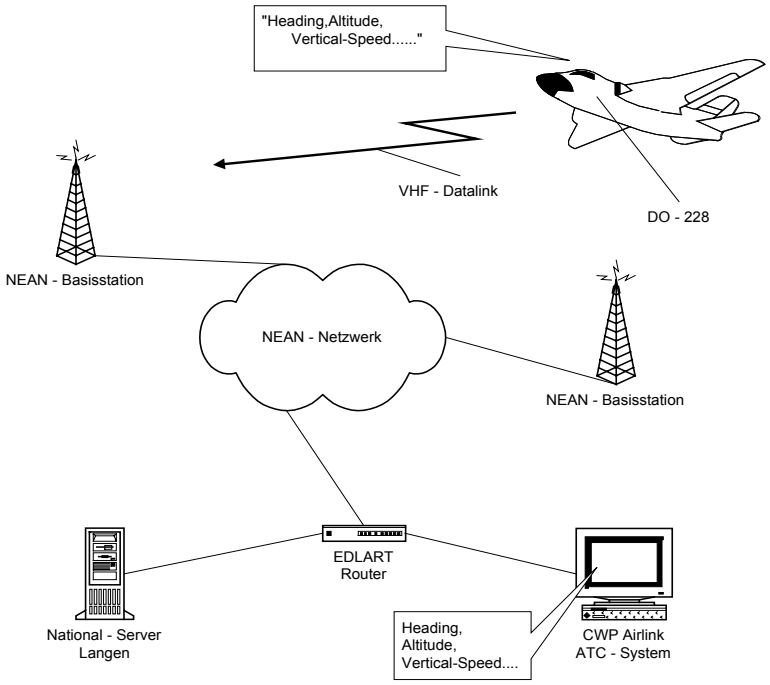


Figure 4.2.4.3.1 - Test infrastructure

4.2.4.3.2 Airborne equipment

The ARCO-system (ARINC 429 converting software) onboard of the aircraft is permanently activated if power supply of the aircraft is engaged. The experimental aircraft automatically broadcasts the requested avionics data coming via the ARINC 429 - system.

The ARINC 429 - labels are converted into the defined STDMA/VDL Mode 4 format and forwarded to the STDMA R2-transponder installed onboard. The ENH encoded information logfile is generated during each start-up of the system. This scenario runs automatically.

Figure 4.2.4.3.2 - DLR experimental aircraft DO - 228

4.2.4.3.3 Ground equipment

The ENH data received by the NEAN ground station was forwarded to the NEAN national server via the local servers.

The AIRLINK controller working position (see figure 4.2.5.3.3 a), connected via TCP/IP node, stores the selected ENH data in the dedicated file. The ARINC-view tool presents the data on the display.

The ARINC-view software tool was developed by DASA NFS. The tool presents the incoming DAP data from the aircraft. Several windows can be opened to present the data of several aircraft simultaneously. The ARINC-view comprises the display unit and DBF database. The tool requires Windows NT V/4.0.

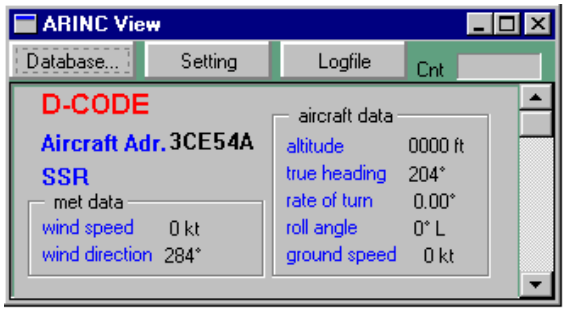


Figure 4.2.4.3.3 b) - ARINC-view window

The first part of the test was the verification of the ARINC-coder conversion. ARINC labels were generated in a defined order by an ARINC 429 generator. The labels were delivered to the ARINC interface of the generator and forwarded to a PC run-

ning the ARINC-coder application. All settings for the ARINC-coder were made in the ARCO ini-file.

The second part of the test was the verification of the data transmission and the decoding of the information. The recorded data from the recording PC was output to the transponder for broadcast on the data link. The data was received by the Braunschweig ground station and forwarded to the AIRLINK PC located in Langen. The received ENH messages were decoded by the ARINC-view application running on the AIRLINK system. The decoded information was displayed on the desktop of the AIRLINK controller working position and was manually compared with the original data from the ARINC generator.

4.2.4.4 Testing and evaluation

4.2.4.4.1 Test environment

The test was performed in the NEAN infrastructure environment, which is an experimental system. The test itself was performed by using experimental equipment. Definition and co-ordination activities between the different ADS-B projects had been carried out prior the test. Influencing activities (e.g. PETAL II/FARAWAY/DEFAMME) or possible distortions by other ongoing projects were not taken into consideration. The costs for the comprehensive analysis of all parameters of the common environment were not practicable for the NEAP project (and certainly not a goal).

4.2.4.4.2 Scientific approach

The tests were based on the NEAP test methodology. The evaluation of the test results was based on hypotheses established before the examination.

4.2.4.4.3 Test realisation

The conversion tool ARCO was developed between January 1998 and March 1998. The software was tested and verified by using an ARINC Label test generator in the DFS - Laboratories.

DLR equipped their aircraft in August 1998 with the ARCO software and the ARINC interface card. Before the installation of the test set-up, DLR had to certify the necessary onboard PC system. The aircraft was not equipped with adequate PC system prior to the tests.

DFS rented the DLR DO-228 aircraft for three flight hours. These flight hours were used for logging data for the above-mentioned purposes.

The test flight was performed on 21 September 1998. The DLR experimental aircraft departed from Braunschweig airport to Frankfurt/Main. In the Frankfurt airspace the aircraft made five low approaches to runway 07L of Frankfurt airport. After that the aircraft returned to Braunschweig.

During the test flight all data received by one of the participating ground stations was recorded by the COM-Manager of the AIRLINK system. Therefore both ADS-B reports and enhanced surveillance messages (ENH messages) were recorded in a combined logfile. The data transmission between the local servers and the AIRLINK system was based on TELNET connections.

For the evaluation of the flight tracks of the aircraft all received ADS-B reports were transferred into a SQL database. The evaluation of the ENH messages was based directly on the AIRLINK logfile.

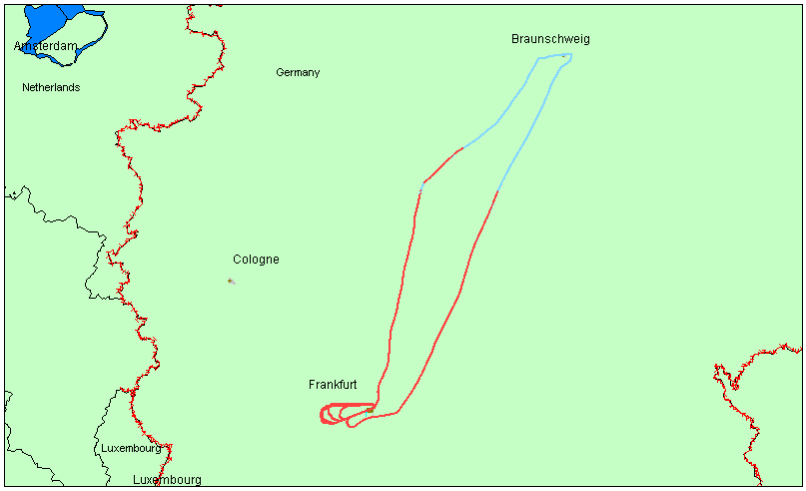


Figure 4.2.4.4.4 - View of test flight pattern

4.2.4.5 Results and conclusions

4.2.4.5.1 Principal results and conclusions

The results provided a perception of how ground system functions such as radar tracking could be improved by using downlinked aircraft parameters. Aircraft intentions and manoeuvres could be detected faster than when using common radar systems.

The following points summarise the principal results and conclusions:

- The evaluated system STDMA is capable of supporting the downlink of aircraft parameters.
- The format used for the downlink of aircraft parameter has to be improved and adjusted to operational requirements.

The DFS Project JANE (Joint Air Navigation Experiments) has determined that with improved strategic and tactical planning the potential number of conflicts (delays, sector load etc.) may be reduced significantly. The onboard FMS is one of the major elements in the information chain. Only the FMS knows at take off time the exact four dimensional flight profile, better than a ground system could ever compute this profile. There is a unified synchronised time required for all users and systems. The STDMA/VDL Mode 4 system uses the GPS UTC time and could provide this time to other systems.

4.2.4.5.2 Conversion

The test of the ARCO-Coder application was divided into several steps:

- Generation of ARINC labels using the ARINC T1200 Generator.
- Feeding of the ARINC-Coder with the output of the ARINC T1200 Generator.
- Recording of the output from the ARINC-Coder.
- The recording of the ARINC-Coder was output to the transponder for transmission.
- Reception of the data using the Braunschweig ground station.
- Forwarding of the received data to the AIRLINK system in Langen.

- Comparison of the received data with the data produced by the ARINC-Coder application.
- Forwarding of the received data to the ARINC-view application of the AIRLINK system for presentation.
- Comparison of the presented data with the original data provided by the ARINC T1200 Generator.

No outages were found during the test procedure. The data passed through the transmission line without distortion.

4.2.4.5.3 Reliability

The reliability of message delivery was up to 98,97 %. A message delivery problem was, however, experienced in the enroute phase. When the aircraft had reached a position between the Frankfurt and Braunschweig ground stations the reliability of message delivery dropped to 70 %, which could have been caused by equipment malfunction or uncoordinated activities by different STDMA users. As the NEAP did not have the technical resources for resolving the problem, an in-depth study should be made outside of the project. However, this problem resulted in worse than expected performance in the en-route segment.

4.2.4.5.4 Downlink of weather data

The objective of this experiment was to downlink onboard weather information. The trial sufficiently fulfilled this objective. The typical changes of wind direction and the increasing velocity during the climb phase of the aircraft could be demonstrated.

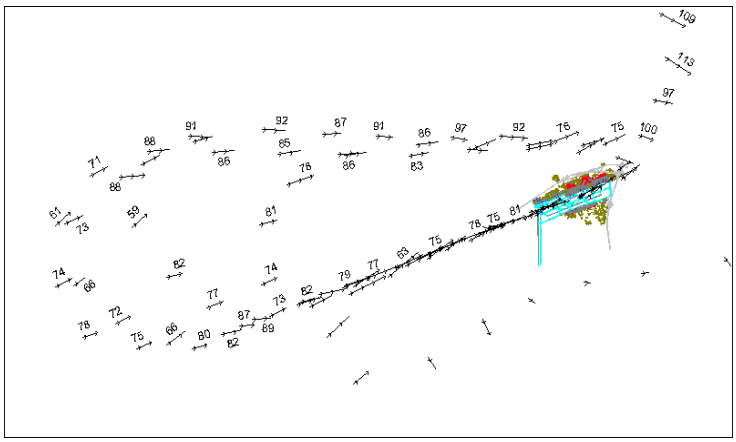


Figure 4.2.4.5.4 - View of weather data (wind/velocity)

A next step would be the comparison between the logged data and the data of the Vortex Warning system at Frankfurt airport. Weather data provided by the regional weather service could be used in a similar way.

Unfortunately the preparation of these results could not be performed within the scope of this project. Nevertheless the results of the tests performed indicate the potential of a weather downlink function.

The broadcast methodology itself is practicable to distribute this kind of information. In fact, it could be included into the ADS-B position report.

4.2.4.5.5 Operational Benefits Test

In accordance with the NEAP Test plan, Project Jane (Joint Air Navigation Experience) addresses this issue for the Enhanced Surveillance application.

4.2.4.6 Recommendations for system improvements

The limiting factors with regard to the evaluated implementation of the Enhanced Surveillance application are;

- The free text ENH message data source is limited by the current STDMA/VDL Mode 4 text message format.
- Currently only experimental equipment is available.
- Standardisation of the STDMA/VDL Mode 4 format is not complete.

An in-depth analysis of the data flow is required from a process perspective to establish which process contains the ”best” information at a time. With respect to the whole ATM process we only have a specific and limited knowledge. The following information systems should be integrated and used for improvements:

- FMS should be integrated into ATM systems and information flow. Only the FMS knows at take-off time the exact 4D profile (better than a ground system could ever compute this profile). Today just a limited subset of functions is used at pilots’ discretion. AOC only receives a few information elements, whereas ATC has no FMS information at all. Note that future FDPS should be capable of processing FMS data.
- Airports and airport information systems are insufficiently integrated into the overall ATM systems. Heartbeat of a co-operative system might be ETA or take-off time. Synchronisation has to be assured and updates may be required from AOC in co-ordination with ATC.
- Delays are more often caused on ground than when the flight is airborne. Half an hour before take-off is a ”black hole” from an information point of view. For instance, in Frankfurt the average elapsed time between pushback request/engine start-up given and take-off varies enormously ($\pm$ 15 minutes).
- A unified synchronised time is required for all users and systems. GPS time provides a possible solution.

4.2.4.7 Future plans

The DFS Data link strategy was presented at the 41st Conference of the DFS SYSCOM. The strategy outlined a possible implementation of data link services as shown in Figure. 4.2.4.7.

ADS-B is a fundamental technical basis for future concepts, allowing aircraft to automatically broadcast air-derived data such as 4 -D position and identification at regular intervals. At the same time, signals broadcast by other aircraft can be received on board and are then used to create a situational display of the surrounding airspace, comparable to the radar display of an air traffic controller. DFS is participating in the development of ADS-B and in the test procedures of potential transmission technologies. At the moment, Mode S Extended Squitter and VDL Mode 4 might be suitable candidates for transmitting ADS- B data.

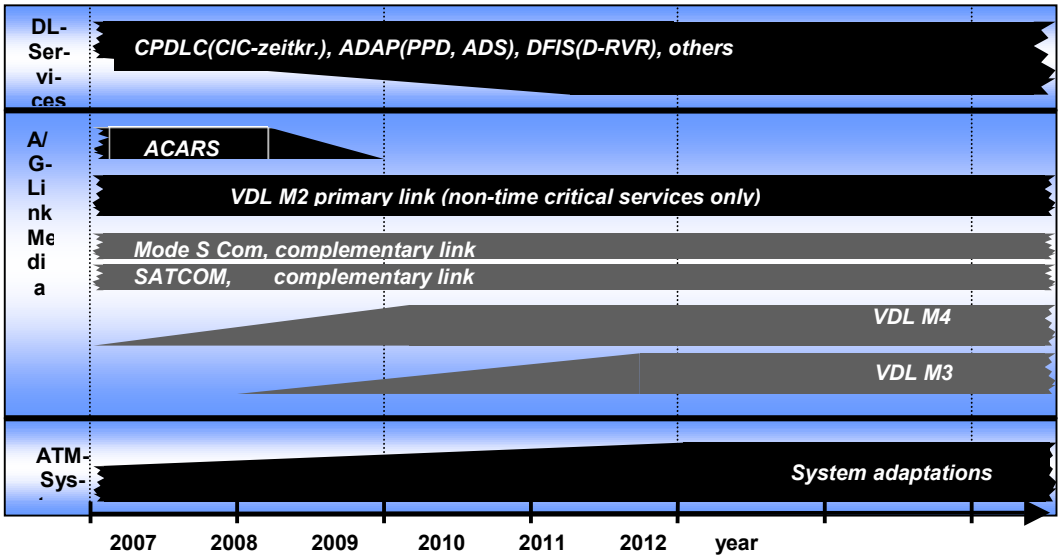


Figure 4.2.4.8 – DFS data link strategy

ICAO is currently standardising VDL Mode 4. The advantages of VDL Mode 4 are, on the one hand, high spectrum efficiency by means of the access procedure and, on the other hand, favourable propagation properties within the frequency range. In the VHF band, it is possible to achieve long ranges with relatively small efforts. On-board and ground components are therefore comparatively simple and cheap.

Weather ADS-B will, in the long run, replace radar- based surveillance, depends on its capability to fulfil - at economically acceptable costs - the high performance requirements imposed on a sole means surveillance technique, especially with regard to availability and integrity. Radar will remain the vital backbone of the air navigation services, at least until these questions are solved.

4.2.5 Automatic Terminal Information Service - Broadcast

This application was developed by DFS.

4.2.5.1 Service description

4.2.5.1.1 Operational context

One of the standard operating procedures in today's operational environment is for pilots to obtain weather and airport information from the Terminal Information Service prior to departure and arrival. The Air Traffic Service Providers are providing the information on the Automatic Terminal Information Service (ATIS) frequency as voice information. The pilot selects the appropriate ATIS frequency and listens to the information. For a written copy of the ATIS information the pilot has to write down the information manually.

Picture 4.2.5.1.1 MMI 5000 installation (lower right) in the DLH B747-200 cockpit

The ATIS-B service evaluated in NEAP provided a data link broadcast service to deliver the ATIS information into the cockpit. The pilot used the ATIS function on the cockpit display to access the information. The same channel was used as that for receiving DGNSS information and for receiving and transmitting ADS-B position data.

4.2.5.1.2 NEAP application

The ATIS-B service evaluated in NEAP is based on the datalink functionality of the NEAN STDMA system. The ATIS information received from the German weather information systems (WIAS) was automatically broadcast by all German NEAN ground stations. When an appropriately equipped aircraft was in the coverage of a German ground station, ATIS messages from all participating airports were received. The pilot had the option to display the current as well as previously received ATIS messages from different German airports using the cockpit display system MMI 5000.

4.2.5.1.3 Relevance to the gate-to-gate concept

The use of a digital ATIS is a basic part of the gate-to-gate concept. The NEAP ATIS-B service provides the ATIS information to the pilot in the approach as well as in the departure phase of flight.

4.2.5.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate the suitability of STDMA/VDL Mode 4 as the basis for Automatic Terminal Information Service (ATIS-B).
- Evaluate the concept for an ATIS Broadcast Service.
- Develop and evaluate a common cockpit platform for supporting implementation and evaluation of future ATIS-B services.
- Demonstrate ATIS-B service as a component of a gate-to-gate concept.

4.2.5.2 Assumptions

4.2.5.2.1 General

The expected benefits to be achieved from the ATIS-B services were defined as:

For the pilot:

- Receive ATIS reports independently of the aircraft position (distance from the airport from which the ATIS originated).
- ATIS reports for multiple airports at any time.
- Clear, structured ATIS display.
- No need to listen to and manually copy the ATIS voice broadcast.
- Quick access to ATIS information.
- Automatically received and updated ATIS information.

For the controller:

- Possibly reduced workload due to the improved ATIS delivery process

4.2.5.2.2 System characteristic hypotheses

System function or property	Tested mainly by
Receive ATIS reports independently of the aircraft position	System characteristic test
ATIS reports of multiple airports at any time	System characteristic test Questionnaire
No need to listen to and manually copy the ATIS voice broadcast	System characteristic test Questionnaire
Quick access to ATIS information	Questionnaire
Clear, structured ATIS display	Questionnaire
Automatically received and updated ATIS information	System characteristic test
Coverage	System characteristic test

4.2.5.2.3 Operational benefit hypotheses

Assumed operational benefit	Tested mainly by
Reduced work-load for the pilot	Questionnaire
Additional information for the pilot	Questionnaire
Reduced work-load for the controller	Theoretical discussion
Reduced work-load for ATS employee	Theoretical discussion

4.2.5.2.4 Sensor system performance test items

These tests addressed the performance of the STDMA technical platform.

Sensor system parameter	Tested mainly by
ATIS data source (WIAS interface)	System characteristic test
STDMA transponder interface	System characteristic test
STDMA presentation	System characteristic test Questionnaire

4.2.5.3 Test set-up

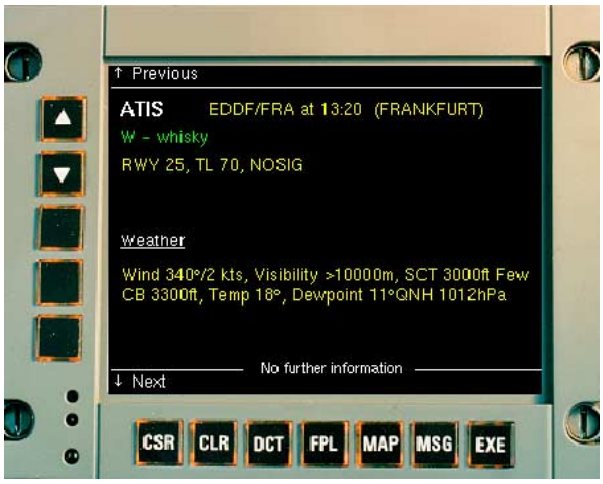
4.2.5.3.1 General

The use of trial equipment on revenue flights limited the testing to a certain degree. Restrictions were mainly caused by:

- only revenue flights used for trials,
- only questionnaires used for contact to the pilots,
- trials only during autumn 1998 although the ATIS information varies with the seasons

4.2.5.3.2 Airborne equipment

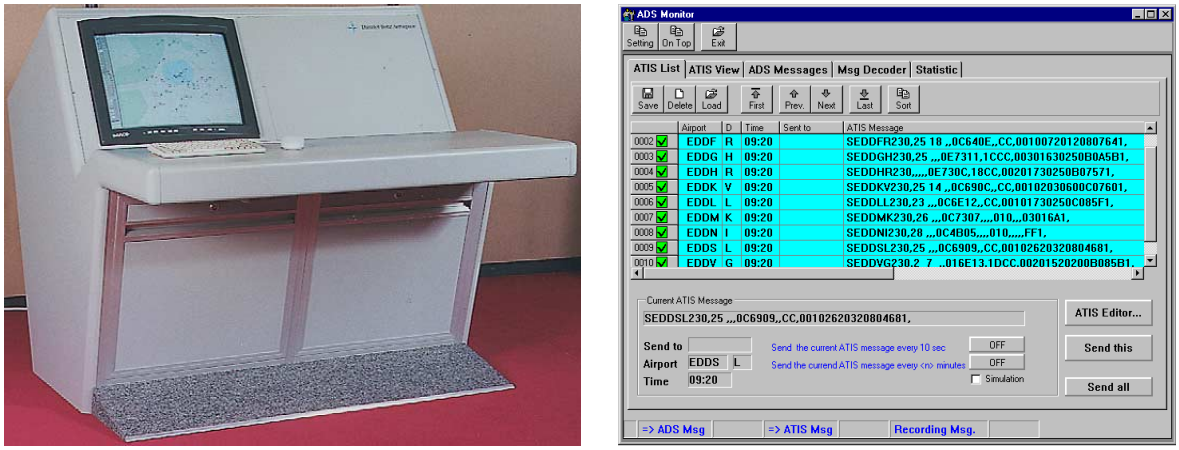
The cockpit display system MMI 5000 was used for the presentation in the aircraft. The ATIS application was only one of several services running on the display system during the test phase.



Picture 4.2.5.3.2 ATIS presentation on the MMI 5000

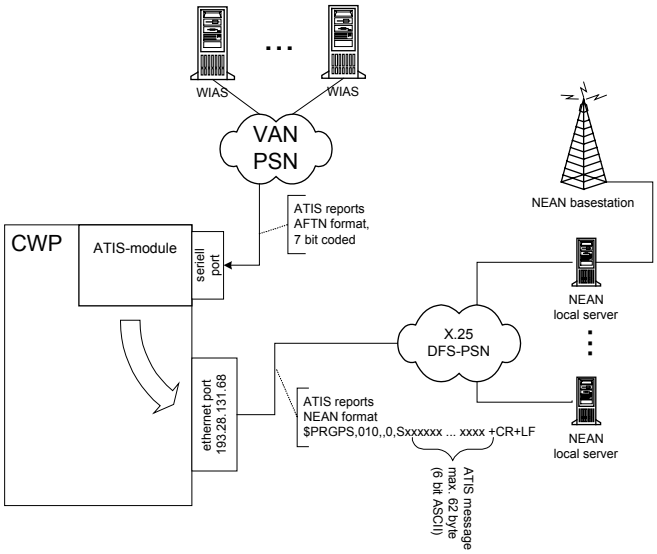
4.2.5.3.3 Ground equipment

The main part of the ground installation was the controller working position (CWP) located in Langen. The control of the ATIS application was done by the ADS-Monitor application running on the CWP.



Pictures 4.2.5.3.3 a) Controller Working position AIRLINK b) ADS-Monitor application

The CWP was connected to the weather information systems (WIAS) to receive the current ATIS messages. The received AFTN ATIS messages had to be converted into the appropriate STDMA/VDL Mode 4 ATIS format by the conversion module of the ADS-Monitor application. After conversion the messages were sent to the NEAN ground stations for broadcast transmission to users. The NEAN ground infrastructure was used for the connection to the NEAN ground stations.



Picture 4.2.5.3.3 c) Ground installation

4.2.5.3.4 Questionnaires

To obtain information from the pilots two different questionnaires were developed in co-operation with DLH. A short-term questionnaire was distributed to the pilot on each flight. This questionnaire addressed operations on that particular flight only. After a period of practical experience a long-term questionnaire was distributed to acquire more detailed information. That questionnaire addressed the general benefits and advantages of the system.

4.2.5.4 Testing and evaluation

4.2.5.4.1 Test environment

The system test was divided up into a system characteristics test and an operational benefits test.

The system characteristics test was based on monitoring the message flow through the system. Different steps were defined:

- Applicability of the ATIS conversion tool: The ATIS conversion functionality of the ADS-monitor application was verified.
- ATIS reception on a selected flight: The ATIS broadcast functionality of the ADS-monitor application was verified
- ATIS coverage: The ATIS coverage map of the Frankfurt ground station was evaluated.

The operational benefits test was based on the questionnaires developed in co-operation with DLH. A statistical evaluation of the questions concerning the ATIS service was done. The results should produce statements concerning the functionality of the service:

- Reliability.
- Design of presentation.
- Availability.
- Utilization.

As all tests were based on revenue flights by the DLH aircraft, it was not possible to define special scenarios for the tests.

4.2.5.4.2 Scientific approach

The tests were based on the NEAP test methodology. The evaluation of the test results was based on hypotheses established earlier.

4.2.5.4.3 Test realization

The evaluation and pre-test phase of the ATIS ground installation was completed by July 1998. After August 1998 the application was running continuously.

Logfiles used for the ATIS coverage test were received from DLH. The logfiles were recorded between 29 August and 16 September 1998 in five DLH B747-200 aircraft on revenue flights.

The system characteristics test concerning the applicability of the ATIS conversion tool had to be divided into two phases because preliminary results had shown that the error rate of the conversion routine was too high. The software of the conversion routine was reviewed and upgraded in the first week of September. After that, the system performance test of the conversion tool was continued.

4.2.5.5 Results and conclusions

4.2.5.5.1 Principal results and conclusions

From a technical point of view, the application worked without problems during the test phase. Problems were found in the suitability of the data sources and also in the definition of the STDMA/VDL Mode 4 ATIS format.

4.2.5.5.2 Applicability of the ATIS conversion tool

The operational ATIS messages were received from the weather information systems (WIAS) by the controller working position (CWP). The ADS-monitor application running on the CWP had to convert the AFTN coded messages (which are based on free text) into the STDMA/VDL Mode 4 ATIS format (which is a fixed format). The purpose of this test was to verify the functionality of the conversion routine and to describe possible problems.

Using the first release of the conversion tool, 25 % of all incoming AFTN ATIS messages were not converted correctly into the STDMA/VDL Mode 4 ATIS format. As the high error rate was unacceptable for the application, an upgrade of the software was required. After the software upgrade the error rate decreased to 9 %.

The main parts of the AFTN ATIS message are based on free text without using an exactly defined “phraseology” for the message elements. Therefore most of the problems of the conversion routine were caused by deviations from the standard phraseology. The phraseology varied with time as well as between different airports (different operators).

The second problem when converting the AFTN ATIS messages into the STDMA/VDL Mode 4 ATIS format was the limited capacity of the currently defined STDMA ATIS format to accommodate all variations of message contents.

To reduce the error rate of the conversion routine two changes of the current definitions were required:

- The format and phraseology used in the operational AFTN ATIS messages needs to be precisely defined.
- The capacity of the currently defined STDMA/VDL Mode 4 ATIS format needs to be enhanced.

4.2.5.5.3 ATIS reception on a selected flight

The purpose of the test was to demonstrate the functionality of the complete ATIS-B application on a representative flight.

For the demonstration only the Frankfurt ground station was used for the broadcast of ATIS messages. The selected aircraft was arriving from Miami to Frankfurt airport. During the flight the aircraft was within the coverage of the Frankfurt ground station for 70 minutes. 15 ATIS messages were expected to be received by the aircraft, but the logfile shows that only 14 messages actually were received. When the aircraft was on ground at Frankfurt airport one ATIS message broadcast by the ground station was not received by the aircraft.

On the selected flight the ATIS application was usable during the whole time the aircraft was in the ATIS coverage.

4.2.5.5.4 ATIS coverage

The purpose of the test was to develop an ATIS coverage map for ATIS messages broadcast by the Frankfurt ground station. To evaluate the coverage map logfiles from five DLH B747-200 aircraft recorded between 29 August and 16 September were used.

The map showed the aircraft positions when an ATIS message broadcast by the Frankfurt ground station was received. The ATIS coverage had nearly the same characteristics as the ADS-B coverage.

Generalizing these results from a single ground station to all NEAN ground stations, this indicates that, from a technical perspective, all aircraft in the NEAN coverage could potentially use the ATIS service.

This figure below shows the ATIS-B coverage from the Frankfurt ground station. Individual plots represent a received ATIS-B message.

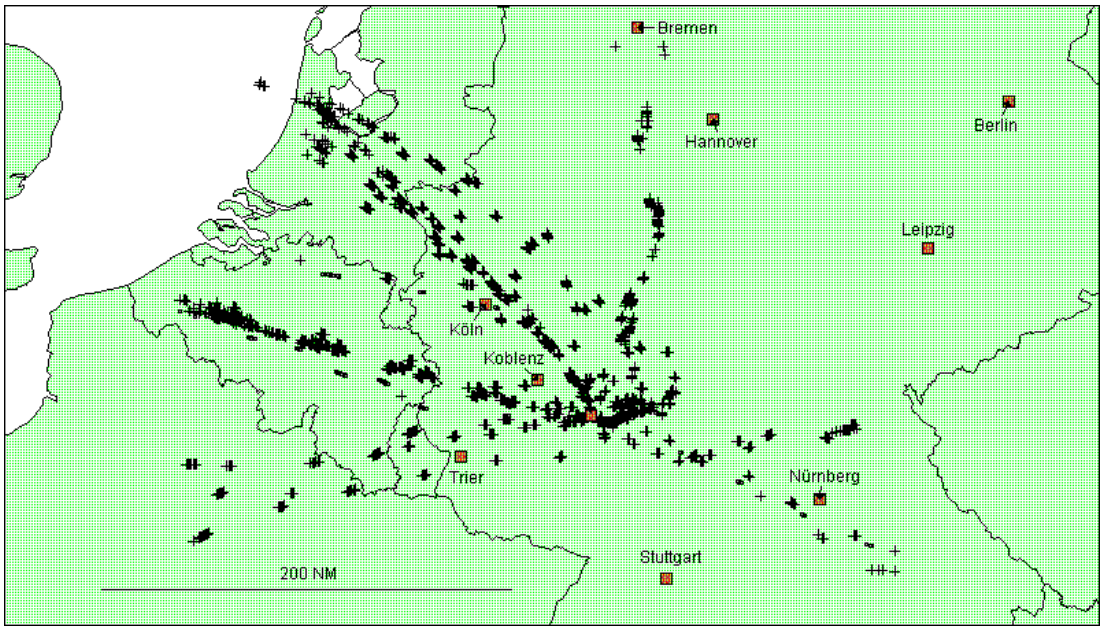


Figure 4.2.5.5.4 - ATIS coverage from the Frankfurt ground station

4.2.5.5.5 Operational benefits test

The pilots impression of the ATIS service was generally positive. However, the suitability is strongly limited by the use of experimental equipment. For operational use DLH pilots have the possibility to request the ATIS message from the ACARS system. The ACARS system is a point-to-point datalink service. The time delay between requesting an ATIS message and receiving the message can amount to a few minutes. Therefore the the pilots prefer the STDMA/VDL Mode 4 ATIS broadcast.

The pilots gave some suggestions concerning the presentation: They strongly prefer the availability of a cockpit printer and the use of standard abbreviations instead of using plain text for the presentation.

It was felt that safety could increase by using an ATIS broadcast service instead of the current procedures to request the ATIS information. The current procedure is considered to require too much of the pilot's attention and capacity.

4.2.5.6 Recommendations for system improvements

The limiting factors for the current implementation of the ATIS-B application are:

- the free text AFTN ATIS source message with imprecisely defined phraseology, and

- the limited capacity of the current STDMA/VDL Mode 4 ATIS format to accommodate all variations within the AFTN ATIS message.

It is recommended that a future realisation of ATIS-B service use a tabled AFTN source message instead of a free text based message. The capacity of the current STDMA/VDL Mode 4 ATIS format also needs to be enhanced. The definition of the future STDMA/VDL Mode 4 ATIS-B format should be adapted to the definition of the tabled ATIS source message.

4.2.5.7 Future plans

The DFS future data link strategy is outlined in section 4.2.4.7.

4.2.6 Extended Helicopter Surveillance

This application was developed by the DCAA.

4.2.6.1 Service description

4.2.6.1.1 Operational context

In uncontrolled airspace without radar coverage situation awareness for Air Traffic Control (ATC) relies entirely upon flight plans and position reports from the pilots using voice radio communication during flight. At regular intervals and at designated locations the pilots will contact the ATC centre. If radio contact with the aircraft is lost a Search and Rescue (SAR) operation will be initiated. Visual and continuously updated information on aircraft position would improve ATC situation awareness and reduce the tension should a position-over-voice arrive later than expected. Precise information regarding last known position would greatly improve the probability for successful SAR operations especially in hostile environments where weather conditions can be rough and visibility low. Pilot situation awareness relies upon visual observations and traffic information provided by controllers.

4.2.6.1.2 NEAP application

Offshore installations in the North Sea depend on services provided by helicopters. The airspace in the North Sea used for helicopter operations is not fully covered by radar, especially not at lower altitudes, and is uncontrolled from sea level to FL85, implying that only flight information and alerting services are available.

The purpose of the Extended Helicopter Surveillance (EHS) service was to provide extended situation awareness for controllers who provide radar-supported flight information services. The EHS service was intended to extend their visual capabilities for an area which is only partly covered by radar. The EHS service was augmented with a Cockpit Display of Traffic Information (CDTI) in a helicopter and an ADS-B display system on ground to obtain feedback from the pilots and helicopter operator.

A segment of the North Sea was used as the geographical area of interest for the NEAP trials.

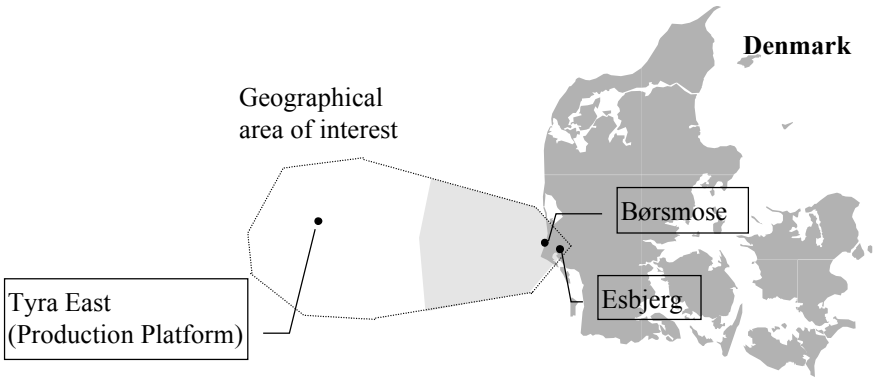


Figure 4.2.6.1.2 - Geographical area of interest

Only the light-grey shaded part of the geographical area of interest is covered by radar for lower flight levels.

The EHS Service was based on ADS-B position reports broadcast by an STDMA/VDL Mode 4 equipped helicopter and received by ground stations installed in Esbjerg, Børsmose and on the Tyra East platform which is located in the North Sea, approximately 125 nautical miles from the coast, outside radar coverage. The ADS-B position reports were distributed through the already existing North European ADS-B Network (NEAN) infrastructure and finally displayed together with conventional radar data (when within radar coverage) on a dedicated Controller Working Position (CWP). The CWP was situated in the Copenhagen ATC centre close to the controllers who provide traffic information and alerting services for the area.

4.2.6.1.3 Relevance to the gate-to-gate concept

The EHS service is an ATM tool aimed at improving the controller situation awareness (and hence surveillance) capability during the en-route phase (from take-off to initiation of an approach) and therefore covers one aspect of the gate-to-gate concept for the ATC user group.

4.2.6.1.4 Application-specific objectives

The following application-specific objectives were adopted for the evaluation:

- Evaluate the suitability of STDMA/VDL Mode 4 for extended ground surveillance tools for ATC (reliability, availability, etc.).
- Record experiences and opinions from controllers who provide radar supported flight information services for the area.
- Record experiences and opinions from helicopter pilots regarding the CDTI.

4.2.6.2 Assumptions

Benefits expected to be achieved from the service provided by EHS were:

- Provision of a supplementary surveillance functions for an area outside radar coverage.
- Improved situation awareness for controllers who provide flight information services.
- Enhanced functions for localising a crash site in SAR operations.
- Improved situation awareness for helicopter pilots.

The following paragraphs list system characteristics and operational benefits investigated in order to evaluate the EHS service.

4.2.6.2.1 System characteristics tests

These tests were related to the overall function of the system.

System Characteristics	Evaluation Method
1 System Availability	Technical data and discussion
2 System Reliability	Technical data and discussion
3 System Coverage	Technical data and discussion
4 System Capacity/performance	Technical data and discussion
5 System Resilience	Technical data and discussion

4.2.6.2.2 Operational benefits tests

These evaluations are related to the assumed operational benefits

Operational benefits	Evaluation method
6 Controller benefits	Questionnaire
7 Helicopter pilot benefits	Questionnaire
8 Helicopter operator benefits	Interview/Written statement

4.2.6.3 Test set-up

The system components were divided into two types:

- Ground system components.
- Airborne system components.

4.2.6.3.1 Ground system components

The ground system consisted of:

- A Controller Working Position (CWP) located at a Flight Information position in the Copenhagen ATC Centre.
- An ADS-B display system for MAERSK HELICOPTERS operations.
- An interface to an RMCDE unit providing live multi-radar data (ASTERIX Category 3) from the Copenhagen Air Traffic Control Automated System (CATCAS).
- A section of the NEAN network.

The section of the NEAN network includes:

- STDMA/VDL Mode 4 sensors in Esbjerg, Børsmose and on Tyra East.
- A local NEAN server on Tyra East.
- A regional NEAN server in Esbjerg.
- A national NEAN server in Copenhagen.
- A satellite link between Tyra East and Esbjerg.
- A Wide Area Network (WAN) backbone connecting the NEAN servers.
- A log server in Copenhagen.

The CWP could display ADS-B and radar tracks (when within radar coverage) including prediction vectors (up to 5 minutes) on maps covering the designated area. The maps were zoomable from views of the total area to views of airports/helipads.

The end-users at Copenhagen Flight Information interacted with the system through the CWP.

Figure *4.2.6.3.1* shows a CWP target OY-IVA with a radar (round) and an ADS-B (square) label.

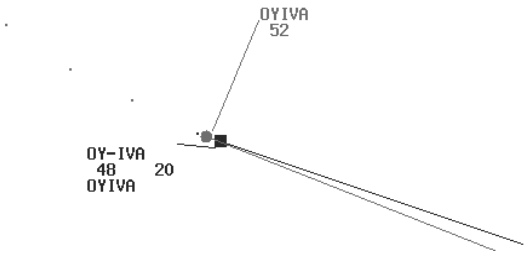


Figure 4.2.6.3.1 – Target representation on CWP

Information about identity, position (latitude, longitude, height), heading and speed was available. The system provided lists of ADS-B and radar tracks for fast localisation of aircraft. A range and bearing vector could be attached to either fixed points or moving targets providing the range and bearing between the end-points. If the vector was attached to moving targets the range and bearing was continuously updated.

4.2.6.3.2 Airborne system components

The airborne system consisted of:

- A Super Puma helicopter (OY-HMH) operated by MAERSK HELICOPTERS.

Figure 4.2.6.3.2 a) – MAERSK HELICOPTERS Super Puma OY-HMH

- An STDMA/VDL Mode 4 transponder installed in the helicopter.
- An MMI5000 CDTI installed in the helicopter.

Figure *4.2.6.3.2 b)* shows the physical location of the MMI5000 in the cockpit of OY-HMH.

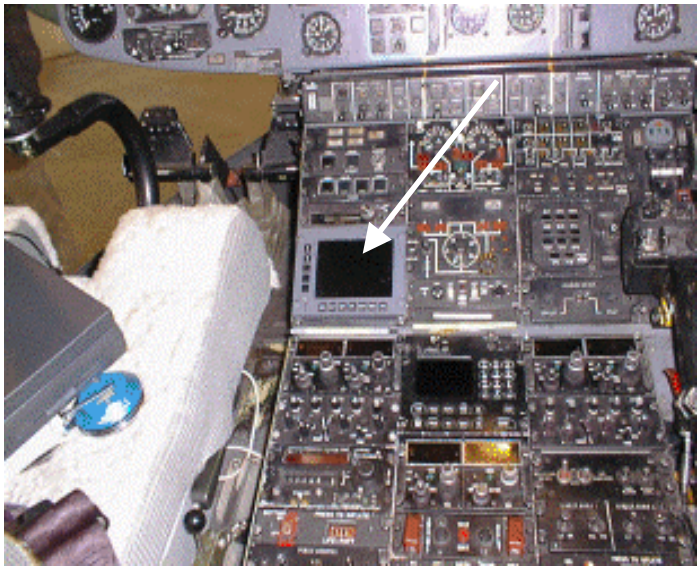


Figure 4.2.6.3.2 b) - MMI5000 installed in the helicopter cockpit

- The helicopter is in regular service between Esbjerg Airport and offshore installations in the North Sea. Offshore operations include approaches to platforms and vessels with helidecks.
- The STDMA transponder contains a Leica GPS receiver and is responsible for broadcasting ADS-B position reports. The frequency used for the STDMA VHF data link is 136.950 MHz.
- The MMI5000 CDTI shows the helicopter position on a rolling map together with ground stations and other STDMA equipped aircraft within VHF coverage. The maps are zoomable from views of the total area to views of the helipad.

4.2.6.4 Testing and Evaluation

4.2.6.4.1 Test Environment

Figure 4.2.6.4.1 a) shows the test bed for the EHS service including relevant NEAN stations. The light-grey shaded area represents the geographical area of interest.

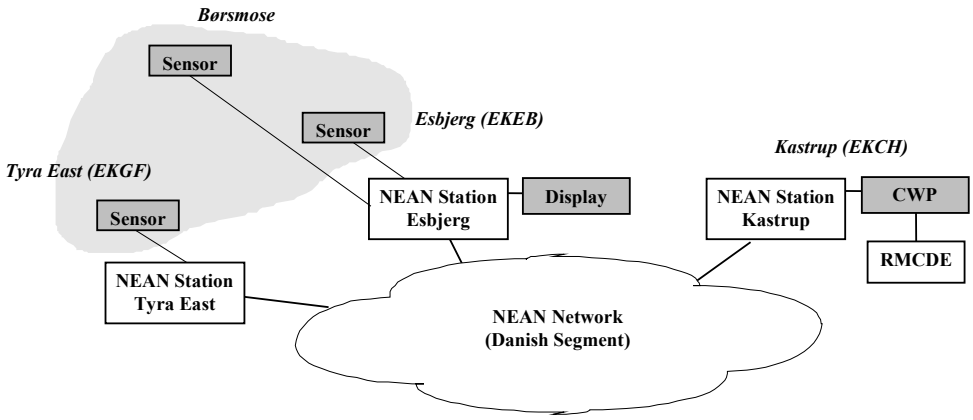


Figure 4.2.6.4.1 a) - EHS System Components and NEAN

The Esbjerg, Børsmose and Tyra East sensors provided ADS-B data, and the Radar Message Conversion and Distribution Equipment (RMCDE) at Copenhagen/Kastrup provided operational multi-radar data from CATCAS in ASTERIX format, category 3 for the CWP. The radar data originated from the en-route monopulse SSR radar at Esbjerg Airport.

The ADS-B position reports broadcast by the helicopter in the area of interest were received by the sensors and distributed through the NEAN ground network infrastructure to Copenhagen/Kastrup and the CWP.

Figure 4.2.6.4.1 b) shows the system schematically in terms of the data sources (ADS-B and radar data), sinks (the CWP and ADS-B display) and data flow.

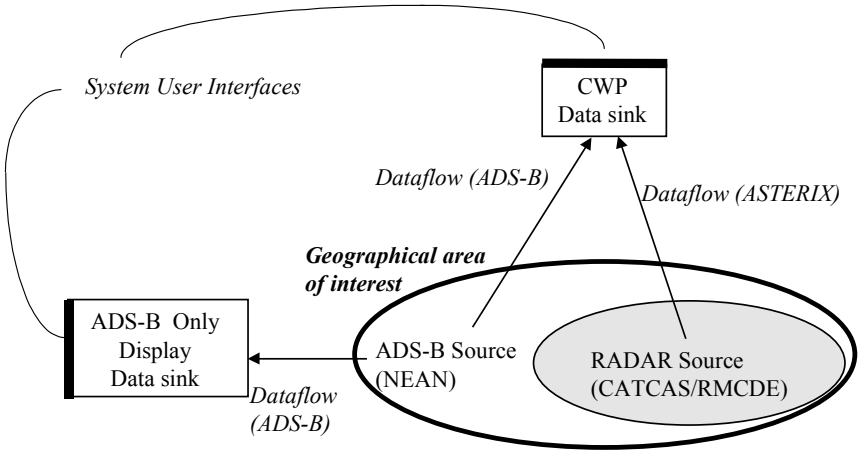


Figure 4.2.6.4.1 b) - Data sources, sinks and flow

The ADS-B and radar data originated from the designated area of interest. The ADS-B source was expected to cover the entire area of interest, whereas the radar data was known to only partially cover the area.

4.2.6.4.2 Scientific Approach

In the test methodology defined for the project two classes of tests were described: System Characteristics Test (SCT) and Operational Benefits Tests (OBT).

Evaluation of the EHS service focused on;

- Recording a sufficient amount of data, in the form of log files of position reports, enabling an evaluation of the EHS Service's system-wide technical parameters (e.g. reliability, availability).
- Recording experiences, through questionnaires, from controllers who provide radar supported flight information services.
- Recording experiences from pilots using the MMI5000 CDTI.
- Evaluating the potential surveillance aspects of an STDMA/VDL Mode 4 system for the designated area, based on the collected data and ATC experiences.

There were no special test flights. All tests relied on data from regular commercial flights with the STDMA equipped MAERSK HELICOPTERS Super Puma.

The following table lists the EHS test parameters and assigned priority.

Test Parameter	Type	Priority	Objective
System Availability	SCT	High	Calculate system availability for the EHS service.
System Reliability	SCT	High	Determine the reliability of the system's ADS-B functionality during normal operation in the area of interest. Parameters like *Completeness*, *Timeliness* and *Accuracy* are examined.
System Coverage	SCT	High	Determine the VHF coverage per sensor within the geographical area of interest in terms of VHF coverage and weaknesses/holes in expected coverage area.
System Capacity/Performance	SCT	Low	Verify that the CWP can process a large number of ADS-B tracks.
System Resilience	SCT	Low	Examine the system resilience for different crash scenarios.
Specified Benefits Thesis	OBT	High	Examine that the specified benefits in the Service Description are fulfilled by the implemented service. This will be done mainly using questionnaires. The focus was twofold: Firstly, feedback from ATC personnel was collected. Secondly, feedback from the helicopter operator was processed.

4.2.6.4.3 Test Realisation

Early in the project it was realised that the existing NEAN VHF coverage from Esbjerg Airport and Tyra East alone was insufficient for providing full VHF coverage for the whole area of interest, especially for altitudes around 1000 ft. It was therefore decided to install another sensor at Børsmose. Figure 4.2.6.4.3 shows a typical flight from Esbjerg to Tyra East and back. Inbound a large coverage hole was detected when the additional sensor at Børsmose was not used (a). The coverage hole disappeared when using the additional sensor (b).

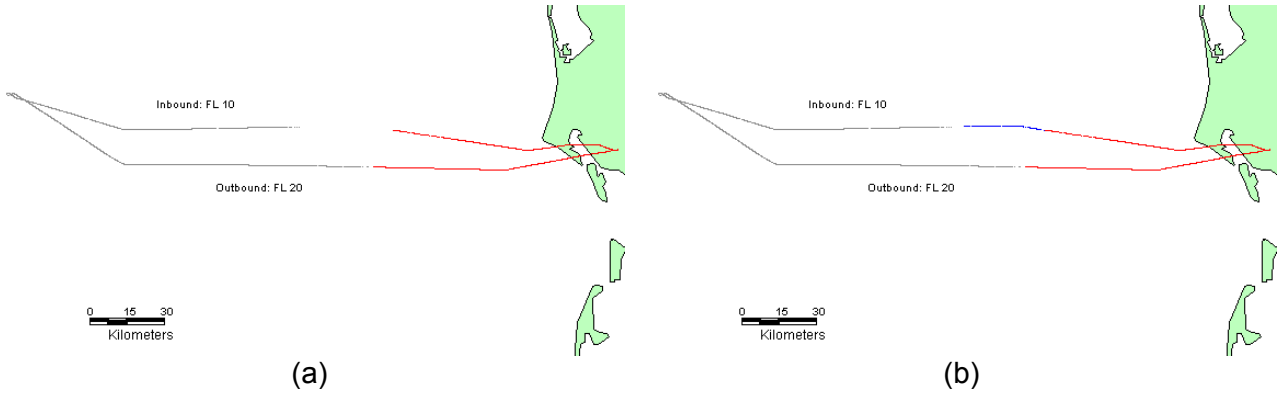


Figure 4.2.6.4.3 – (a) ADS-B track received by Esbjerg and Tyra East sensors. (b) ADS-B track received by Esbjerg, Tyra East and Børsmose.

Prior to the evaluation, a system acceptance test was performed. The CWP was tested with combined feeds of ADS-B and radar data. It was also ensured that the anticipated data flows through the system from the helicopter to the CWP were in place. During the test, minor problems were found in the CWP software but after modification and re-test it was prepared for installation in the Copenhagen ATC centre.

A detailed test plan was developed specifying the SCT and OBT tests.

For the System Characteristics Tests a log-server was installed at Copenhagen Airport and log scripts were developed for monitoring all relevant sensors. For the Operational Benefits Tests three questionnaires were prepared, one for the controllers in the Copenhagen ATC centre and two for the helicopter pilots.

4.2.6.5 Results and Conclusions

4.2.6.5.1 Principal results and conclusions

Considering the experimental nature of the system, where little effort was made to provide a highly available and resilient solution (as would be required by an operational system), the results indicate that a future extended surveillance service could be established using the STDMA/VDL Mode 4 technology. Such a surveillance service could be implemented in a cost-effective manner, and provide benefits to both airspace users and service providers.

Most System Characteristics Tests were conducted in October 1998. The conclusions can be summarised by the following bullet points

- The availability must be judged as fair for an experimental system, as ADS-B data from all EHS sensors was available approximately for 85% of the test period.
- When looking at the amount of received position reports, the system as a whole must be judged less than fair, as only 80% of the expected reports were received.
- The timeliness of the system, however, must be judged as good as the average transport time for position reports received was approximately one second.
- The accuracy of these positions reports, must also be judged as good - the R2 transponder resolution (1,8 m) taken into account - as all recorded landing-positions at Tyra East during the test period proved to be within the boundaries of the helipad.
- The VHF coverage seems adequate for helicopter surveillance in areas not covered by radar. The coverage must be judged as fair despite detected areas with specific problems.
- In spite of registered crashes of NEAN servers, the resilience of the system must be judged as fair as recovery of most crashed components were achieved automatically.

From the operational feedback the following can be summarised. It should be noted that no responses to questionnaires could be collected from controllers, and that therefore potential ATC benefits were derived from the technical results. Moreover, very few questionnaires were collected from the helicopter pilots. A statistical analysis - as intended – was not possible. For that reason the essence of the received feedback and additional comments made by the pilots and MAERSK HELICOPTERS management is presented in narrative form.

- Operators were very interested in possibilities for Search and Rescue (SAR), since the system can provide improved co-ordination between remote and on-scene SAR resources.
- Issues like navigation, pilot situation awareness, the possibility of uplink of traffic and meteorological information were also seen as potential benefits.
- The experience gained by the operator was that the GNSS transponder provides information of the correct position of the helicopter to the ADS-B display system almost continuously.
- There is also a view that the system, with an onboard CDTI, could replace the use of Non Directional Beacon (NDB) and radar in poor-weather approaches to offshore installations.
- The helicopter pilots were critical of the human-machine interface of the MMI5000 display and its physical location in the cockpit. This mostly related to the fact that the display was not designed specifically for helicopters.
- Operating the menu-system of the MMI5000 was generally considered time-consuming and troublesome. Flight time between platforms is often no more than a few minutes and the flight is performed at low altitude, leaving limited time for operating the MMI5000. Using 1-2 minutes for entering new waypoints when on deck may very well increase deck time up to 100% and cause loss of revenue.
- Integration with existing avionics was desired.
- Pilots showed interest in seeing other rescue helicopters directly on the MMI5000 during SAR operations.
- Equipping vessels with STDMA transponders were also seen as a potential enhancement to the existing environment.
- Matching views 'out-of-the-window' with that provided on the MMI5000 was desired, since helicopter movements - especially at low speed and in strong winds - often are sideways. In the existing implementation, the display shows the helicopter track, but it was suggested that heading information be included to have the map orientation aligned with the true heading.
- MMI maps should be simplified. It would be sufficient with a symbol showing a platform's position and orientation together with the location of the helideck. Since IFR/IMC is not possible, too many details in the maps are more confusing than beneficial.
- The service enabled ATC to monitor helicopter traffic from Esbjerg Airport to offshore installations in the North Sea, beyond radar coverage and down to 1000 ft.

4.2.6.5.2 Comments and Observations

Availability

All sensors were available to the CWP for 85% of the test period. Although this is not satisfactory for an operational system, one should take into account that the system is a prototype not designed for high availability operation. Moreover, the system was unattended during nights and weekends when most of the major downtime periods occurred. In addition, disruptive trials/experiments took place during the test period, since the project was sharing the test-bed with the NEAN project and Preliminary Eurocontrol Test of Air/ground data Link project (PETAL II).

The major outage periods were caused by the unavailability of the National Server. If the national server stops then no data is available at the CWP.

Data Completeness

Average data completeness percentages (i.e. the received number of position reports seen in relation to the expected number) of around 80% are quite low. To some extent, the low data completeness is related to problems in the ground station installations in Esbjerg and Børsmose, and problems on the satellite link to the Tyra East sensor. Interestingly, this percentage did not prevent identification and use of ADS-B plots as displayed on the CWP.

With improved ground station installations and tracking capability, the technology could augment existing radar surveillance at a competitive price.

Timeliness

An average message transport time of approximately one second is quite good as ground system performance has not been given highest priority. It is well within the assumed 2 second limit. However, the high loss of messages (approximately 11%) is less satisfactory. A closer examination of the data indicates that the messages were lost at primarily two places in the system:

- From the transponder and outwards (probably on the data link or in the MMI5000, as it was noticed that ping-messages leaving a local server did not always receive a response).
- In the ground network. Known problems in the NEAN server software caused erroneous routing decisions resulting in packets not being sent to their proper destinations.

Some of the losses might also have been caused by conflicts with uplink of differential corrections on the same frequency. In an operational system, differential corrections are envisaged to be uplinked on a separate channel.

Accuracy

All assumed landing positions (ADS-B positions with zero speed) were situated within the lateral boundaries of the helipad. Correcting for the fact that the GPS antenna location on the helicopter is offset from the helicopter centre of mass, a majority of positions were registered between zero and three meters from the helipad centre.

The vertical positions were influenced by the vertical resolution of the transponder. The geoid model used by the transponder may result in biased heights. Some of the positions included in plots and statistics may not be true landing spots, since the helicopter could have been hovering, and multipath effects might also have influenced GPS measurements, resulting in erroneous heights. Despite these facts, the majority of assumed landing positions are vertically within 7 m from the helipad elevation and all are within 25m.

Coverage

It was possible, using ADS-B surveillance data, to follow flights at altitudes down to 1,000 ft from take-off in Esbjerg airport to the landing on the production platform Tyra East.

Despite problems with the sensors in Esbjerg and Børsmose - and bearing in mind that the system relies only on three sensors without any integrity monitoring - the coverage seems adequate for helicopter surveillance in areas not covered by radar.

Capacity/Performance (CWP)

In a simulation where positions from 300 simulated aircraft were fed into the CWP, the system did not crash but showed only a "sluggish" behaviour.

Resilience

The EHS service – from sensor to CWP – appeared to be quite resilient. The service restored itself in all simulated crash cases but one.

4.2.6.6 Recommendations for system improvements

Further studies are recommended on the following topics:

- Enhanced ATC tools. ADS-B position reports provide extended coverage and hence new possibilities for improved surveillance, e.g. automatic detection of alert situations. These new possibilities should be further investigated involving ATC personnel.
- Human-machine interface for helicopter pilots. The MMI5000 CDTI was developed in co-operation with SAS pilots and was neither intended nor suitable for helicopter operations.
- SAR operations. The exact knowledge of the last known position in case of a lost aircraft combined with exact knowledge of the rescue team's own position would provide new possibilities for SAR operations.

4.2.6.7 Future Plans

Since the Danish Civil Aviation Administration (DCAA) began its involvement in the NEAN/NEAP projects in 1996, several initiatives have been taken to further investigate the use of ADS-B supported by STDMA/VDL Mode 4.

- DCAA has initiated the North Atlantic ADS-B Network project (NAAN) for conducting further studies of STDMA/VDL Mode 4 in the North Atlantic region, where harsh climatic conditions makes the deployment and maintenance of traditional surveillance equipment expensive. It is expected that up to nine reference stations will be distributed over Greenland, Iceland, The Faeroe Islands, United Kingdom, Ireland and Norway.
- DCAA is participating in NEAN Update Programme (NUP), which will follow up on the initial steps taken in NEAN.
- Future operational systems being specified by DCAA will consider ADS-B as an option.
- The future CNS concept is under consideration by the DCAA, and technologies like STDMA/VDL Mode 4 and ADS-B are being discussed.

4.2.7 Runway incursion monitoring

This application was developed by the SCAA.

4.2.7.1 Service description

4.2.7.1.1 Operational context

Unauthorised or unintentional entry onto runways and taxiways by aircraft and vehicles constitutes a serious threat to aviation safety. Hazardous conflict situations may develop between aircraft and airport ground vehicles in, for instance, snow clearing situations when several vehicles operate on, or close to an active runway. The threat is more critical when poor visibility conditions prevent the controllers in the control

tower (TWR) to visually monitor ground movements and aircraft on final approach. Busy airports are usually equipped with surface movement radar (SMR) allowing controllers to view the traffic on radar display in the TWR. However, an SMR is a major investment, and most airports still lack this equipment. Also, unlike modern radar systems, most SMR displays do not display the identity of aircraft targets, and there are no means for identifying vehicles. The lack of identity indications on the SMR, and the absence of alerts and other supporting functions, require the controller to closely monitor the traffic on the display screen and mentally associate the targets with aircraft and vehicle callsigns kept on paper strips. The SMR therefore requires constant attention and vigilance by the controller.

Previous trials have demonstrated that ADS-B based on STDMA/VDL Mode4 works equally well on the ground as in the air. The position accuracy offered by DGNSS is better than that of an SMR and the display is clean and not cluttered by echoes from buildings and other structures on the airport as is often the case with SMR. As ADS-B reports include the identity of the transmitting aircraft or vehicle, this information is included in the target representation on the TWR display. Whilst SMR only provides data to the controller, ADS-B reports are also received by aircraft and ground vehicles. These reports can be displayed to pilots and drivers to provide a much-improved awareness of nearby traffic. Moreover, the gap that normally exists between the terminal radar and SMR is not present in ADS-B, which constitutes a seamless system covering both the air and ground segments.

The high-level assumption is that ADS-B based on STDMA/VDL Mode 4, with appropriate functionality, could support a safety enhancing runway incursion prevention system.

4.2.7.1.2 NEAP application

The runway incursion (prevention) service tested in NEAP is based on ADS-B reports from appropriately equipped aircraft and airport vehicles being received by an STDMA/VDL Mode4 ground station at the Stockholm-Arlanda international airport and presented on a dedicated display in the TWR and participating vehicles. The *Runway Incursion Monitoring System (RIMS)*, developed for the NEAP test programme, included functions that enabled TWR controllers and vehicle drivers to be automatically alerted when a hazardous situation developed.

The test programme included the TWR and specially equipped airport vehicles. A flight inspection BE200 aircraft participated in test scenarios that involved airborne traffic. Other STDMA/VDL Mode4 equipped aircraft and vehicles served as “background traffic” that only played a passive role in the tests.

The test scenarios were designed to replicate potential airport conflict situations such as:

- vehicle too close to active runway as aircraft is landing,
- vehicle on runway as aircraft is taking off,
- aircraft still on runway as next aircraft is landing.

Alert conditions that apply to these and similar situations were developed. Alert conditions included *warning* when a conflict risk was present, and *alarm* when there was an actual conflict.

Through the ADS-B reports presented on the TWR display, the controller was able to monitor airport ground traffic, as well as air traffic in the immediate vicinity of the air-

port. Target representation included identity and a speed vector, allowing the controller to easily assess the movement. The controller was provided with a number of features designed to ease the monitoring of the traffic and the detection of conflicts. Display features included, for instance, a set of precise and detailed digital maps showing runways and taxiways with protected areas, stop bars and other relevant map details. In addition, the controller was provided with information on runway status (passive, active or busy), visibility conditions and currently used ATC procedures (Cat I or Cat II), as well as visual warnings and audible and visual alarms on potential runway incursion and conflict situations. The type of alert was a function of target data (such as speed, heading and altitude), current runway status and ATC procedures in use. For instance, a warning would be issued if a vehicle were inside a specified polygon covering the active runway and adjacent areas while an aircraft on final approach to the same runway was 1-2 NM from touchdown in Cat I conditions. An alarm would be issued if the vehicle were still within the polygon and the aircraft within 1 NM from touchdown. In Cat II conditions, the specified polygon for runway incursion was larger, and warning and alarm would be triggered 2-3 NM, and within 2 NM of the runway respectively. Alerts caused the labels of the conflicting targets to flash, and the tracks to be displayed in a different colour.

RIMS functionality also included a system component in one of the test vehicles. In order to minimise the occurrence of potential conflicts, audible and visual alerts warned the driver when penetrating specified boundaries or coming too close to aircraft on the ground. As for the controller, the alerts were dependent on runway status and ATC procedures applied. The second test vehicle, used to replicate a taxiing aircraft, was only equipped with an STDMA/VDL Mode4 transponder for generation of ADS-B reports. No alert functions were implemented in the participating aircraft.

RIMS is a *distributed system* in which the fixed and mobile components co-operate to provide the total system function.

4.2.7.1.3 Relevance to the gate-to-gate system

A runway incursion monitoring system is an ATM tool for enhanced monitoring and control of aircraft and ground vehicles on runways and taxiways and between such traffic and aircraft on final approach. RIMS therefore represents the first and last links in a gate-to-gate ATM system. One objective of NEAP is to show that this other components of a gate-to-gate concept can be provided in a seamless fashion by the STDMA/VDL Mode 4 technical platform.

4.2.7.1.4 Application-specific objectives

The following application-specific objectives were adopted for the tests:

- Evaluate the suitability of STDMA/VDL Mode 4 as the basis for a runway incursion monitoring system (RIMS).
- Evaluate the concept of a distributed RIMS.
- Develop and evaluate a common TWR-HMI platform for supporting implementation and evaluation of future RIMS functions.
- Demonstrate RIMS as a component of a gate-to-gate concept.

4.2.7.2 Assumptions

4.2.7.2.1 General

The expected benefits to be achieved from the services provided by RIMS were defined as:

- A single seamless system supports movements both on the ground and in the air.
- Coverage and accuracy enable the definition of very precise limits and thresholds.
- Possibility to filter out targets and define complex sets of conditions based on position, speed, heading, altitude and type of mobile unit (aircraft/vehicle).
- Automatic and secure identification and labelling of targets.
- Enhanced information on approaching aircraft.
- Total independence of weather conditions.
- Reduced radio traffic and hence controller workload.
- Minimum-delay alert functions both in the TWR and vehicles.
- Redundant system architecture.

These expected benefits served as the basis for *hypotheses*, or assumptions on expected results, which were to be accepted or rejected by the tests, and for defining a set of technical test items. The assumptions related to RIMS *technical system functions*, such as coverage and feasibility of the distributed system concept, and *operational benefits*, such as reduction of controller workload and improved ATC capacity in low visibility conditions. Technical test items related to the ability of the sensor and control system components to provide the necessary technical support for RIMS in terms of, for instance, update rate and time to alert. The latter tests focused on the analysis of recorded data, whereas questionnaires were used to accept or reject operational hypotheses.

The following paragraphs list the hypotheses and the method(s) used for accepting or rejecting each of them.

4.2.7.2.2 Function hypotheses

These tests related to the overall function of the system and are summarised in the following table.

System function or property	Tested mainly through
Seamless system *RIMS provides seamless surveillance of aircraft in final approach and landing phases*	*Technical data* *Analytical discussion*
Improved coverage *RIMS provides improved coverage compared to SMR.*	*Questionnaire* *Documentation*
Flexible and comprehensive set of rules *RIMS provides facilities for defining algorithms that cover all ATC procedures currently in use at Arlanda.*	*Questionnaire* *Documentation*
Automatic target identification *RIMS provides automatic target identification*	*Questionnaire* *Analytical discussion*
Enhanced information on approaching and landing aircraft: *RIMS provides enhanced information on approaching/landing aircraft*	*Questionnaire* *Analytical discussion*
Weather independence *RIMS is independent of weather and visibility conditions*	*Questionnaire* *Analytical discussion*

System function or property	Tested mainly through
Distributed implementation supported *STDMA/VDL Mode 4 supports a distributed implementation of RIMS*	*Technical data on control system performance*

Distributed system	
Distributed RIMS is technically feasible	*Technical data on control system performance*
Distributed RIMS reduces response times *D-RIMS reduces times to generate alerts compared to centralised RIMS (C-RIMS)*	*Technical data on control system performance*
Distributed RIMS improves position accuracy *D-RIMS improves the accuracy of position information*	*Technical data on sensor performance*
Distributed RIMS provides system redundancy *D-RIMS provides system redundancy*	*Technical data on control system performance*

4.2.7.2.3 Operational benefit hypotheses

Assumed operational benefit	**Tested mainly through**
Improved safety *RIMS based on STDMA/VDL Mode 4 will improve safety*	*Questionnaire* *Discussion*
Reduced controller workload *RIMS based on STDMA/VDL Mode 4 will reduce controller workload*	*Questionnaire* *Discussion*
Improved situation awareness *RIMS based on STDMA/VDL Mode 4 will improve the situation awareness for controllers*	*Questionnaire* *Discussion*
Improved capacity in low visibility procedures (LVP) conditions *A RIMS based on STDMA/VDL Mode 4 will improve capacity in LVP conditions*	*Questionnaire*

4.2.7.2.4 Sensor system performance test items

These tests addressed the performance of the STDMA/VDL Mode4 technical platform.

Sensor system parameter	Tested through
Position accuracy	*Technical data*
Update rate	*Technical data*
Coverage area	*Technical data*
Altitude coverage	*Technical data*
Approach coverage	*Technical data*

4.2.7.2.5 Control system performance test items

These tests addressed the operation of RIMS.

Control system parameter	**Tested through**
Probability of conflict situation detection	*Technical data*
Probability of false conflict detection (integrity)	*Technical data*
Response time	*Technical data*

4.2.7.3 Test set-up

4.2.7.3.1 General

The realisation of these tests required the installation of new equipment and functions in the TWR and in the two participating airport ground vehicles. One aircraft, normally used for flight inspection, took part in test scenarios involving air traffic. Other STDMA/VDL Mode4 equipped aircraft and ground vehicles played a passive part as “background traffic”.

The runway incursion monitoring system (RIMS) was developed for the purpose of NEAP testing by PIXUS Consulting AB of Sweden, in close co-operation with the SCAA.

4.2.7.3.2 Airborne equipment

The flight inspection aircraft, a BE200, is fitted with an STDMA/VDL Mode4 transponder as part of its normal equipage, and no additional equipment or functionality was required. No alert functions were implemented in the aircraft.

4.2.7.3.3 Ground equipment

RIMS contained the following subsystems and system functions:

- A TWR-HMI (human-machine interface), providing the controller with a view of the airport and STDMA/VDL Mode4 equipped aircraft and vehicles, and audible and visual alerts.
- A mobile system, providing alerts to the vehicle driver on a portable PC. D-RIMS also logged and time-stamped alerts for post-processing.
- An Alert Condition Definition (ACD) tool, allowing definition of combinations of alert conditions.
- An “engine” generating alerts based on conditions defined by means of the ACD-tool and received ADS-B reports.

To support a distributed architecture, the “engine” and the database of alert conditions were designed as separate system components, enabling portability to external systems. In RIMS, these components were used both by the TWR-HMI and mobile system.

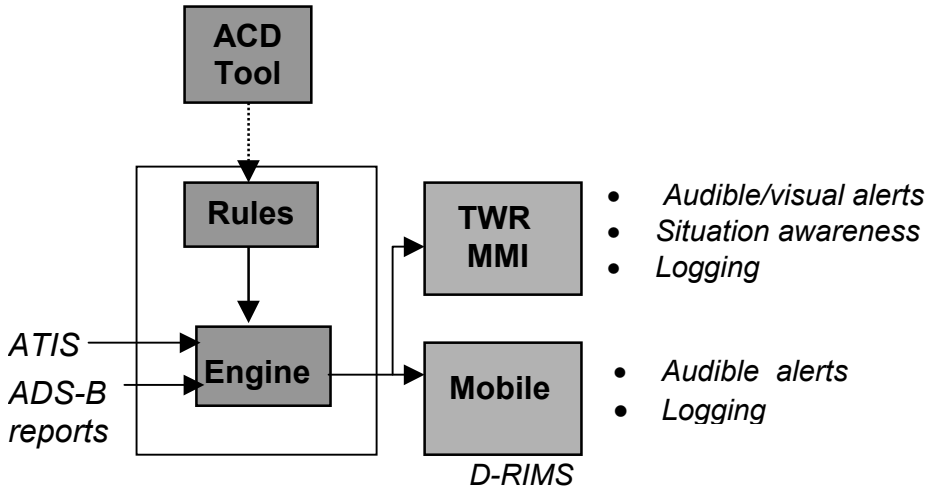


Figure 4.2.7.3.3 - RIMS system architecture

TWR HMI

The development of the TWR-HMI involved a substantial software upgrade of the existing radar processing unit (RPU), used for presentation of ADS-B reports. The RIMS display picture included an inset (window) showing the approach areas, allowing the controller to view both air and ground movements simultaneously and a seamless fashion. HMI features also included very detailed maps, indication of runway status (passive, active or busy) and audible and visual alerts.

Mobile system

The mobile subsystem, designated D-RIMS (distributed RIMS), was installed on a laptop. It included the alert generation engine and the alert condition file created by means of the ACD tool. Own position, ADS-B reports from other STDMA/VDL Mode4 equipped users and alerts were recorded and time stamped. Audible and visual alerts were presented to the driver. The second ground vehicle was only fitted with an STDMA/VDL Mode4 transponder for generation of ADS-B reports. This vehicle was used in some test scenarios to replicate a taxiing aircraft.

ACD tool

The ACD tool enabled the definition of detailed alert conditions based on:

- position, heading, altitude and speed of targets,
- sets of ATC procedures (different procedures apply to Cat I and Cat II conditions).

Definition of “macros” and “high level objects” such as *aircraft_on_runway* was supported. The algorithms created by means of the ACD tool were condensed into a text file, which could be read by the alert generation “engine”. The ACD tool was installed on the RPU hardware in the TWR.

"Engine"

The "engine" generated alerts (warning and alarms) based on the ADS-B reports and information in the alert condition file created through the ACD tool. Information on the "formal" runway status (active/passive) and currently applied set of ATC procedures (Cat I or Cat II) was intended to be optionally obtained through an interface to the ATIS system, but this function was not implemented as planned and was replaced by manual input only. "Busy" runway status was determined by presence of aircraft or vehicle on, or close to the runway. The engine fed the TWR-HMI with the current runway status.

4.2.7.4 Testing and evaluation

4.2.7.4.1 Test environment

Stockholm-Arlanda airport has two intersecting runways (RWY), 01/19 and 08/26. Work has commenced on a third runway parallel with 01/19. A new control tower will be built to enable controllers to have full vision over all three runways.

Cat II ILS approach is available to runways 01 and 19, whereas RWY 26 is only fitted with a Cat I ILS. For noise abatement reasons, runway 08 is only used for departures and runway 26 only for landings unless otherwise required by wind and runway conditions.

The monitoring and control of landing and taxiing aircraft and vehicles on runways and taxiways in visual conditions is usually straightforward, but the complexity increases significantly during snow conditions when a large number of snow clearing vehicles operate on the runways and taxiways. The complexity also increases in Cat II conditions when a specific set of ATC procedures are in force, impacting on, for instance, the minimum allowed distances between aircraft and between aircraft and vehicles and a busy runway.

Arlanda TWR is fitted with an SMR, allowing controllers to view traffic in conditions when visual control cannot be maintained. The SMR does not provide target identification, and does not cover the final approach areas.

An STDMA/VDL Mode4 ground station is installed at Arlanda, and tests and demonstrations of various applications have been ongoing for some years. Dual VHF installations including a repeater station provides excellent ADS-B coverage of the airport and approach areas. In order to increase safety and efficiency of the snow clearing operations, a project has was launched in early 1998 to equip some 25 vehicles engaged in such operations with an STDMA/VDL Mode4 transponder (and some with a display as well). This system allows the tower controller to view, on a display in the TWR, the location of all units and their identity. The system is also very useful for co-ordinating the operations on a tactical level by the field team-leader and on a strategic level by the "snow co-ordinator". Both have a display providing a view of the airport, map features and targets with identity based on ADS-B reports from STDMA/VDL Mode4 equipped aircraft and vehicles.

Most of the scenarios developed for testing of the RIMS in NEAP were based on realistic conflict situations using the runway and taxiway system at Arlanda as the test scene.

As only dedicated vehicles and aircraft were used, it was possible to control the test scenarios in detail. However, ADS-B reports from revenue SAS STDMA/VDL Mode4 equipped aircraft were used in some tests.

4.2.7.4.2 *Scientific approach*

The test methodology included the collection and evaluation of *technical data*, such as recorded and time-stamped ADS-B reports and alerts in TWR and one vehicle, and *subjective data*, i.e. opinions expressed by controllers in response to questionnaires. Some hypotheses had to be tested by non-technical analysis, or *discussion*.

Scenarios were developed as the basis for collection of technical data to be post-processed and analysed with regard to STDMA/VDL Mode4 system performance (i.e. position accuracy, update rate) and RIMS performance (i.e. probability of conflict detection and time to alert). Most scenarios were designed to replicate conflicts between aircraft and ground vehicles and between two aircraft, both airborne and on ground. Other scenarios focused on the penetration by the test vehicle of a specified protected area and the accuracy of the position reports by a moving vehicle in different parts of the airport.

One set of scenarios was specifically designed to serve as the basis for assessment by controllers and addressed many different conflict situations. Such assessment was made by *questionnaires*, which addressed operational aspects of individual RIMS functions and the usefulness of the system. The completed questionnaires were processed and used to draw conclusions regarding operational benefits. In many cases, the completed questionnaires reflected not only the function of RIMS with regard to the set of recorded conflicts, but the experience of the system over a longer period when the system was up and running in the TWR.

4.2.7.4.3 Test realisation

After development and implementation of RIMS and the development of the test scenarios, the actual tests were conducted between August and October 1998. Evaluation of the technical and operational aspects of RIMS was completed in December 1998.

Scenario testing involved the TWR, two airport vehicles, and a BE200 flight inspection aircraft. One of the vehicles was equipped with D-RIMS. The second vehicle was equipped with an STDMA/VDL Mode4 transponder, and was used to replicate an STDMA/VDL Mode4 equipped aircraft in some of the scenarios.

ADS-B reports and data on alerts were logged both in the TWR (C-RIMS) and in the C-RIMS equipped vehicle. All data was time-stamped. The dual collection of data allowed comparisons to be made with regard to a distributed system.

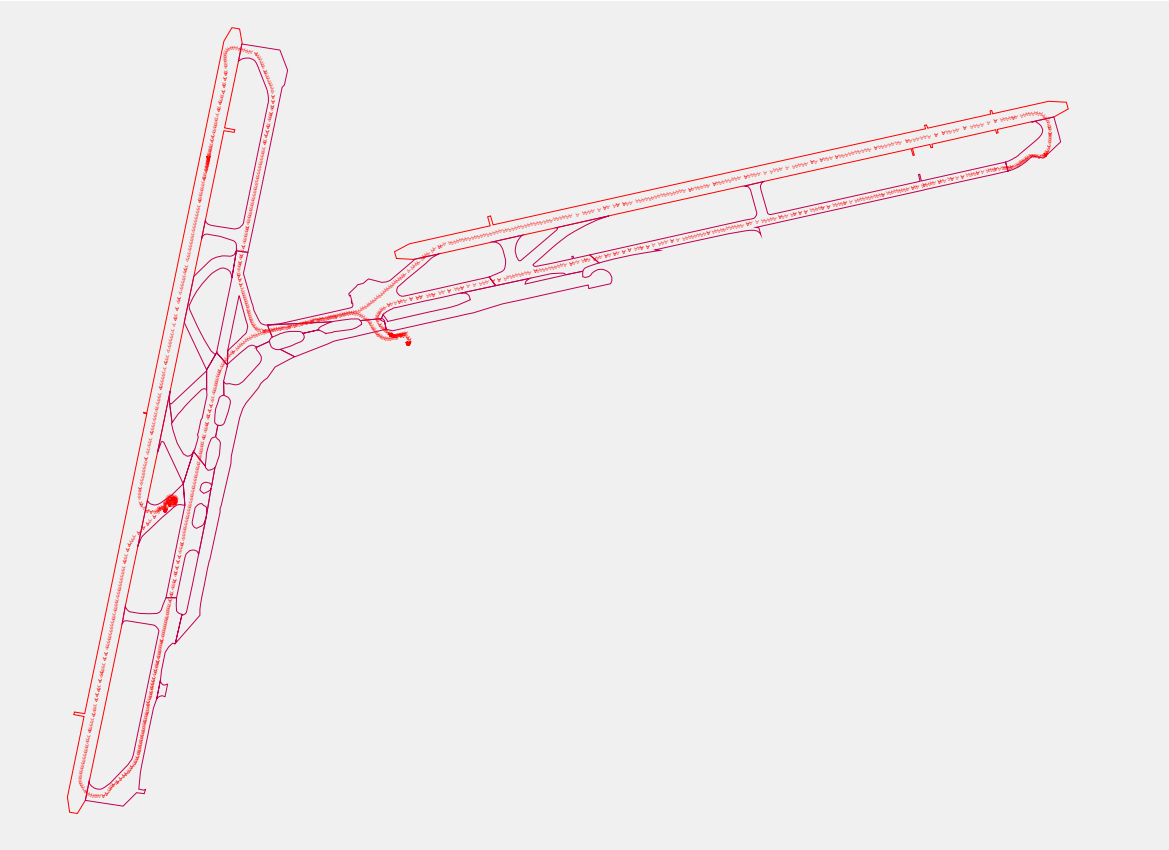


Figure 4.2.7.4.3 - Track of the test vehicle in one of the test scenarios. The ADS-B position reports were logged on the mobile transponder (own position).

One set of scenarios was based on recorded ADS-B data and addressed many different conflict situations. These scenarios were shown on the TWR HMI to groups of controllers who were afterwards asked to fill out a questionnaire that addressed various operational aspects with regard to safety, workload, situation awareness, and low visibility procedures. The controllers were also invited to give general observations and comments on individual RIMS functions and the usefulness of the system.

4.2.7.5 Results and conclusions

4.2.7.5.1 Principal results and conclusions

The following bullet points summarise the principal results and conclusions. Comments are provided in subsequent paragraphs.

- All assumptions on system functions and properties were accepted, with the exception of the hypothesis on *Flexible and comprehensive set of rules.* That function is addressed below.
- All assumptions on expected operational benefits were accepted.
- It is possible to realise, through relatively limited technical and economic means, a powerful RIMS based on ADS-B and the STDMA/VDL Mode 4 technical platform. For full benefits, however, both aircraft and ground vehicles should be transponder equipped.
- Full operational implementation of a distributed system (i.e. with C-RIMS and D-RIMS components) would offer significant benefits in terms of enhanced safety and improved situation awareness for controllers, vehicle drivers and pilots at

Arlanda. Obviously, such benefits would be dependent on the number of appropriately equipped vehicles and aircraft.

- Significant safety benefits would also be achieved from the operational implementation of only a C-RIMS (i.e. alerts would be provided to the controller but not to mobile users) provided that the mobile users are transponder equipped.

4.2.7.5.2 Comments and observations

Overall system function

As expected, tests with regard to coverage, automatic target identification, and enhanced information on landing/approaching aircraft fulfilled relevant criteria. Coverage of airport and approach areas fulfilled ICAO requirements for a seamless transition.

However, the syntax used for defining the the detailed algorithms for the ATC procedures did not cover all situations, and could not be successfully modified during the course of the trials. The ATC procedures were used in the definition of alert conditions by means of the ACD tool. In some cases, alert "oscillations" occurred as a result of condition definitions using relative parameters. The corresponding hypothesis was rejected as a consequence of the demonstrated problems.

With regard to STDMA/VDL Mode 4 support of a distributed implementation of RIMS, the measured throughput of ADS-B messages between aircraft and the base station and between aircraft and vehicle was 98% or better in both cases. This confirms the feasibility of a distributed concept. Other assumptions addressing the distributed system concept were also accepted.

Responses to questionnaires

The controllers´ general opinion of the RIMS was overwhelmingly positive, with "yes" answers reaching 100% on high-level questions, such as;

- *Do you think that an operational implementation of RIMS could improve the safety in the runway areas?*
- *Do you think that RIMS improves the situation awareness?*

A lower percentage, 67%, of the controllers believed that RIMS could reduce the workload in the TWR. Those who believed so were appreciative of the complete system (100%), the seamless display of airborne and ground traffic (88%) and the automatic alerts (100%). 91% believed that RIMS could improve the capacity during low visibility operations.

Questions on aspects of possible future control techniques, such as…

- *Do you think vehicles could be allowed to use parts of the taxiway system under own supervision if they were equipped with a D-RIMS system?*
- *Do you think RIMS could reduce the voice-com traffic between controllers and the vehicle drivers?* and
- *Could RIMS support a "strip-less TWR"?*

…resulted in 65, 48 and 89% "yes" answers respectively. 86% believed that the human-machine interface worked properly, whereas a minority 15% believed *that "the system could cover all procedures and [conflict] situations".*

Verbal comments indicated that an operational RIMS would be particularly useful in heavy traffic, snow clearance situations, at night, in reduced visibility situations, “when there are many vehicles on the runway and one is forgotten”, “when a vehicle is repeatedly entering and leaving the runway and you get out of synch” and as a backup and safety net.

Sensor system performance

These assumptions related to the performance of the STDMA/VDL Mode4 technical platform. Post-processing of recorded data gave the following results:

Position accuracy (lateral):	*in the order of 2 m (95%)*
Update rate:	*1.7 sec (95%)*
Coverage; runways, taxiways:	*report throughput better than 97.8% in all locations*
Coverage; approach area up to 500 feet altitude:	*report throughput from aircraft better than 98.8% both to base station and vehicle*
Altitude coverage:	*same as above*

The update rate does not comply with ICAO provisional requirements, which is 1 sec. The other performance parameters comply with these requirements.

Control system performance

These assumptions related to the operation of RIMS. Analysis of recorded data showed that the probability of conflict detection was 100%, and the probability of false conflict detection was zero. However, as noted above, algorithms that covered the entire set of ATC procedures could not be defined, and the figure therefore applies to conflict situations actually used in the system.

The mean time to alert, i.e. the elapsed time between the occurrence of the conflict and the alert being displayed in the TWR and vehicle was less than 1 second. The delay was greater in the TWR, probably due to fluctuations of the load on the server and LAN.

4.2.7.6 Recommendations for system improvements

It is recommended that further studies be made on the following topics:

- “Oscillating alerts”. These studies should preferably be based on transponders incorporating a GNSS receiver with higher update rate and accuracy.
- Conflict situations. Further analysis of what conflict situations could be detected, and the precise conditions that apply to those situations.
- Integration between RIMS and SMR.

4.2.7.7 Future plans

An analysis of the feasibility to certify and approve RIMS for operational use will be initiated. Industry will be encouraged to participate and take the lead in the development of a RIMS based on ADS-B technology.

Operational use of ADS-B to support monitoring of ground traffic is being implemented at Stockholm-Arlanda. A pre-operational system is being tested under operational conditions during the 1998-99 winter season. The system, known as SNOWCARD, is mainly intended to facilitate monitoring in the TWR of vehicle traffic during snow clearing operations when often a large number of vehicles operate on

runways, taxiways and aprons under limited visibility conditions. The system is also being used for tactical and strategic co-ordination between the snow clearing co-ordination facility and the on-field team leader. Management of operations is facilitated by the presence of a situation display in the co-ordination facility and team leader's vehicle, allowing the location of all units to be continuously monitored by both parties.

It is planned to upgrade to VDL Mode 4 equipment complying with ICAO standards in the year 2000. In addition to aircraft equipment and ground stations, such an upgrade will also include equipment in ground vehicles at Arlanda and elsewhere.

5. CERTIFICATION ROAD MAP

Certification issues were raised as an essential element of NEAP in order to identify and resolve potential regulatory problems that might impede or delay bringing NEAP applications to the market. The Certification study was carried out as a relatively small investigation, rather than attempting to solve all the certification issues that might arise in the very wide-ranging nature of the NEAP applications. Not all NEAP applications were covered and those that are covered, are not addressed in great detail. A more comprehensive treatment will be necessary in other programmes, such as the NEAN Update Programme (NUP).

The following NEAP Applications are covered by this report:

- *Station Keeping* using Airborne Situation Awareness – CDTI.
- *ATIS Broadcast* at European Airports.
- *RNP Approach* using a combined ADS-B/DGPS broadcast ground-station.

The Certification process has been analysed from a European perspective, assuming that the applications will be certified in Europe before the US. The study outlines:

- The content of a certification application.
- Potential certification owners.
- Identification of required certification bodies.
- Possible road map for certification of applications.
- Potential problems.
- Required time for certification.
- Proposed EC activities supporting European certification of these applications.

A legal survey was carried out to identify European legislation supporting certification.

5.1 Analysis: General overview

NEAP Certification studies illustrate fundamental problems inhibiting EU airlines and airports capitalising on the benefits of CNS/ATM technologies. These include the:

- Fragmented European Regulatory Framework
- Lack of enforcement and confusion over the status of existing EU legislation
- Critical dependence of European Regulation on the FAA and US Industry bodies
- Predominance of US influence at ICAO
- Dominant position of US manufacturing interests

NEAP Application projects also show that Europe is able to develop cost/effective solutions for global capacity and safety issues. The exploitation of these solutions is constrained by the limitations of European Regulations, affecting and limiting their

access to the market. Specifically, by a regulatory system that assumes that such solutions will emanate from the US and seems profoundly unable to respond to European developed technology.

This situation is further exacerbated by the inability of the regulatory authorities to devise, co-ordinate and implement regulatory instruments to enable the wide-scale introduction of CNS/ATM technologies and solutions. This has been illustrated in many other areas, including recent European “Mandates” e.g. ACAS/TCAS, 8.33kHz radio etc. - where implementation of these mandates has been impeded by the lack of FAA TSOs. This demonstrates the critical European dependence on US regulations and condemns Europe to follow, rather than lead.

The reactive nature of regulation has lead to its failure to grasp key issues, including:

- The uncertain status of GPS, allowing partial use - but well short of full exploitation.
- Need for Europe-wide effort to support exploitation of CNS/ATM solutions.
- Poor regulatory support for digital and software related technologies.
- The vested interests of Service Providers.
- The confusion between technological preferences and regulatory requirements.
- The lack of effective standardisation support.

5.2 Legal issues

A survey of relevant European legislation shows that appropriate legislation does exist to support the certification of aircraft and avionics and ATM applications. However, a key problem is the lack of implementation and enforcement of this legislation and the uncertain status of many of its elements. The two most significant items are EU Council Regulation 3922/91/EEC for aircraft and EC Council Directive 93/65/EEC for ATM systems and equipment.

5.2.1 EU Council Regulation 3922/91/EEC: Aircraft and Avionics

EU Council Regulation 3922/91/EEC adopts Joint Aviation Requirements and makes them mandatory on member States. It sets out the technical requirements and administrative procedures to be applied to aircraft and aircraft products to ensure their free movement in the market. It is directly binding on member States. These requirements cover the design, manufacture, maintenance and operation of aircraft and the persons and organisations involved in those tasks. Some JARs are still under development and are to be notified to the Commission for inclusion in the Council Regulation when complete.

Currently, it appears that the member States and the JAA believe that this Council Regulation is not presently legally effective as, apart from JAR 145, none of the JAR codes have been translated into the "11 official languages". Although it is debatable whether such translation is actually required (it is not required for any other Technical Regulations), this has effectively stalled the process of adopting JARs - making the working of this Directive unsatisfactory. In the author’s opinion, only the *title* of a regulation must be published in the 11 versions of the European journal - not the text.

In addition to the above, the legal status of many of the 'standards' used to certify individual products, is even less clear. These 'standards' are at the end of a long chain of JARS, AMJs (acceptable means of compliance), JTSOs (Joint Technical Standards Orders) which in turn, refer in general terms to other 'standards' such as RTCA or Eurocae documents. Many of these indirectly referred RTCA documents are of a general nature, which can lead to significant variations in interpretation. It is surpris-

ing, given the adoption of the JAR Codes, that an effort has not been made to adopt these technical standards into EU legislation, e.g. as European Standards.

Little work is currently being done to clarify and resolve this unsatisfactory position. It may be that in the medium to long term, this situation may be resolved by the creation of the European Aviation Safety Authority (EASA). However, that leaves a long and significant period during which there will be many technical and operational changes in aviation, for which the regulatory environment in Europe will be quite unsatisfactory. This will result in significant economic disadvantage for Europe, which may be potentially damaging to the capacity and efficiency of the Air Traffic System and to European manufacturing industry.

5.2.2 Council Directive 93/65/EEC: The ATM Directive

Council Directive 93/65/EEC is intended to hasten the harmonisation process in Europe in the field of Air Traffic Management (ATM), to enable competition and the free movement of ATM equipment. In particular, the Directive allows the Commission to adopt 'Eurocontrol Standards' and technical specifications into Community law, making them mandatory on member States. Each State is responsible for implementing legislation and identifying an enforcement authority. An initial list of Eurocontrol Standards is given in the Annex to the Directive. The Directive also permits the EC to issue Mandates to the official Standardisation Bodies to develop European Standards complementary to Eurocontrol Standards.

There has been very limited progress in the development and adoption of Eurocontrol Standards. Benefits have been even less tangible. Eurocontrol Standards have not been subject to 'open development' and wider industry input to their development has been very limited. Significantly, little effort has been made to develop European Standards complementary to the Eurocontrol Standards – implying that European industry may be losing the procurement benefits to be gained and that little success has been achieved in opening this market.

5.2.3 Other legislation

5.2.3.1 Council Regulation 83/189/EEC: Technical Standards and Regulations

Council Regulation 83/189/EEC lays down the procedure for the notification by States of National Standards to the European Commission and to the European Standards Institutions. It requires member States to notify the European Commission of new Standards and gives the Commission the power to take action if there is a risk of barriers being created, including the power to request the European Standards Institutions to develop a European Standard within a given time limit. This Council Directive is fundamental in the field of Standardisation and is used as the basis for developing an open market between member States, by the removal of technical barriers to trade caused by individual State's technical regulations. In this sense, this Regulation can be considered as part of the foundation for much of EU policy.

5.2.3.2 Council Decision 93/465/EEC: The Module Directive

Council Decision 93/465/EEC specifies the generic procedures for conformity assessment to be applied across all technical harmonisation Directives. In essence, it details the different procedures that may be used in conformity assessment from self certification through to third party Type Approval. It lays out the roles, procedures and guidelines to be applied by Notified Bodies. The actual text consists of only two short articles, the main body being the annexes which specify the 8 conformity as-

sessment modules. Each module specifies an 'approval procedure', with different levels of assurance, testing, proof etc. The relationship between manufacturer and notified bodies is clearly specified.

This Directive provides the framework processes and procedures to be applied for the certification in all industry sectors, including Aeronautical equipments, systems and services.

5.2.4 Summary of legal survey

EU legislation should set out the framework in which equipment, systems and services can be certified. Yet this legislation is disputed by the member States and not enforced by the EC, leading to uncertainty and confusion. The result of this legal confusion, is that member States apply a mixture of JARS and National legislation in certification, with no uniform interpretation of requirements. Furthermore, the process still relies critically on regulations and standards developed in the US, with little corresponding standardisation machinery in Europe to support the certification of European CNS/ATM technologies and solutions. It is also clear that the Public Procurement problems endemic to this market, have yet to be solved.

- Europe is broadly suffering from “regulatory paralysis”.

5.3 Certification status of NEAP applications

NEAP applications are currently limited in their operational potential by the “No Hazard/No Credit” certification given to the GNSS Transponder and the difficulty of obtaining certification to a higher operational capability e.g. for Communication, Navigation and Surveillance functions. The current regulatory structure leaves this as a National function, but most National Authorities are unwilling to move forward without International consensus. However, no framework exists to establish such consensus, other than that embodied in organisations such as the FAA, ARINC and the RTCA. European bodies such as the JAA and Eurocae are a pale shadow in comparison.

As an example, Lufthansa has worked with its National Authority, the LBA, to obtain operational certification for applications such as FMS approaches, initially as ‘company only’ approvals. Lufthansa has been obliged to follow a careful step-by-step path to achieve its goals. Lufthansa has had the benefit of the tacit support of Airbus, and been able to base FMS approaches on the existing certification of the navigational capabilities of its aircraft and Flight Management System (FMS).

However, obtaining certification for the integration of the GNSS transponder with the FMS and EFIS (critical for operational approval of safety related functions) within the current regulatory framework, can only occur with the active co-operation and commitment of the Airframe Manufacturers (e.g. Airbus and Boeing). This means that, not only do airlines have to be convinced of the benefits, but it is also necessary to convince the Airframe manufacturers that it is in their commercial and business interests too. Separate business cases have to be made for new and retrofit aircraft respectively.

5.3.1 Station keeping using airborne situation awareness – CDTI

Two situation awareness services were investigated by Lufthansa:

- On-Ground Situation Awareness/Taxi Guidance
- In-Flight (En-route) Situation Awareness.

Only the in-flight aspects are addressed below.

Lufthansa's rationale for this investigations was given briefly as: 'The increasing number of aircraft and their use of the limited availability of airspace as well as airport runways, taxiways and gate positions are a growing concern for airlines. Therefore it becomes increasingly important to make best use of available resources. Establishment of an integrated planning from gate-to-gate will be a major challenge for all participating parties'.
The Scope and Objective of this task within NEAP is given as the improvement of pilot's in-flight situation awareness with the aid of Cockpit Display of Traffic Information (CDTI). This task takes advantage of the fact that today's aircraft have a very precise knowledge of their present position as well as their intentions - much more accurately than other aircraft or ground systems could ever calculate or predict. Thus the distribution of this data via ADS-B, will allow better surveillance and improved conflict detection by all suitably equipped aircraft - with strategic (conflict) solutions, at long range, as the goal.

Station keeping applications require careful clarification of the role of the CDTI in monitoring separations between aircraft, careful drafting of the Flight Manual and appropriate crew training. It is closely related to Airborne Separation Assurance functions. To date, functions such as Collision Avoidance and Terrain Warnings have been provided as standalone functions and have not been fully integrated into the aircraft – despite the need for non-conflicting cockpit guidance to pilots. Station keeping can also be provided as a standalone function. Indeed, this may be desirable in order to achieve short-term benefits in older aircraft. It can also be seen as an initial step towards a fully integrated solution in the longer term.

5.3.1.1 FMS/EFIS integration

To provide such integration requires the extension of the functionality of the FMS and appropriate interfaces to both the FMS and EFIS. This ideally requires an *Operational Concept* to enable proper definition of requirements. The co-operation of aircraft and FMS/EFIS manufacturers is essential. Necessarily, some reluctance on the part of proprietary manufacturers is to be expected due to their direct and vested interest in the result. Due to the effort required to achieve integration, the operational concept will have to accommodate a wider range of functions than that for simple Station-Keeping e.g. Conflict Negotiation, In-Trail Climbs and Approach and Landing.

5.3.1.2 The CDTI vs RDP vs visual

The CDTI offers the potential for sophisticated monitoring of aircraft, due to the availability of real-time ADS-B data via VDL Mode 4. Ground ATC displays used for this function employ lower resolution displays, often with unreliable and less frequent radar data, (compared with that potentially available from VDLmode4/ADS-B) to provide separations to under 3 nautical miles longitudinal separation. Radar displays are also relatively 'dumb' – concentrating on signal processing and target identification functions. Indeed, radar separations are performed purely by visual estimation by controllers using such traffic display systems. More sophisticated Short Term Conflict Alert (STCA) functions are only just being developed (but still rely on relatively imperfect data).

Equally, pilots are permitted to maintain visual separation from other aircraft, in circumstances which may involve significant visual 'approximation' (e.g. distances, relative speeds, descent rates etc.). Thus, in principle, station-keeping using CDTI

should be achievable, subject to concerns regarding pilot workload and the respective responsibilities of the pilot and ATC. This needs to be tested. However, regulatory authorities are likely to be reluctant and slow to directly certify this capability. Much of this reluctance relates to liability issues. Pilots may already be (informally) using TCAS displays for this purpose.

A key question is the interface to the FMS and its role in monitoring separations. This is important for many reasons e.g. the need to present consistent information to the pilot.

Currently, responsibility for aircraft separation lies with ATC authorities in controlled airspace. Outside controlled airspace or in airspace without adequate surveillance services, separations have been increased to minimise risk. This increased separation reduces airspace capacity and increases airline costs. Transferring the function to the cockpit introduces additional potential liabilities to airlines and aircraft manufacturers. Thus airlines, manufacturers and regulatory authorities must carry out several independent but related calculations:

a) They must ensure that the potential increase in risk from reduced separations is, at least, offset by the calculated improvements in the position of both aircraft and assurance and monitoring of their relative separation.
b) The increased liability from the transfer of the separation function to the cockpit is met by the commercial benefits of increased capacity and efficiency.
c) That Crew Resource Management is not adversely affected.

There is a need to establish a JAA Working Group to address these aircraft functions in order to develop consensus in the User community and establish flight crew “best practice”. The development of appropriate electronic Flight Rules (EFR) is desirable and a debate is required about the designation of airspace to enable benefits to be achieved.

The station-keeping application raises key issues for certification, including:

- Integration of VDL Mode 4 in the aircraft.
- CDTI interfaces and certification.
- Where does the station keeping function ‘live’?
- Transition issues e.g. uplinking of radar data.
- Designation of Airspace e.g. EFR

Certification of this function will depend on aircraft equipage. This may imply operational limitations, but does not prevent exploitation. Straightforward safety benefits include:

- Improved pilot orientation and situation awareness.
- Additional and redundant conflict monitoring.
- Potential for improved and more accurate conflict monitoring.
- Improved range leading to improved resolution times.
- Transition strategy available with up-linked radar data.
- Reduced ATC workload.

5.3.2 ATIS Broadcast at European airports

The provision of ATIS is not specifically limited by the communication medium and is provided in many different ways at different airports in different countries. There are no obvious restrictions on the means of providing ATIS that affect this application. Thus providing ATIS via VDL Mode 4 should present no special difficulties or certification problems. Technically, the certification of ATIS is a National function, with requirements depending on the National legislation in place. Some States have little or no formal regulatory requirements in place at all – largely because ATIS is most often provided by the National Aviation Administration. It may be necessary to fill this legal 'gap' in some States.

Significant automation is possible e.g. with Meteorological ground-stations. Certification of Met equipment and their interfaces may be a market issue (requiring European Standards to overcome public procurement problems) and in certain cases (e.g. IRVR) a safety and certification issue.

However, the format and presentation of ATIS is an issue and would benefit by a common standard to ensure that data is presented correctly in the cockpit. Loss of ATIS is an operational issue, corruption or incorrect representation of ATIS may be a safety and certification issue.

- The development of a European Standard for ATIS as a VDL Mode 4 service, would seem sensible and would assist in the convergence of National practices.

ATIS Broadcast also provides a relatively simple and straightforward avenue to certify early standalone functions and also provides a platform to investigate integration and interfacing with the aircraft EFIS/FMS for some relatively non-critical functions.

Co-operation between European ATS providers on the provision and coverage of ATIS is essential.

5.3.3 IPV approach with combined ADS-B/DGPS broadcast ground station.

The potential benefits for IPV approach using a combination of ADS-B/DGNSS groundstation are very significant and could lead to dramatic changes in operations and costs at European airports. This particular NEAP application investigates the potential benefits of DGNSS Instrument Approach with vertical guidance at Angelholm airport in Sweden and also the benefits of direct routes between Swedish airports.

Certification of ground equipment in this trial, depended on the modification of FAA SCAT-I equipment requirements and RTCA specifications. This was done to:

- To provide a 'fast track' solution.
- To ease acceptance of the trials.

Certification requires, at least, the following components:

- Certification of the Ground Infrastructure
- Certification of Aircraft Equipment:
- Published changes to Airspace and Procedures, including phraseology
- Flight Inspection Requirements

However, CAT I landing system technical requirements can be clearly stated in terms of:

- Accuracy
- Integrity
- Reliability/Continuity
- Availability

The distribution of Flight Technical Errors then fully defines certification requirements. Current ICAO CAT I specifications tend to be technology dependent and even contain several inconsistencies (e.g. different reliability requirements for ILS and MLS) – rather than being expressed in RNP terms – this is a major obstacle for change. Some States even ban the use of software in Landing System design. In addition, there are many implicit requirements – which lead to misleading and incorrect technical assumptions at ICAO forums. This may be due to the fact that representation at ICAO is from Service Provider interests, rather than Flight Safety Authorities. Certification of DGNSS/RNP based approaches requires a re-statement of fundamental CAT I requirements.

For example, the ICAO GNSS Panel assumes that GNSS/DGNSS coverage is required to ground level in landing systems. This is not the case. CAT I requires the aircraft to be visual with the runway threshold at 200 feet and be positioned in a substantial 3D box to enable a manual landing by the pilot. (For passenger comfort, such positioning should (preferably) not require further manoeuvring by the pilot).

Certification of the aircraft capability requires certification of the design, components, installation and associated procedures including:

- Certification of the navigational capability of the transponder (i.e. certification of the GNSS receiver plus differential corrections and integrity monitoring).
- Certification of the data link.
- Certification of the display.
- Certification of the aircraft design installation.
- Certification of flight deck operational procedures.
- Crew training and experience.

Physical installation of equipment and aerials is unlikely to cause difficulty.

Some analysis is required to extract the fundamental requirements to support certification, but this is not a technically difficult task. Formal certification may depend on progress within the JAA and on aircraft manufacturer support (to develop aircraft installation and modification bulletins – in the absence of a TSO). Certainly, JAA involvement in practical trials are preferable.

- Equipment can be certified by the direct inclusion of European Standards for VDL Mode 4 in JTSOs specially drafted for this purpose (rather than waiting a very long time for FAA TSOs!).
- Although this process has not been attempted yet, it is a legally acceptable route to certification.

A relatively small number of co-operating National Flight Safety Authorities would be sufficient to achieve a common certification. This would be similar to the process which lead to the certification of ILS CAT I, II and III during the 1960's. Technically,

such certification must be accepted under the ICAO constitution by ICAO and its members – whether they support the particular technological solution or not.

5.4 Aircraft design considerations

There are several options for the installation of VDL Mode 4 in aircraft. These include:

- Standalone installation (i.e. no integration with FMS or EFIS)
- Integrated VDL Mode 4 installation
- VDL Mode 4 integration within MMR

Each of these options has practical advantages and disadvantages, depending on aircraft type, operational scenario, costs etc.

a) A standalone installation is easiest to achieve, but has practical drawbacks due to potential limitations in operational payback. However, this solution will yield short term benefits and may be the only practical option for older aircraft. It may also be the most practical and cost/effective solution, during the initial implementation period for VDL Mode 4 i.e. during the early period of exploitation of applications, when operational benefits may be limited by existing procedures.
b) An integrated solution (see diagram 5.4.a) offers the potential for high integrity applications including landing systems, airborne separation assurance and conflict detection and resolution. However, these applications require the active participation and commitment of the Airframe Manufacturers and will incur high costs for certification.

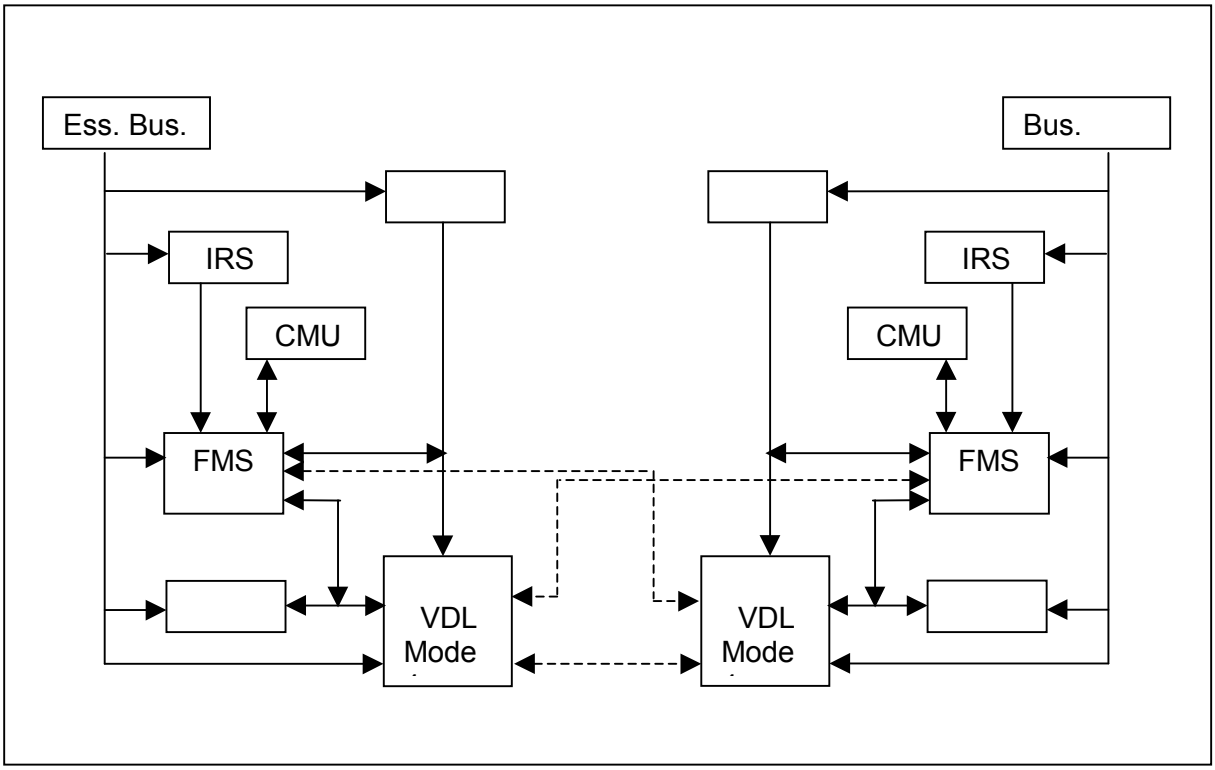


Diagram 5.4. a – Integrated VDL Mode 4 Transceiver

c) Integrating VDL Mode 4 into the MMR (see diagram 5.4.b) may prove to be a very attractive option for airlines who have opted for the MMR. Integration can be

achieved relatively easily as the interfaces to the MMR are already well defined, so avoiding some of the difficulties and costs of integrating VDL Mode 4 alone.

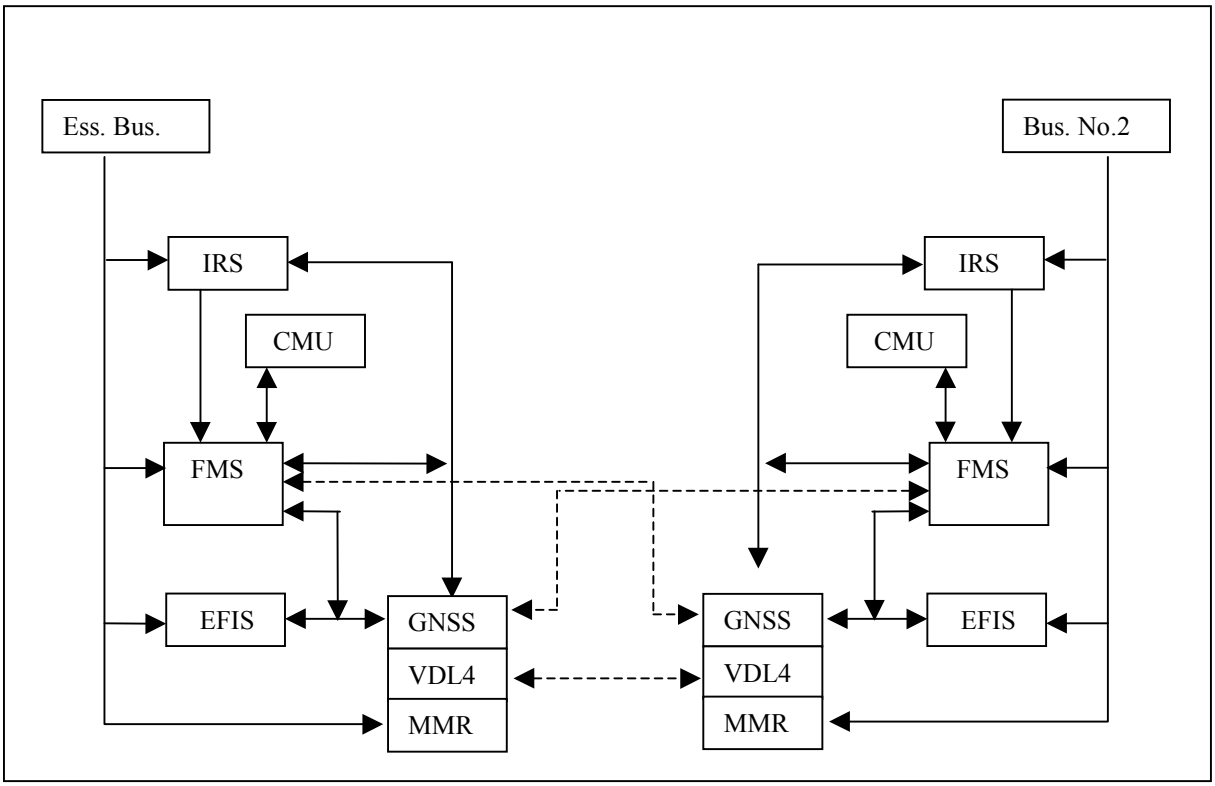


Diagram 5.4.b -- MMR Integrated VDL Mode 4 Transceiver.

5.5 Ground infrastructure design requirements

A corresponding redundant design is required for the ground equipment. In principle, it should be straightforward to achieve the necessary requirements for safety (i.e. performance, integrity, reliability and availability) and certify accordingly for the ground equipment. The safety requirements are defined by the application and can be calculated directly.

Current custom and practice assumes that ICAO will design ground equipment, yet ICAO material is actually only provided for guidance and is not mandatory. Common specifications are provided to assist interoperability between States, ensuring that aircraft equipment can operate globally and that safety standards are preserved. The development of de facto designs outside of is quite normal.

ICAO's fundamental task is in the definition of safety requirements – not in design or procurement. For key services such as CAT I landing systems, the technical safety requirements (as noted above) are already defined (whether for ILS, MLS or GNSS). A European developed technology need not wait for ICAO standards, but could develop ground-stations of its own design (perhaps standardised at ETSI) for certification by the respective National Authorities. European Standards could be offered "as is" to ICAO and its member States. Formal adoption by ICAO is not actually required.

A key factor in the construction of a Landing System Design, is the apportionment of Error Limits in the airborne and ground-side equipment. Traditional ILS designs,

made assumptions about the distribution of errors that continue to be propagated today. These assumptions related to power, weight, computational power, the performance of electronics available to aircraft and other factors that no longer hold true. This resulted in the major portion of the error budget being assigned to aircraft and minimal margins available on the ground. Advances in technology, mean that the distribution of errors can be made more equitably and without distortion. This, in turn means that the design and certification of GNSS Landing Systems based on the RNP concept (for example) can be made without some of the difficulties that plague ILS even today.

5.6 Required certification standards

In order for certification to take place, a considerable number of supporting standards are required. These range from ICAO SARPs for VDL Mode 4 (in progress) to aircraft design standards (typically developed by the RTCA/AEEC), to aircraft installation standards. Operation of the data-link also requires performance standards for the link and additional Network standards. The table below deals with the standards required for the aircraft alone.

A key point to note is the dependence on US organisations, such as the FAA, RTCA/AEEC etc. It is unreasonable to expect such support from the US and, if it were forthcoming, such support would certainly aim to benefit US industry first and foremost. Thus Europe needs to recognise the need to develop and promote its own standards.

Aircraft Architecture	**VDL Mode 4 Specification**	**Performance**	**Aircraft Design Implementation**	**Aircraft Installation**	**Operational Approval**
FORUM	**ICAO**	**ETSI**	**ARINC/AEEC**	**ARINC/AEEC**	**JAA National CAAs**
Output	Specification	Radio and Technical Performance	Certification Requirements	Installation Requirements	Operational Requirements
'Regulatory Instrument'	SARPs	European Standards	JAA adopt ACJ/AMJ	JAA adopt JTSO	JAA States adopt AIC
Related Aspects	RTCA, Eurocae MOPS & MASPS	Incorporation into JTSOs.	Airlines, Equipment and Aircraft OEMs	Aircraft and Equipment manufacturers	Applications, Flight Deck Procedures, Airlines, IFALPA, CAAs

Diagram 5.6 -- Overview of Required Standards and Legal Instruments.

5.7 Ground equipment standards

In addition to the above required standards, it will be necessary to develop standards covering the design, implementation, performance, installation, procedures and operation of the ground equipment. This implies a significant effort.

5.8 Developing a road map

In order to develop a roadmap for Certification, it is important to recognise the very large number of possible applications that are possible. In addition to this, must be added the analysis required to identify the certification levels required for each application. Safety critical applications may seem an attractive target to demonstrate maximum benefits but they are also the most difficult to achieve and require wide consensus on standards and operational procedures.

An essential step is to place the VDL Mode 4 applications within a possible implementation plan. From this plan can be synthesised the required standards and the operational evaluations that are required (matched with the appropriate cost/benefits). Strategies then have to be developed for achieving certification to obtain a maximum operational return on the investment made within the shortest feasible time. Certification of safety related applications should ideally be tied to new aircraft purchases as this reduces the cost and makes their absorption within the overall cost of the aircraft purchase more acceptable.

5.9 Certification costs

The Airframe Manufacturers role is critical to certification, as most of the work and the costs incurred to provide regulatory approval will be carried out by them (i.e. Airbus or Boeing). These certification costs can be VERY high and may exceed the cost of the installed equipment itself (certification costs can run into many millions). These costs are also tied to the commercial interests and objectives of the airframe manufacturer - a fact which has serious consequences in itself. An airline would have to consider the cost/benefits to their operation VERY carefully before making such a commitment.

A key issue in certification costs relates to the lifecycle of an aircraft. It is usually easier to certify technology on new aircraft prior to delivery, as the cost is relatively small compared to the overall cost of the aircraft (and can be recovered against the total operational life of the aircraft). Manufacturer support is readily available at this time – largely because the manufacturer has an incentive to assist, in order to secure the sale. However, certification of a retro-fit is another matter. The costs are generally much higher and must take account of factors such as down-time during retro-fit, but more significantly must be met from airline revenues – with a much shorter recovery cycle (typically two years) than that applied at purchase. These are critical factors in any Certification Plan.

As noted, certification costs are best absorbed in new aircraft purchases.

5.10 Benefits and certification strategy

The individual NEAP Applications have demonstrated the potential benefits of STDMA/VDL Mode 4 and the very wide range of applications possible. These benefits give very clear indications that safety, capacity and efficiency would be improved – and with lower infrastructure costs. These provide attractive arguments for the benefits of VDL Mode 4. Benefits can be gained from partial equipage i.e. with a mixed fleet of equipped and non-equipped aircraft. However, benefits are greater when significant numbers of aircraft are properly equipped. This is a common characteristic of most attempts to improve capacity in the Air Traffic Management System and has caused delay and disruption to many of Eurocontrol's recent programmes (e.g. 8.33kHz radio, ACAS/TCAS etc. have required mandatory equipage of all aircraft to work at all).

Mixed operations can have their pitfalls. Equally, many airlines would complain, if some aircraft were given priority or benefit over others merely due to their equipage. There is some justification for this view, as older aircraft are more difficult and more expensive to modify and update than new (and have a shorter remaining operational life to recover such costs). In general, airlines prefer mandatory carriage with fully certified equipment, backed up by clearly defined benefits. Certification must also make clear the operational qualifications and limitations of the equipment (i.e. what it may and may not be used for).

For maximum benefits to be derived from the implementation of VDL Mode 4 applications, it would be advisable to introduce certified applications in such a way as to accommodate equipped and non-equipped aircraft, and new certified aircraft alongside retrofit aircraft. This requires a *Certification strategy* that takes these factors into account as part of an implementation programme. Such a strategy has to make it possible for airlines to gain benefits if equipped, but not be penalised during normal operations if not equipped – providing a simple operational and financial incentive.

The strategy should include the safety classification of applications and the means to mitigate the certification overhead for safety related and safety critical applications.

Equally, it is essential that such a strategy not penalise older aircraft (which form the majority of the aircraft population) by beginning with applications that required a fully integrated solution i.e. the Certification Strategy must permit 'standalone' and retrofit solutions in the first instance. However, by setting out a programme of implementation and benefits, such a strategy would encourage airlines to procure fully integrated solutions in new aircraft purchases. Given the very long periods required for the implementation of any change programme in aviation, such a strategy could be developed as a natural consequence of proper planning and a co-ordinated implementation between Air Traffic Providers and Airlines – truly Collaborative ATM.

A Certification Cost/Benefit strategy has been outlined by the author.

5.11 Further certification work

A more detailed and properly funded study of the certification issues associated with VDL Mode 4 applications is required. This study is required in order to provide support and rapidly reduce the time to certification and operational implementation of VDL Mode 4 applications. An especially useful function that such a task would provide, is the co-ordination of certification of different applications which would reduce both the time and the cost of achieving individual certifications (e.g. co-ordinate air and ground component certification).

5.12 Summary

In general then, the support of the airframe manufacturer is essential and it is easier to certify in new aircraft than in old. Retrofit costs are higher than those for new aircraft. The benefits from VDL Mode 4 applications can be obtained, even with partial equipage - but the benefits improve for all, when a significant number of aircraft are equipped. In general, it is more difficult to justify certification costs for technologies that increase *long term capacity* as these do not always translate *into short term economic benefits.* An essential element of an implementation programme must include the development of a *Certification strategy* that takes account of fundamental cost/benefit issues without unduly penalising older aircraft or requiring fully integrated solutions in the transition phases of CNS/ATM development.

5.12.1 Recommendations

The following key recommendations are made:

- Urgent development of European Standards - to support VDL Mode 4 and its exploitation. These European Standards (ENs) should include:
  - radio performance characteristics, to support radio Type Approval.
  - data link performance characteristics.
  - Cockpit Display and Traffic Information (CDTI)
  - communication services and applications
  - network standards and performance requirements
- Incorporation of these European Standards for VDL Mode 4 into JAA Joint Technical Standards Orders (JTSOs) for certification and installation in aircraft.
- Development of JAA Operational Standards for ADS-B airborne applications.
- Safety analysis and classification of applications.
- Development of a more detailed Certification Study in the NEAN Update Programme (NUP).
- Development of a Certification Strategy for VDL Mode 4 to be incorporated as part of a general implementation strategy.
- The Certification Strategy should take account of cost/benefit issues.

6 CONSOLIDATED CONCLUSIONS AND RECOMMENDATIONS

Like the project objectives, the results and conclusions from NEAP should be viewed on two levels:

- The results and conclusions from the individual applications. These also included evaluation of new operational methods. These results and conclusions are stated in the application descriptions earlier in this document.
- The results and conclusions on a “system” level based on the results and conclusions from the applications level. These overall results and conclusions relate to the capability of a common technical platform, i.e. the STDMA/VDL Mode 4 technology, to support applications and services through-out all phases of flight (“gate-to-gate”) and across CNS domains. They also relate to conclusions drawn with regard to operations in a wider context.

Likewise, the recommendations made in this section below relate to the system level.

6.1 Conclusions

The following bullet points summarise the main findings on the system level. They are based on results from all applications evaluated within NEAP.

Operations:

- Surveillance, both for ATC and cockpit, provided by ADS-B is feasible in all phases of flight, including surface operations. It works equally well on different types of aircraft, helicopters and ground vehicles.
- ADS-B can support several applications currently being developed, e.g. Airborne Situation Awareness – AIRSAW and Advanced Surface Movement Guidance and Control – A-SMGCS.
- Operational use of ADS-B in airborne and ATC installations requires careful analysis of Human Machine Interface (HMI) issues.Capacity and safety can be improved in unserved airspace by using ADS-B.
- Capacity and safety can be improved in unserved airspace by using ADS-B.
- Uplink of radar based information i.e. TIS-B is needed when introducing ADS-B applications in the cockpit.
- The operational concept of ADS-B is not complete and needs to be developed further taking into account the actual and expected European ATM requirements in terms of capacity and safety.
- Operational implementation of STDMA/ VDL Mode 4 requires close co-ordination between ground service providers (CAA's).
- The aviation community currently lacks sufficient guidance on emerging CNS/ATM concepts.

Technical

- The combination of CNS broadcast services using a common technical platform is feasible. STDMA/VDL Mode 4 provides a suitable system solution.
- Organised broadcast services of DGNSS, TIS-B and FIS-B (e.g. ATIS) is feasible and potentially very spectrum efficient. Coverage is the same as for ADS-B.
- STDMA/VDL Mode 4 is a feasible system solution for a ground-based regional augmentation system (GRAS). The combination of a SCAT-1 ground station with an STDMA/VDL Mode 4 data link is potentially a viable technical solution for GRAS.
- STDMA/VDL Mode 4 message throughput is not fully satisfactory under all conditions and needs further investigation and validation.

6.2 Recommendations

The following bullet points summarise the high-level recommendations made:

- Introduction of ADS-B in Europe should be encouraged, especially in unserved airspace where near term benefits can be expected.
- Further development of ADS-B and associated applications requires close co-operation with airframe, ATC and airport system manufacturers. Discussions to that end should be initiated.
- Develop operational procedures related to the use of ADS-B in Europe
- Initiate research on human factors regarding cockpit layout of traffic information (CDTI).
- Initiate extensive cost/benefit analyses with respect to ADS-B and other broadcast applications.

- Analyse certification issues for ADS-B and other broadcast services. Promote the development of European Standards (e.g. ETSI), JAA Joint Technical Standards Orders (JTSOs) and JAA Operational Standards.
- Analyse certification issues for ADS-B and other broadcast services. Promote the development of European Standards (e.g. ETSI), JAA Joint Technical Standards Orders (JTSOs) and JAA Operational Standards.
- Analyse safety, certification and operational approval aspects of using a common data link standards and a mix of different applications.

6.3 Lessons learned

The NEAP project was conducted in a short time frame(15 months). Another aspects was the fairly broad scope of work including both technical and operational development. The results were achieved with a tremendous effort by the partners. Based on experiences from the project work a number of lessons learned can be mentioned:

- Proof of concept trials, like NEAP, can be set-up and completed on a short time scale.
- A clear operational concept is required as a basis for the operational and technical assessment.
- Time and effort must be spent on defining the applications and services as well as the potential benefits.
- Liaison with other activities in the field e.g. industry, Eurocontrol, EC-projects, US activities is important to avoid duplication of work.
- Avoid mixing of technical and operational evaluation methods.
- Differentiate between prototype systems and operational systems and the impact on the evaluation.
- It is important to have the support from both airlines, airports and ATC when conducting CNS/ATM projects.
- Support and commitment from manufacturer of air(avionics and airframer) and ground equipment is essential.