PHARE Demonstration 3: A contribution to the future of Air Traffic Management

Ir. Wim Post

National Aerospace Laboratory NLR, The Netherlands

Anthony Fokkerweg 2, 1059 CM / P.O. Box 90502, 1006 BM Amsterdam

Phone: +31-20.511.36.17 Fax: +31-20.511.32.10 E-mail: wimpost@nlr.nl

PROGRAMME FOR HARMONISED AIR TRAFFIC MANAGEMENT RESEARCH IN EUROCONTROL

PHARE

EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION, **EUROCONTROL**

Abstract

From 1989 till 1999 NLR has participated in the Programme for Harmonised Air Traffic Management (ATM) Research in EUROCONTROL (PHARE). From 1994 onwards the main activity was PHARE Demonstration 3 (PD/3), which was organised to further develop and demonstrate a future gate-to-gate ATM operational concept. With a target ATM system capacity of at least twice that of 1995 the concept was designed to be drastically different from today's. Essentially the concept is based on the exchange of aircraft trajectory information in support of more advanced planning. Through a flexible and dynamic process of planning aircraft trajectories up to 20 or 30 minutes ahead with high fidelity, potential conflicts can be avoided before they invoke workload for the tactical air traffic controller. Advanced ATM support tools use this high fidelity trajectory information to facilitate many tasks of air traffic controllers, like medium term conflict detection, conflict resolution, flight path conformance monitoring, co-ordination and negotiation and arrival and departure management. This paper describes the achievements of NLR within PHARE on the integration of arrival management and en-route traffic management. The advanced operational concept that was eventually demonstrated in November 1998 is elaborated and lessons learnt are presented.

Introduction

In Europe, the culminating delays in air traffic led around 1990 amongst others to the start of the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP, [2]). This programme was managed by EUROCONTROL on behalf of the European Civil Aviation Conference (ECAC). In this four phase programme the harmonisation and integration of existing European ATC systems would be followed by the definition of a European Air Traffic Management System (EATMS, [3,4]) that should provide Europe with the means to manage air traffic even by the year 2015. Also, around 1989, a number of European research establishments, assisted by the ATC authorities concerned, decided to combine their research efforts in a comprehensive effort to *'prove and demonstrate the feasibility and merits of future air-ground integrated ATM in all phases of flight'.* This was the beginning of the Programme for Harmonised ATM Research in EUROCONTROL (PHARE, [5,6]). The programme was later put under the EATCHIP umbrella as support for the definition of the EATMS.

Within PHARE, advanced ATM tools were developed in support of a line of advanced operational concepts. The feasibility and merits of these concepts were validated through a series of large-scale real-time simulations, called **PHARE Demonstrations (PDs)**. First, demonstrations PD/1 and PD/2 were performed in the UK and Germany , investigating en-route and TMA issues for the 2000 timeframe respectively. The last demonstration was PD/3, which was planned to investigate multi-sector, multi-centre and Terminal Area planning issues for the 2005 to 2015 time frame. It concluded the PHARE programme.

Next to the EUROCONTROL Experimental Centre (EEC) and the Centre d'études de la navigation aérienne (CENA) of France, the National Aerospace Laboratory (NLR) of the Netherlands was one of the sites at which PD/3 took place. Other establishments that contributed to PD/3 were National Air Traffic Services (NATS) of the UK and the Deutsches Zentrum für Luft- und Raumfahrt (DLR) of Germany.

Operational concept development

The PHARE programme started in 1989 on an immense task: to develop a new gate-to-gate operational concept with double the capacity of 'current' ATM operations. Although the principle ideas of the concept had been present from the beginning [1], the work involved in elaborating them to the current level of detail was significant. Never before has anyone defined and demonstrated in a real-time environment a new concept of operations that was so much more advanced than today's. It was the collaborative spirit of the PHARE partners that made it possible to achieve what no one could have achieved alone.

The first operational concept description of PHARE was completed in 1990. It was a collection of novel ideas presented at a high level, yet the essence of which is the exchange of flight status and planning information between on-board systems and the ATC system, which allows air traffic controllers to work more pro-active than reactive. This was expected to reduce the amount of work for dealing with a flight, thus allowing to handle more flights.

On the basis of this concept, development began of a number of advanced automated tools for air traffic controllers and of a new type of Flight Management System. Together with the development of a number of advanced applications on top of an ICAO compliant Aeronautical Telecommunication Network (ATN) demonstrator these developments would make it possible to demonstrate the merits and acceptability of the advanced concept.

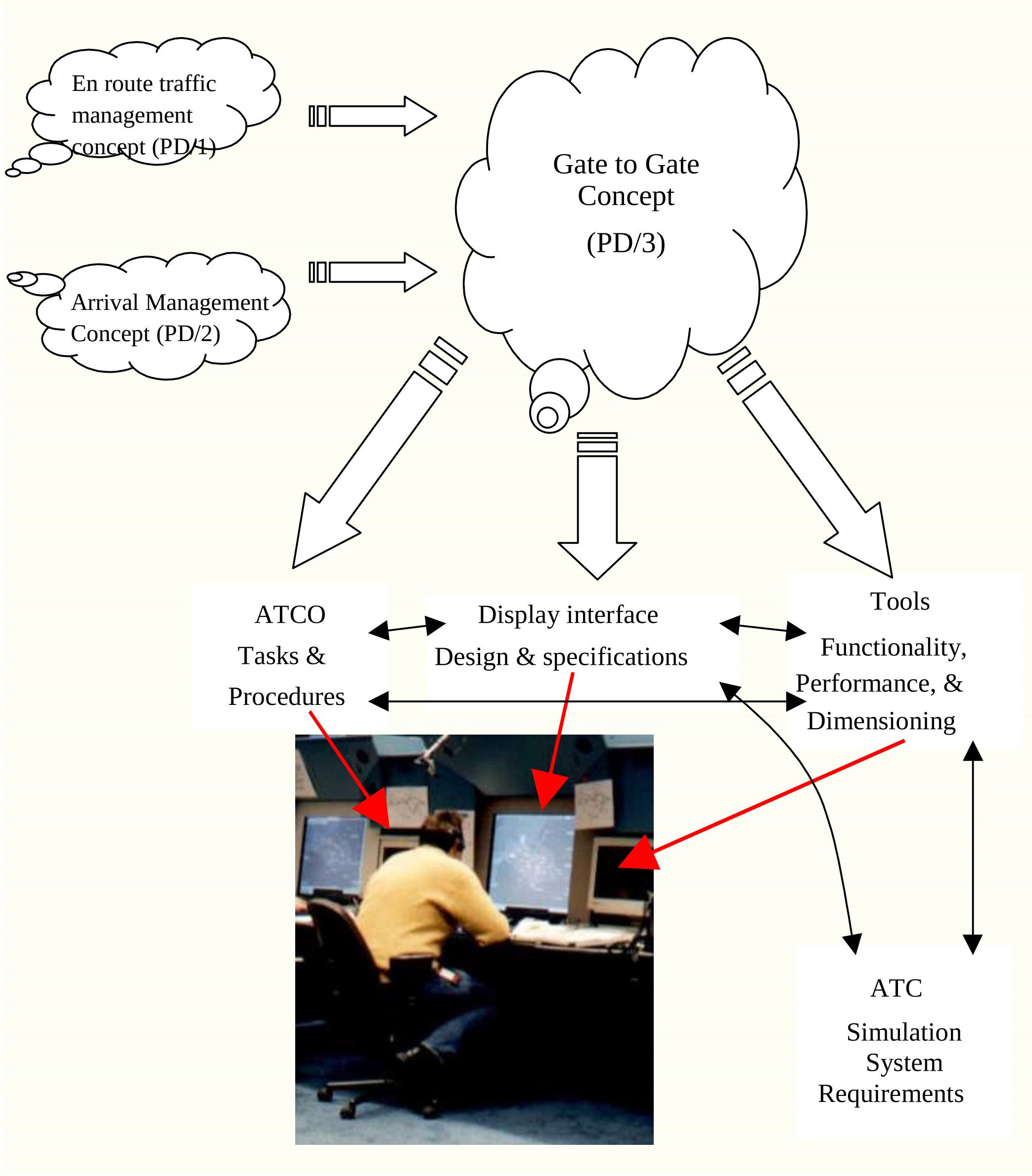

Fig.1 - The process of developing the PD/3 concept and system specifications

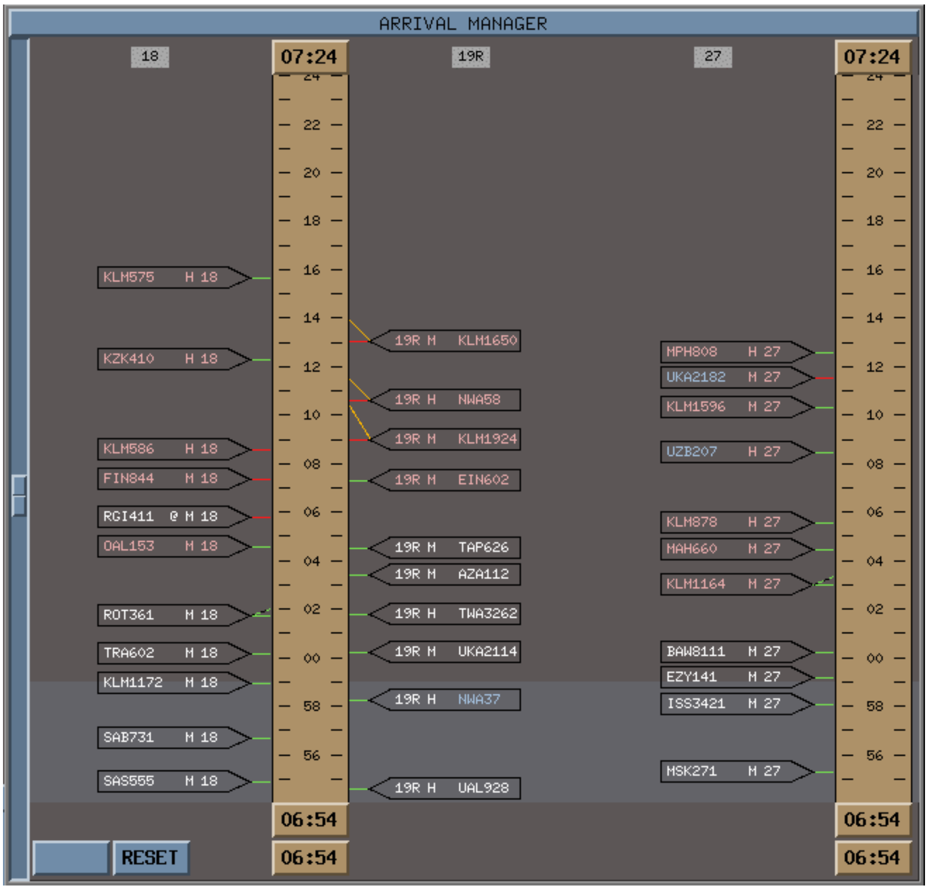

Fig. 2 - Arrival Manager Display for three runways.

This demonstration was performed through a number of large-scale simulation exercises called PHARE Demonstrations (PDs).

Since gate-to-gate ATM operations have a very broad scope, the first PHARE demonstration (PD/1), performed for the ATC service organisation in the UK, NATS, was limited in focus on en-route traffic handling. It explored the principle ideas of negotiating planned trajectories between air and ground and the accompanying changes in controller roles.

While PD/1 was successful in demonstrating the feasibility of the operational concept, it proved difficult to quantify a capacity increase potential. Yet, many lessons were learnt that helped to further refine the operational concept.

The second demonstration of PHARE was focussed on the principles of arrival management within the new concept. It was performed successfully by DLR in 1997 [6]. Technical limitations of the simulation system prevented the issue to be fully explored, but valuable lessons were learnt that contributed to the further refinement of the concept.

Already before PD/1 was completed, the work on PD/3 had started. The large gate-to-gate scope of this final demonstration forced the simulations to be spread over three separate simulations. Each of the PD/3 partners covered one of these parts.

In preparation for the final demonstrations each of the partners performed an internal operational research project that allowed studying operational aspects that had not been explored before. At NLR the focus in this study aligned with the subject of the final demonstration: the optimum integration of en-route and arrival traffic management. Shortly after the PD/2 trials at DLR, NLR performed some small-scale real-time experiments on this topic that contributed significantly to the definition of the final concept that was demonstrated. The study highlighted e.g. the need to eliminate explicit co-ordination between different sectors as much as possible and to distribute arrival time constraints as early as possible.

The refinement of the final operational concept was to a large extent related to the functionality that was available from the advanced tools and the Human Machine Interface (HMI) between the air traffic controllers and the system. The whole development process that is described above is illustrated in figure 1 and this concept is explained briefly below.

Final PD/3 operational concept

Controller Workload

An essential element of controller workload is related to the detection and resolution of potential conflicts. With the current operations, accurate planning over more than a few minutes is not possible since flight execution is an open-loop process without feedback from trajectory planning.

Closed Planning Loop

The basis of the PHARE concept is to close the planning loop. This is done by generating an accurate trajectory prediction for every flight. For future aircraft that have data-link and an advanced 4D Flight Management System (4D FMS), the prediction can be made onboard the aircraft itself and then down-linked to the ATC system. The aircraft (crew) therefore has all opportunity to plan an optimal flight for his or her specific purposes or route, satisfying company and other preferences. For other aircraft the ground system will make this prediction by using the Trajectory Predictor tool.

These predictions will be based on a set of so-called *constraints* that describe the freedom that is available in all four dimensions to execute the flight. The Negotiation Manager tool supports the data-link negotiation process that exchanges these constraints and the resulting trajectories between air and ground. The idea is presented in fig 3.

Once a prediction has been made it is the basis for the further execution of the flight. When the trajectory is also negotiated with the aircrew, the 4D FMS will accurately guide the aircraft along the planned trajectory, both in position and time.

For every flight that has a detailed trajectory prediction, the advanced Conflict Probe tool in the ATC system will be able to detect potential conflicts with other predicted trajectories.

Another advanced tool, the Problem Solver, supports the air traffic controller in interactively resolving a potential conflict in the planning stage of a flight through a sector. Every re-planning will lead to a change in the predicted trajectory of the flight.

In figure 4 the working of the problem solver is illustrated. The green line shows the planned trajectory of a flight. The red “blob” shows a no-go zone where the planned flight will meet another flight too close to avoid a conflict, unless the planning of the flight is changed by moving the green trajectory. The yellow “blob” shows a risk area, indicating not so much a conflict as well as the imposed restrictions for moving successfully the planned green trajectory during a re-planning action.

The benefits of this concept increase as flights follow their predicted trajectory more accurately. An advanced Flight Path Monitor tool is therefore introduced to support the controllers in monitoring the adherence to the predicted trajectory. Deviations are reported so that ap-

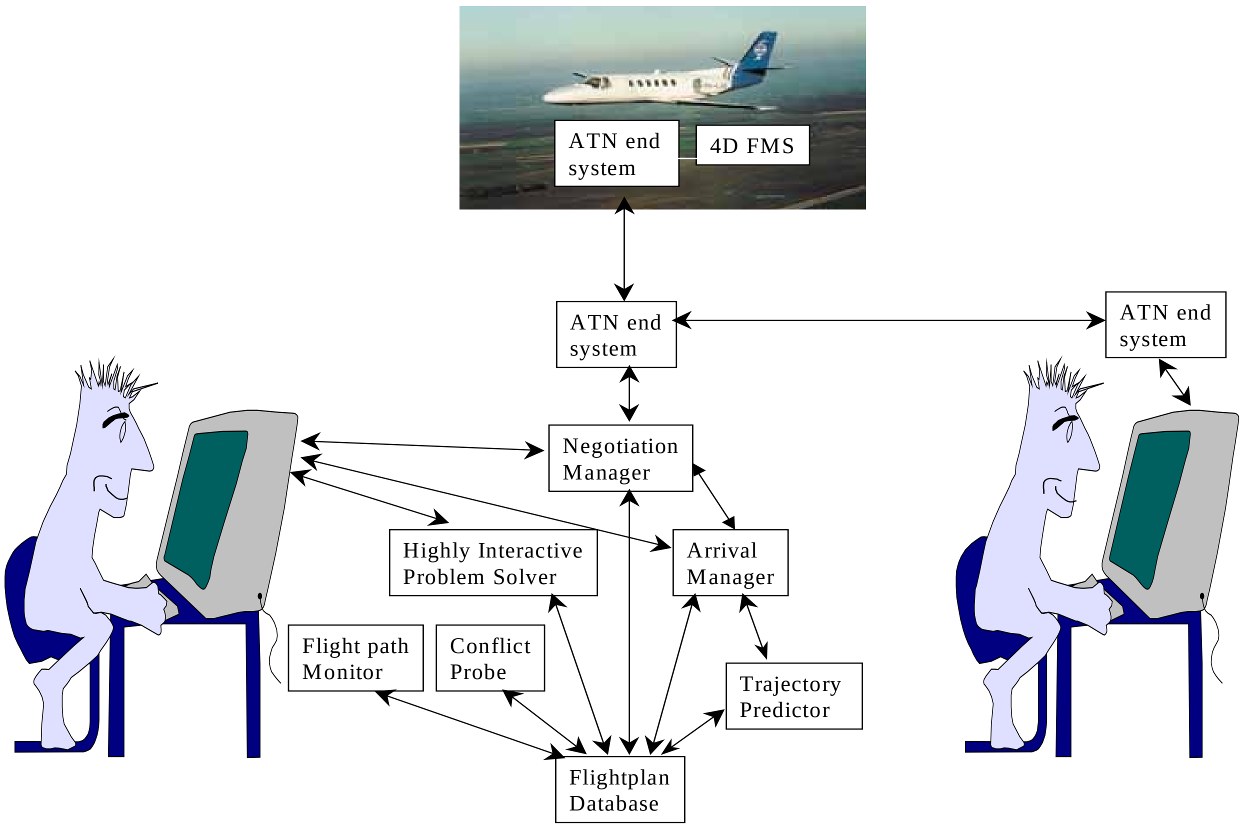

Fig. 3 The linked processes of flight planning, co-ordination and negotiation

propriate action can be taken by the controller team to ensure that flight planning and execution closely match.

Also, the controller is released of the mentally intensive task of monitoring if aircraft stay on their contracted trajectory. The capacity of the controller is thus increased.

For aircraft that do not have data-link equipment, the planned trajectory is only available in the ATC system since R/T is not really suitable to transfer trajectory information. The ATC system will therefore advise the air traffic controller on R/T clearances that are required to keep the flight as close as possible to its planning.

User Preferred Trajectories

In order to increase flight efficiency and to increase system capacity, the concept includes the use of User Preferred Trajectories. This allows operators to select their optimal flight profiles and routes and, with the process described above, negotiate them via data-link with ATC. There is no need to follow any standard route network. As a consequence, crossing of sector boundaries will no longer occur at fixed waypoints and at flight levels that follow relevant letters of agreement, and therefore this will reduce significantly the number of potential conflicts and this will enhance again the capacity.
The PHARE advanced support tools will allow the planning controller to plan the flight across the whole sector. In order to support the controllers in the co-ordination of plans between sectors the Negotiation Manager tool indicates when co-ordination is required, and facilitates the electronic co-ordination process. For aircraft that have data-link equipment, the Negotiation Manager also automatically takes care of the sector hand-over process. Only non-data-link-equipped aircraft need to be transferred via R/T. Again, automation helps the controller to execute his work faster and more efficiently, freeing up capacity to handle more aircraft.

Arrival Management

Building a good arrival sequence for inbound aircraft is currently one of the most labour intensive tasks of ATC. An advanced Arrival Manager tool supports the planning of inbound aircraft. It optimises the arrival sequence for every landing runway in use.

In order to do so it uses the flight plan information of aircraft that are still in the en-route flight phase, or that have not taken off yet. As soon as such plans become available the tool will automatically allocate a landing runway to each flight, taking into account a rule base that includes minimum wake vortex separation, minimum flying distance and any other optimisation rule that is defined. It will also allocate a scheduled time of arrival (STA) for each of these flights on the basis of the estimated time of arrival and the available runway slots. This process is automatically updated for every flight until it has approached its initial top of descent to within a configurable number of minutes. The allocated runway and the STA are disseminated to each centre that will handle the flight. Any subsequent sector planning will aim to comply to these ’constraints’ so that early convergence is achieved.

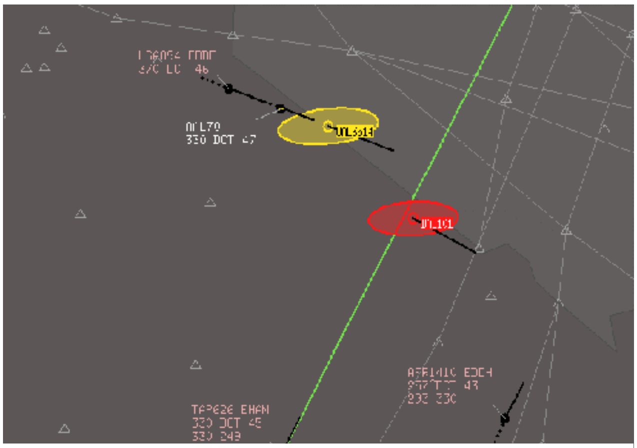

Fig. 4 – Display of conflict zone (Red - where a conflict will occur) and no-go zone (Yellow - where a conflict could easily be created) by the Highly Interactive Problem Solver

When a flight has approached the top of descent to within the configurable time limit, its arrival schedule is frozen. The system will stop its automatic optimisation of the arrival sequence for this flight. It is now the responsibility of the arrival sequence planning controller to eliminate any remaining planning conflicts for the Terminal Manoeuvring Area (TMA), by re-planning trajectories or changing the arrival sequence or runway allocation.

Finally, upon entry into the TMA, the aircraft is taken under control of the approach controller who will make sure that the aircraft meets its arrival plan. During the approach the aircraft will be able to make full use of its optimum continuous descend profile, which will reduce its contribution to the environmental pollution, and which will reduce considerably the noise load on the ground.

Demonstrations at NLR

Demonstrations of PD/3 took place twice at NLR [7]. In May 1998 a baseline scenario was simulated for two weeks. During this period some flights were also made with the NLR Citation II aircraft. It was equipped with a 4D EFMS and an ATN end system. These were coupled to an ATN end system which was integrated with the NLR ATC Research Simulator. (NARSIM). These flights demonstrated the actual operational integration of flight management systems with the air traffic management system.

Fig. 5 – A PD/3 simulation running on the NLR ATC Research Simulator (NARSIM)

The advanced operational concept was demonstrated to the ATC community in November 1998. For each of three days a group of some 25 to 30 visitors from all over Europe visited NLR to witness these demonstrations. Fourteen air traffic controllers and the same number of pseudo-pilots had been trained for only seven days to operate a system totally new to them. On each of the demonstration days they performed two extensive real-time simulation sessions that lasted more than an hour each. The sessions covered a simulated area that ranged from the North of France up to the North of the Netherlands and from the Dutch / English FIR boundary up to Luxembourg. Over a period of one hour nearly four hundred aircraft entered this airspace, which represents nearly twice the traffic level of the busiest day in 1996. Schiphol was operated with the future five-runway layout but, and this is rather uncommon, with five active runways (three for landing and two for departures), whereas the normal configuration is three active runways. The three controllers working in the Terminal Manoeuvring Area (TMA) managed to handle the increased traffic load while allowing the inbound aircraft to follow continuous descends and the outbound aircraft nearly unrestricted climbs.

Controller comments were generally positive and very enthusiastic with remarks like "I wish I had this operational at [ATC Centre]" and "It works great! Where can I buy it?". Critical controllers stated "What is it doing now" and "What if the system makes a mistake?" or "Are you sure that was 5 NM separation?".

Operational Lessons

Despite the fact that no objective measurements are available on the merits of the final operational concept, a number of issues are apparent.

Observations have shown that in general less work is spent per aircraft, resulting in an increase of the number of flights that can be handled by a sector. Contributions to this reduction, as explained before, come from the advanced support from the system in detecting conflicts in the planning, and in supporting the inter-sector co-ordination and hand-over processes. The applications of user preferred routing and RVSM also reduce the conflict occurrence, while the Highly Interactive Problem Solver reduces the effort to solve a planning conflict.

As a consequence of the changing roles and tasks of the air traffic controllers their situational awareness changes. While taking more of a managing role than a controlling role, they may not always be aware of every detail of every flight in their sector. It may be that this is the only way to break the current human workload barrier and it will have large consequences for system reliability requirements.

Concerning the integration of arrival traffic handling and en-route traffic handling it was noticed that by disseminating arrival time constraints as early as possible to up-stream sectors it is possible to generate a smoother flow of traffic into the TMA. Consequently stacks were hardly used and arrival time predictability increased. These effects can be considered as significant operational benefits! In addition the concept appears to make it possible to apply user preferred Continuous Descent Approaches even at high traffic density. Also this will provide in the future important operational benefits!

Concept Validation

During the lifetime of PHARE the issue of validation of new operational concepts has become more and more important. Due to high investment costs and long lead times in introducing new systems and operations, the need for validation of the fulfilment of requirements is now very strong. The validation process as performed in PHARE has certainly contributed to the knowledge gained over the past decade in the field of ATM validation.

In PHARE, validation meant the preparation and execution of a number of large-scale real-time simulations through which a comparison could be made against a reference system. Measurements would be made of controller's workload, system use, flight efficiency, and etceteras. In this way the three PHARE demonstrations were set-up as described before. Only in PD/3 were there preparatory fast-time and small-scale investigations into previously unexplored issues.

The PHARE Demonstration 3 has run to demonstrate the feasibility of a new 4D ATM concept. In principle, no issues were found that would refute it. The concept holds significant potential benefits to the customers: more capacity, more optimal profiles, less delay, less fuel costs, less environmental pollution and less noise. At this stage, no definitive measurements have been made to substantiate the above claims. This will be realised in subsequent Eurocontrol programmes.

Concluding remarks

An overview has been presented of the achievements of the PD/3 project, with a particular focus on the work performed at the National Aerospace Laboratory NLR. The project lasted for five years during which all aspects related to the development and evaluation of new Air Traffic Management operational concepts were dealt with. The lessons are therefore numerous. The following are however considered being the most important conclusions that can be drawn form this work:

The development and validation of a new concept of operations for ATM is a lengthy and expensive task. The high level operational description of the early days of PHARE has matured for over a decade, which ultimately resulted in a number of realistic real-time dem-

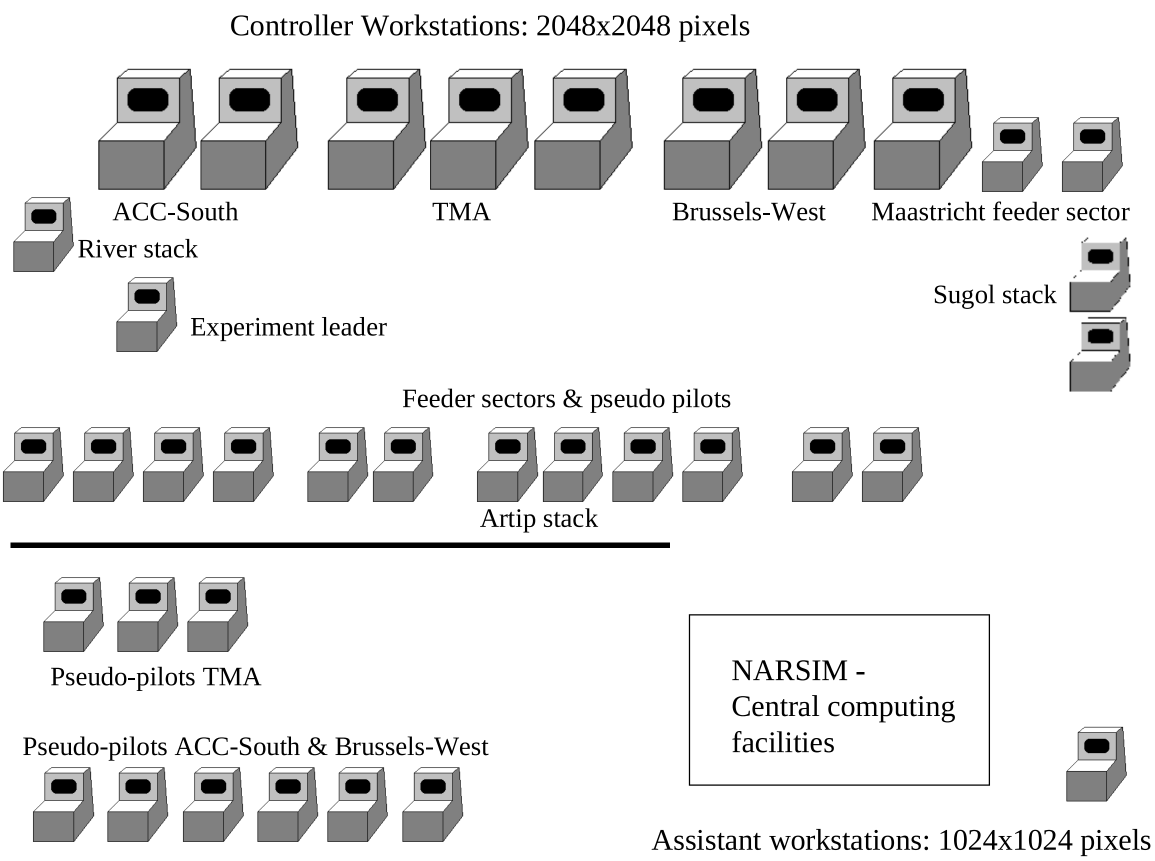

Fig. 6 – Set-up of the NARSIM facility for the PD/3 Continuation Trials

onstrations. During this decade, more and more details were elaborated. Side branches were explored and often discarded as not the way forward. The reasons for discarding are also among the results of the PHARE programme. The 'validation' that had to be performed through the three demonstrations should be considered as checks that the concept development was going in the right direction.

The operational concept of PHARE, to integrate air and ground systems in support of an advanced layered planning system, has proven to be viable, operationally acceptable and most of all holds the promise of providing the ATM capacity that will be required within two decades. The concept also supports the ATM users to fly their user preferred routing and levels with minimal intervention.

With this development a target is set for future ATM operations that should be the guide for developments in the shorter term. The experience gained within the PHARE programme should be used to its maximum to provide input to these developments. Fortunately we can already see existing and new programmes within EUROCONTROL taking on board the PHARE knowledge.

PHARE will be a guiding light for many developments to follow.

References

[1] GARTEUR Action Group FM (AG)03, Integration of flight management and air traffic management systems, GARTEUR-TP-57, 1990

[2] EATCHIP, the European Air Traffic Control Harmonisation Programme, 6 Years of Progress, Eurocontrol, Brussels, January 1997.

[3] Operational Concept Document (OCD), EATCHIP Doc.: FCO.ET1.ST07.DEL01, Edition 1.1, Eurocontrol, Brussels, 4 January 1999.

[4] ATM Strategy for the years 2000+, Eurocontrol, Brussels, January 2000.

[5] Dr. H. Schröter, A Report of Eurocontrol's PHARE Programme, Proceedings of Airline Navigation '96 Flight International and Air Nav. Int. Conference, Amsterdam, 9-11 Oct 1996.

[6] M.van Gool and H. Schröter, PHARE Final Report, PHARE/EHQ/MAN/FR;1.0, DOC 99-70-09, Eurocontrol, Brussels, November 1999.

[7] W. Post, NLR PHARE Demonstration 3 Final Report, PHARE/NLR/PD3-4.4.2/FR;1.0, DOC 99-70-01 Volume 4 of 4, EUROCONTROL, Brussels, December 1999

Biography

Ir. Wim Post graduated as an Aerospace Engineer from Delft University of Technology in 1989. After that he served his conscript period as an officer in the Royal Netherlands Air Force, concerned with the introduction of new radar training equipment for military air traffic controllers. In 1991 Wim Post joined the National Aerospace Laboratory NLR and soon became involved in Air Traffic Management research. After an initial involvement in the development of a prototype Aeronautical Telecommunications Network (ATN), he started to work in 1994 on the PHARE Demonstration 3 project for which he was the local project leader until its finish in 1999. He was actively involved in the definition of the PD/3 Operational Concept and in the set-up and execution of the various experiments. In parallel with the PD/3 work Wim Post participated in EUROCONTROL's EATMS Concept Task Force (ECTF) that wrote the target operational concept for the European ATM Programme. At this moment he is still actively involved in the co-operation between the FAA and EUROCONTROL on future operational concepts and in the building of a prototype Validation Data Repository.