LESSONS LEARNT FROM CENA-PHARE EXPERIMENT AND REQUIREMENTS FOR FUTURE EVALUATION OF NOVEL CONCEPTS IN ATC

Didier Pavet

CENA
1 rue de Champagne
91200 ATHIS-MONS
pavet@ath.cena.fr

ABSTRACT

This paper aims at presenting some lessons learnt from the CENA-PHARE PD/3 experiment. This experiment took place in May and June 1998, and the subsequent analysis ended up with a detailed report extracting the major findings (see reference [1]).
Introducing the purpose of the PHARE project and of the PHARE Demonstrations, it emphasises major lessons learnt at a human factor level concerning introduction of the PHARE new concepts. From the major conclusions, it derives some tracks which would be worthwhile if one would continue the challenge to validate novel and ambitious concepts as those underlying PHARE with the required level of confidence.
Based on this analysis, the conclusion of this paper highlights the differences between 2 approaches followed by ATM research centre in Europe at that time in order to improve efficiency of the overall ATM system.

Key words : PHARE, Air/Ground integration, Data-Link, 4D planning, evaluation methodology, training methodology.

INTRODUCTION

PHARE Context

The Programme for Harmonised Air traffic management Research in EUROCONTROL (PHARE) was launched in 1989 in order to investigate way to increase capacity in the most busy areas of European airspace. Indeed, EUROCONTROL traffic growth scenarios predicted at that time, and confirmed by update-to-date figures, showed that in 2005, traffic demand would increase by 56 % compared to that observed in 1995 and around 121 % in 2020. Whereas Air Traffic Services should adopt drastic strategies to cope with the demand (airspace and airways restructuration, negotiation with Military authorities, ...), PHARE focused efforts on the most limiting factor of the ATM system i.e. ability of Air Traffic Controllers to handle the traffic with the required level of safety within a given cell of airspace. The effort has lain in designing new operational concepts, new tools and procedures which could be applied within the targeted time frame 2005-2015.

PHARE objectives

To measure the performance of the new concepts taking advantage of enhanced technologies, a series of real-time simulations, or PHARE demonstrations, was planned. These demonstrations addressed the evaluation of computer assistance tools and the introduction Data-Link in En-Route (PD/1), in TMA-Terminal Manoeuvring Area (PD/2) and combined En-Route/TMA environment (PD/3), each demonstration being led by one or more PHARE partners.
These large scale validation activities, comprising integrated ground system, air system and Air/Ground Data-Link facilities were the last step in the validation process consisting of functional testing, basic evaluation of individual tools and partial validation of subsystems of increasing complexity.

PHARE Demonstrations « in a nutshell »

The first PHARE demonstration - PD/1, was hosted by the National Air Traffic Services Ltd. (NATS). The trial was conducted over a period of 8 weeks towards the end of 1995 (see reference [8]). The primary aim of PD/1 was to investigate the introduction of computer assistance tools, Data-Link equipped aircraft and a 4D Flight Management System (4D FMS) within En-Route airspace.
The second PHARE demonstration - PD/2, was hosted by the Deutsches Zentrum für Luft-und Raumfahrt (DLR) in Germany (see reference [9]). The trial was conducted over a period of 8 weeks in late 1996, early 1997. PD/2 pursued the assessment of the introduction of computer assistance tools and aircraft equipped with 4D-Data-Link Flight Management System in a TMA environment, using the Frankfurt TMA as simulated airspace. The main computer assistance tool to be demonstrated during the trial was the Arrival Manager (AM), which sequenced arrival traffic into a conflict free stream at a designated point before the runway (the metering fix).

PHARE Demonstration 3

PD/3 concluded the series of PHARE Demonstrations ; CENA, NLR and EEC were the main participating research organisations that hosted the PD/3 demonstrations, assisted by NATS (for evaluation aspects notably). 3 real time simulations (one for each site) were settled in order to evaluate PHARE concepts on a quite complete volume of airspace stretching from the En-Route environment to the Extended TMA of several airports. The different site specific operational environments, gathered as a whole, was approximately the airspace from Amsterdam/Schipol to Paris/Charles de Gaulles plus the overall Enroute airspace between the 2 airports. Key input parameters were common to the 3 simulations :

- focusing on an airspace representative of the Europe Core Area airspace,
- using the year 1996 as a reference for operational environment and traffic level,
- using traffic samples matching the predicted traffic level according to the expected time frame 2005-2015.

Note : this paper concentrates on CENA/PD3 experiment. The experiments hosted by NLR and ECC have been documented in other respects (see references [11], [12]).

CENA PHARE Demonstration 3

CENA-PD/3 provided evaluation of a future ATM concept for the time period 2005 - 2015, which supports the transitional introduction of 4D and Data-Link equipped aircraft by combining :

- Air/Ground integration,
- introduction of new tools to support the controllers,
- while keeping the man in the loop following a « Human Centred Approach ».

CENA-PD/3 was applied in an operational environment stretching from a TMA/DEPARTURE sector, an ETMA/DEPARTURE sector to an En-Route sector thereby covering areas left unexplored by previous PHARE Demonstrations.

For the En-Route environment, CENA-PD/3 intended to demonstrate the capacity increase and productivity benefits of the core PD/3 operational philosophy, i.e. the traffic organisation planning philosophy, including the following and progressive ATC enhancements :

- introduction of advanced assistance tools among which CO-OPERATIVE TOOLS aiming at organising the traffic in a « human-in-the-loop » philosophy,
- introduction of 4D trajectory negotiation and 4D planning.

In a similar way for the TMA environment, PD/3 intended to cover the experimental domains related to the traffic organisation planning philosophy with the following ATC enhancements :

- introduction of advanced assistance tools,
- introduction of planning functions : the DEPARTURE MANAGER tool,
- introduction and extension of the concept of 4D trajectory negotiation and planning.

The CENA-PD/3 main phase demonstration took place over seven weeks in May and June 1998. One week was devoted to a successful Airborne demonstration in collaboration with the DERA (Defence Evaluation and Research Agency - UK) using the NATS BAC1-11 live aircraft equipped with an Experimental Flight Management System (EFMS) and using an experimental ATN [13] network based on the INMARSAT satellite.

EVALUATION METHODOLOGY

Experimental design

The process of evaluation was conducted in a comparative manner : an Advanced scenario supported by an Advanced system and a Baseline scenario supported by a Baseline System were defined (see references [2], [3], [4]). The Baseline system was settled in order to lead simulations in the same conditions as the ones led with the Advanced system, giving reliable reference measurements. This system did not mimic trustfully a real system since no paper strips were provided to the controllers. Instead, the information was presented through interactive track data blocks or simple computer aided assistance.

As shown in the Table 1, added to the Baseline scenario, the Advanced scenario was utilised according 3 sub-scenarios ; these so-called A0, A30, A70 scenarios have allowed to measure effects of the introduction of PHARE Advanced Tools and a new GHMI on the one hand, and the progressive introduction of aircraft equipped with 4D FMS and Data-Link on another hand. The traffic samples elaborated for the experiments were derived from the 21st June 1996 traffic data (summer peak for French ACCs) ; this level of traffic (x 1.0) was set as the reference level (Low level).

The Medium traffic samples corresponded to this traffic $\times$ 1.5 ; and the High traffic samples corresponded to this traffic $\times$ 2.25.

Each controller participated in two weeks of measured runs and performed alternate role (either as Planning or Tactical controller) on the same sector for each run. A sophisticated rotation between controllers has been designed so that statistical tests could be run reducing the effect of variability between controllers while avoiding learning effect as far as possible.

Scenarios	Traffic sample	PHARE Advanced Tools	Procedures
Baseline	3D equipped a/c 3 traffic volumes	None Limited planning aid tools	Controller plans ahead ; limited computer assistance for detection of conflicts. Procedures to suit strip-less system.
A0	As above	Co-operative Tools (CT), Departure Manager (DM), Trajectory Editor and Problem Solver (TEPS)	Advanced planning ; computer assistance looks up to 20 minutes ahead to conflict-free trajectories.
A30	Mixed population : 30% 4D equipped a/c 2 traffic volumes (medium and high)	As above	As above plus procedures for negotiating with 4D FMS and Data-Link equipped a/c.
A70	Mixed population : 70% 4D equipped a/c 2 traffic volumes (medium and high)	As above	As above

Table 1 Summary of scenarios

Measurements

As prepared by the CENA experimental team (assisted by the PHARE VALidation group), an experimental protocol has defined a quite complete set of data to be recorded for post-run analysis. This protocol (see references [4], [6]) has been set to enable to evaluate the concept towards major external criteria as Workload, Safety of control, Quality of Service (Capacity being a parameter) and to evaluate more thoroughly the operational working of the couple Human Machine.

These measurements were split as is :

Subjective measurements consisted in some kind of self assessment performed by the controllers. Measuring the effect of the PD/3 operational concepts on controller's workload was one of the main aims of PD/3. Two major subjective measures of workload were used to record and analyse controller's workload : the Instantaneous Self Assessment (ISA) and the NASA developed Task Load indeX (TLX). Questionnaires were administered at the end of each trial to collect the controllers' opinions and comments. The questionnaires were designed to make possible the quantitative analysis and significance testing of the controllers' answers.

Objective measurements were automatically recorded by the ground system. During the PD/3 trial a large number of these objective data were collected which contributed to assess the PD/3 main topics (workload, safety, sector capacity and quality of service) and also the use of the tools.

To allow the auto-confrontation with the controllers just after a run, **the video and audio recording** provided the human factors specialists with an efficient means to deeper investigate the overall strategy for using one specific HMI object or to better interpret the reason why a specific event occurred.

Finally, **direct observations** (supported by analysis chart) by one human factor expert dedicated to each control suite were an invaluable source of information.

Controllers

The two Main Phase trials for PD/3 were carried out over a 6 week period with 9 controllers participating per session of 3 weeks. The controllers selected for the PD/3 trial covered a range of ages, nationalities and backgrounds as shown in Figure 1.

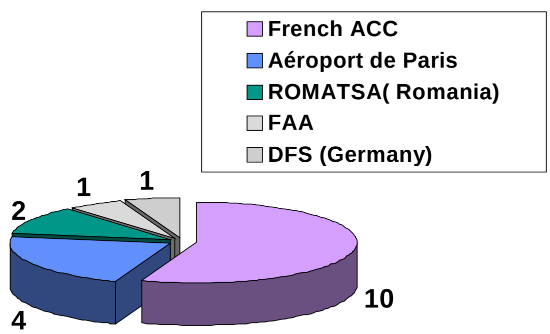


Figure 1 controllers' professional origin

LESSONS LEARNT

Training aspects[1]

The controllers were taught a six day-course. A full week was devoted to theoretical lessons supported by slides shows (450 slides were designed - see reference [7]) and practical training either on a very convenient standalone system either on the full system. These sessions were led in a very guided manner. The day before the measured runs, all the controllers performed 2 refresher runs.

The excellence of the preparation[2] and the very directive policy to interlace theory and practice counterbalanced the still too short period of time allocated for training. This method has enabled the controllers to catch HMI, concepts, sharing of tasks, airspace. The controllers' answers to questionnaires illustrate this point (cf Figure 2).

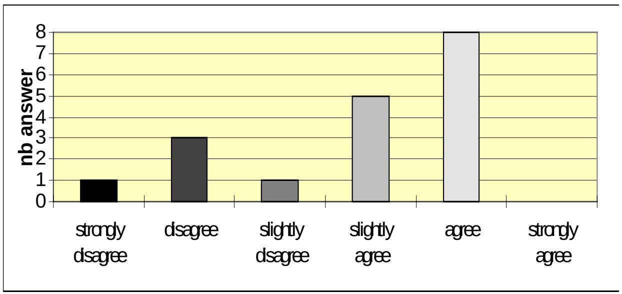


Figure 2 controllers' answers to the question : « there was enough training to get familiar with the HMI tools and functions »

External evaluation

Here are the main trends emerging from the evaluation of the external criteria which will be useful to illustrate the following discussion.

Perceived workload

The combination of ISA, TLX indicators and controllers feedback showed that the Advanced scenarios promoted a transfer of workload from the Tactical Controller to the Planning Controller. The traffic load had a major influence on PC's workload whatever the percentage of 4D/DL equipped aircraft. On the other hand, we can consider that TC's workload remained extremely high. While a light drop has been observed for a high percentage of 4D/DL (70%), the mixed situation (30% DL equipped aircraft) emerged as the worst situation to manage.

On a very subjective point of view, Frustration and at a less extent Time Pressure were the two major TLX indicators badly scored by controllers for Advanced scenarios.

The reduction of VHF activity (and thus the drop of Time Pressure) explains the gain TC has felt while operating for Advanced scenario with 70% of 4D/DL aircraft.

The increase of workload for PC was expected. The introduction of planning activities - manifested in concrete form by quite a long time spent to edit trajectory (20-40 seconds knowing that 20 flight plans per hour were concerned) and management of Air/Ground communication - has taken up a lot of PC's time.

The fact, as a finding, that TC's workload remained higher in all Advanced scenarios than in Baseline, has stemmed from the difficulty to build and maintain a structured working method. Especially, the feeling to be powerless in front of silent equipped aircraft (lack of an immediate awareness of what has been decided by the PC) and the difficulties to manage the prepared clearances for unequipped aircraft have strengthened their frustration. Moreover, these elements have lessened the ability of the TC to intervene tactically when needed. As a consequence of the increase of PC's workload, the TC was not always assisted by PC when requested.

Some « parasite workload » due to long response times appeared during the experiment. Though some improvement could be obtained on long response times requested to edit a trajectory (as a gorgeous HMI should promised it), times requested to compute a trajectory (as a Trajectory Predictor empowered by huge computing capacity could offer), time requested to exchange data through the air (as a « lightning speed » Data-Link network would allow), the delay required for the pilot to acknowledge, analyse and validate will still remain in the loop. As a consequence, even if answer to uplinked request from ATC would become a high priority to the crew member in the future[3], basing any new operational scenario on the fact that Air-Ground negotiation would become immediate is utopian.

Safety of control

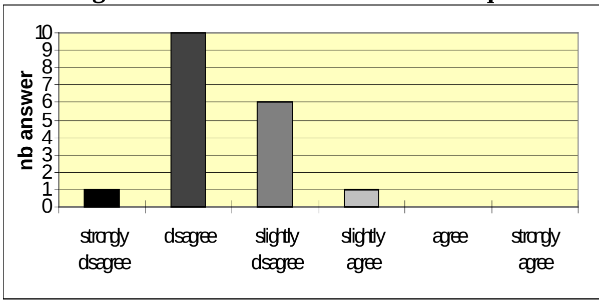
Based on the occurrence of safe separation infringements, an in-depth analysis showed that Safety was less ensured in Advanced scenarios than in Baseline. While this topic remains hard to study (the occurrence of event remains low in every case), these results added to controllers' feedback (see Figure 3) demonstrate that the situation awareness of the Tactical Controller was modified.

[1] One of the PD/1 lessons was to reinforce training especially on the working method.

[2] This method was inspired of what has been applied for several years on the ERATO project at CENA/Toulouse.

[3] that is not the case today !

Figure 3 controllers' answers to the question :



« It was always possible to keep aircraft well separated»

Quality of service

PD/3 did not allow to assess interesting objective results on this topic. The use of anticipated planning could enhance the systematic optimisation of trajectories and this at a multi-sectors level which could yield some benefit for the airlines. On the other hand, the anticipated planning forces the controller to take larger margins[4].
This topic will deserve to be specifically studied in the future.

Capacity

Capacity level is an input factor that experimental experts tune as the experimental protocol has defined it. Capacity has been assessed in PD/3 measuring whether the desired level of operators' Workload, Safety of control, Quality of services could be maintained or improved comparing with the ones obtained with the Baseline scenarios.
At this stage, this evaluation of PHARE concept does not allow to predict an increase of Capacity.

PD/3 Concepts : consequences on the role of the man

New methods to accomplish the work

The capability to plan and to implement in advance a new trajectory (concept of **Advanced planning - Trajectory Negotiation**) showed a great potential for trajectories optimisation and conflicts resolution in comfortable conditions. The 4D Trajectory Negotiation concept allowing to use Airborne calculated trajectory as a basis of negotiation and co-ordination is an indisputable plus which could enhance the way Air Traffic Control is operated. A greater accuracy in the forecast trajectory (based on aircraft trajectory) and a significant decrease in VHF occupation (mostly for transfers action) can be obtained. However, this attempt to introduce operationally this concept in the working method of a team of Tactical Controller and Planning Controller puts into light some major matters of concern :

- the use of an asynchronous and silent medium obliges to establish a strict **sharing of tasks** between controllers inside the same sector and to define strictly the rules to manage **planning authority** (right to use DL for planning the trajectory). Letting controllers managing resources like a distributed database does not meet time pressure constraints in ATC. Probably, **a strict procedural** system allowing operators to intervene one at a time in a pre-ordered manner is a clue to set a scenario from which ambiguity is withdrawn ;
- introduction of DL management into the Planning Controller framework is not a minor issue : the experiment shows that under heavy traffic load, the Planning Controller is more and more absorbed by DL activities and ahead in the time frame, becoming less available to follow behaviour of the traffic in real time inside the sector. An **operational gap**, both on temporal and spatial dimensions, appears between the 2 actors; this fact contrasts with the current strategy of planning controllers to become a « Tactical assistant » during peak of traffic ;
- the performances of the system especially when Air-Ground Data Link applications intervene remain crucial if one wants to introduce this medium in the framework of tactical operators for whom time is critical. It means that no overhead due to pure calculations should participate at the overall response delay.

New mental awareness

The PHARE time scope (2005-2015) addressed clearly a transitional period where new equipped aircraft will share the sky with traditional aircraft, and whilst new mode of operation could appear, « old fashioned radar control » will still be applied ; therefore PHARE and PD/3 settled « the Human Centred Approach » as a major principle, this statement meaning that Controller should keep in mind the current and future situations as they do today. Experiment showed that clearly **situation awareness of the tactical controller was changed**, for many reasons : as previously mentioned, an unclear sharing of tasks spoiled a good transfer of knowledge between Planning and Tactical operator ; basic unit tasks which contribute to the memorisation process were withdrawn in a too carelessly way regarding to mental awareness.
One of the PD/1 experiment recommendations was « to either improve how the system helps TC's to maintain situation awareness or fully persuade them that it is no longer necessary ». Unfortunately, efforts at the HMI side did not allow to make some progress on the first track. Nor, no persuasive elements have been brought up until now guessing that controller could get rid of a clear awareness of what happens in the cell of airspace they have the responsibility to manage.

[4] As reported by an controller, « we have the feeling to be less sharp as today on radar separation with PD/3 Advanced system ».

DISCUSSION : REQUIREMENTS FOR FUTURE DEVELOPMENTS OF NOVEL CONCEPTS

Technical maturity

This is a « one thousand time written requirement » but any attempt to evaluate such new concepts must gather the minimum conditions to allow an operational evaluation. In this area, PD/3 taught us that performances (response times, quality of information) at an operator level point of view (Human Machine Interface) as an utmost priority, puts strong requirements on the technical management of the project.

It is now obvious that a stepwise approach (where technical components are integrated smoothly) is more prone to the building of a technically mature experimental system (as opposed to a « one shot big bang » venture).

« Trial controllers » to reach operational maturity

In the path through the real assessment of new concepts, a first step should be to co-opt one team of « trial controllers » capable to be involved in the design, the tuning of the system, and to make the proof that the system is workable, efficient and safe. This first target which probably should take several months to achieve, once technical maturity is obtained, is a compelled step.

A second step would be to perform evaluation/validation of the system by current controllers in order to measure external criteria with the suitable experimental procedure, validation tools. This second step would surely benefit from the PD/3 experience to organise both an evaluation methodology and a training phase. Having a set of « trial controllers » would allow to tame more easily new controllers gaining the gap in trust which every controller may miss when facing any new philosophy to perform his/her job.

Evaluation methodology

The experimental comparative approach as proposed by the PHARE/VAL Group and set up for PD/3 turned out perfectly adequate as regards to the principles used. This methodology should be applied in any attempt to validate new concepts in real time simulations. To be more robust, using a Baseline system very close to the current ones is mandatory : if paper strips are a part of the current system, the Baseline system should mimic this working.

A complete new, well defined scenario

PHARE scenario kept the idea that while introducing new method and new tools for Air Traffic Controller, letting the Controller in the loop should be pursued because He or She remains a key element to ensure security in case of non nominal event. Though, it could sound too definitive to conclude this, we can however question the possibility to build a system capable to both offer Air-Ground integration principles and to help to maintain the same level of situation awareness as controller should maintain currently. The report « Role of the Man within PHARE » (see reference 10 p.69) concluded on Situation Awareness that :

« … If the policy is that the maintenance of the controllers' picture is not required, however, then all the consequences of this must be defined and allowed in advance : they are likely to include the inability of the human controller to intervene quickly and successfully in an emergency. … ».

Despite this, PHARE did not investigate if the requirement of «maintaining the man in the loop» could be escaped, still addressing the targeted time frame. This idea could lead to study in more detail what could be potential strategies capable to cope with non nominal situations. The goal would be to provide operators with a ready-to-use temporary but immediately applicable set of solutions letting them the time afterwards to analyse the problem with the required delay.

This paper just suggests that this track was not deeply followed yet and could bring some interesting spin-offs.

CONCLUSION

Almost 2 R&D directions are followed at that time to enhance ATC in order to cope with the traffic demand :

- The first category attempts to improve the same skills which currently are required to work as a controller : i.e. these projects promote a reinforcement of cognitive capability of controller. In a certain way, these projects push to the edge the capability of the same engine : the brain of the controller ; their indisputable advantage is to ensure continuity with today practice.
- The second category explores ways to provide a quite automated system where controllers' role- in scenario where there are still some controllers - becomes routine interlaced with exception management. Even if one could assess that in the long run, ATC will be performed like that, the coming of this project will require additional effort to assure the transition between today practice and target scenario.

The concepts proposed by PHARE on the one hand promote skills of the controller which are different from those required today : the required skills are not anymore to monitor, construct mentally a situation, but to plan and to solve ahead in advance ATC problems, and a procedural mode is more suitable to these tasks. On the other hand, as they have been applied up to now, the PHARE concepts are likely to diminish ability of controllers to maintain the current picture of the traffic.

To conclude, we definitely count PHARE concepts amongst the projects of the second category ; it is not an appalling finding. It just means that any project applying the essence of PHARE concepts should make the proof, through a complete scenario taking in account non-nominal solution and transition aspects, that the overall system is workable. This task is not impossible but additional efforts should have to be made to make this second category come out with operationally usable systems.

Beyond all doubt, PHARE and PD/3, have delivered brand new operational concepts, strengthened R&D on Data-Link technology, Computer-Aided ATC tools, procured innovating HMIs, evaluation methodology, teaching method.
PHARE also allowed to seize the extent of what remains to be performed to build a new workable mode of operation in future ATC.

ACKNOWLEDGEMENT

PD/3 was by nature a collaborative venture, gathering efforts from many participants among the ATM R&D community. CENA PD/3 could not have taken place without the co-operation of the PHARE partners : DERA of the UK, DLR of Germany, EEC (the Eurocontrol Experimental Centre), NATS of the UK, NLR in Netherlands.
A special thought to the CENA's staff : 30 persons very deeply committed themselves in the project, often at the expense of their private life.

REFERENCES

1. CENA - PD/3 Final Report
   DOC 99-70-01 Volume 2 of 4
   PHARE/CENA/PD/3-2.4/FR/2.0 (May 1999)
2. PD/3 Operational Scenario Document, Vol I,
   DOC 97-70-04 - PHARE/PD3-1.1.3.2.2/OSD1;2.2
   (January 1997)
3. PD/3 Operational Scenario Document, Vol II,
   DOC 97-70-08 - PHARE/PD3-1.1.3.2.2/OSD1;2.0
   (March 1997)
4. PD/3 Ground Human Machine Interface Specifications v 1.2
   PHARE/GHMI 4.6 (May 1997)
5. CENA Experimental Protocol for PD/3,
   CENA/NR98-156 J. Garron, C. Chabrol (May 1998)
6. PD/3 Measurement and Analysis Specification
   DOC 98-70-08 - PHARE/NATS/VAL-4.4.2/WP005 ;1.0 (February 1998)
7. PD/3 Training Course Support
   CENA/NT98164 C.Chabrol - (April 1998)
8. PD/1 Final Report
   DOC 96-70-24 - PHARE/NATS/PD1 - 10.2 /SSR ;1.1
9. PD/2 Final Report
   DOC 97-70-13 - PHARE/DLR/PD/2-10.2/SSR ;1.2
10. Role of the Man within PHARE
   DOC 93-70-35 (June 1993)
11. EEC PD/3 Final Report
   DOC 99-70-01 Volume 3 of 4
   PHARE/EEC/PD/3-3.20/FR/1.0 (February 2000)
12. NLR - PD/3 Final Report
   DOC 99-70-01 Volume 4 of 4
   PHARE/NLR/PD/3-4.4.2/FR/1.0 (February 2000)
13. PATN Final Report
   DOC 99-70-03
   PHARE/CENA/PATN-5.2/FR; 2.3 (August 1999)

ACRONYMS

4D FMS	a four dimension Flight Management System
CT	Co-operative Tools
DM	Departure Manager
HMI	Human Machine Interface
TEPS	Trajectory Editor and Problem Solver
TP	Trajectory Predictor

BIOGRAPHY

Didier Pavet is head of the « Controller System Interface » division at CENA/Paris. He graduated at Ecole National de l'Aviation Civile (Toulouse, France) in 1987. He has worked at CENA since 1992 as project manager of the prototype of new generation of Controller Working Position (HEGIAS). Committed in PHARE as a member of the Ground Human Machine Interface Group, he acted as the Experimental Manager for the CENA-PD/3 experiment.