

PROGRAMME FOR  
HARMONISED AIR TRAFFIC  
MANAGEMENT RESEARCH  
IN EUROCONTROL



**DOC 96-70-24**

Volume 1 of 2



EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION, EUROCONTROL



## **PD/1 FINAL REPORT**

PHARE/NATS/PD1-10.2/SSR;1.1



**EUROCONTROL**

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Date: January 1997

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**REVISION HISTORY**

June 1996	Draft version 0
August 1996	Draft version 1, incorporating NATS' review comments
September 1996	Draft version 2, with changes following review by the PD3CG
October 1996	Version 1.0, with changes following review by the PCC
January 1997	Version 1.1, with minor changes, issued in two volumes, approved by the PHARE Management Board

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## EXECUTIVE SUMMARY

This document is the final report for the PHARE Demonstration 1 (PD/1). It aims to give those with little or no experience of the Programme for Harmonised Air Traffic Management Research in Eurocontrol (PHARE) an appreciation of what PD/1 has achieved. For those with closer involvement in the PHARE project, it provides a synthesis of the results, presents recommendations, and references the detail available in source data and in the annexes to this main report.

PD/1 brought together research organisations from four European nations to design, build and trial an advanced air traffic control (ATC) concept. The work programme was led by the National Air Traffic Services Ltd. (NATS), a subsidiary of the UK Civil Aviation Authority, with the participation of CENA of France, DLR of Germany, NLR of the Netherlands and the Eurocontrol Experimental Centre at Brétigny. The PHARE programme is managed as a whole by Eurocontrol HQ in Brussels. The ability of Europe to co-operate in an extensive ATC research programme and to demonstrate its achievements to a world-wide audience is a significant achievement.

The PD/1 system was demonstrated on NATS' real-time ATC simulator, the NATS Research Facility, using 32 controllers from 7 countries to evaluate an experimental system which included: advanced computer assistance tools; a live aircraft; simulated and real 4-D flight management systems (FMS); and an air-ground datalink. The aim was to explore the effectiveness of the negotiation of conflict-free trajectories; can they reduce the workload of primarily the tactical controller, but also the planning controller, and thus increase airspace capacity?

The PD/1 airborne demonstration programme, with the participation of the NATS-funded Defence Research Agency BAC 1-11, was extremely successful. It confirmed, as a matter of routine, the ability of an aircraft to agree conflict-free trajectories with ATC and to fly these trajectories, while operating within continuous 4-D constraints. The flights also provided a convincing demonstration to the aviation community of the 'silent cockpit'.

The training programme showed that one week's training was insufficient for the controllers fully to assimilate the new facility and concepts. This lack of training and familiarisation time will have influenced the results described below.

Controllers approved of the PD/1 trials environment. Fundamental aspects of the system were well accepted, such as electronic co-ordination and colour coding of track data blocks. The computer assistance tools received a mixed degree of controller approval; the primary planning tool, the Highly Interactive Problem Solver, was particularly well received. There was agreement from the controllers that the tools and functions should continue to be developed. This requirement to develop the tools further is to be expected, since the PD/1 system was experimental rather than pre-operational.

The PHARE programme is driven by the clear need to increase airspace capacity. However, no specific targets for workload or capacity gains were set for PD/1. The results presented herein show that, at high traffic levels, the introduction of computer assistance tools increased the workload of the planning controllers while the tactical controllers' workload remained unaffected by using the computer assistance tools. Specific reasons are identified in this report for believing controller workload could be reduced more generally.

Further examination of the data is necessary to understand fully the workload results, e.g. to explore the effectiveness of the tactical-planner teams. Only further research will answer questions such as the extent to which the tactical controller duplicated the planning controller's work and how the balance of work between the controller roles can be optimised.

The statistical analysis shows little evidence of a change in airspace capacity. However, the study of capacity measures highlighted two important issues: the question of whether, under the operational concept examined, the controller needs to maintain the same level of awareness of the ATC picture as in today's system; and the representation of aircraft separation on the controller's display. Addressing these two issues would improve the chances of capacity gains.

Although the most advanced system gave better service to airlines than the baseline system, in the sense that there was a 5-7% improvement in the time the aircraft spent near its requested cruise flight level, the full picture is more complex and deserves further analysis. The existing data need to be analysed more deeply, for example looking at the impact on 3-D and 4-D FMS aircraft separately.

Recommendations for the development of the PHARE concepts and systems are:

- Explore ways to achieve the acceptance by the tactical controllers of their new role.
- Consider whether controllers need to 'maintain the picture'; then either improve how the system supports this, or fully persuade tactical controllers that it is no longer necessary.
- Address the difficulties in using the ground human machine interface (GHMI - i.e. the complete display used by the controllers) and mistrust by the controllers of the reliability and accuracy of the tools, through tool and GHMI refinements and improved training.
- Consider whether to change how aircraft separation is represented in the GHMI, or train controllers to accept the current representation.

Recommendations for future ATM real-time simulations, including the remaining PHARE Demonstrations, are that they should:

- Use controllers who will accept that an experimental trial is different from a pre-operational evaluation and manage their expectations accordingly.
- Consider using a team of 'technicians' familiar with the system who could provide a reference for speed of use of the interface, even if they would not fully represent the quality of control solution that would be generated by trained and validated controllers.
- Develop a broader and more detailed set of quality of service measures.
- Examine existing quality of service data in more detail.
- Use airspace which is 'real', in as many aspects as possible, i.e. one that represents the airspace sectorisation and aircraft routes that might be implemented were the computer assistance tools in use.
- Extend the range of objective workload measures.
- Start planning and designing the training course for controllers participating in the trials as soon as possible, and use controllers in the training team to lessen any resistance from the controllers taking part in the trials.
- If possible, take those staff who are computer literate, who are willing to investigate new operational concepts, and who are able to apply the concepts under investigation.

In summary, PD/1 was a major, successful demonstration of the integration of air and ground air traffic management, in en route airspace, through computer assistance tools, 4-D FMS and air-ground datalink. The evidence suggests that gains are achievable in controller workload, airspace capacity and quality of service to airlines. The recommendations suggest how PHARE can help further to make the most of these promising new technologies.

**DOC 96-70-24 has been produced in two volumes**

**Volume 1 - MAIN REPORT**

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## **1. INTRODUCTION**

### **1.1. SCOPE**

This document is the final report for the PHARE Demonstration 1 (PD/1). It aims to give those with little or no experience of the Programme for Harmonised Air Traffic Management Research in Eurocontrol (PHARE) an appreciation of what PD/1 has achieved. For those with closer involvement in the PHARE project, it provides a synthesis of the results, presents recommendations, and references the detail available in source data and in Volume 2 with the Annexes to this main report, namely:

Annex A: Experimental Design and Methods

Annex B: Controller Subjects and Training

Annex C: Results

Annex D: Analysis of Questionnaires

Annex E: Airborne Aspects of PD/1

Annex F: Lessons Learnt from PD/1

## 1.2. CONTEXT

Today's ATC system in Europe (and elsewhere) is, at times, unable to handle the traffic demands made upon it. Flow restrictions lead to delays during peak periods. The scope for increasing further the capacity of the system through existing ATC methods and technology is limited. Although developments in airspace, routes and sectorisation must, and will be, pursued, changes in the technology and process of ATC must also be envisaged if the necessary capacity gains are to be secured. The limiting factor in much of the present ATC system is the workload of the controller. A means has to be found to help the controller handle more aircraft in a given airspace without a significant increase in workload and without compromising system safety.

One proposed method of increasing controller productivity is by providing 'computer assistance tools' to both the planner and tactical controllers and by the use of datalinks for air-to-ground communication. The provision of such automated assistance to the controllers will support them in the resolution of conflicts and in the planning of efficient use of the airspace. The introduction of datalink to communicate between the airborne systems and ground environment will remove some of the current communication load from the controller and, in addition, will enable the use of onboard data to improve the precision of the ground system's model of aircraft performance which is used for track prediction and conflict prediction. In providing such support, it is necessary to ensure that the tasks removed from the pilot and controller are those which are best executed by computer, and those which remain are those best executed using the flexibility and adaptability of human skills.

The areas where computer support is expected to yield improvements are the accurate prediction of aircraft profiles, the analysis of potential options for the resolution of conflicts and the sequencing of aircraft for optimum use of airspace and runways. These, together with the monitoring of the flight's actual trajectory to detect any deviations from its cleared path, could provide a support environment that would allow a safe increase in the number of aircraft handled. To achieve this, detailed aircraft performance data, meteorological condition information and information concerning the aircraft's operational requirements would need to be made available to the ground environment using datalink communications. These proposals raise a number of questions concerning the resulting division of responsibility and tasks between the aircraft and the ground as well as the differing strengths and weaknesses of the human and the computer. It is the need to address some of these questions that has shaped developments within the PHARE Programme.

## 1.3. PHARE DEMONSTRATION 1

To achieve its objective of demonstrating a fully integrated future ATC system, PHARE set up a series of projects each led by one of the participating research organisations. These projects each contribute to the development of the various elements of the PHARE Operational Concept, which is to be tested in three major trials - termed demonstrations - of the proposed ATC system. The first demonstration, known as PD/1, was hosted by NATS on its real-time simulator - the NATS Research Facility. This was based at DRA Malvern, but has since been moved to the NATS Air Traffic Management Development Centre at

Bournemouth International Airport. PD/1 took place in autumn 1995 and explored the application of computer assistance tools and datalink to the en-route ATC system.

The NATS PD/1 team was responsible for the successful execution of PD/1; however, significant collaboration from other organisations within PHARE was required to ensure PD/1's success. This collaboration took the form of support to those tasks led by NATS and of specific deliverables to PD/1 from other PHARE projects. Besides the PD/1 Team itself, the projects which contributed significant elements to the PD/1 System included:

- the PHARE Ground/Human Machine Interface (GHMI) project;
- the PHARE Airborne Human Machine Interface (AHMI) project;
- the PHARE Advanced Tools (PATs) project - provided computer assistance tools;
- the PHARE Common Modular Simulator (CMS) project - provided tool integration;
- the PHARE Experimental Flight Management System (EFMS) project - provided the datalink, EFMS elements and live aircraft;
- the PHARE Validation project, - specified the experimental data to be collected and the framework for the analysis of the data.

Within the general objectives of PHARE, the specific objectives of the PD/1 trial were, within an en-route environment:

1. To determine the effect on controller workload and traffic throughput of the introduction of computer assistance tools from the PATs programme;
2. To determine the effect on controller workload and traffic throughput of the increasing proportion of 4-D FMS aircraft equipped with full duplex datalink;
3. To gain a degree of controller approval for the computer assistance tools introduced.

#### 1.4. REPORT STRUCTURE

The operational concept and advanced tools are described in Section 2, with a description of the research facility being presented in Section 3. The experimental design and the primary 'measures of merit' used in the analysis are given in Section 4, with a discussion of the controllers' training in Section 5. The main results derived from the PD/1 trial are given in Section 6 and discussed in Section 7. The report's conclusions and recommendations are presented in Sections 8 and 9.

This report is designed to present an overview of the PD/1 trial, the results achieved, conclusions reached and recommendations made. Full details of all these aspects are available in the aforementioned Annexes and References.

## 2. THE PD/1 SYSTEM

This section briefly describes the operational concept and advanced tools. More detail is given in the PD/1 Operational Scenarios document (Ref. 1).

### 2.1. OPERATIONAL CONCEPT

The PD/1 operational concept was built around the basic assumption that the human would retain the ultimate authority for ensuring the safety of all flights. The current controller roles of planner and tactical were retained and the PD/1 baseline system was derived from the Operational Display and Input Development (ODID) work programme conducted by Eurocontrol (Ref. 2). Thus no paper or electronic flight strips were used within PD/1; instead, the information was presented to controllers through interactive track data blocks and lists

displayed on the controller's main radar screen. The PD/1 baseline concept also contains some simple computer assistance tools.

The PD/1 concept was based upon aircraft having modern flight management systems that would allow them to navigate with high precision on any desired track. Some of the aircraft would be able to fly 4-D trajectories; that is, fly a three dimensional path in space whilst arriving at specified locations at specified times. When an aircraft first enters the airspace the pilot would datalink details of the requested trajectory to the planning controller on the ground; typically, such a trajectory would cover the next 20 to 30 minutes of flight. Using the computer assistance tools (see Section 2.2) the planning controller would check for conflicts with other aircraft and, if any were found, suggest a different trajectory to resolve the conflict. The alternative trajectory would be sent back to the aircraft to check that it could indeed fly the requested path. Once the trajectory is agreed by both pilot and controller, it would be input to the aircraft's flight management system which then flies the aircraft along the trajectory whilst being closely monitored by the pilot. The ground surveillance system would also monitor the aircraft's actual flight path and warn the tactical controller if any significant deviations were detected. The controller would then intervene tactically to prevent any conflicts occurring.

In the early years of a PD/1-type ATC system there would be many older aircraft still flying. In particular, not all aircraft could be expected to have a 4-D trajectory capability. Instead, they would be restricted to fly three dimensional paths without time constraints. These aircraft would also not have the avionics systems necessary to allow the dialogue between the ground and the airborne system. In such cases the ground system would calculate a 'good' trajectory for the aircraft based on its type, its origin and destination, its height and other factors. Whilst such a trajectory cannot take into account, in detail, the individual preferences of that particular airline for that particular flight's operation, it would be a reasonably good trajectory which would allow the flight to operate efficiently. Again, the proposed trajectory would be checked by the planning controller to ensure it was conflict free, and modified if necessary. For those 3-D aircraft without datalink facilities, individual clearances would be passed, at the appropriate time, to the pilot by the tactical controller over the voice R/T channel.

## 2.2. PHARE ADVANCED TOOLS

An ATC system such as that implemented in PD/1 depends critically on the controller having appropriate computer assistance tools. To implement the PD/1 system as described above, the ground system must be able to predict where the aircraft will be in the future; the controller must be able to tell whether the predicted trajectory will be in conflict with any other aircraft's predicted trajectory; and the controller must be warned when an aircraft is not following its agreed trajectory. To perform these tasks a number of computer algorithms, or tools were developed. The PHARE advanced tools (PATs) used in PD/1 were:

- the trajectory predictor;
- the conflict probe;
- the flight path monitor;
- the problem solver.

The **trajectory predictor** (TP) is a ground-based version of the tool used in the EFMS to predict the trajectory of the aircraft. The ground TP uses a database of aircraft performance characteristics, the initial flight plan and trajectory constraints entered from the GHMI to generate close-to-optimal 4-D trajectories for each flight. This allows the controller to carry out accurate 'what-if' modelling with tools such as the Problem Solver (see below).

Although the TP is capable of forecasting an entire flight from take-off to landing, in PD/1 the forecasts were limited to the 20-30 minutes flying time for flight across the simulated airspace.

The **conflict probe** (CP) operates automatically on each trajectory in the flight database comparing it with every other trajectory to identify any loss of separation. If a conflict is found, the CP reports the 2 aircraft involved, including details such as start of conflict and closest point of approach. This information is thus available to other tools and to the GHMI for display to the controller. The conflict probe will also pass information to the tools and GHMI when a conflict is cleared allowing the system displays to be updated.

The **flight path monitor** (FPM) checks every 'radar' reported aircraft position against the stored 4-D trajectory for the aircraft. If the aircraft has deviated significantly in any dimension from the modelled 4-D trajectory the FPM raises a deviation alert for the GHMI to display to the controller. The deviation alert gives full information on the deviation in all dimensions. However, in the PD/1 system not all information is displayed to the controller by the GHMI. The FPM also has the task of reporting when an aircraft has passed a significant point on its trajectory. Such a point is identified to the FPM by one of the system tools and the FPM alerts the tool when the subject aircraft passes that point.

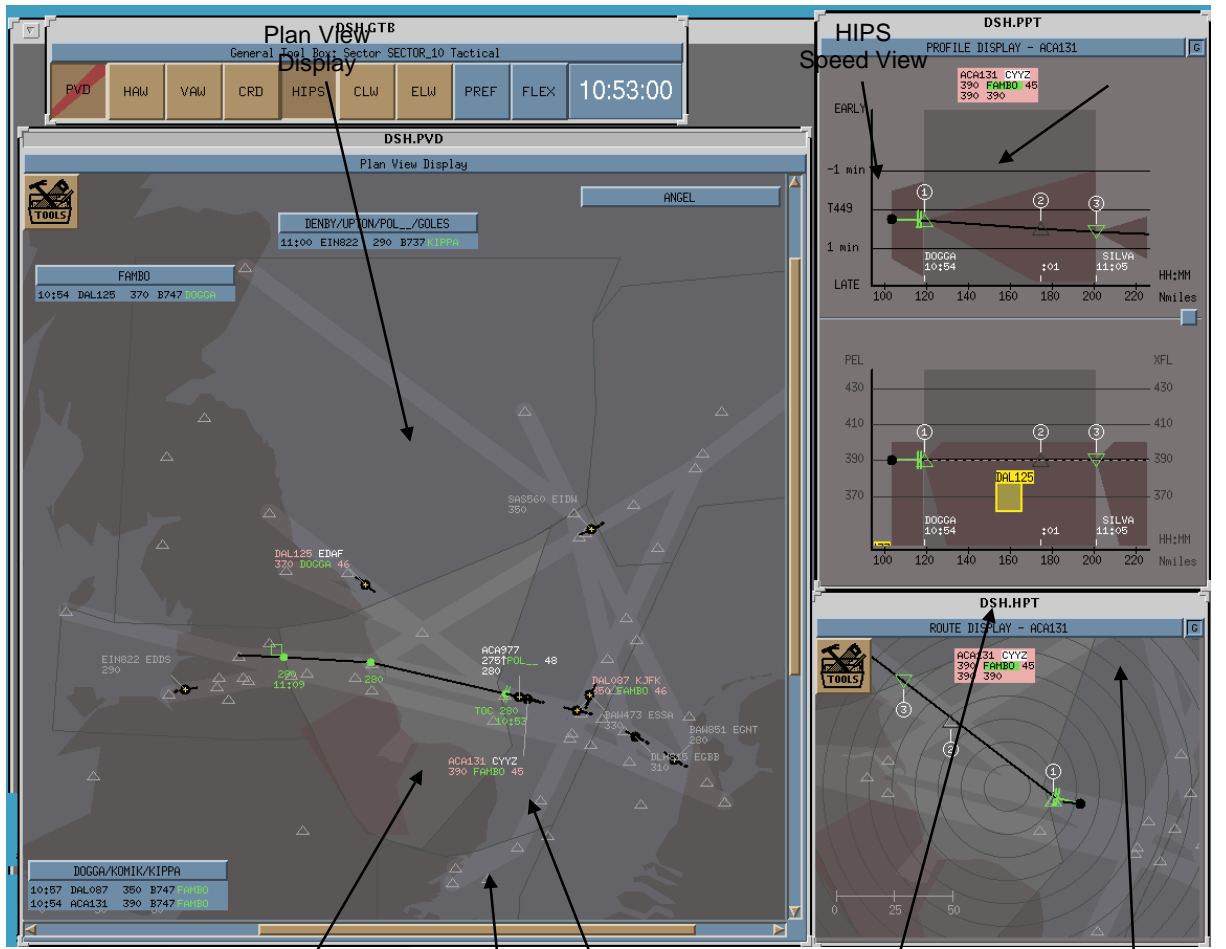
Unlike the other PATs, which are not immediately visible to the controller, the **highly interactive problem solver** (HIPS) was one of the main GHMI interfaces for the controller with system. HIPS is a sophisticated computer assistance tool which allows the controller to view the aircraft's proposed trajectory to check that it is conflict free and to edit, negotiate and agree trajectories using a horizontal, altitude or speed view of the aircraft's predicted trajectory. An example of the GHMI is shown in Figure 2-1.

In addition to the HIPS, other components of the GHMI used by the controllers drew information from the tools. They included:

- The augmented dynamic flight leg (ADFL) - which allowed controllers to highlight an aircraft's trajectory in the plan view display ('radar screen') and to accept it or propose changes;
- The conflict risk display (CRD) - which showed all potential losses of separation between aircraft in terms of how soon they could occur and what the minimum separation would be;
- The conflict zoom window (CZW) - which showed a forecast of the aircraft tracks for a particular conflict at the time of closest approach;
- The horizontal and vertical assistance windows (HAW and VAW) - these may be thought of as limited versions of the HIPS;
- The communications list window (CLW) - this prompted the tactical controller to issue instructions in a timely manner to aircraft which were not datalink-equipped.

A more detailed description of the tools and GHMI displays may be found in reference 3.

<i>ACA131 is the currently selected aircraft</i>
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ADFL

Track data block of ACA131

Position of ACA131

DAL125 will cross below ACA131's requested FL390

HIPS Horizontal Altitude View

### 3. THE TRIALS FACILITY

The PD/1 trial was conducted on the NATS Research Facility (NRF), a real-time ATC simulator (see Figure 3-1). This section provides a brief overview of the facility and its configuration for the trial. Full details of the facility developed for PD/1 are provided in the PD/1 Facility Specification (Ref. 3).



*Figure 3-1 - The NATS Research Facility (NRF)*

### 3.1. NRF HARDWARE

The NRF was configured as described below:

- a network of Intergraph and Sony workstations, providing the controllers with an interface to the system;
- a cluster of Sun workstations, supporting the simulation and basic software functions;
- pseudo-pilot Sun workstations providing an interface into the ‘air server’, which simulated the actual aircraft;
- ISA boxes (see Section 4.2);
- a connection to the UK experimental Mode S facility, using the ground station based at DRA (Malvern), to communicate with the DRA BAC 1-11 flying laboratory;
- an Ericsson phone system providing simulated R/T and telephone communication;
- a live R/T channel for use with the BAC 1-11 aircraft.

### 3.2. SOFTWARE

The major software components of the NRF were:

- computer assistance tools (see Section 2.2);
- a ground human machine interface (GHMI);
- a 4-D multi-aircraft simulator (AirSim);
- a surveillance and tracking system;
- a datalink interface;
- a flight plan processor;

- electronic inter-sector co-ordination support;
- supporting databases.

The common modular simulator (CMS) defined a common integration environment for the components, through a client server architecture using an application programming interface (API). A 'bridge' was built from the existing NRF API to allow the NRF to support the CMS API. The system software was written in the Ada and C/C++ programming languages.

### 3.3. AIRSPACE

To conduct the PD/1 trial, the NRF was configured to simulate two NERC sectors, 10 and 11/33, together with a number of manned and un-manned feed sectors. This airspace, illustrated in Figure 3-2, was chosen specifically to examine the PD/1 operational concept within the en-route scenario, with special regard being taken of the route structure, the type and location of route junctions and the type and requirements of the aircraft entering and leaving the sectors. In addition, no airfields are located below the sectors, thus strictly limiting the climbing and descending traffic. The traffic samples used during PD/1 are described in Section 4.

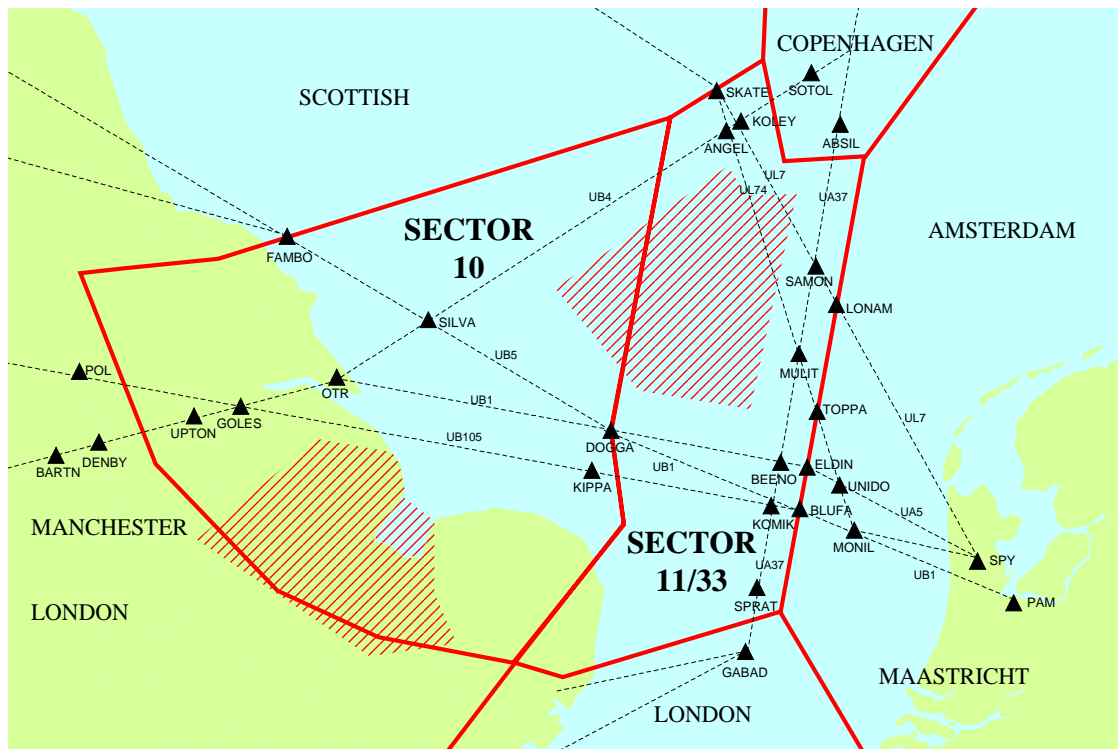


Figure 3-2 - Airspace for the PD/1 Trial

### 3.4. LIVE AIRCRAFT

For two of the runs in each week of the PD/1 trial a live aircraft, the NATS funded Defence Research Agency BAC 1-11, was introduced into the simulated traffic scenario. This aircraft was handled by the controllers in the same way as the simulated aircraft, but with the trajectory negotiation process being conducted directly between the ground based planning controller and the PHARE experimental flight management system (EFMS) installed in the aircraft. The communication between the simulator and the aircraft was conducted over a Mode S datalink. Full details of the EFMS are in Annex E.

The configuration of the simulation facility during the trials is shown schematically in Figure 3-3. (This is a simplified figure, for example the feed sectors have been omitted.)

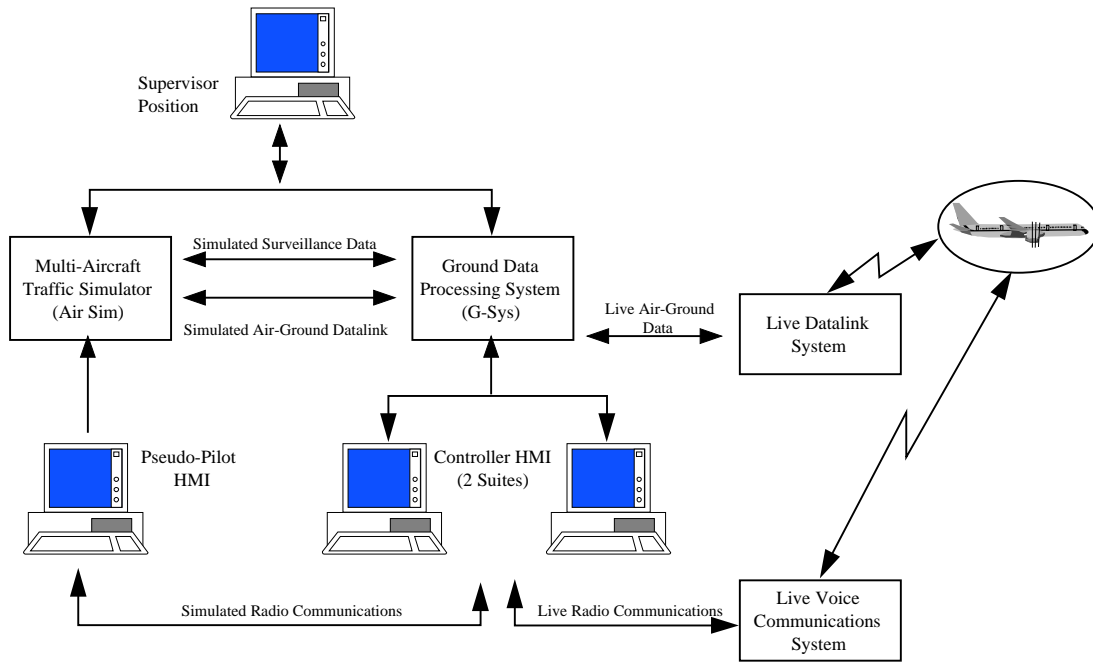


Figure 3-3 - Trials Configuration

#### 4. METHOD

This section briefly describes the design of the PD/1 trial. Full details are in Annex A.

##### 4.1. EXPERIMENTAL DESIGN

The PD/1 main phase demonstrations took place over eight weeks, from 23 October 1995 to 15 December 1995.

Three system ‘organisations’ (ORGs) were defined: the baseline (ORG 0) based on ODID (see Section 2.1); ORG 1, which examined the effect of the introduction of the PHARE Advanced Tools to assist the controller in implementing the PD/1 operational concept of ‘advanced planning’; and ORG 2, which examined the effect of introducing aircraft equipped with 4-D FMS and datalink. The objectives of the trial, namely to measure the impact of the PATs, 4-D FMS and datalink (see Section 1.3), were met by comparing the results from the various organisations whilst keeping other factors, e.g. controller role and traffic sample, the same. Table 4-1 summarises the organisations.

Organisation	Traffic sample	PATs	Procedures
ORG 0	Mixed population (eg including military aircraft) All 3-D FMS aircraft 3 traffic volumes	None	Controller plans ahead based upon flight data Procedures to suit paperless system
ORG 1	As above	Trajectory predictor Flight path monitor Conflict probe Highly interactive problem solver (HIPS)	'Advanced planning'; computer assistance looks up to 20 minutes ahead to design conflict-free trajectories. Procedures to suit PATs
ORG 2 (30%)	Mixed population 30% 4-D aircraft 1 live aircraft 2 traffic volumes	As above	As above plus procedures for 4-D FMS and datalink aircraft
ORG 2 (70%)	Mixed population 70% 4-D aircraft 1 live aircraft 3 traffic volumes	As above	As above

*Table 4-1 - Summary of organisations*

The traffic samples used in the experiments were based on samples previously used and validated for the NATS' Computer Assistance for En-Route (CAER) trials (Ref. 4). The samples consisted of projected 'busy day' traffic flows for the year 2000, and were generated by 'growing' a selected base day, Friday 17 July 1992, to the traffic demand forecast for the year 2000. These samples were then grown further by increasing the numbers of aircraft per route by 20% and 40% to provide 'medium' and 'high' volume traffic samples. Finally, the traffic demand was smoothed, so that predicted hourly capacity limits of the major airports were not exceeded, and a 75 minute 'slice' was taken from the day's traffic. For each level of traffic volume, several samples were used to ensure the generality of the results and to prevent learning effects perturbing the results of the later simulation runs.

Each controller participated in one week of measured runs and performed the same role on the same sector in each run from that week. Fixing the role of the controller in this way meant that statistical tests could be used which allowed the response to be measured of each controller individually to the different organisations and it also reduced the effect on the comparisons of variability between controllers.

The number of runs that could be conducted during the PD/1 trials was limited by time and controller availability. Mondays were used for refresher training, and during the other four days a total of fourteen simulation runs were carried out, scheduled according to the weekly timetable. Full details of the timetable are provided in Annex A.

#### 4.2. MEASUREMENTS

For each of the measured runs a complete set of system data was recorded for subsequent analysis within PD/1 and other PHARE projects and to enable the trial runs to be replayed. This data can be broadly split into two categories, objective and subjective.

**Objective data** are those which are directly recorded by the NRF. During the PD/1 trial a large number of these objective data were recorded, resulting in approximately seven and a half gigabytes of data. These ranged from information as to the number of aircraft under the responsibility of a particular controller at any one time to the exact sequence of mouse clicks required to execute a particular action when using a particular tool.

While **observations** are not the same as objective data, the use of video recording produces a definitive account of the controller's actions. During the trial each controller was recorded on video, both from behind to record the radar screen, and from in front to record their actions. These video recordings are extremely helpful for conducting detailed analysis of individual runs, and will be used extensively in the PD/1 follow-on analysis currently being conducted under the PD/3 IOCP work programme.

**Subjective performance measures** are those where the controllers perform some form of self assessment. As with the objective data, a large number of subjective measures were taken during the trial. Measuring the effect of the PD/1 operational concept on controller workload was one of the primary aims of PD/1 (see Section 1.3); however, controller workload is one of the most difficult parameters to record and analyse in any real-time simulation. For the PD/1 trial, the two major subjective measures of workload used were Instantaneous Self Assessment, or ISA, and the NASA developed Task Load Index, or TLX.

ISA, as its name suggests, is an assessment by the controller of his, or her, current workload at the instant of being asked. For all simulations conducted in the NATS Research Facility, an ISA cue flashes on the screen every two minutes. When the controllers notice the flashing cue they respond by pressing one of five buttons dependent upon how 'loaded' they feel, 1 corresponding to under utilised, through 3 for comfortable, to 5 for excessive. ISA, therefore, gives the analysts a measure of the controller's workload throughout every run, as well as an overall indication as to each run's average workload.

NASA TLX is a questionnaire administered immediately at the end of every trial and asks the controllers to estimate their workload over a number of measures, such as frustration experienced, mental effort, physical effort, etc. The results may be examined individually or combined to give an overall TLX score for that particular run.

Finally, and perhaps most important, are the comments from the individual controllers. These were obtained from questionnaires administered during the course of each week and through debriefs. While the numerical analysis is, by itself, extremely important, the controllers' comments are equally important when trying to understand what the numbers are telling us. This element of the results gathering must not be underestimated.

Annex A and Reference 5 describe the measurements recorded during the PD/1 trial in detail.

#### 4.3. CONTROLLERS

The controllers selected for the PD/1 trial covered a range of ages, nationalities and backgrounds. Their degree of computer literacy ranged from those who had never used a mouse to those who had experienced some computer assistance in their own current ATC systems.

The main phase trials lasted 8 weeks, with 4 controllers participating per week. The 32 controllers for the PD/1 Trials were made available by the following organisations:

Country	Organisation	Number of participants
Canada	Transport Canada	4
Denmark	LV - CAA Denmark	2
France	CRNA Ouest	2
Germany	DFS	5
Maastricht	Eurocontrol	2
The Netherlands	RNAF	4
Sweden	LFV - CAA Sweden	4
UK	NATS	9

*Table 4-2 - Summary of participants*

## 5. TRAINING

The aim of the training was to provide the controllers with confidence and proficiency in the use of the PD/1 system, thus enabling them to participate fully in the PD/1 experiment. Full details of the training and of lessons learned during the course are given in Annex B.

### 5.1. THE COURSE

The controllers were trained using a specially designed one week course, entailing a mixture of classroom lessons and hands-on training on the full system. For most controllers, training was the week before the trials. However, for some controllers their training was during the pilot phases of PD/1, which took place in April and September 1995. The day before the measured runs began, all controllers undertook three refresher runs.

In preparing and conducting this intense training course, a number of lessons were learned. In the first instance, at least one of the training staff needed a sound knowledge of course design in order to establish a realistic approach to the tasks. Secondly, it was not feasible to use technicians working on developing the system to assist in the preparation of training material - they would assume too much prior knowledge. Moreover, the system was experimental and continually evolving; hence, it was necessary to have instructors who were capable of fully understanding the system and its concepts, and who were also kept completely up to date with all changes to the system, however minor. Finally, whilst the well established teaching philosophy of 'building blocks' implemented by the NATS-designed 'instruction sets' was shown to provide a comprehensive course, it required a high ratio of instructors to controllers and a constant source of technical staff to satisfy the controllers' questions and concerns during both planned and spontaneous discussions.

### 5.2. CONCLUSIONS FROM THE TRAINING

The concepts and equipment of PD/1 are quite different to current ATC practices and systems. The general consensus of those involved in conducting the training was that, despite the intensity of the course, one week was not sufficient for the controllers to assimilate all facets of both the new facility and the new concepts

It became apparent during the training - and reinforced during the PD/1 trial - that some controllers had not fully recognised the underlying concepts of PD/1, such as the time element of a 4-D trajectory or the co-ordination of such trajectories. Controllers who saw the

new system as a 'threat' or those who had not worked on an operational system for many years had particular difficulty.

For training in future experimental system trials, the PD/1 Training Team offers the following recommendations:

- plan and design the training course as soon as possible within the project plan;
- work closely with the technical team to establish a complete and continually updated knowledge of the system;
- for concepts, such as PD/1, that are significantly different from current ATC systems, controllers with a full understanding of the concept should be employed as part of the training team to lessen any resistance from the controllers taking part in the trials;
- if selection of controllers is possible, take those staff who are computer literate, who are willing to investigate new operational concepts, and who are able to apply the concepts under investigation.

## **6. RESULTS**

### **6.1. INTRODUCTION**

PD/1 was not designed to be a pre-operational system, but instead is an experimental system used to evaluate the PD/1 operational concept within an integrated air/ground simulation. A programme of this nature will not - and should not - produce a single, simple result. This report, therefore, focuses on those results closely related to the trial objectives (see Section 1.3). The extensive database of results collected during PD/1 has been made available to all of the PHARE projects for use in developing the tools and operational concepts to be tested in the PD/2 and PD/3 demonstrations.

This section summarises the results presented in Annex C - the effect of the PATs and datalink on workload (Section 6.2), capacity (Section 6.3) and quality of service to airlines (Section 6.4); and in Annex D - the controllers' questionnaire responses on many aspects of the advanced system (Section 6.5). For an extended programme such as PD/1, the lessons learned by the project team are important to the interpretation of the results, especially for understanding the variability inherent in the results. They are presented in Annex F and summarised in Section 6.6. The results of the airborne demonstration are presented in Annex E and summarised in Section 6.7.

The results from the PD/1 trial are presented in Section 6 without comment. The implications of these results are discussed in Section 7.

### **6.2. CONTROLLER WORKLOAD**

This section brings together the results of ISA, TLX and the objective workload measures to compare the organisations, sectors and controller roles. A large number of hypotheses were tested (see Annex C, Section 2) using a number of non-parametric tests which were most suitable for the recorded data (see Annex A). The analysis concentrated on identifying whether the change in results between the different organisations was 'statistically significant', i.e. the observed difference in the results was unlikely to have occurred by chance. A five percent level was used to identify a statistically significant difference in results, and a ten percent level used to identify a trend. This section concentrates on those results which were statistically significant; the complete results obtained from the statistical analysis are given in Annex C.

The results can be examined both in terms of statistical significance (for example Table 6-1) and the size of any observed differences (eg Figure 6-1). The size of the difference between statistically significant results needs to be interpreted in the context of the ATC operational concept, so this is addressed in Section 7.

Table 6-1 summarises the ISA results, showing the impact of changing the organisation on the workload of the controllers, taking each traffic volume separately. The ‘=’ indicates that there was no statistically significant change in workload for that controller role and traffic volume. The ‘↑’ and ‘↓’ symbols indicate statistically significant increases and decreases respectively. The ‘.’ symbol indicates that no comparison was possible between those organisations at that traffic level. The subsections which follow discuss individual results from this table.

Organisations compared Traffic level	Planner			Tactical		
	low	medium	high	low	medium	high
From ORG 0 to ORG 1	=	↑	↑	=	↑	↑
From ORG 0 to ORG 2 (70%)	=	↑	↑	↓	=	=
From ORG 1 to ORG 2 (70%)	=	=	=	=	↓	↓
From ORG 2 (30%) to ORG 2 (70%)	.	=	=	.	=	↓

Table 6-1 - Summary of results: mean workload (ISA) per measured run

The alternative view of the ISA workload results, indicating the size of the changes, is given in Figure 6-1. For each combination of organisation and controller role, the distribution was calculated over all runs of mean ISA score for each run. The 25th, 50th and 75th percentiles of this distribution are shown. Only medium and high traffic volumes are included in the picture, since ORG 2 (30%) was not evaluated against low volume traffic. For example, from the graph it can be seen that the median of mean ISA for the tactical controller is about the same in ORG 0 and ORG 2 (70%) (2.16 and 2.15 respectively). The line connecting ORG 1 to the ORG 2 values is, in effect, interpreting ORG 1 as ORG 2 (0%), i.e. ORG 2 with no aircraft with 4-D FMS and datalink. Note that the statistical tests employed in the PD/1 analysis were chosen to reduce the impact on the comparisons of the variance of the results highlighted in Figure 6-1.

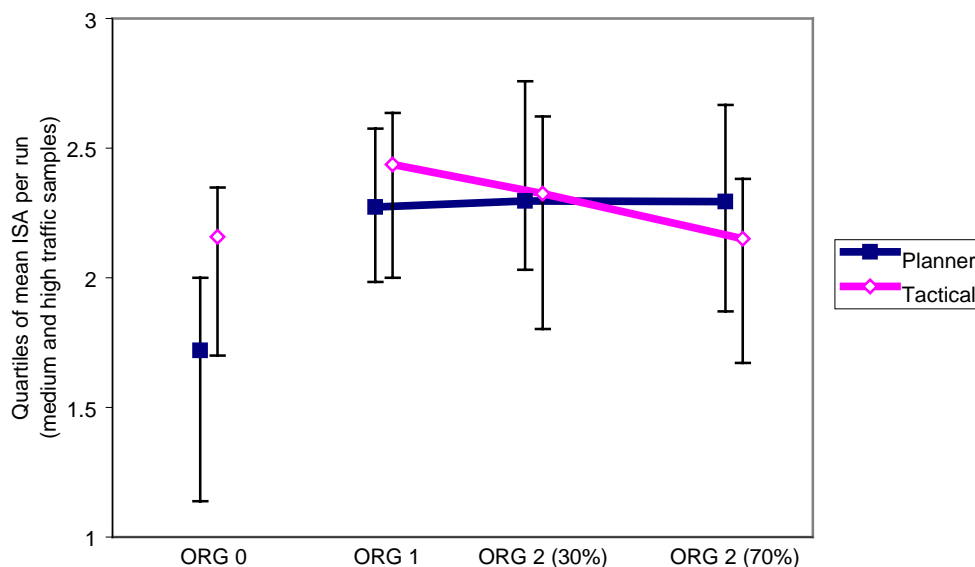


Figure 6-1 - Comparison between ORGs and controller role of mean ISA scores

6.2.1. Workload comparison of ORG 0 and ORG 1

A change from ORG 0 to ORG 1 would correspond to the introduction of the computer assistance tools (PATs) and the associated ATC procedure changes, e.g. planning conflict-free trajectories for 20 minutes ahead. This change was associated with a significant increase in controllers’ subjective workload (as measured by mean ISA and most of the TLX measures). However, it had a less obvious impact on the objective measures of workload: sector 11 had a significant increase in the percentage of time the tactical controller spent using the R/T, whereas in sector 10 there was a non-significant trend in the opposite direction (this might be explained by the differing geography of the two sectors). There was no significant difference in the number of air traffic control instructions issued by the tactical controller between ORG 0 to ORG 1. Thus, some, but not all objective measures supported the subjective result.

Turning to the individual TLX factors, for both the tactical and planning controllers the frustration experienced showed the greatest proportionate increase between ORG 0 and ORG 1. Time pressure also showed a significant increase from ORG 0 to ORG 1 for both roles; for the tactical controllers, this result was driven by the data from sector 10.

6.2.2. Workload comparison of ORG 0 and ORG 2 (70%)

A change from ORG 0 to ORG 2 (70%) would correspond to the introduction of computer assistance tools (PATs), the associated ATC procedure changes and 4-D FMS and datalinked aircraft. The impact of this change on workload was dependent on the controller role.

For the planning controller there was a significant increase in both the ISA and TLX subjective measures of workload. The individual TLX factors all showed a significant increase except for mental demand (see Table 6-2). The primary objective measures for the planning controller, namely the number of and time spent on phone calls, accounted for too small a proportion of all the elements making up the planner’s workload to be considered to support or to contradict the subjective results.

While the mean ISA score of the tactical controller decreased at low traffic volume it was not significantly different at medium and high traffic volume. Although the tactical controllers' overall TLX was unchanged, the physical demand component of TLX decreased significantly and there was a trend for mental demand also to decrease. The objective measures for the tactical controller (R/T usage and the number of ATC instructions issued) were consistent with the subjective measures: they decreased significantly. These results are summarised in Table 6-2 below for both sectors combined. The square brackets indicate the general direction of the trend, where the result was significant at the 10% level only.

Controller role	TLX Factor	Effort Expended	Mental Demand	Time Pressure	Physical Demand	Frustration Experienced
Planning controller		↑	=	↑	↑	↑
Tactical Controller		=	[↓]	=	↓	=

Table 6-2 - Comparison of ORG 0 and ORG 2 (70%) in terms of workload (TLX) components

### 6.2.3. Workload comparison of ORG 1 and ORG 2 (70%)

A change from ORG 1 to ORG 2 (70%) would correspond only to the introduction of 70% 4-D FMS and datalink-equipped aircraft, with computer assistance tools (PATs) and the PD/1 ATC procedures already in place. This change was associated with statistical differences in both objective and subjective measures of workload, which were strongly dependent on the controller role.

For the tactical controller there was a significant decrease in both mean ISA and overall TLX with the introduction of 70% 4-D FMS and datalink-equipped aircraft. The objective measures of workload also decreased significantly, supporting the subjective evidence. However, for the planning controller, while ISA was unchanged, there were significant increases in TLX and all of its components.

### 6.2.4. Workload comparison of ORG 2 (30%) and ORG 2 (70%)

The results here were consistent with the view of ORG 2 (30%) as an intermediate stage between ORG 1 and ORG 2 (70%) - remembering that ORG 1 may be considered as equivalent to ORG 2 (0%).

### 6.2.5. Workload comparison of controller roles

When comparing the workload between the tactical and planning controllers, the results are best graphically illustrated in Figure 6-1, and may be summarised as:

- The mean ISAs of the tactical controllers were significantly greater than those of the planning controllers in ORG 0 for high traffic levels; in terms of TLX the workloads were the same;
- The mean ISAs and overall TLX were the same for both controllers in ORG 1;
- There is a trend for the planning controllers to have higher mean ISAs than the tactical controllers in ORG 2 (70%); in terms of TLX this difference is statistically significant.

Thus, as illustrated in Figure 6-1, the PD/1 system has transferred some of the workload from the tactical controller to the planning controller through the introduction of the PATs and the applied PD/1 operational concept.

#### 6.2.6. Workload comparison of sectors

The mean ISAs of the controllers in sector 10 were found to be significantly greater than the mean ISAs of the sector 11 controllers over all the organisations combined together. Since the ISA workload scores in sector 10 were significantly higher than those of sector 11 in the baseline organisation, sector 10 was inherently more difficult to control than sector 11. Furthermore, the introduction of the computer assistance tools and 4-D FMS/datalink did not change the relative difficulty of controlling the two sectors although, for ORG 2, the difference between the sectors was only a trend, not a significant result.

#### 6.2.7. Workload summary

The workload results presented in Sections 6.2.1 to 6.2.6 may be summarised as follows:

- The introduction of the advanced organisations (i.e. the PATs, the operational concept and the system) significantly increased subjective workload - as measured by ISA and TLX - for both the tactical and planning controllers;
- The subsequent introduction of 4-D FMS and datalink brought the subjective workload level back to, or below, its original level for the tactical controller, but not for the planning controller;
- For those components of controller workload measured objectively, the full implementation of tools and datalink caused a significant reduction in objective workload.

### 6.3. AIRSPACE CAPACITY

The workload results are not sufficiently clear cut that either a positive or a negative change in airspace capacity can be deduced from them. If a significant reduction in workload for a given traffic level had been achieved between, say, ORG 0 and ORG 2 (70%), it would have been possible to state that additional capacity should be achievable with the advanced organisation. Since this was not the case, a number of additional measures were considered.

The controllers were asked for the percentage of the time during each run that they considered they maintained the ATC picture. A reduction in this percentage between ORGs for a specific traffic level would be an indication of a reduction in sector capacity. There were few recorded differences in this subjective measure - the controllers stating that they were able to maintain the ATC picture for 100% of the time in nearly 90% of runs, irrespective of organisation. There is some evidence of a trend for the planner and tactical controllers to differ in this measure in a manner consistent with the differences between them for the workload measures.

The number and duration of Short Term Conflict Alerts (STCAs) were examined between organisations. An increase in this objective measure could be seen as indicating an unsafe level of traffic being handled and hence indicative of a decrease in airspace capacity between organisations. There were no statistically significant differences between organisations in the number or duration of STCAs.

Finally, the number of minimum separation infringements was examined as a similar indicator of airspace capacity to STCAs. ORG 2 with 70% 4-D FMS and datalink-equipped aircraft had statistically significantly more minimum separation infringements than ORG 0 (or ORG 1). However, the difference was small: in more than 90% of cases each controller had about the same number of infringements (i.e. at most one more or one fewer) in ORG 0 as in the matched traffic sample in ORG 2 (70%). There was considerable variation between

controllers, including a (non-significant) trend for sector 10 controllers to have more than sector 11.

Thus, there is little evidence of a measurable difference in airspace capacity between the organisations.

#### 6.4. QUALITY OF SERVICE

The quality of service is an important measure of the effectiveness of any ATC system. To address the impact of the PATs and the associated operational concept on the quality of service to airlines, two objective measures were evaluated: time at or near requested cruise flight level (RCFL); and time spent in sector.

In ORG 2 (70%) aircraft spent significantly longer at, or near, their RCFL than in ORG 0. There was little difference, by this measure, between ORG 0 and ORG 1, so the effect must have arisen either due to the datalink or the 4-D FMS. The size of the difference, is five to seven percent (averages for sector 11 and sector 10 respectively). If this effect held operationally, it could provide a direct, fuel-saving benefit to airlines.

Rather more difficult to interpret is the significant increase in time spent in each sector which the advanced organisations represent, compared to the baseline. The picture is confused further by two effects: the averages per run showed slightly different results to the comparisons aircraft by aircraft; and the differences in time were small (0% to 5% or 0.4 to 25.6 seconds, being the averages for sectors 10 and 11, respectively), but statistically significant by virtue of there being many data points available. It might be that the effect was due to climbs or descents missed, or additional heading instructions, but it is not appropriate to draw conclusions without more detailed investigation. It should also be noted that for most aircraft the transit of sector 10 or 11 is a small part of their journey, hence losses may be counter-balanced by changes elsewhere en route.

Thus, at least one indicator suggests that ORG 2 (70%) represents better service to airlines than in ORG 0, with a 5-7% improvement in time near RCFL. The other, indicating the opposite, is more difficult to interpret and has wider variation; the experimental design of PD/3 may allow this to be looked at more accurately.

#### 6.5. CONTROLLER VIEWS: THE QUESTIONNAIRES

Annex D presents the analysis of the controller questionnaires. The controllers were asked to reply to a number of questions by ticking the following responses: strongly disagree; disagree; slightly disagree; slightly agree, agree, strongly agree. In addition, room was available for the controllers to enter any comments they felt applicable. The results are summarised below based on the different sections of the questionnaires. In each case, the main comparison was between the number of controllers recording one of the three 'agree' categories versus those recording one of the three 'disagree' categories.

##### 6.5.1. Training and Simulation Environment

These questions covered the simulation room, use of ISA, traffic samples, feed sectors, pseudo-pilots and training. In each case, the majority of controllers were in favour of the way these items were implemented by the PD/1 team, although only a few of the results were statistically significant.

The tactical controllers tended to find that responding to the ISA cue was distracting whereas the planning controllers did not. Comments indicated that the reasons preventing full

acceptance of the traffic samples were some minor shortcomings in the aircraft performance models underlying the simulation. This is not seen as a criticism of the traffic samples. As for acceptance of the feed sectors, a common criticism was that traffic was occasionally released from feed sectors already in conflict.

The vast majority of the positive responses support the conclusion that the training and simulation conditions provided in PD/1 had been accepted sufficiently well by the participating controllers. This is also an important factor for increasing trust in the simulation results.

#### 6.5.2. HMI: Displays, Dialogues, Interaction

The advanced system GHMI is illustrated in Figure 2-1. The use of the mouse to interact with data presented in the windowing environment with pop-up menus was significantly accepted by the controllers. The colour coding concept for indication of aircraft status was also accepted as being comprehensible and useful. However, there was a clearly negative overall response on the readability of text.

A significant majority of controllers agreed that electronic co-ordination was an improvement as compared to co-ordination by telephone.

STCA presentation was rejected by the majority of the participants. Written comments, six in total, indicated the main reason was “too many false alarms” or “mistakes”.

The controllers clearly indicated that aircraft whose track data blocks they felt should have responded to inputs from the controllers’ mouse were sometimes not accessible - notably to gain information on aircraft not yet under that controller’s responsibility. This was true for all ORGs, with the strongest negative responses being for ORG 0.

#### 6.5.3. Operational Aspects: Traffic Handling, Procedures

A significant proportion of the controller sample - three quarters - agreed in saying that the datalink reduced their workload.

When tactical controllers were asked whether it was acceptable to them that 4-D FMS aircraft follow a trajectory with no further tactical instructions being given, i.e. fly as cleared by the planning controller, there were two groups of controllers with opposite opinions. Comments indicated that those tactical controllers who were against this concept had difficulties in accepting level and heading changes occurring without explicit approval from the tactical controller.

Asked about safe handling of traffic, keeping aircraft separated and how well the system helped to ‘maintain the picture’, ORG 0 received overall approval while the advanced ORGs did not. Indeed, a majority (not statistically significant) were against the advanced ORGs. On the other hand, the advanced ORGs were perceived to be relatively better in supporting conflict detection and resolution.

The roles of tactical and planning controllers were generally accepted as being clear and unproblematic. Significant positive overall responses were obtained for each ORG. The controllers generally would have liked to co-ordinate traffic with other sectors earlier than the system sometimes allowed them to do.

A significant number of controllers were confident that they could have handled even more traffic with the ORG 0 system. No such significant response distributions could be observed for ORG 1 and ORG 2.

Controllers were asked to estimate their workload as compared to the today's system. Although one might argue that "today's system" is quite an imprecise term in this context, the controllers' *relative* view of the ORGs revealed some markedly basic differences. ORG 1 received the most significant negative overall estimates. In ORG 0 as well as in ORG 2 a considerably higher number of controllers gave better workload estimates compared to their estimate for today's system, but the differences were not significant.

#### 6.5.4. Individual Tools and Functions

Among the tools available to both the tactical and planning controllers, only the augmented dynamic flight leg<sup>1</sup> (ADFL) was reported as being used frequently and as being relevant to the controllers' work. This view was clearly rejected for the conflict zoom window (CZW). The ADFL was also significantly approved of as being helpful for avoiding conflicts - a majority (not statistically significant) thought the conflict risk display (CRD) unhelpful in this respect. Finally, the ADFL was seen as a useful means for reducing workload; whereas the CRD and CZW were not seen as in this light by a significant number of the controllers.

All the planning controllers reported that the highly interactive problem solver (HIPS) was used frequently, relevant for their work and helpful to avoid conflicts, whereas the horizontal and vertical assistance windows (HAW and VAW) were much less accepted. A controller comment which was typical says "...when you have the HIPS, the HAW and VAW are not used". In terms of workload reduction, the planning controllers rated the HIPS in a positive tendency. Written comments on the HIPS showed a desire to continue with development of the HIPS through both general criticisms - "...it distracts from the radar" (i.e. from the plan view display (PVD)), "ADFL could be used..." (instead), "...waste of airspace (i.e. taking-up PVD room which could be used to display airspace)" - and also positive suggestions - to allow better "...identification of aircraft which block altitudes", or "...it should be possible to leave exit /entry levels out of the trajectory".

The tactical controllers reported that they used the communications list window (CLW) frequently and that it was highly relevant for their work. Some written comments indicated that two different views may have governed the tactical controllers' assessment of the CLW: a positive view which was to concede in principle that a CLW "...is a main control tool in ORG 1 and 2", and a negative view which is to criticise particularly the consequences of the CLW's importance, e.g. "...the CLW distracts...", or "...the computer is controlling you."

There was significant controller agreement that improvements were desirable for all tools and functions. For instance, comments on the ADFL indicated that some controllers would have liked to make more extensive use of it than it was foreseen in PD/1. So, it was suggested "...to extend it to waypoints outside of the sector", in order to "...use it to propose a trajectory in an other sector", - this would then be an enhancement of ADFL functionality rather than an improvement.

#### 6.6. OBSERVATIONS OF THE PD/1 TEAM

In addition to their experience in integrating the PD/1 system, the PD/1 Team had the opportunity to talk to controllers throughout the training and trial period. The team therefore

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<sup>1</sup> See Section 2.2 for a brief summary of the tools and other components.

made a large number of informal observations which may be useful in interpreting the analytic results. These are discussed in detail in Annex F and summarised here.

In response to a specific question “What are your views on the advanced planning concept” the majority of the controllers thought the concept of advanced planning, with computer assistance and air-ground integration, would be beneficial. They considered that it would improve capacity through more efficient use of the airspace and a reduced controller workload, and would provide a better service to the user. In particular, they thought it would be very useful for oceanic control, regions with many overflights, and when there was a substantial number of 4-D FMS/datalink fitted aircraft. However, a number of reservations were also expressed. The comments provided by the controllers together with the PD/1 teams interpretation are discussed below.

The controllers, while expressing their approval of the PD/1 operational concept of ‘advanced planning’ in principle, had a number of reservations about the concept:

The PD/1 team noted that the controllers expressed concerns about the role of the Tactical Controller. The Tactical Controllers considered that they were under involved in the control strategy and that their role had been deskilled since in many cases it involved merely passing clearances according to the Planner’s plans and in other cases it merely involved monitoring. They considered that this could have safety implications, there were three main issues contributing to this view, namely the TC:-

- had to trust his Planner;
- had to trust the output of the system;
- would be unable to cope with an emergency situation.
- Some tactical controllers saw their role as merely monitoring and passing clearances according to the planner’s plans. They thought that this might affect safety, since they had to trust the tools and might be unable to handle an emergency situation;

There was also a general consensus that the Tactical Controller was not able to build a mental picture of the traffic situation and was consequently not adequately in control. This was deemed to be a problem if an emergency arose. Although actual emergencies were not simulated in PD/1, an emergency situation could arise when aircraft were deviating and immediate action was required to resolve a near-term conflict. The Tactical Controllers felt that they would be unable to cope in many of these situations since they did not have a mental picture of the aircraft in their sector. Particular problems were reported by the Tactical Controller with datalink-fitted aircraft, since these would execute their planned manoeuvres without any input from the Tactical Controller, and the only way a Tactical Controller could discover its intended trajectory was by displaying the flight leg. With the current concept, it was felt that further advisory tools to help in such emergency situations would be needed, and that some indication of the future intentions of a datalink-fitted aircraft was necessary.

- The view was expressed that the tactical controller was not able to build a mental picture of the traffic. Again this could be a problem in an emergency;

As the plans were generated by the Planner, the Tactical Controller usually had no part in developing them and often could not understand why a certain manoeuvre had been chosen. Some Tactical Controllers were therefore unhappy with the plans, and blamed either the system or the Planning Controller. These controllers often tactically intervened and manoeuvred an aircraft differently from that planned. This resulted in the aircraft’s agreed trajectory, or contract, with the ground being broken and therefore an increase in workload occurred as the aircraft had to be re-planned. Other controllers accepted that the Planner had

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chosen the plans for good reasons and followed them even though they could not appreciate the reason for some of the planned manoeuvres.

- Some tactical controllers were unhappy with the plans they had to implement, and blamed either the system or the planner. If they intervened unnecessarily to change an agreed trajectory, as was sometimes observed, this would unnecessarily increase workload;

Tactical Controllers seemed happiest when the two controllers worked as a team, with the Planner discussing the plans for certain aircraft so that the Tactical Controller was aware of the reasons for these plans, and the Tactical Controller making suggestions in the light of the evolving traffic situation such that the Planner might replan an aircraft more efficiently. Several pairs of controllers were observed to work well as teams, but others rarely spoke to one another and some commented that they felt that they were working in different timeframes so couldn't communicate.

- Tactical controllers seemed happiest when the two controllers worked as a team. Several pairs were observed to work well as teams, but others rarely spoke.

TMany Tactical Controllers were unhappy about the output of the computer assistance tools, this was apparent from both discussions and results of the debriefing questionnaires (see Annex D).

TTTactical controllers were sometimes unhappy about the output of the tools, for example:

For example, they were often unwilling to accept the planned conflict resolution derived using the tools. As, based on their own predictive capabilities, they considered that the aircraft would not maintain separation without further manoeuvres. Quite often the comment was made that "the aircraft involved will violate separation criteria if they continue along this path." This was compounded by the HIPS not distinguishing between aircraft climbing in front or behind another aircraft, see section 10.3, and Planners often therefore planned to climb aircraft in front of another.

- The HIPS could sometimes lead the planning controllers to safely plan an aircraft to climb in front of another. The tactical controllers would not trust such a plan and monitored these cases closely, expecting loss of separation and thereby possibly increasing cognitive workload;

Equally, if Planners had planned an aircraft to climb after one at a higher flight level had passed it, the Tactical Controller was unhappy at the time delay that was often present. This was a result of the error bounds around the aircraft's position that had to be included in deciding when it would be safe to climb. The result was that the aircraft was planned to climb later than it would have done if under purely tactical control. (Note that this is an apparent anomaly of the advanced planning concept which is generally considered to make more efficient use of airspace - error bounds have to be included in any prediction of an aircraft's position and these will grow with time for 3-D FMS aircraft. Aircraft may therefore be planned to manoeuvre at less optimum times than if they were under purely tactical control). A lot of time was spent by the controllers monitoring these aircraft as they progressed along their planned trajectories and explicitly checking the separation when they crossed or passed although this monitoring facility was provided by the tools. While they were continually monitoring these aircraft other aircraft were needing planning etc. hence a backlog of aircraft built up needing attention.

- Similarly, error bounds in the HIPS meant that an aircraft might be planned to climb later than it would have done under tactical control. The tactical controllers might increase their workload by monitoring these cases and possibly even intervening to climb the aircraft earlier.

Observations on the nature of the trials included:

However, one controller stated that controllers built up pictures by being familiar with the airspace and traffic flows and not purely by viewing the current traffic situation ; within this trial it would therefore be unreasonable to expect a good mental picture to be established given the time the controllers were exposed to the traffic scenarios.

- One controller said that it would be unreasonable to expect a good mental picture to be established given the length of exposure to the traffic scenarios;

Several controllers noted that there were problems with using the concept in the airspace simulated since Sector 11 had very short east-west routes, but thought that it would be better in larger sectors allowing a greater time for advance planning. A number of discussions centred around whether fictitious or real airspace should be used for the measured sectors. The argument being that one of the sectors chosen, NERC Sector 11, was too narrow to give sufficient time for the Planning Controller of Sector 10 to perform his tasks for Westbound traffic and therefore wouldn't it be better to use larger sectors that would be more suited to the tools. While this would undoubtedly make it easier to use the tools the disadvantage is the criticism that "it works in the simulation but what about the real world".

- Several controllers noted that there were problems with using the concept in the airspace simulated, since sector 11 had very short east-west routes;

One recurring problem was the difficulty that some controllers had in appreciating that they were taking part in a trial rather than a pre-operational evaluation. This led to the common comment "this is not how we do it today" It was evident during the trials that controllers who had had exposure to trials or experimental programmes found it easier to accept that they were taking part in an experimental evaluation rather than a pre-operational evaluation.

- Some controllers found it difficult to accept that PD/1 was an experimental system on trial and not a pre-operational evaluation. Those with experience of trials appeared to find it easier;

The drawbacks of using an existing airspace and traffic patterns is that controllers familiar with it will tend to attempt to use the techniques they employ in that airspace today which is not always conducive to introducing new tools and concepts. They also become very concerned about details of the traffic sample e.g. when increasing the traffic density during the trials comments such as "...that airline would not fly that number of 737s on that route..." were common. Both of the previous points could have an adverse effect on the evaluation of the tools.

- Use of real airspace led some controllers to comment on details of the traffic sample, e.g. "...that airline would not fly that number of 737s on that route...".

The controllers only had a week of training to learn new operational concepts, new interfaces etc.. This was insufficient time to be familiar enough to operate the system efficiently, particularly for the advanced organisations. There was considerable variation in the controllers ability to interact with the interface. This was evident from observations during the trials and from studying the video recordings of their actions made during the trials. Those controllers who had difficulty in operating the interface tended to become frustrated, and reported this on their questionnaires. Some of the controllers showed no difficulties at all in performing the graphical manipulations required. This makes it very difficult to draw simple conclusions from controllers perceptions of general system aspects. It is essential to follow up the reasons for their comments. Specifically it was observed that most controllers were much slower at manipulating the interface than members of the project team who had considerable experience of it. The slowness resulted from two main factors - firstly, being

unsure of how to do something, not aware of the quickest way of achieving a certain result or trying to do something at an inappropriate time. These are expanded on below:-

The PD/1 team observed considerable variation in the controllers' ability to use the interface and in their understanding of the concepts. Some controllers seemed comfortable with the interface, whereas others were observed:

Unsure of how to do something:

Examples observed of the first factor were trying to do non-permitted actions i.e. attempting to interact with fields in a label or menu when they were not available due to lack of control authority at the time.

- trying to do non-permitted actions, e.g. interact with an aircraft which was not available due to control authority for that aircraft not yet being transferred;

Understanding of appropriate tool for task:

For example in the advanced system, two tools were available to the controller for editing, validating and registering trajectories. These were the Augmented Dynamic Flight Leg (ADFL) and the Highly Interactive Problem Solver (HIPS), both used in conjunction with the Trajectory Support Tool (TST). The ADFL was particularly useful for registering a trajectory if it required no editing (i.e. aircraft did not need climb or descent manoeuvres inserted and trajectory was conflict-free). If the trajectory needed editing, the HIPS was generally the optimum tool to use since it showed possible conflict regions, though the ADFL used in conjunction with the HIPS provided a faster means of putting aircraft on parallel routes. Controllers who were using the system efficiently would choose the tool most appropriate to the task required, and usage would be divided between the two tools.

- not picking the best tool for the task, e.g. using the HIPS when the ADFL would have been quicker, or vice versa;

Speed of interaction with the tools:

Some controllers were observed to take a long time over certain actions. This would be justifiable on occasions since they may have been thinking over the traffic situation, but it was apparent that they sometimes forgot to complete a sequence of related inputs. e.g. they would edit and validate a trajectory but forget to complete the registration process (i.e. inputting the trajectory into the system).

- failing to complete a sequence of actions, e.g. not registering an edited trajectory;

Additionally, with the advanced organisations, controllers were not fully familiar with using the system/concept to control traffic. This resulted in them not using the system optimally, though this could also have been the result of controllers not accepting the concept and therefore not using the system as intended.

Some controllers had difficulties in fully understanding the concept of trajectories and their error bounds. For example, they could not understand why trajectories had to be re-coordinated with the next sector if they had only changed the sector exit time, and not the exit flight level or position. They also did not fully appreciate the meaning of potential conflicts identified by the PATs Conflict Probe - this did not just indicate aircraft that would definitely lose separation, but those that might dependent on their actual positions within the

trajectory error bounds. One particular situation which arose quite often was where an aircraft wanted to climb but was prevented by another aircraft above it. The error bounds around the predicted trajectory were often such that although the Planner had planned the aircraft to climb as soon as it was apparently safe to do so in the HIPS, the actual traffic positions made it safe to do so at an earlier time. Some TCs understood the reasons for the climb being when it was while others did not, and blamed either their Planner or the system, and tactically intervened to climb the aircraft earlier than planned. Another situation in which it was apparent that some controllers understood well the information the tools were presenting was in the use of the HIPS: these controllers often manipulated trajectories in such away that they clipped error zones so that an aircraft was apparently in a potential conflict on the assumption that the probability of a loss of separation was small.

- failing to re-coordinate trajectories with the next sector if they had only changed the sector exit time, and not the exit flight level or position;
- clipping 'error zones' shown in the HIPS, thus creating a potential conflict, on the assumption that the probability of an actual loss of separation was small.
- the speed profile window was considered difficult to use and interpret. This was due in part to the fact that the speed was not given directly within the window it was represented indirectly as the time at a point relative to an average speed. The controller being able to propose an early or late time at a given point;
- when manipulating the trajectory within the HIPs windows it was not possible to see very far into the previous or next sector. This resulted in some trajectory proposals failing due to manoeuvre planned for the aircraft in other sectors which were not visible to the controller;
- it was generally considered that the ability to set up parallel routing using the HIPS lateral display would be an advantage.

Some particular observations were made about the HIPS:

- the speed profile window was considered difficult to use and interpret, due in part to the fact that the speed was represented only indirectly in it (in terms of time);
- it was not possible to see very far into the previous or next sector;
- it would be an advantage to be able to set up parallel routing using the HIPS.

The first factor that can be noted from the data is that in the mean number of instructions issued per aircraft for each of the sectors there is a considerable variation between the Tactical Controllers. Whilst this is to be expected for ORG 0 where control is of the classical form i.e. there are no tools to provide the controller with manoeuvre advisories, it is less evident why it should be so variable for the other organisations where the Planning Controller and the tools are attempting to provide a stabilised conflict free traffic flow for the sector.

Considering week 1 for Sector 10 it is noticeable that the number of ATC instructions issued in ORG 1 is low compared to other weeks. Further analysis has shown the following:-

- the number of instructions generated as a result of the Planning Controllers task is comparable to those for other weeks;
- the Communications List Window is approximately the same size as for the other weeks.

Particular problems were observed with the communications list window (CLW), which presented timed messages to the tactical controller which they were supposed to issue over the R/T. Tactical controllers were observed, on occasion:

- to indicate in the CLW that a message had been sent, but not to issue the instruction over R/T;

Tactical Controllers were supposed to pass clearances to 3-D FMS aircraft over the R/T in accordance with the plans generated by the Planning Controller. The clearances and times at which they should be sent were listed in the Communications List Window (CLW). On many occasions it was observed that the Tactical Controllers forgot that they were supposed to send the instructions from this list and gave aircraft an instruction when they decided it was appropriate. It was also observed that they sometimes forgot the mechanism for informing the system that the clearance had been sent (clicking on the message in the CLW) and interacted with the track data block (as in the reference system), thereby inputting a tactical intervention. The result of these actions was that aircraft were no longer following planned trajectories. As the tools were working on the planned trajectories and not the actual flight paths of the aircraft loss of separation occurred which could not be predicted by the tools but only by the STCA.

- to give the instruction when they thought right, rather than at the time the CLW indicated;
- using the track data block to enter an instruction sent over the R/T, rather than just clicking in the CLW. This effectively adds a tactical intervention and produces unnecessary workload.

## 6.7. AIRBORNE DEMONSTRATION

As was described in Section 3.4, a live aircraft - the NATS funded DRA BAC 1-11 (see Figure 6-2) - was used for two of the measured runs in each week of the PD/1 trial. The airborne demonstration element is fully described in Annex E. This section summarises the results.

The PD/1 airborne demonstration programme was extremely successful, confirming as a matter of routine the ability of an aircraft to agree conflict-free trajectories with ATC and to fly them, while operating within continuous 4-D constraints. Specifically, the demonstration flights confirmed that

- A digital datalink enabled detailed information on proposed trajectories and imposed 4-D constraints to be transmitted between the aircraft and ATC;
- The airborne system was sufficiently flexible to be able to implement revised trajectories needed to satisfy ATC short term conflict avoidance requirements;
- The aircraft followed the trajectory successfully, operating within a continuous 4-D envelope;
- The EFMS demonstrated the ability to function in a demanding trials environment;
- Accurate weather forecasting and engine performance models are essential if the aircraft is to fly close to its optimal performance parameters;
- 4-D control was remarkably accurate: in summary, the results suggest the predicted number of occurrences of height deviations greater than 300 feet or time errors greater than 10 seconds would be of the order of 0.5 per hour.

Finally, the flights provided a convincing demonstration to the aviation community of the direction of ATM research, enabling them to visualise the environment of the 'silent cockpit'.



*Figure 6-2 - The BAC 1-11 Experimental Aircraft*

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## 7. DISCUSSION

This section draws together the results of the statistical analysis, controller questionnaires and the PD/1 Team's observations. The results will have been influenced by a number of factors, some of which are inherent in such a trial but which need to be understood to draw proper conclusions, while others could be the subject of further experiments or analyses. Such factors will be discussed in this section.

Although the results are discussed under separate headings, they are not independent of each other. In particular, controller approval (Section 7.4) colours most of the other results.

### 7.1. WORKLOAD

The workload results are discussed in terms of two stages of development of the advanced system: ORG 0 to ORG1 and ORG 0 to ORG 2 (70%). These stages may not correspond to real stages of implementation, but they are convenient for bringing out the main lessons of PD/1.

#### 7.1.1. Introduction of advanced planning and advanced tools

A change from ORG 0 to ORG 1 would correspond to the introduction of advanced planning and advanced tools (see Section 2). ISA, TLX (Section 6.2.1) and the questionnaire responses (Section 6.5.3) all point to both controller roles having a heavier subjective workload in ORG 1. The consistency of the three subjective measures, ISA, TLX and the questionnaires, reinforces this result.

On the other hand, the objective measures of workload show few differences between the organisations. However, these measures cover only a subset of the activities which a controller would undertake in a current-day system and none of the unique activities in the advanced system: the effort involved in advanced planning, for example, would not be expected to show in these objective measurements. Nor does the 'number of ATC instructions' measure take into account the fact that the nature of instructions, and therefore the associated workload, issued by the tactical controller differs between the ORGs. In ORG 0, an instruction is how the tactical controllers implement their own plans, whereas in ORG 1, the tactical controller issues instructions when prompted, to implement the plans of the planner - therefore, it may be expected that the workload associated with issuing an instruction in ORG 0 is greater than in ORG 1.

Is it, therefore, possible to identify what contributed to the perceived workload increase? TLX suggests it was frustration and time pressure (Section 6.2.1). The questionnaire responses and other observations include a number of factors which could have contributed to these two factors. This is not to say that every controller suffered from all of these effects -it is in the nature of observations of this type to be individual cases; sometimes from someone representative of a 'typical' controller, and sometimes from an extreme, but perhaps illuminating, case. These subjective results and observations are, in any case, the best evidence PD/1 provides for why the workload effects were observed, and are summarised below:

- i. Any mistrust of the tools by the tactical controllers (see Section 6.6) and checking of their output would increase time pressure; the controllers would feel they were monitoring and hence manually planning traffic flows to the same extent as in ORG 0 and, in addition, trying to reconcile their views with those reported by the tools;

- ii. Difficulties experienced with the GHMI by either controller (see Sections 6.5.4 and 6.6), due to lack of familiarity or other reasons, could increase both frustration and time pressure;
- iii. Any dissatisfaction with the concepts of the tactical controller's role could increase frustration, e.g. worries about manoeuvres taking place without their explicit approval (Section 6.5.3), merely monitoring and passing clearances (Section 6.6), or "the computer is controlling you" (Section 6.5.4);
- iv. Any dissatisfaction with the tactical controller's role in practice, e.g. the quality of the control strategies they were required to implement (Section 6.6), could also increase frustration;
- v. Any misinterpretation of the trials as being a pre-operational evaluation (Section 6.6) could lead to expectations of the tools that were too high and thus cause frustration with ORG 1.

Given the introduction of advanced planning, the measured increase in the subjective workload of the planning controllers between ORG 0 and ORG 1 is not unexpected. The increase for the tactical controller is perhaps more surprising. However, the evidence cited above points to a number of actions which could reduce the apparent impact, for one or both controller roles, and lead to results that might represent more closely what would occur after a full development and training programme, were the tools implemented in the operational system:

- a. Use controllers who will accept that an experimental trial is different from a pre-operational evaluation and manage their expectations accordingly. A team of technicians familiar with the system could provide a reference for speed of use of the interface, even if they would not represent the quality of control solutions that would be generated by fully trained and validated controllers;
- b. Explore ways to make more of the tactical controllers accept their new role, e.g. give them clearer information about the plans, change the way the role is taught or even consider combining the roles of tactical and planner or having a tactical controller cover the airspace of more than one planning controller;
- c. Address the difficulties in using the GHMI and mistrust of the tools through tool and GHMI refinements and improved training (see also Section 7.4.).

Future trials would benefit from the use of a more comprehensive set of objective measures of workload which were more applicable to the advanced operational concepts being investigated.

#### 7.1.2. Introduction of advanced planning, advanced tools, 4-D FMS and datalink

A change from ORG 0 to ORG 2 (70%) would correspond to the introduction of advanced planning, advanced tools, 4-D FMS and datalink for most aircraft; however, it is also instructive to consider the differences between ORG 1 and ORG 2 (70%) - this corresponding solely to the introduction of the aircraft equipped with 4-D FMS and datalink capability.

For the tactical controller there were fewer instructions to issue over R/T because of the datalink. This not only reduced the objective measures of workload, but also resulted in a reduction in perceived workload (ORG 2 compared to ORG 1, see Section 6.2.3 and the relative workload responses to the questionnaires in Section 6.5.3). Indeed, this reduction was enough to counteract the frustration and time pressure associated with the introduction of ORG 1 (see Section 6.2.2), so that the net effect was that the tactical controller had a similar workload in ORG 2 as was recorded in ORG 0.

Yet largely the same factors that were assumed to underlie the workload increase in ORG 1 (Section 7.1.1 (i) to (v)) are still present in ORG 2 (70%); the only one which can be assumed to have reduced significantly is part of (iii) - frustration at issuing instructions to 3-D FMS aircraft, which now only account for 30% of the traffic sample. Therefore, if the issues of the tactical controllers' role - mistrust of the tools and difficulties with the GHMI (Section 7.1.1 (b) to (c)) - are successfully addressed, it is reasonable to expect that ORG 2 (70%) would have a lower workload than ORG 0 for the tactical controller in all traffic samples, not just at low volumes.

This gain for the tactical controllers is at a cost to the planning controllers, who have more aircraft with which they have to negotiate over datalink; so, not surprisingly, their workload was similar to that recorded for ORG 1. In terms of TLX the planning controllers' workload showed a significant increase but this was not repeated by the ISA results (Section 6.2.3). This increase must, therefore, be considered to be a marginal result - i.e. it is safe to say that the planning controllers' workload in ORG 2 was not less than, and may be more than, ORG 1; however, both these organisations recorded a workload significantly greater than ORG 0 for the planning controller. There is little other evidence as to whether the planning controllers preferred ORG 2 to ORG 1. Some problems were observed with the idea of 4-D aircraft - e.g. training issues (Section 5.2) and failure to re-coordinate after a change of time at the sector boundary (Section 6.6) - but the questionnaire results (Section 6.5.3) suggests ORG 2 might have been preferred in spite of these.

One of the goals of the introduction of computer assistance tools and datalink was to transfer some of the tactical controller's workload to the planning controller. This is desired to counteract a current perception that the tactical controllers' workload, *in present day systems*, is significantly greater than that for the planning controllers<sup>2</sup>. The switch-over in subjectively measured workload from the baseline to full implementation of tools and datalink suggest that this goal can be met (see Figure 6-1).

In summary, it was to be expected that the controllers' perceived workload would increase with the introduction of computer assistance tools, given the novel concepts, the new procedures - especially the increased planning time-frame - and the limited training period. The result that the tactical controllers' workload did not increase is, therefore, encouraging, particularly since specific reasons have been identified for believing it could be reduced.

## 7.2. CAPACITY

The results for how well controllers were able to maintain the picture are confused. When asked the percentage of the time that they had maintained the picture for each run, the answer was 100% of the time in nearly 90% of cases (Section 6.3), basically irrespective of ORG. However, when asked whether the system supported 'maintaining the picture' well, only ORG 0 received a positive response (see Section 6.5.3). Moreover, worries were expressed informally by the tactical controllers that they were not able to build a mental picture of the traffic (see Section 6.6). Neither of the first two data sets supports the idea that this was more a problem for the tactical than the planning controller, say due to lack of involvement in the control strategy. A possible explanation for this apparent discrepancy in the controllers' response may be that the 'percentage of time' question was so phrased that, to get a value other than 100%, a controller first had to admit that he or she had not maintained the picture and had therefore failed in what is currently seen as a vital element of the controller's task. In

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<sup>2</sup> This perception is not generally supported by real-time simulations conducted with the UK on either NERC evaluation trials or within the CAER Trial programme. The planner and tactical controller's workload is generally of the same order, as would be expected from a well designed ATC system. Their exact relationship would appear to be highly dependent upon the sector under consideration.

these circumstances a bias to 100% would not be unexpected. It might also be easier for a planning controller to give a value less than 100% since their role did not require maintaining the picture. It might also be questioned to what extent, given the advanced tools, the tactical needs to maintain a picture at all. Thus, on balance the evidence points to an important problem for PHARE: how better to support picture-formation, or how to circumvent the need for it and persuade controllers that they do not need it.

ORG 2 (70%) had more separation infringements than ORG 0 (Section 6.3). It is possible that these separation infringements arose through tactical controller mistakes, such as those observed in handling the CLW (Section 6.6). In a trial such as this, with just one week's training, a difference of one minimum separation infringement between runs could be considered to be in the 'experimental noise'. If this is accepted to be the case, then the actual difference between the systems was negligible. However, from the questionnaire (see Section 6.5.3), controllers approved of ORG 0 in terms of its support for separation, but were divided on the advanced ORGs. The cases quoted earlier (Section 6.6) of some tactical controllers being unhappy with the output of the tools are a likely explanation of why some tactical controllers disapproved of the advanced ORGs' approach to separation assurance. Whether it is how separation is represented in the GHMI which needs to change, or how the controllers are taught about the tools, is an issue the PHARE GHMI group should consider.

Thus, the study of capacity measures suggests that the further investigation of two issues would improve the chances of achieving capacity gains: namely maintaining the picture and the representation of separation.

### 7.3. QUALITY OF SERVICE

Only two measures of quality of service to airlines were calculated (Section 6.4) and the interpretation of the results is fraught with difficulties. To begin with, the two measures disagree. If time near RCFL increases, then time in sector might be expected to decrease (rather than the increase found). If the increase in in-sector time is due to an increase in heading instructions (i.e. sending the aircraft on a longer route), why is it greater in sector 11 where there is little scope for long diversions for most aircraft? The contradictions widen further when informal observations are included: why were tactical controllers worried (Section 6.6) about delays before climbing, which resulted from error bounds in the HIPS, if on average aircraft must have been climbing earlier or descending later in order to generate the longer time spent near RCFL? One possibility is that the controller reports highlight a few exceptional events rather than the average flight's profile.

Thus, although it is true to say that ORG 2 (70%) gave better service to airlines than ORG 0, in the sense of a 5-7% improvement in time near RCFL, the full picture deserves further analysis. The existing data need to be analysed more deeply, for example looking at the impact on 3-D and 4-D FMS aircraft separately. Future trials need to develop a broader and more detailed set of quality of service measures.

### 7.4. CONTROLLER APPROVAL

Controller attitudes to individual tools and functions are addressed by the questionnaire and the informal observations of the PD/1 Team. Controllers generally approved of the training and simulation conditions provided in PD/1 (see Section 6.5.1). Fundamental aspects of the system, such as electronic co-ordination and colour coding of track data blocks were well accepted (see Section 6.5.2). There was agreement that all tools and functions could be improved (see Sections 6.5.4 and 6.6 for examples), which is not surprising given the experimental nature of the system. However, the tools and functions were not all equally popular:

- Responses about the ADFL were uniformly positive; indeed the evidence is that controllers would have used it beyond the role originally planned, if they could.
- The planning controllers approved of the HIPS.
- Tactical controllers seemed to divide into those who accepted that the CLW was their main tool (Section 6.5.4) and those who objected to the way the CLW dictated what they would do.
- The CRD and associated CZW were not well liked, nor were the HAW and VAW.

It is not for this report to propose a response to these, but two strategies might be considered:

- Aim to bring the worst tools up to the acceptability of the best. Use limited GHMI resources to improve those tools the controllers objected to most and review the training to encourage their use.
- Focus on improving the best tools and review the requirement for the others. For example, could a simple conflict list replace the CRD and CZW? Reducing the complexity of the GHMI would simplify training.

As for other aspects of the GHMI, it appears that linking accessibility with the ‘advanced information’ status of aircraft was not well accepted by the controllers (Section 6.5.4). Controllers would have liked access sooner to the track data block (e.g. to change its position) and the ability to co-ordinate aircraft. Some of this may be due to the inevitably restricted extent of the trial airspace, but it appears to establish a principle that aircraft should be made available to controllers as soon as possible.

Controllers familiar with the trial airspace can become overly concerned about details of the traffic sample (see Section 6.6) or attempt to use control techniques which are also familiar, rather than the new tools and concepts. However, if a fictitious airspace had been used, lessons such as the difficulty of advanced planning in narrow sectors (Section 6.6) might not have been learned. A level of credibility would also have been lost. On balance, the results support the decision to use real airspace and sectorisation, and suggest that there is further potential for workload savings by introduction of the airspace sectorisation and aircraft routes that might be implemented were the computer assistance tools in use.

## 8. CONCLUSIONS

The PHARE Demonstration 1 (PD/1) brought together the research organisations from four European nations to design, build and trial an advanced ATC concept. The ability of Europe to co-operate in an extensive ATC research programme and demonstrate its achievements to a world-wide audience is a significant achievement.

The PD/1 research programme culminated in the participation of 32 controllers from 7 countries to evaluate an experimental system which included: advanced computer assistance tools; a live aircraft; simulated and real 4-D flight management systems; and an air-ground datalink. The aim was to explore the effectiveness of air/ground negotiation of trajectories which are conflict free for the next 20-30 minutes ahead; can they reduce the workload primarily of the tactical but also the planning controller and thus increase airspace capacity?

The PD/1 airborne demonstration programme, with the participation of the NATS funded DRA BAC 1-11, was extremely successful. It confirmed, as a matter of routine, the ability of an aircraft to agree conflict-free trajectories with ATC and to fly them, while operating within continuous 4-D constraints. The flights provided a convincing demonstration to the aviation community of the ‘silent cockpit’ (Section 6.7).

The training programme showed that one week's training was insufficient for the controllers fully to assimilate the new facility and concepts. This limited training time is highly likely to have influenced the outcome of the trial.

Controllers generally approved of the PD/1 trials environment. Fundamental aspects of the system, such as electronic co-ordination and colour coding of track data blocks were well accepted. The Augmented Dynamic Flight Leg (ADFL) and Highly Interactive Problem Solver (HIPS) were particularly well received, but there was also agreement that all tools and functions could be improved, which is to be expected given the experimental nature of the system (Section 7.4).

Given the novel concepts, new procedures (especially conflict-free planning over a 20 to 30 minute time-frame) and the limited training, it might have been expected that controllers' perceived workload would increase with the introduction of computer assistance tools, 4-D FMS and datalink. In fact, while the planning controllers' workload increased, the tactical controllers' workload did not. Indeed, at low traffic volumes the tactical controllers' workload decreased, and specific reasons have been identified for believing it could be reduced more generally (Section 7.1.2). Overall, within the inevitable restrictions of the trial, PD/1 has been shown to succeed in passing some of the tactical controllers' workload onto the planner and to have the potential for workload savings.

There is little evidence of a measurable change in airspace capacity. However, the study of capacity measures highlighted two issues: maintaining the picture and the representation of separation. Addressing these would improve the chances of capacity gains (Section 7.2).

Although the most advanced system gave better service to airlines than the baseline system, in the sense of a 5-7% improvement in time near Requested Cruise Flight Level, the full picture is more complex and deserves further analysis. The existing data need to be analysed more deeply, for example looking at the impact on 3-D and 4-D FMS aircraft separately. Moreover, future trials need to develop a broader and more detailed set of quality of service measures (Section 7.3).

Further examination of the data is necessary to understand the workload results, e.g. to explore the effectiveness of the tactical-planner teams. Only further research will answer questions such as the extent to which the tactical controller subconsciously duplicated the planning controller's work and how the balance of work between the tactical and planner roles could be optimised.

In summary, PD/1 successfully demonstrated the integration of air and ground air traffic management, in en route airspace, through computer assistance tools, 4-D flight management systems and air-ground datalink. The evidence suggests that gains in controller workload, airspace capacity and quality of service to airlines are achievable. The recommendations below suggest how PHARE can help further to make the most of these promising new technologies.

## **9. RECOMMENDATIONS**

Recommendations for the development of the PHARE concepts and systems are:

- Explore ways to achieve the acceptance by the tactical controllers of their new role. (Section 7.1.1.)
- A related item is either to improve the way the system supports 'maintaining the picture' or fully to persuade tactical controllers that it is no longer necessary. (Section 7.2.)

- Address the difficulties in using the GHMI and mistrust of the tools through tool and GHMI refinements and improved training. (Sections 7.1.1 and 7.4.)
- Consider whether to change how separation is represented in the GHMI, or train controllers to accept the current representation. (Section 7.2.)

Recommendations for future ATM real-time simulations, and all future PHARE Demonstrations, are that they should:

- Use controllers who will accept that an experimental trial is different from a pre-operational evaluation and manage their expectations accordingly. (Section 7.1.1)
- Consider using a team of technicians familiar with the system who could provide a reference for speed of use of the interface, even if they would not represent the quality of control solutions that would be generated by fully trained and validated controllers. (Section 7.1.1)
- Develop a broader and more detailed set of quality of service measures. (Section 7.3)
- Examine existing quality of service data in more detail. (Section 7.3)
- Use airspace which is 'real', in as many aspects as possible, i.e. one that represents sectorisation and aircraft routes that might be implemented were the computer assistance tools in use. (Section 7.4)
- Extend the range of objective workload measures. (Section 7.1.1)

The airborne trials emphasised the importance of providing accurate weather forecasts and engine models for efficient four-dimensional flight management (Section 6.7).

For training in future experimental system trials, the PD/1 Training Team offers the following recommendations (Section 5.2):

- Start planning and designing the course as soon as possible.
- Work closely and continually with the technical team to understand the system.
- Use controllers in the training team to lessen any resistance from the controllers taking part in the trials.
- If possible, take those staff who are computer literate, who are willing to investigate new operational concepts, and who are able to apply the concepts under investigation.

## 10. ACKNOWLEDGEMENTS

PD/1 was a collaborative venture, involving many participants from Europe and beyond. It would not have been possible to conduct the work programme without the close co-operation of the PHARE partners: CENA of France, DLR of Germany, Eurocontrol, NATS of the UK and NLR of the Netherlands. Everyone from these research establishments who participated in the trial shares in its success.

Special acknowledgement goes to:

- The NATS programme manager, Mr Chris Metcalfe - now retired;
- The PD/1 project leader, Mr Rod Gingell, and his complete team from CGP;
- The Defence Research Agency at Malvern where the NATS Research facility was based prior to its move to the Air Traffic Management Development Centre;

- The Defence Research Agency at Bedford for their participation in the flying programme.

Finally, the controllers and their supporting organisations deserve a special mention. Without their participation, PD/1 could not have taken place.

## 11. GLOSSARY

3-D	three dimensional
4-D	four dimensional
ADFL	augmented dynamic flight leg
AHMI	airborne human machine interface
API	application programming interface
ATC	air traffic control
ATM	air traffic management
CAA	Civil Aviation Authority (UK)
CAER	Computer Assistance for En-Route
CENA	Centre d'Etudes de la Navigation Aerienne
CGP	CGP Ltd (UK)
CLW	communications list window
CMS	common modular simulator
CP	conflict probe
CRD	conflict risk display
CRNA	Centre Regional de la Navigation Aerienne
CZW	conflict zoom window
DFS	Deutsche Flugsicherung GmbH
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
DRA	Defence Research Agency (UK)
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme
EFMS	experimental flight management system
FMS	flight management system
FPM	flight path monitor
GHMI	ground human machine interface
HAW	horizontal assistance window
HIPS	highly interactive problem solver
HMI	human machine interface
IOCP	internal operational clarification project
ISA	instantaneous self assessment
LFV	Luftfartsverket (Sweden)
LV	Luftfartsvæsen (Denmark)

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NATS	National Air Traffic Services Ltd (UK)
NERC	New En-Route Centre
NLR	Nederlands Nationaal Lucht- en Ruimtevaartlaboratorium
NRF	NATS Research Facility
ODID	Operational Displays and Input Devices
ORG	organisation: a set of facilities and ATC procedures that together define one of the ATC systems being tested
PATs	PHARE advanced tools
PC	planning controller
PCC	PHARE Co-ordination Committee
PD/1	PHARE Demonstration 1
PD/2	PHARE Demonstration 2
PD/3	PHARE Demonstration 3
PD/3 CG	PHARE Demonstration 3 Co-ordination Group
PHARE	Programme for Harmonised Air Traffic Management Research in EUROCONTROL
R/T	radio/telephony
RCFL	requested cruising flight level
RNAF	Royal Netherlands Air Force
STCA	short term conflict alert
TC	tactical controller
TLX	task load index
TMA	terminal manoeuvring area
TP	trajectory predictor
UK	United Kingdom
VAW	vertical assistance window

## 12. REFERENCES

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