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MANAGEMENT RESEARCH
IN EUROCONTROL

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PD/1++ Trial Report

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EXECUTIVE SUMMARY

The NATS PD/1++ project was a continuation of the previously conducted PD/1 and PD/1+ trials and was specifically designed to explore the use of the PHARE tools and operational concept within alternative en-route airspace structures and controller practices.

The following concepts were explored, initially through the use of Fast-Time simulation techniques and subsequently through the PD/1++ trial, a real-time simulation conducted on the NATS Research Facility:

- the introduction of aircraft flying direct routes within an airspace containing aircraft flying on traditional, structured routes;
- the use of larger sectors compared to those typically used in current day airspace designs;
- the introduction of alternative controller operating practices.

The baseline scenario against which these concepts were compared included the introduction of Reduced Vertical Separation Minima (RVSM) and the availability of the PHARE Advanced Tools (PATs) to the controllers.

The PD/1++ trial took place in late August 1998 at NATS' Air Traffic Management Development Centre, Hurn. The airspace simulated was based on the two UK New En-Route Centre sectors 10 and 11, each sector being staffed by one planning controller and one tactical controller. Eight controllers participated in the trial. This report describes the background to the PD/1++ trial, its aims, the design, results, conclusions and recommendations.

The main aim of the PD/1++ trial was:

- to examine the effects on controller workload, airspace capacity, quality of service and the usability of the ATC system of the introduction of alternative airspace structures and alternative operating practices. This aim was achieved through the collection and subsequent analysis of both subjective and objective data in accordance with a pre-defined analysis plan.

The major conclusions resulting from the analysis are that, within the very specific scenarios investigated:

- the PD/1++ operational concept enabled the controllers to handle the increased traffic that resulted from the introduction of larger sectors and direct routes;
- the increase in traffic resulted in an increase in controller workload that was within the controllers' acceptable working limits.

However, it cannot be stated which elements of the operational concept under investigation – ie RVSM, PATs, direct routes or larger sectors – led to the controller's ability to successfully manage the traffic.

Within the limits described above, it may be stated that the PD/1++ trial successfully achieved that part of the PHARE objective designed to "demonstrate the feasibility and merits of an air-ground system" for the en-route phase of flight.

The main recommendations from the PD/1++ trial are:

- Further work must be done to understand the effect on controller workload and sector capacity of the introduction of either direct routes or larger sectors;

- Further work must be done to understand the relationship between controller workload and both sector capacity and total airspace capacity (ie groups of sectors) before conclusions can be drawn from the PHARE programme with respect to either;
- Further work must be done to establish appropriate controller roles for a PHARE type environment;
- Further work must be carried out to refine the method by which aircraft without datalink are controlled within a PHARE type concept.

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Appendices

1. INTRODUCTION

1.1. General

This report details the aims, design, results, conclusions and recommendations of the Programme for Harmonised Air Traffic Management Research in Eurocontrol (PHARE) Demonstration 1++ (PD/1++) trial. The trial was the final demonstration to be carried out by National Air Traffic Services Ltd (NATS) as a part of their contribution to the overall PHARE programme.

1.2. Context

Today's Air Traffic Control (ATC) system in Europe (and elsewhere) is, at times, unable to handle the traffic demands made upon it. Thus 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 implemented 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 controller workload and without compromising system safety.

One proposed method of increasing controller productivity is by providing 'computer assistance tools' to both the planning and tactical controllers and by the use of datalink for air-to-ground communication. The provision of such automated assistance to the controllers will support them in the detection and 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. In addition, it will enable the use of data from onboard the aircraft to improve the precision of the ground system's model of aircraft performance that is used for track prediction and conflict prediction. In providing such computer assistance, 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.

It is the need to address some of these issues that has shaped developments within the PHARE Programme.

A series of real-time simulations, or PHARE demonstrations, was planned to evaluate the introduction of computer assistance tools and datalink in en-route airspace and the Terminal Manoeuvring Area (TMA), each demonstration being led by one or more of the PHARE partners.

The first PHARE demonstration, PHARE Demonstration 1 (PD/1), was hosted by National Air Traffic Services Ltd (NATS) on the NATS Research Facility (NRF) then resident at the Defence Evaluation and Research Agency (DERA) Malvern, but since moved to Hurn. The trial was conducted over a period of eight weeks towards the end of 1995 (see reference 1). The primary aim of PD/1 was to investigate the introduction of computer assistance tools and aircraft equipped with datalink and a 4D Flight Management System (4D FMS) within en-route airspace. The computer assistance tools were designed to assist controllers in planning, and then implementing, conflict-free trajectories through the airspace. It was envisaged that these tools, together with the datalink equipped aircraft, would reduce the controllers' workload and thus help to increase airspace capacity.

The PD/1 results did not, however, indicate the anticipated reduction in controller workload following the introduction of the tools and datalink. While some preliminary assessment of this result was given in the PD/1 Final Report (see reference 1), it was apparent that further investigation of the PD/1 results, followed by further development of the tools, would be beneficial to both PHARE Demonstration 3 (PD/3) and the overall PHARE work programme.

The NATS Internal Operational Clarification Project (IOCP), within the overall PD/3 work programme, re-examined the outcome of the PD/1 trial, in particular addressing tool utilisation and controller workload. Specifically, the project used the Performance and Usability Modelling in ATM (PUMA) workload assessment tool set to identify potential improvements to the PHARE advanced tools, Ground Human Machine Interface (GHMI) and procedures which should, if implemented, reduce controller workload. These changes were evaluated through the PHARE Demonstration 1+ (PD/1+) trial, a real-time simulation which took place on the NRF at the ATMDC, Hurn, in early 1997 (see reference 2).

Although PD/1+ made a number of detailed recommendations with respect to each of the tool and GHMI changes, the main recommendation for PD/3 and any future PHARE trials was that realistic traffic samples, an operational concept and a new airspace structure must be developed in order to maximise the potential of the system under evaluation and gain acceptance of the new system by the participants.

The NATS PD/1++ trial was therefore designed to explore the use of the PHARE tools and operational concept within an airspace structure, and hence traffic scenario, in line with that likely to be in place within the anticipated timescales for the implementation of the PHARE concept.

1.3. Report structure

The report is divided into the following sections and detailed Appendices.

Section 2 places the PD/1++ trial within the PHARE work program as a whole.

Section 3 details the specific aims and objectives of the PD/1++ trial.

Section 4 describes the Fast-Time simulation contribution to the PD/1++ trial.

Section 5 describes the PD/1++ baseline system and ATC concept.

Section 6 describes the PD/1++ advanced system and ATC concept.

Section 7 describes the trial's environment and contains a brief description of the trial facilities, each computer assistance tool, the associated components used during the trial, the airspace and the traffic samples.

Section 8 describes the trial method encompassing the design, participants and training. In addition the measurements, data collected, and the statistical methodology are described.

Section 9 gives an account of the trial and summarises the results of the measurements made against each of the objectives of the trial.

Section 10 contains a full discussion of the results. The conclusions and recommendations are given in sections 11 and 12 respectively.

Five Appendices are attached: Appendix A details in full the Fast-Time simulation activities carried out in support of the PD/1++ trial; Appendix B details the Temporary operating instructions issued to the participants; Appendix C contains a detailed account of the trial design and analysis plan; Appendix D records the detailed results of the trial; Appendix E records the detailed results relating to the usability of the PD/1++ system.

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2. PD1++ TRIAL DESIGN

2.1. BACKGROUND

The anticipated timescale for the implementation of the PHARE concept is 2010 to 2015. Within this timeframe it is not unreasonable to expect that Reduced Vertical Separation Minima (RVSM) will have been introduced within domestic en-route airspace. Equally it is quite likely that the routes flown by aircraft may be more direct than those flown today. Any future concept must take account of these likely changes, whilst ensuring that current levels of safety, usability, airspace capacity, service to aircraft and controller workload are at least maintained following their inclusion.

Within the main PHARE demonstrations, the introduction of an advanced airspace structure, coupled with both the PHARE tools and the PHARE operational concept would have been a difficult and risky process. The PD/3 demonstrations planned to be run at EEC, Bretigny and NLR, during the first half of 1998 were to provide a limited investigation into the effects of combining the introduction of the PHARE tools and operational concept with an advanced airspace structure. However, within the PHARE programme a more thorough understanding of the implications of combining the introduction of the PHARE tools and operational concept with an advanced airspace structure was required to gain credibility in the ATC and airline communities. Furthermore one of the main conclusions from the PD/1+ trial, carried out by NATS in early 1997, had been that:

“The use of a contemporary operational concept and airspace structure hindered the outcome of the trial...”

The NATS PD/1++ trial was therefore designed to begin the process of exploring in more detail the use of the PHARE tools and operational concept within alternative en-route airspace structures. Specifically the following concepts were to be explored:

- aircraft flying direct routes;
- larger sectors compared to current day;
- alternative operating practices.

2.2. AIMS AND OBJECTIVES OF THE PD/1++ TRIAL

The following specific aim was defined for the PD/1++ trial.

Within the overall PHARE concept of the introduction of advanced planning, computer assistance tools and datalink, PD/1++ will examine the effects on controller workload, on airspace capacity, on quality of service and on the usability of the system under test, of the introduction of:

- *alternative airspace structures;*
- *alternative operating practices.*

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3. PRELIMINARY FAST-TIME STUDY

Prior to the PD/1++ trial, the NRF had not been used to simulate aircraft flying through anything other than the current structured route system in UK en-route airspace. This posed a number of problems for the trials team, not least of which was “Where would aircraft route if flying direct and at what point on the sector boundary would they enter or leave the sector?”

The Department of Air Traffic Control Systems Research (DASR) Fast-Time simulation team simulated the airspace and operations for traffic passing through the proposed New En-Route Centre (NERC) sectors 10 and 11, on both direct and structured routes, prior to the PD/1++ real-time trial. The Total Airspace and Airport Modeller (TAAM) computer simulation was used to perform this investigation, which is described in full in Appendix A. To define a direct route, TAAM flew an aircraft on a great circle routing from its departure airport to its destination airport. The portion of the aircraft’s great circle routing that passed through the simulated sectors was considered to be the aircraft’s direct route.

The primary objective of the study was to investigate a number of experimental organisations that could be used to address the aims of the PD/1++ trial, in particular to explore and define a baseline organisation and possible advanced organisations, consisting of an airspace definition, traffic sample and relevant ATC procedures, to allow a decision to be made as to whether they could feasibly be simulated in real-time. Inherent in this process was the examination of each proposed organisation to handle traffic levels above those seen today. Any advanced organisation had to consider both increased sector size, compared to current day and the inclusion of aircraft flying direct routes.

A secondary objective was to provide the airspace definition, traffic sample data and ATC procedures used in the TAAM simulations for each organisation, to the data preparation team for conversion into a format suitable for input to the real-time system. This would reduce the time taken to produce and test the real-time traffic samples, and ensure compatibility between the organisations run in fast-time with those run in real-time.

To achieve these objectives, the Fast-Time simulation team:

- Extracted a suitable day’s traffic from the NAS database and selected two, two-hour periods with the characteristics required for the study;
- Modified the selected two, two-hour traffic samples to include aircraft flying on RVSM routes – resulting in baseline traffic samples;
- Developed a direct route traffic sample. This was accomplished by using TAAM to fly all aircraft in the original 24 hour sample from their origin to destination airport on a great circle route and then extracting those aircraft which flew through NERC sectors 10 and 11. The same two, two-hour periods were selected as for the base samples. These traffic samples were then modified to include RVSM flight levels – resulting in direct route traffic samples;
- Grew the traffic samples by 25, 50 and 75%.

This work was conducted in close co-operation with the Air Traffic Control Officer (ATCO) assigned to the project to ensure that the resultant traffic samples were suitably realistic for use in the subsequent real-time simulation exercises.

The following were produced as a result of the Fast-Time study:

- A feasible baseline organisation;
- A feasible advanced organisation which increased the sector size, compared to current day;
- A feasible advanced organisation, which included aircraft on direct routes;
- An airspace definition, traffic sample data and ATC procedures for each of these organisations.

The Fast-Time study is described in full in Appendix A.

4. THE PD/1++ BASELINE SYSTEM AND CONCEPT

The PD/1++ baseline was not intended to be representative of a current day system or concept. Instead it incorporated computer assistance tools and assumed that 70% of aircraft had a 4D FMS and datalink capability. It was not the intention of PD/1++ to examine the transition phase from aircraft not quipped to aircraft equipped with a 4D FMS and datalink capability, as represented by the 30% equipage figure chosen in previous PHARE trials. Neither was it the intention to examine the unlikely environment of 100% equipage. 70% was therefore chosen as representative of a state where the majority of aircraft in European airspace are equipped with a 4D FMS and datalink capability. No met data was simulated.

The PD/1++ baseline was based upon the second advanced organisation used in the PD/1+ trial (see reference 2) with one major difference, RVSM was included above flight level (FL) 295. The aim of the trial was not specifically to investigate the effects of the inclusion of RVSM; however any advanced system and concept for use within Europe over the next 20 years must demonstrate that it can successfully incorporate RVSM.

The design of the PD/1++ baseline was not intended to facilitate any direct comparisons between the PD/1++ advanced organisations and current day. However, one of the conclusions from the PD/1+ trial had been that the second advanced organisation, on which the PD/1++ baseline was based, reduced the controller workload for both the planning and tactical controllers when compared to current day.

The controller roles simulated in the PD/1++ baseline concept were en-route planning controller and en-route tactical controller (see Appendix B). The planning controller was responsible for planning a conflict free route through the sector for all aircraft. The tactical controller was responsible for acknowledging each aircraft on first call, irrespective of flight level and whether datalink equipped or not, and releasing each aircraft verbally to the next sector. In addition, the tactical controller was responsible for maintaining the separation of all aircraft within the sector. In the case of aircraft without datalink, this involved issuing advisories to the aircraft to maintain them on their conflict free trajectories. Advisories prompted the controller to issue specific ATC instructions via radio telephony (R/T) to the aircraft. It was not necessary for the tactical controller to issue advisories to datalink equipped aircraft to maintain them on their trajectories as the required trajectory had been passed to the aircraft via the datalink. A set of temporary operating instructions was produced (see Appendix B), which gave guidance to the controllers on the implementation of the baseline concept.

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5. THE PD/1++ ADVANCED SYSTEM AND CONCEPTS

The PD/1++ advanced system and concept were also based upon the second advanced organisation used in the PD/1+ trial (see reference 2). Computer assistance tools and RVSM were included and it was assumed that 70% of aircraft had a 4D FMS and datalink capability. No met data was simulated. Direct routes and larger sectors were simulated:

- In the direct route organisations only aircraft with a 4D FMS and datalink flew above FL295, where they followed direct routes. 4D FMS equipped aircraft departing from airports within the UK FIR flew along the structured routes system until they reached FL295, when they then flew a direct route towards their destination. The converse was true for 4D FMS equipped aircraft landing in the UK FIR. Aircraft which were not equipped with 4D FMS were restricted to flying the current structured route system below FL295;
- A larger sector was created by removing the boundary between NERC sectors 10 and 11.

The controller roles simulated in the PD/1++ advanced concept were en-route planning controller and en-route tactical controller (see Appendix B). When direct routes were simulated, the planning controller was responsible for planning a conflict free route for all aircraft through the sector. In addition the planning controller was now responsible for maintaining the separation of all aircraft above FL295. The tactical controller was responsible for acknowledging each aircraft on first call, irrespective of flight level and whether datalink equipped or not, and releasing each aircraft verbally to the next sector. In addition, the tactical controller was responsible for maintaining the separation of all aircraft within the sector below FL295. In the case of aircraft without datalink, this involved issuing advisories to the aircraft to maintain them on their conflict free trajectories. A set of temporary operating instructions was produced (see Appendix B), which gave guidance to the controllers on the implementation of the advanced concept.

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6. THE TRIALS ENVIRONMENT

This section describes the hardware and software used in the trial.

6.1. The Trials Facilities

The PD/1++ trial took place on the NRF, a real-time simulator, based at the NATS Air Traffic Management Development Centre (ATMDC), Hurn. Figure 1 depicts the layout of the NRF during the PD/1++ trial.

Figure 1 - Layout of the NRF for the PD/1++ trial

6.2. NRF Software

The PD/1++ software was based on the PHARE Demonstration 2+ (PD/2+) system rather than the PD/1+ system. The PD/2+ trial was conducted by NATS on the NRF in late 1997 and considered the introduction of the PHARE concept within a TMA environment (see reference 3). For PD/2+ a great deal of effort was invested in making the underlying software more robust than it had been for PD/1+, resulting in a more reliable client/server interaction. PD/2+ introduced the TP-based Aircraft Simulator (TPAS) which simulated 4D datalink equipped aircraft. It was important that TPAS was also used within PD/1++ since it more realistically simulated the capabilities of aircraft equipped with a 4D FMS than air simulators used in previous PHARE trials on the NRF.

The specific changes made to the PD/2+ software were:

- removal of the Arrival Manager (AM);
- removal of the Stack Manager (SM);
- removal of the TMA user interface.

The PD/1++ trial used the PD/2+ en-route user interface, since this was identical to that used during the en-route PD/1+ trial.

The PD/1++ software was adapted to handle:

- RVSM;
- coordination and representation of aircraft on direct routes.

The software used during the PD/1++ trial within the NRF was:

- GSys, a ground data processing System;
- GENESIS, an aircraft track generator;
- a GHMI or user interface.

6.2.1 GSys

GSys comprised the following:

- Data bus mechanisms;
- an aircraft surveillance and tracking system;
- a simulated datalink interface;
- a flight plan database;
- inter-sector coordination support;
- supporting databases;
- PHARE Advanced Tools (PATs).

6.2.2 GENESIS

GENESIS comprised the following:

- a TP-based Aircraft Simulator (TPAS) which simulated 4D datalink equipped aircraft;
- a control process which combined both 3D tracks from the air simulator and 4D tracks generated by TPAS;
- an interface for the pseudo pilots.

6.2.3 GHMI

The GHMI used during the PD/1++ trial was the PD/2+ en-route user interface. This included a number of tools which were specific to either the control of aircraft within a TMA environment or the PD/2+ baseline. These tools were removed. The remaining vertical planning tools and flight level selection menus were adjusted to support RVSM.

6.3. NRF Hardware

The hardware components of the NRF used during the PD/1++ trial were as follows:

- a network of Sony displays, providing the controllers with an interface to the system;
- a Metheus PC driving each Sony workstation;
- two DEC Alphas running GENESIS;
- a cluster of Sun workstations, supporting the simulation and basic software functions;

- Sun workstations providing an interface to GENESIS for the pseudo-pilots;
- an Ericsson phone system providing telephone communication;
- a Redifon system providing simulated R/T communications;
- a PC controlling the logging of data for subsequent analysis (the History PC);
- a PC displaying an instantaneous measure of the controllers' workload;
- video recording facilities controlled from the History PC.

6.4. PHARE Advanced Tools (PATs);

The PHARE advanced tools used during the PD/2+ trial were as follows:

- the Conflict Probe (CP) compared all new active trajectories against the active trajectories of all other aircraft to detect potential conflicts;
- the Flight Path Monitor (FPM) monitored all active aircraft for deviations from their agreed trajectories;
- the Highly Interactive Problem Solver (HIPS) provided a graphical interface, which allowed a controller to identify potential conflicts and then to plan a set of strategic constraints for an aircraft passing through their sector which would avoid those conflicts;
- the Trajectory Predictor (TP) encapsulated software from the airborne Experimental Flight Management System (EFMS). The TP generated trajectories which met sets of strategic constraints; these constraints were either pre-planned within the traffic sample in accordance with standing agreements or were input by the controller to resolve conflicts.

With the exception of the TP, all the tools used during the PD/1++ trial were the same as those used during the PD/2+ trial. They had been developed from those used during the earlier PD/1 and PD/1+ trials and hence any limitations were known to the development team as a result of the analysis carried out following these trials.

With the exception of the TP, the versions of the PATs used during the PD/1++ trial were not those intended for use in the PD/3 series of trials, since none of these had been fully tested and evaluated prior to the PD/1++ trial and hence any limitations were unknown. The PD/2+ TP however, generated unrealistic trajectories and took an unacceptable amount of time to do so. To resolve these problems the PD/2+ TP was replaced with the PD/3 TP, which incorporated the latest version of the EFMS. As a consequence of using the PD/3 TP, the aircraft performance model used was upgraded to Base of Aircraft Data version 2.6 (BADA 2.6).

6.5. Additional components of the PD/1++ trial

The following additional components of the system used in the PD/1++ trial drew information from the tools described in Section 6.4:

- the **Plan View Display (PVD)** provided the processed radar picture containing maps, airways, reporting points, aircraft tracks and labels. The PVD also contained the Radar Tool Box (RTB) and Sector Inbound Lists (SILs);

- a **Track Data Block (TDB)** was attached to each aircraft target via a line on the PVD, and could be re-positioned relative to the respective aircraft. It contained information such as the aircraft callsign, current flight level, and cleared flight level. With the exception of the sector exit point field in the label the information displayed remained the same in all organisations. When structured routes were flown the exit point was the last waypoint in the aircraft's route within the sector. When direct routes were flown the exit point was either a named waypoint close to (within 10nm), the actual sector crossing point or a default waypoint, depending on which sector the aircraft was leaving. The colour of the TDB was dependent upon the aircraft state ie plannable, assumed, or unconcerned;
- the **Sector Inbound Lists (SILs),** provided sector entry details and planning information for aircraft scheduled to come into the sector. When structured routes were flown the information contained in the SIL was identical to that contained in the SILs during PD/1+. When direct routes were flown the information contained in the SIL with respect to the sector exit point was the same as that displayed in the TDB;
- the **Message In/Out Windows (MIW/MOW)** displayed text messages to the controller which were received from the neighbouring sectors or were system messages (MIW), or which were sent to the neighbouring sectors (MOW);
- the **Extended Label Window (ELW)** provided additional information on aircraft which was not available within the TDB, such as requested flight level (RFL) and origin and destination airfields;
- the **Preferences Tool (PRT)** enabled the controller to save and re-load a preferred display configuration;
- the **Augmented Dynamic Flight Leg (ADFL)** provided a two-dimensional representation of an aircraft's trajectory within the PVD;
- the **Conflict Risk Display (CRD)** indicated potential conflicts, giving the time to loss of separation and the separation at closest approach;
- the **Conflict Zoom Window (CZW)** gave a snapshot view of a conflict in the CRD at the time of closest approach;
- the **Communications List Window (CLW)** provided a list of the advisories to be given over the R/T to the pilots of aircraft without datalink;
- the **Trajectory Support Tool (TST)** enabled the controller to validate, reset, propose, accept or register trajectories;
- the **General Tool Box (GTB)** allowed the controller to turn on or off, as appropriate, the main set of tools, such as the CRD, HIPS, ELW and the PRT.
- the **Radar Tool Box (RTB)** allowed the controller to change the display characteristics of the PVD.

Figure 2 gives an example of the PD/1++ user interface. A full description of each tool can be found in the PHARE Advanced Tools Problem Solver final report (see Reference 4).

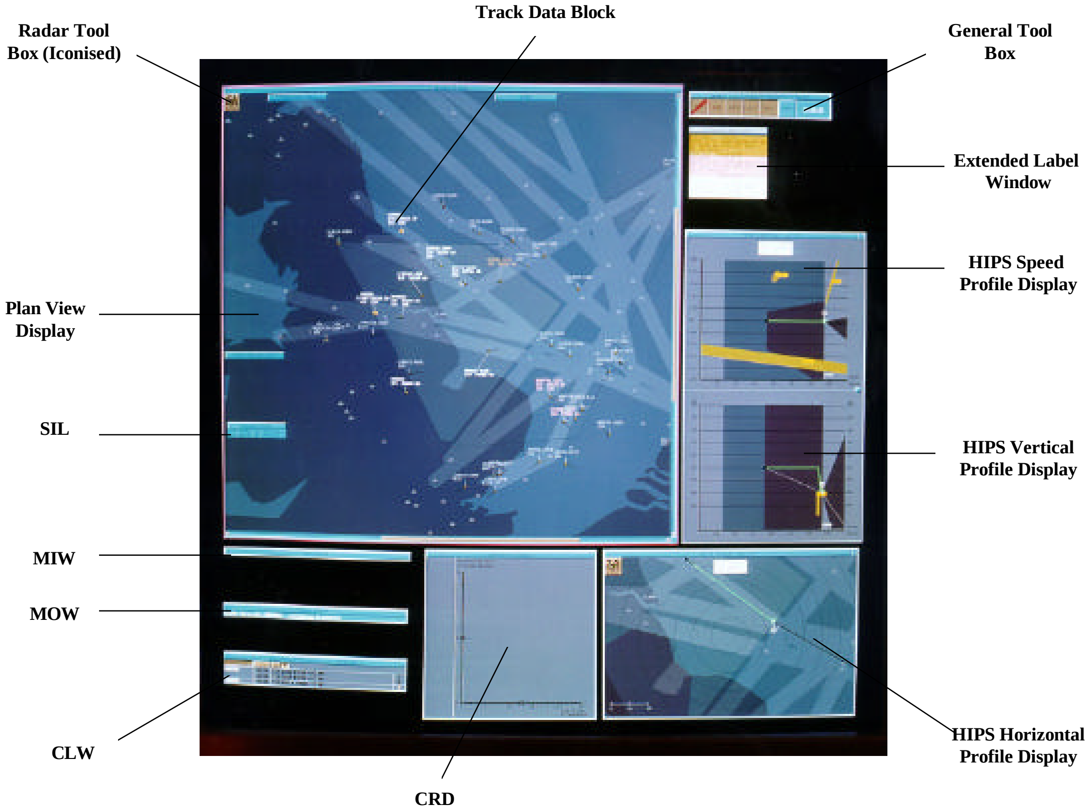

Figure 2 - User Interface

6.6. Airspace

The NRF was configured to simulate en-route airspace based on the future NERC sectors 10 and 11 and, in addition, a new sector 'Hornsea', which combined sectors 10 and 11. Figure 3, Figure 4 and Figure 5 show the airspace and sectors simulated. In each Figure a black boundary has been added around the sector for clarity. Each sector had one tactical controller and one planning controller. The sectors were 'fed' by three adjoining feed sectors: one the London FIR known as 'Feed South'; one encompassing Manchester and Scottish airspace known as 'Feed North'; and one encompassing Maastricht, Amsterdam and Copenhagen airspace known as 'Feed Europe'. The feed sectors were located adjacent to the measured sectors. There was no vertical sectorisation.

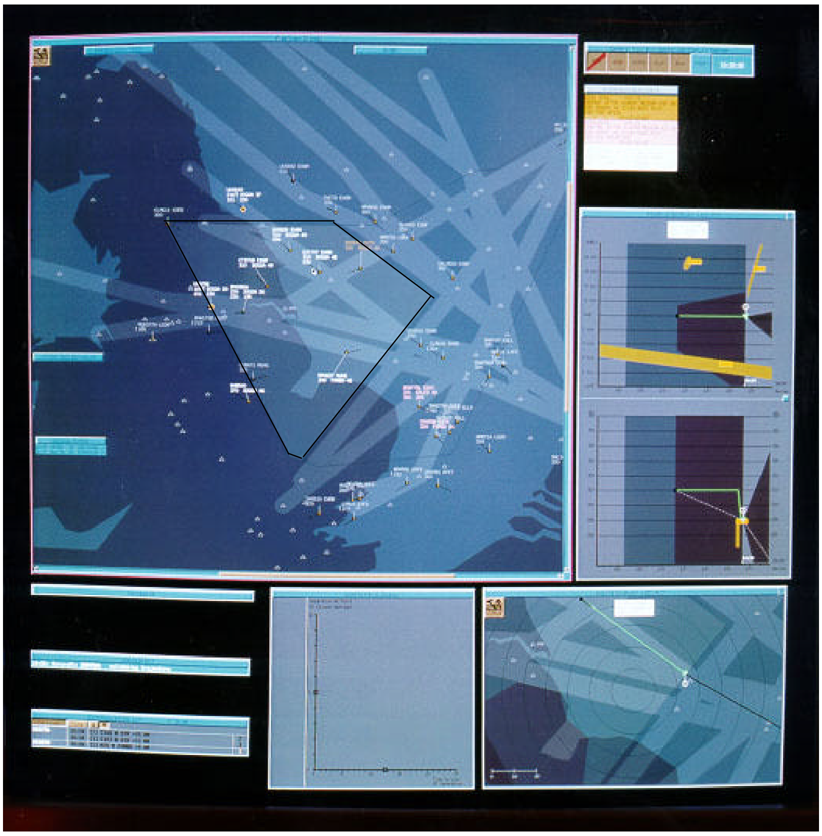

Figure 3 - Sector 10 Airspace

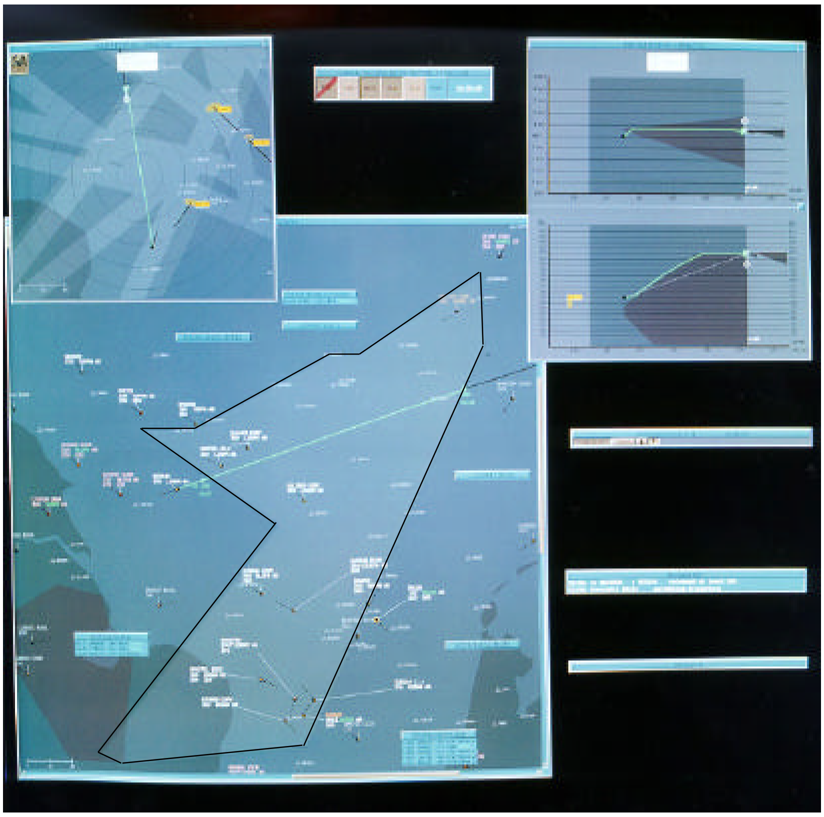

Figure 4 - Sector 11 Airspace

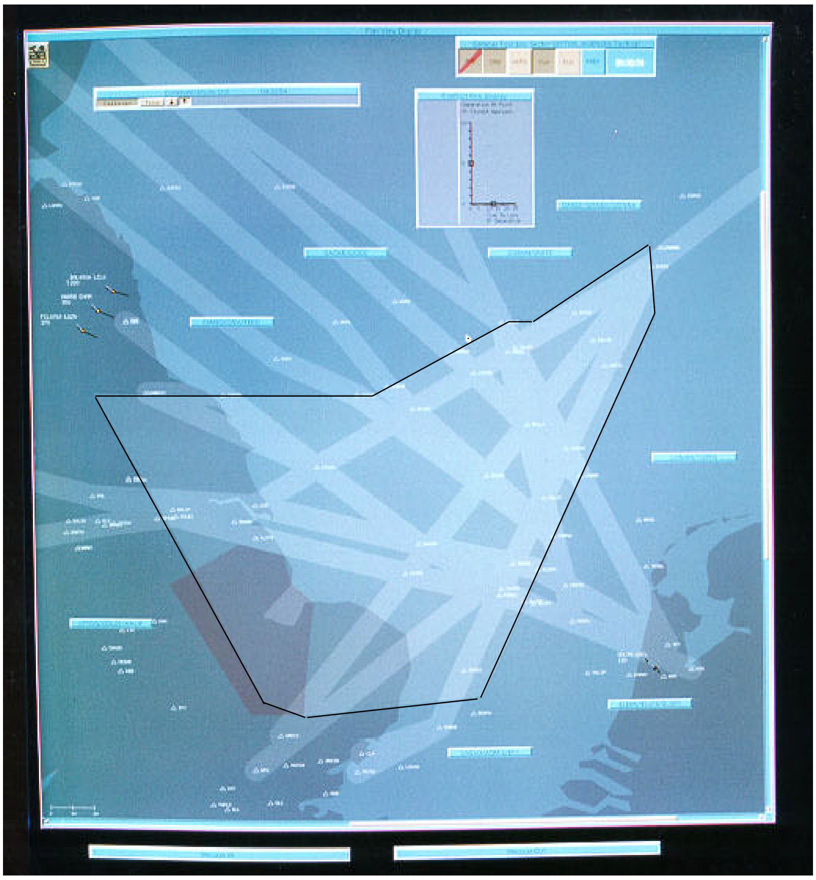

Figure 5 - Hornsea Airspace

6.7. Traffic Samples

16 traffic samples were developed, eight suitable for a structured route environment and eight for a direct route environment. All were based on two, two-hour time slices, or base samples, taken from data extracted from the National Airspace System (NAS) database for Sunday 8th June 1997. This data was chosen following consultation with the project ATCO, since it was representative of a typical 'north-about' day for which many trans-Atlantic aircraft pass through the North Sea sectors 10 and 11. The base samples were increased by 25%, 50% and 75% resulting in eight traffic samples suitable for a structured route environment. The process was repeated, following adjustment of the base samples to model direct routes, to produce a further eight samples, giving sixteen in total. Up to 75% of the aircraft within each of the direct route samples transferred from a direct route to a structured route or vice versa. 70% of the aircraft in each sample were equipped with a 4D FMS and data link capability. Appendix A contains details of the Fast-Time methods used to create the direct route samples and a description of how the levels were increased for all samples. Further details of the traffic samples, their throughput, characteristics and naming convention are included in Appendix C.

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7. TRIAL METHOD

7.1. Trial Design

The PD/1++ trial was designed to meet the objectives of the trial (see section 2.2), and ran for a total of two weeks from the 17th August 1998 to the 28th August 1998 inclusive. A full account of the trial design can be found in Appendix C of this report.

Four distinct 'organisations' (referred to as ORGs) were developed to address the aims of the trial. The same set of PATs and their associated GHMI was available for use by the controllers in all ORGs and 70% of aircraft were assumed to have a 4D FMS coupled with bi-directional air/ground datalink. All ORGs included RVSM above FL295. Figure 6 (the curve in ORG2 and ORG3 is only for illustration), illustrates the ORGs which were as follows:

- ORG0 NERC sectors 10 and 11 were simulated with all aircraft flying structured routes;
- ORG1 As ORG0, but with the Hornsea sector in place of sectors 10 and 11;
- ORG2 NERC sectors 10 and 11 were simulated. All aircraft equipped with a 4D FMS and datalink capability were allocated FL295 and above and flew direct routes. Aircraft without datalink flew structured routes and remained below FL295;
- ORG3 As ORG2, but with Hornsea sector in place of sectors 10 and 11.

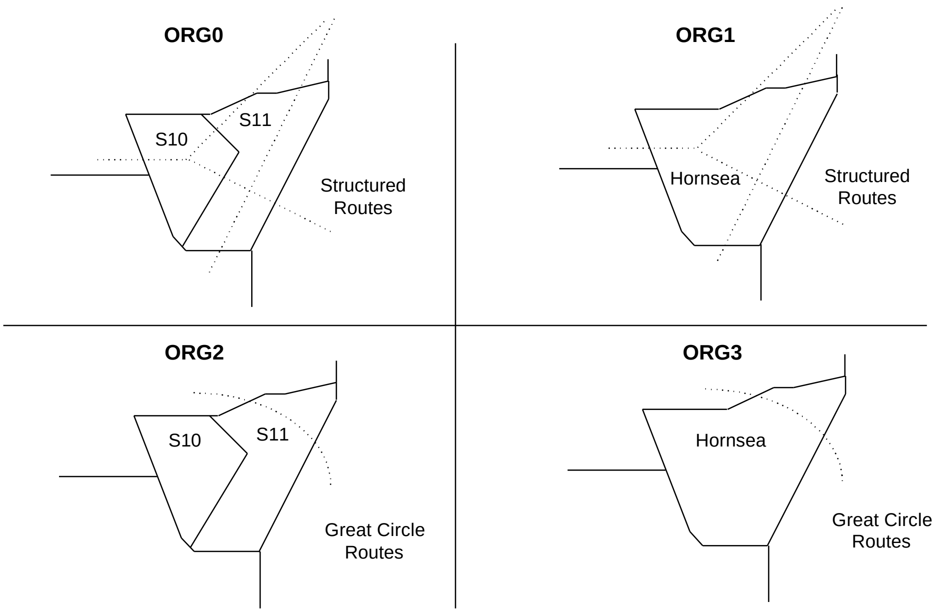

Figure 6 - The PD/1++ Organisations

7.2. Trial Variables

The main aim of the trial was to compare the use of: structured routes with direct routes; current sectorisation with larger sectors than currently in use to day; and controller operating practices. In each case these comparisons were achieved within an environment that incorporated the PHARE concept - of the introduction of computer assistance and advanced planning - alongside RVSM. The traffic samples used varied from those representative of current day traffic levels and patterns to those incorporating direct routes and 75% more traffic than current day. However in addressing the main aim of the trial, the traffic sample, be it current day or enhanced by 75% was kept constant within any comparisons made and hence was not a measured trial variable. The measurable trial variables were, therefore:

- the route structure;
- the sector size;
- controller operating practices.

7.3. The Participants

The PD/1++ trial ran for two weeks. Eight controllers participated in the trial, each for the full fortnight. One of the controllers was from the London Area and Terminal Control Centre (LATCC) and three of the controllers were recently retired from LATCC; the remaining four controllers were from the ATMDC at Hurn. None of the eight controllers held a current licence, however five had taken part in previous PHARE trials.

Each sector was staffed by a team of one tactical controller and one planning controller. The controllers were allocated randomly to either a planning role or tactical role and in each case remained in the same role and in the same tactical/planner team for the duration of the trial. The controllers did not remain in the same sector for the trial, but rotated through sectors 10, 11, Hornsea and the feed sectors.

7.4. Training

Prior to the trial the controllers took part in a day of computer-based training using the original PD/1 standalone training system. In addition, the first two days of the trial were dedicated to controller training. The aim of the training was to provide the controllers with confidence and proficiency in the use of the PD/1++ system prior to the measured runs. Full details of the training given and the samples used during the training exercises can be found in Appendix C.

7.5. Measurements recorded and data collected

NRF trials gather a great quantity of objective and subjective data from a variety of sources, for analysis in accordance with the trial analysis plan. The measures recorded are outlined below. Full details of the data collection methods and measurements taken during the trial can be found in Appendix C.

7.5.1 Subjective data

The subjective data, that is those measurements representing the opinion of the controllers, were gathered from a variety of sources during the trial. The Instantaneous Self Assessment (ISA) measurement and NASA Task Load Index (TLX) questionnaires (see Appendix C) were used to record the controllers' perceived overall workload. ISA records the controllers perceived workload on a scale of one to five every two minutes; one being under utilised and five representing an excessive level of controller workload. The mid-point, three, represents a busy but sustainable level of controller workload. As in previous PHARE trials carried out by NATS (see Reference 2) , an ISA response of three was used as an indicator of capacity for both the planning and tactical controllers. TLX allowed individual components of controller workload to be analysed. In addition, questionnaires, debriefs and controller comments were used, both to obtain controllers' opinions and, along with a specially-designed psychometric questionnaire, to carry out a usability assessment of each organisation.

7.5.2 Objective data

Objective data, that is those measures not subject to the controllers' opinion, were recorded automatically either by the NRF system, Ericsson and Redifon communications systems or the track generator. For example, 'log files' were produced containing: a record of the pseudo-pilot inputs; radar plot data; the details of R/T usage; or details of interactions with a particular tool. In addition, video recordings were made, giving a definitive record of the controllers' actions for subsequent use in PUMA analysis.

7.5.3 Observations

During a number of both the training and measured exercises in each organisation, the performance of the controllers was observed overtly by specialist observers. The purpose of the observation was to assess, subjectively, controller body language, responses to particular events and the occurrence of certain actions. Throughout the observations, any relevant comments were also noted and formally recorded as part of the post-trial analysis.

7.6. Statistical analysis methodology

In addition to the specific aim for the PD/1++ trial as a whole (see section 3), more detailed aims were required in order to analyse more specifically the effect, for example, of alternative airspace structures on controller workload. Ten such detailed aims, termed herein as low-level objectives, were identified for the PD/1++ trial and are fully described in Appendix C.

In the analysis plan, null and alternative hypotheses were developed for each low-level objective of the trial, and the appropriate subjective and objective data required to test the hypotheses were identified. The analysis plan also described the statistical analysis to be conducted in testing the hypotheses.

A typical detailed objective was:

> *"For each controller role, examine whether alternative airspace structures ie sector 10 and sector 11 versus Hornsea, had a positive impact on controller workload, given the same operating practices".*

The null hypothesis for this detailed objective was:

> *"The individual controller workload in ORG0 was the same as in ORG1."*

Alternative hypothesis:

> *'The individual controller workload in ORG0 was different from that in ORG1.'*

Descriptive statistics, usually in the form of a graph or histogram were produced for each measurement prior to the statistical tests being carried out, to give an indication of the size and range of each measurement. Where it was not possible to carry out statistical tests because of lack of data, analysis was limited to descriptive statistics only. However, it should be born in mind that direct comparisons between one data set and another can not be made using descriptive statistics alone.

Where possible, the Kruskal-Wallis one-way and Friedman two-way analysis of variance tests were used to determine whether a statistically significant difference existed between any of the organisations in each of the measurements indicated.

The level of significance used in the statistical tests was chosen to be 5%[1]. This was chosen by taking into consideration the number of statistical tests planned in the task corresponding to the objective, and deciding on the acceptable risk of a false positive. As only eight controllers participated in the trial, statistical significance testing of the questionnaire responses was not appropriate. Therefore only a qualitative assessment was performed on these results in order to determine whether this subjective evidence supported or rejected the respective null hypothesis.

An outcome of the testing may be that the null hypothesis is not rejected. In these cases, the ‘power’ of the test was estimated to provide a figure for the confidence that can be placed in accepting the null hypothesis correctly. The power of a statistical test could be used to determine if there is evidence to suggest no difference.

Further details of the statistical methodology applied can be found in Appendix C.

7.7. Use of observations, comments and debrief material

The observations, controller comments and debrief material were all documented and classified. They were then combined with the statistical results. This served two purposes: to put the statistical results into context and thus allow easier interpretation; and to highlight areas in which more detailed statistical analysis would be necessary, for example to provide objective evidence to support the views expressed by the controllers.

[1] With a significance level of 5%, it is to be expected that on average for 1 test in 20 the null hypothesis is wrongly rejected. This means that the observed difference did indeed occur by chance and the null hypothesis should not have been rejected.

8. TRIAL RESULTS

The PD/1++ trial was designed to investigate the effect on controller workload, airspace capacity, quality of service and the usability of the system, of the introduction of alternative airspace structures and alternative operating practices. This section summarises the results of the trial, presented in full in Appendix D and Appendix E, against this aim.

Each low level objective asked a very specific question and an appropriate subset of data was collected for analysis. Results are presented within the following sections for the specific data collected against each objective.

Section 9.1 gives an account of the exercises completed during the trial.

Section 9.2 presents the results gathered in relation to the comparison of controller workload between the ORGs. Section 9.3 and section 9.4 show how quality of service and capacity varied respectively between the ORGs. The results on usability are given in section 8.5.

The implications of all the results are discussed in section 10.

8.1. Trial Account

A total of twenty seven measured exercises, out of a planned maximum of thirty two, were completed between Wednesday, August 17th and Friday, August 28th, 1998 inclusive. It was planned to complete eight exercises for each ORG. However, only six exercises were completed for each of ORG0 and ORG1, seven exercises were completed for ORG2 and eight exercises were completed for ORG3.

The descriptive statistics shown in the figures in the following sections use the data collected from all 27 measured exercises. However, to avoid any bias due to more exercises being completed in some ORGs than others, the statistical significance analysis only used data collected from exercises that used the same corresponding traffic samples in all ORGs.

It was noticed during the analysis of the trial data that one planning controller rarely invoked the HIPS tool. For potential conflicts this controller used the conflict zoom window to assess whether any avoiding action was necessary. It was decided to disregard the data for HIPS for this controller since the controller's use was atypical in experience of other planning controllers in this and other trials. Video analysis of the HIPS usage by this particular controller verified the objective results obtained for the number of times the HIPS was used.

In comparing measures between ORGs, alternative airspace structures or operating practices, the trial variables, were the expected causes for any variations observed. The number of aircraft on frequency per hour in each ORG varied considerably, in part due to the very nature of moving to larger sectors and direct routes. This could also have been a cause of differences in the measures, although the trial was not designed to explore this factor. The traffic samples were not a measured variable of the trial. Figure 7 shows the number of aircraft on frequency achieved per hour for each sector in each ORG. The aircraft on frequency per hour has been calculated from all the measured exercises completed during the trial. The vertical bars on the graph represent the 25th to the 75th percentile of the measure, and the centre point is the median.

Thus in all of the results that follow, differences in traffic volume must be taken in to account when comparing measurements between the various organisations.

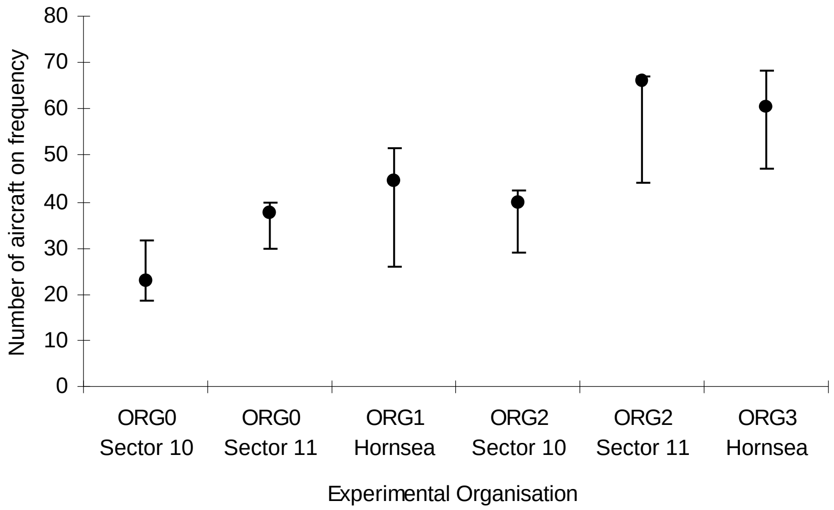

Figure 7 - Number of aircraft on frequency per hour in each ORG and sector

8.2. Controller Workload

The effect on controller workload of either alternative airspace structures or alternative operating practices was compared by using several combination pairs of ORGs. Comparisons between pairs of ORGs used the relevant measurements detailed in Appendix C. These included subjective measures, for instance ISA, TLX and questionnaire responses, in addition to objective measures such as time spent on R/T.

This section initially presents the results from the descriptive statistics for ISA and TLX. The results where there was a statistically significant difference and those where there was evidence to suggest that there was no difference are then summarised in a table for each of the comparisons made between different organisations. Questionnaire results are also presented. Relevant controller comments are included irrespective of whether they support the results obtained from the statistical analysis.

Figure 8 shows the overall TLX scores for each sector in each ORG, and for each of the controller roles. The overall TLX scores range from a possible minimum of 15 to a possible maximum of 300. A high TLX score implies a high level of controller workload. The median score along with the 25th and 75th percentiles are presented. The spread between the percentiles gives an indication of the spread of scores across all controllers. A short spread indicates consistency of scores across all controllers, and vice versa. Statistical analysis of the overall TLX scores between the ORGs was inconclusive as to whether a difference existed for either the planning or tactical controller.

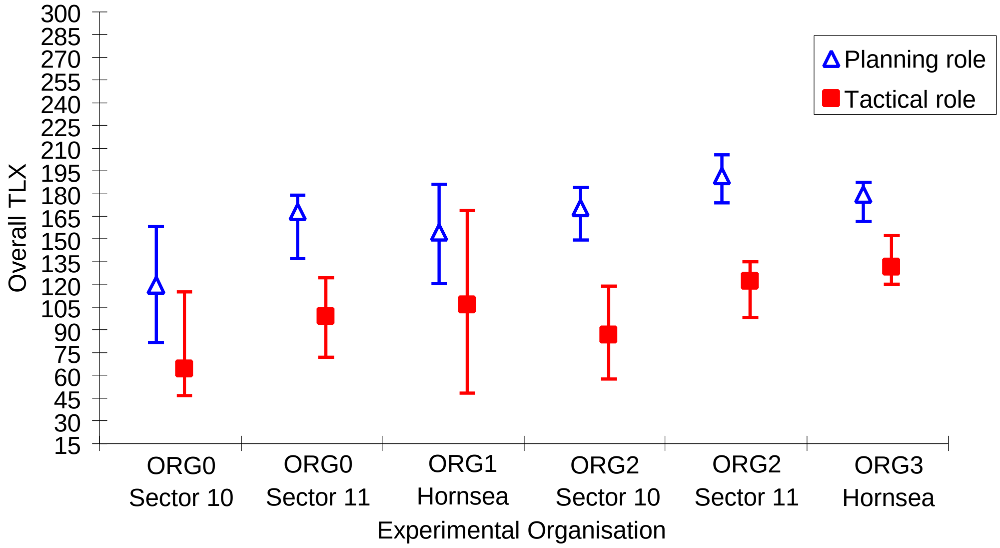

Figure 8 - Overall TLX for each ORG and sector

Figure 9 shows the percentage of ISA scores of each level recorded for each controller in each ORG. The controllers were referred to as a, b, c, d, e, f, g or h. For ORGs 0 and 2, the percentage of each ISA response is given over both sector 10 and sector 11. Where a controller failed to mark any ISA value, an 'x' was recorded.

Figure 8 and Figure 9 are descriptive; thus whether or not there are statistically significant differences cannot be inferred from these figures alone.

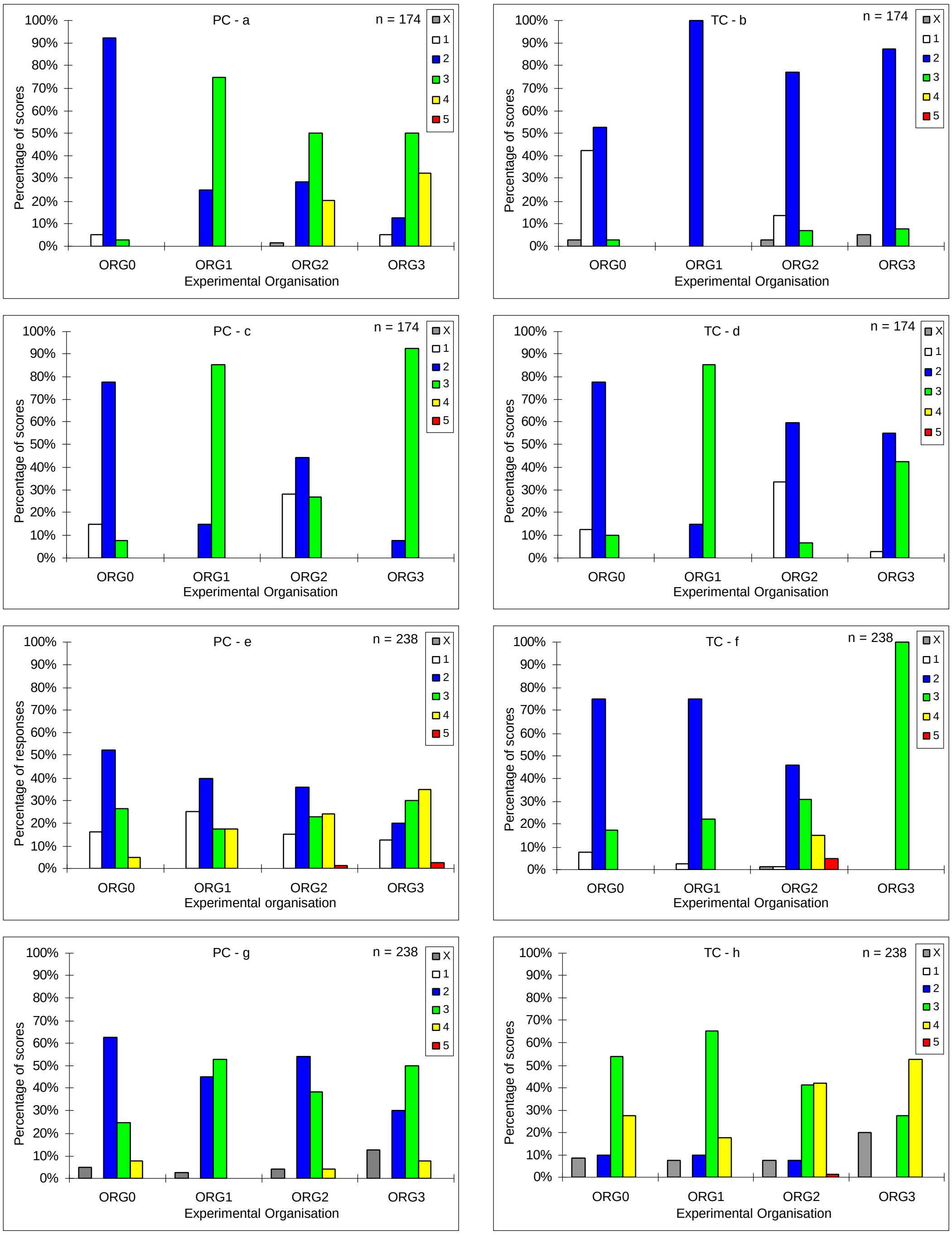

Figure 9 - percentage of ISA scores for each controller

The proportion of aircraft equipped with a 4D-FMS and datalink capability (70%) was the same in each ORG. However, the controllers made the following comments with respect to the effect of the inclusion in the traffic samples of aircraft without datalink.

- *"If as a planning controller you start moving the 3Ds around, it doesn't half generate a lot of work for the tactical controller";*
- *"Most of the work was done by the system, but if more than two 3D A/C were being managed on sector the [controller] workload increased rapidly".*

8.2.1 Controller Workload: ORG0 versus ORG1

Comparing ORG0 with ORG1 enables the evaluation of alternative airspace structures, sectors 10 and 11 versus Hornsea, both with structured routes.

Table 1 gives the measures where there were found to be statistically significant differences between ORG0 and ORG1 and indicates the direction (< ,>) of the difference.

Result	Measure	Controller role
ORG0 sector 10 < ORG1 Hornsea	ISA responses R/T communications Time to first register	Planning and tactical Tactical Planning

Table 1 - Summary of the statistically significant differences, ORG0 versus ORG1

The median percentage of time spent in R/T communications was 68% higher in ORG1 Hornsea than in ORG0 sector 10. The median percentage of time taken to register each aircraft was 23% higher in ORG1 Hornsea than in ORG0 sector 10.

Table 2 gives the measures where there was found to be evidence to suggest no statistically significant difference, (=), between ORG0 and ORG1.

Result	Measure	Controller role
ORG0 sector 10 = ORG1 Hornsea	Release alerts	Tactical
ORG0 sector 11 = ORG1 Hornsea	ISA responses Release alerts R/T communications	Tactical Tactical Tactical

Table 2 - Summary of the measures where there was evidence of no statistically significant difference, ORG0 versus ORG1

Figure 9 shows that all planning controllers marked ISA 3 or below for more than 80% of the time during both ORG0 and ORG1. Other than marking ISA 3 or less, two planning controllers marked ISA 4 between 4% and 8% of the time in ORG0. One of these two planning controllers also marked ISA 4 for 18% of the time in ORG1. Three of the tactical controllers never marked above ISA 3 in either ORG0 or ORG1. The fourth tactical controller marked ISA 3 or less for more than 70% of the time in ORG0 and for more than 80% of the time in ORG1. At no point was ISA 5 pressed by any controller in each of the two ORGs.

Questionnaire responses by two of the four planning controllers indicated that the controller workload in ORG1 was higher than that in ORG0. One of the four planning controllers indicated the controller workload was lower in ORG1 and suggested the controller workload in ORG0 was regularly ‘too high’ to cope. Comments by planning controllers on differences in sectorisation were:

- *“Logically the larger sectors are better because of the time pressure in the small sectors”;*
- *“Planning is much easier with a large block of airspace and less boundary”.*

One planning controller ‘always’ felt frustrated with the system in ORG0 and ‘regularly’ felt frustrated in ORG1. One planning controller ‘regularly’ felt frustrated in ORG0 and ‘rarely’ felt frustrated in ORG1. The remaining two planning controllers ‘regularly’ felt frustrated in both ORGs. Explanations for the level of frustration experienced included comments about the ability to plan across a sector boundary.

- *“Reduction in problems at sector boundaries - consequent reduction in frustration”;*
- *“trying to use tools around the boundary”;*
- *Eased planning task, more subtle and less complex solutions due to removal of 10/11 boundary”;*
- *"It [Hornsea] was frustrating as before - less than 10/11. Reduction in problems at sector boundaries”.*

Only once did one tactical controller feel frustrated with the system and this was in ORG0. Questionnaire responses from all of the tactical controllers indicated the controller workload was either ‘never’ or ‘rarely’ too high.

One tactical controller commented:

- *"less pressure to achieve targets... and more room [in Hornsea]”.*

8.2.2 Controller Workload: ORG2 versus ORG3

Comparing ORG2 with ORG3 enables the evaluation of alternative airspace structures, sectors 10 and 11 versus Hornsea, both with great circle routes.

Table 3 gives the measures where there were found to be statistically significant differences between ORG2 and ORG3 and indicates the direction (< ,>) of the difference.

Result	Measure	Controller role
ORG2 sector 10 < ORG3 Hornsea	ISA responses R/T communications Time to first register	Planning and Tactical Tactical Planning

Table 3 - Summary of the statistically significant differences, ORG2 versus ORG3

The median percentage of time spent in R/T communications was 74% higher in ORG3 Hornsea than in ORG2 sector 10. The median percentage of time taken to register each aircraft was 85% higher in ORG3 Hornsea than in ORG2 sector 10.

Table 4 gives the measures where there was found to be evidence to suggest no statistically significant difference, (=), between ORG2 and ORG3.

Results	Measure	Controller role
ORG2 sector 10 = ORG3 Hornsea	Release alerts	Tactical
ORG2 sector 11 = ORG3 Hornsea	ISA responses Release alerts Time to first register	Planning and tactical Tactical Planning

Table 4 - Summary of the measures where there was evidence of no statistically significant difference, ORG2 versus ORG3

Questionnaire responses from the tactical controllers indicated that there was no difference in controller workload between ORG2 sectors 10 and 11 and ORG3 Hornsea: two of the controllers rating their workload as high but acceptable in both organisations; and two as low but acceptable in both organisations. Questionnaire responses from all the tactical controllers indicated that the controller workload was either ‘never’ or ‘rarely’ too high in either ORG.

Three out of four planning controllers indicated that their workload was high but acceptable in sectors 10, 11 and Hornsea, but ‘never’ or ‘rarely’ too high to cope.

Two planning controllers and one tactical controller felt that ORG3 Hornsea required more mental demand than ORG2 sectors 10 and 11. Three out of the four planning controllers ‘regularly’ felt frustrated with the system in both ORG2 sectors 10 and 11 and ORG3 Hornsea.

The following comment was made during a debrief:

- *“I think the larger sector was a very big plus”.*

8.2.3 Controller Workload: ORG0 versus ORG2 and ORG1 versus ORG3

Comparing ORG0 with ORG2 enables the evaluation of structured versus great circle routes coupled with different operating practices, while maintaining sectors 10 and 11 as the airspace structure. Comparing ORG1 with ORG3 enables the evaluation of structured versus great circle routes coupled with different operating practices, while maintaining the Hornsea sector as the airspace structure.

Table 5 gives the measures where there were found to be statistically significant differences between ORG0 and ORG2 and between ORG1 and ORG3 and indicates the direction (< ,>) of the difference.

Result	Measure	Controller role
ORG0 sector 10 < ORG2 sector 10	ISA responses R/T communications	Planning Tactical
ORG0 sector 11 < ORG2 sector 11	ISA responses Release alerts R/T communications	Planning and tactical Tactical Tactical
ORG1 Hornsea < ORG3 Hornsea	ISA responses R/T communications	Planning and tactical Tactical

Table 5 - Summary of the statistically significant differences, ORG0 versus ORG2, ORG1 versus ORG3

The percentage of time the R/T was in use was 69% higher in ORG2 sector 10 than in ORG0 sector 10.

The median number of release alerts was 313% higher in ORG2 sector 11 than in ORG0 sector 11. The percentage of time the R/T was in use was 50% higher in ORG2 sector 11 than in ORG0 sector 11.

The percentage of time the R/T was in use was 75% higher in ORG3 Hornsea than in ORG1 Hornsea.

Table 6 shows the measures where there was evidence to suggest no statistically significant difference, (=), when comparing direct routes with structured routes.

Results	Measure	Controller role
ORG0 sector 10 = ORG2 sector 10	Time to first register	Planning
ORG1 Hornsea = ORG3 Hornsea	Time to first register	Planning

Table 6 - Summary of the measures where there was evidence of no statistically significant difference, ORG0 versus ORG2, ORG1 versus ORG3

Questionnaire responses by all of the planning controllers indicated that the controller workload in ORG2 and ORG3 was either ‘high but acceptable’ or ‘low but acceptable’. Two planning controllers stated the controller workload was ‘low but acceptable’ in ORG0, and one planning controller stated the controller workload was regularly ‘too high’ to cope. All the controllers indicated the controller workload was either ‘never’ or ‘rarely’ too high to cope in ORG2 and ORG3.

When asked about controlling great circle routes, the planning controllers made the following comments:

- *“I am amazed actually how simple it is to do the direct routings in 4D airspace”;*

- *"I felt it was a bit easier when they were in great circle routes because you had less problems of overtaking or opposite direction";*
- *"Slight reduction in conflicts overall. Made the use of HIPS essential for conflict detection".*

The tactical controllers commented on their change in mental demand and workload:

- *"Monitoring traffic was harder";*
- *"Monitoring traffic off routes [ORG 2 and ORG3 above FL295] and working out which exit fix was closest to their route".*

Inherent in the move from ORG0 to ORG2 and from ORG1 to ORG3 were differences in the controller roles. These are explained in section 6. In an attempt to ascertain the effect this had on controller workload, questions were asked in the questionnaires and the debriefs relating to: the change in roles between the ORGs; and the relevance of the planning and tactical roles within the PHARE concept.

Change in roles between the ORGs

- *"Role did not change, we worked as a team in all ORGs, irrespective of 3D, 4D or level";*
- *[conversation from a debrief:] "[Is the controller] role changing with the organisations or is it the same across the organisations that we're working? Same for everything, Yes, stays the same. Well it stays the same to the extent that it changes with the traffic situation, irrespective of the organisation".*

Appropriateness of the planning and tactical roles

- *"It comes back to the fact that the actual mix is wrong in this environment. It's following the NERC-style planner and tactical break in responsibilities and it's not actually appropriate, I don't think. There's different roles in there that need to be thought out";*
- *"Planning seems to have higher [controller] workload. Maybe some of the simple plans can be registered by the tactical";*
- *"I don't think the planning/tactical relationship is valid in PHARE, two controllers maybe, but task design is unequal and inappropriate - needs a lot of study";*
- *"We worked as a team and shared work. Planning and tactical was used as a loose basis, but it's probably not a long term solution".*

8.2.4 Controller Workload: ORG0 versus ORG3

Comparing ORG0 with ORG3 enables the evaluation of alternative operating practices and alternative airspace structures. The alternative airspace structures in this case are the different routing scenarios and the two sectorisations.

Table 7 gives the measures where there were found to be statistically significant differences between ORG0 and ORG3 and indicates the direction (< ,>) of the difference.

Result	Measure	Controller role
ORG0 sector 10 < ORG3 Hornsea	ISA responses	Planning and tactical
ORG0 sector 11 < ORG3 Hornsea	ISA responses	Planning and tactical

Table 7 - Summary of the statistically significant differences, ORG0 versus ORG3

Questionnaire and debrief comments on how the controller workload changed from structured routes in small sectors, ORG0, to great circle routes in large sectors, ORG3, include:

- *"Great circle routes in Hornsea sector were easier to handle";*
- *"This task and tools work best in large sector without too many boundaries. Great circle tracks reduce the amount of conflicts and makes the tools essential";*
- *"[Controller] Workload decreased when changing from structured routes to great circle and from 10 and 11 to Hornsea";*
- *"Hornsea is easy because you've got more room and you can be more subtle in what you do but the tools don't make a resounding difference between en-route/off route/big sector/small sector".*

8.3. Comparison of quality of service between all the ORGs

There were no significant differences when comparing all ORGs in the percentage of aircraft which had a maximum cruise level that corresponded to the requested cruise level.

In ORG2 and ORG3, there were no 3D-FMS aircraft that had a requested cruise level above FL295. This was a part of the design of the ORGs.

Controllers made the following comments during debriefs and in questionnaires when asked to compare sectors 10 and 11 with Hornsea:

- *"It was easier to give direct routes and better profiles in the large sector";*
- *"Large sectors means less changes";*
- *"Easier and more continuous climbs and descents";*
- *"More violent heading changes required to resolve conflicts in a small sector";*
- *"Not much change ORG1 to ORG3, significant improvement ORG2 to ORG3".*

Controllers made the following comments during debriefs and in questionnaires when asked to compare structured routes with great circle routes:

- *"Aircraft receive less intervention, so 4D better. 3D, no benefit";*
- *"Great circle tracks…less flying time…therefore less fuel used";*

- *"With direct routing there are many advantages to the airline - time and distance particularly";*
- *"In ORG2 the aircraft get what they want".*

8.4. Comparison of airspace capacity between all the ORGs

Figure 10 and Figure 11 show the number of aircraft on frequency when ISA 3 scores were recorded and the number of aircraft on frequency over all ISA scores for each sector in each ORG for the planning and tactical roles respectively. ISA 3 represents a busy but sustainable level of controller workload. As in previous PHARE trials carried out by NATS (see Reference 2) , an ISA response of three was used as an indicator of capacity for both the planning and tactical controllers. The number of aircraft on frequency over all ISA has been included to give an indication of the predominance of ISA 3 scores.

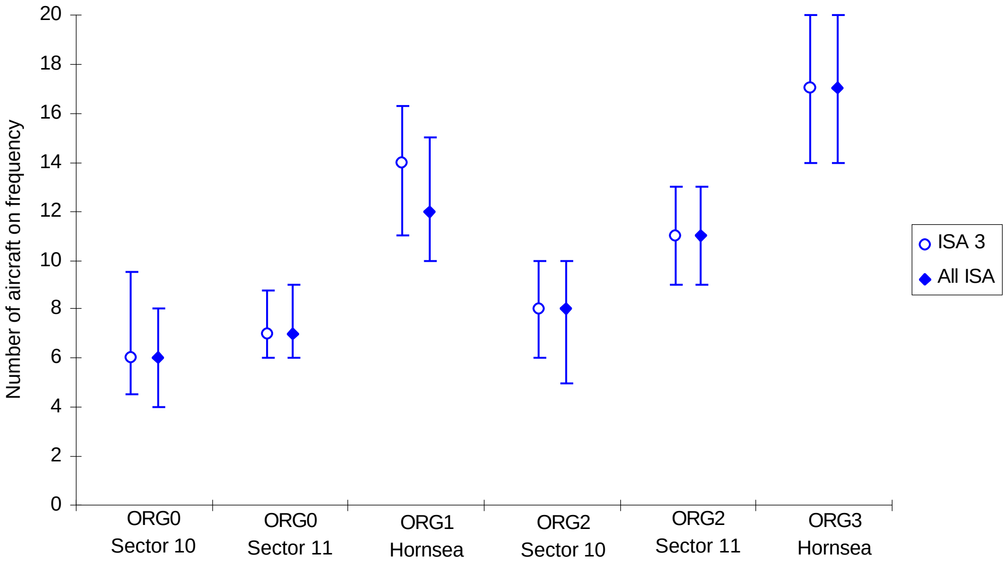

Figure 10 - Number of aircraft on frequency for each sector in each ORG, planning controllers

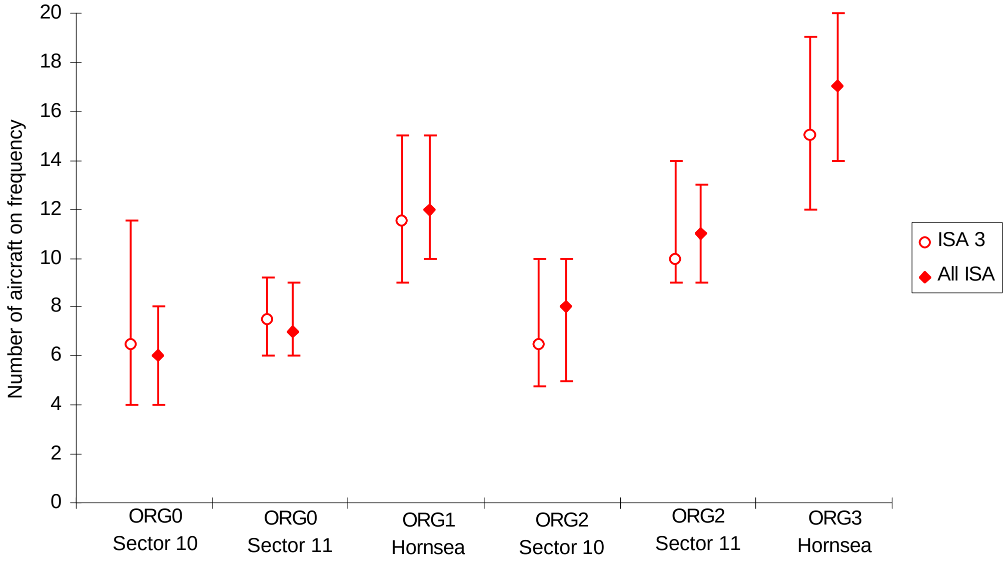

Figure 11 - Number of aircraft on frequency for each sector in each ORG, tactical controllers

Table 8 summarises the comparisons made between two sectors (10 and 11) and one sector (Hornsea) where there was found to be a statistically significant difference in the number of aircraft on frequency when ISA 3 scores were recorded, and indicates the direction (< ,>) of the difference.

Result	Controller role
ORG0 sector 10 < ORG1 Hornsea	Planning and tactical
ORG0 sector 11 < ORG1 Hornsea	Planning and tactical
ORG2 sector 10 < ORG3 Hornsea	Planning and tactical
ORG2 sector 11 < ORG3 Hornsea	Planning and tactical

Table 8 - Summary of the statistically significant differences in the number of aircraft on frequency when ISA 3 scores were recorded, ORG0 versus ORG1, ORG2 versus ORG3

Table 9 summarises the comparisons made between structured routes and direct routes where there was found to be a statistically significant difference in the number of aircraft on frequency when ISA 3 scores were recorded and indicates the direction (< ,>) of the difference.

Result	Controller role
ORG0 sector 11 < ORG2 sector 11	Planning and tactical
ORG1 Hornsea < ORG3 Hornsea	Planning and tactical

Table 9 - Summary of the statistically significant differences in the number of aircraft on frequency when ISA 3 scores were recorded, ORG0 versus ORG2, ORG1 versus ORG3

Table 10 summarises the comparison made between combining direct routes with a larger sector Hornsea and sectors 10 and 11 with structured routes where there was found to be a statistically significant difference in the number of aircraft on frequency when ISA 3 scores were recorded, and indicates the direction (< ,>) of the difference.

Result	Controller role
ORG0 sector 10 < ORG3 Hornsea	Planning and tactical
ORG0 sector 11 < ORG3 Hornsea	Planning and tactical

Table 10 - Summary of the statistically significant differences in the number of aircraft on frequency when ISA 3 scores were recorded, ORG0 versus ORG3

It was planned that the number of separation infringements would be used as a measure of capacity, however, there were too few separation infringements for statistical comparisons of the ORGs to be carried out.

The following comments were made by controllers during debriefs and in questionnaires when asked to compare capacity between great circle routes with structured routes:

- *"Same levels can be given to more A/C as the direct routes separate many tracks naturally";*
- *"Conflict detection abilities reduce [for great circle routes], would have been much worse without HIPS";*
- *"Less concentration of problem at exit points in level flight [for great circle routes]";*
- *"Through easier separation [for great circle routes] and [because of] Reduced Vertical Separation Minima (RVSM), more levels available";*
- *"Less opposite direction conflicts [for great circle routes]";*
- *"Less separation problems [for great circle routes]";*
- *"Probably higher capacity in ORG3 [compared to ORG1], particularly with RVSM".*

A controller made the following comment during one of the debriefs on the subject of capacity:

- *"If you're going to shift this amount of traffic RVSM is a must. That is the biggest asset that has described itself in this trial [RVSM]".*

8.5. Usability

8.5.1 Comparison of tool usage between all the ORGs

Figure 12 and Figure 13 show the number of times the ADFL tool and the HIPS tool were invoked per exercise for each sector in each ORG.

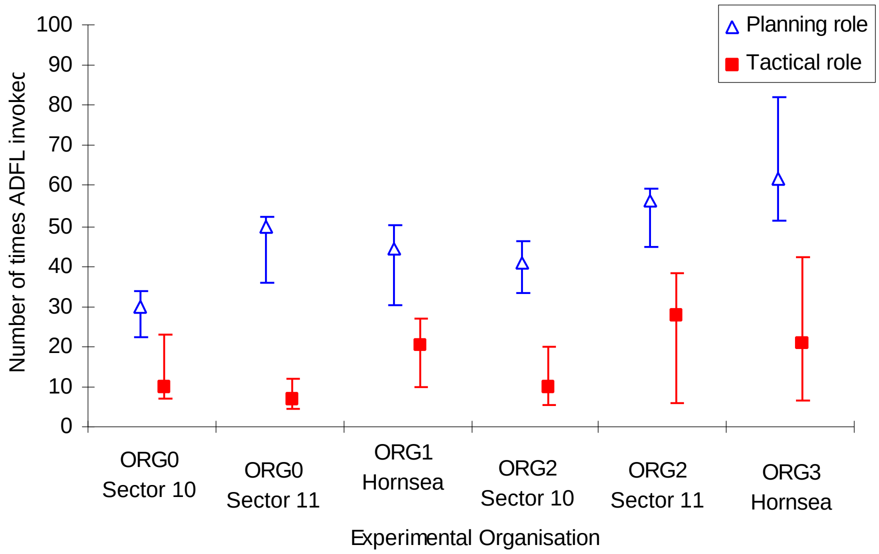

Figure 12 - Number of times ADFL invoked per exercise for each sector in each ORG

Table 11 summarises the comparisons made in the number of times the ADFL was invoked where there was found to be either a statistically significant difference, or where there was evidence to suggest no statistically significant difference. The direction of any difference is indicated, (<, >).

Result	**Controller role**
ORG0 sector 11 = ORG1 Hornsea	Planning and tactical
ORG2 sector 10 < ORG3 Hornsea	Planning and tactical
ORG1 Hornsea < ORG3 Hornsea	Planning and tactical
ORG0 sector 10 = ORG2 sector 10	Planning and tactical

Table 11 - Summary of the comparisons made for the number of times the ADFL was invoked.

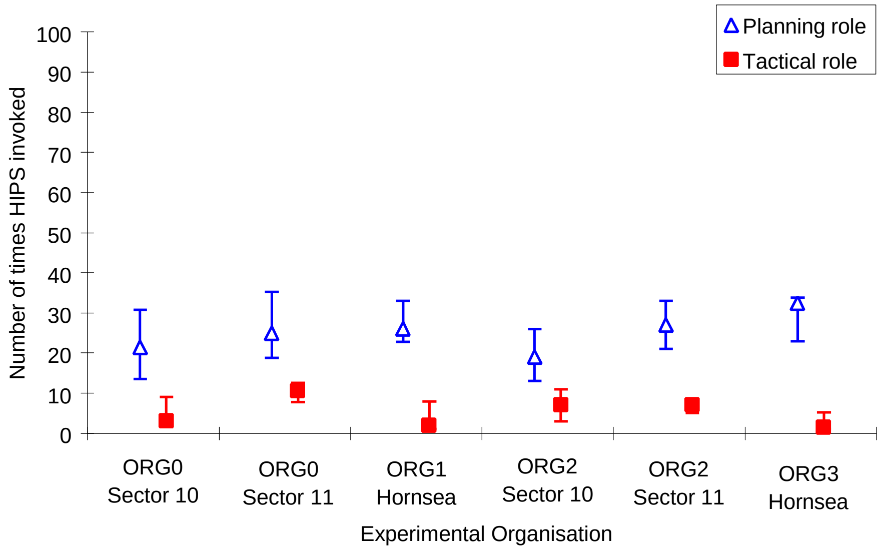

Figure 13 - Number of times HIPS invoked per exercise for each sector in each ORG

The statistical test was inconclusive in comparing the number of times HIPS was invoked between the ORGs.

All the planning controllers indicated in the questionnaires that they used the HIPS, ADFL, CRD and TST tools either 'frequently' or 'regularly'. This included the planning controller for whom the objective measures recorded to determine HIPS use indicated that the HIPS tool had not been used. Video analysis of the HIPS usage by this particular planning controller verified the accuracy of the objective measures. Two of the four planning controllers indicated using the CZW facility 'rarely' for ORGs 0, 1 and 2. In ORG3, one planning controller indicated using the CZW facility 'rarely', with three planning controllers using it either 'frequently' or 'regularly'.

Three of the four tactical controllers 'rarely' used the CRD, and 'rarely' or 'never' used the CZW. Two tactical controllers indicated that they 'rarely' used the CLW.

8.5.2 Usability assessment of system and individual components

This section summarises the controller comments made during either the debriefs or as a result of the observations. The comments are considered under a number of broad headings: planning; conflict detection; tactical intervention; and the control of aircraft without datalink. A summary of the Software Usability Assessment Methodology (SUMI) questionnaire is also included. The functionality of the PD/1++ system, including the PATs, did not vary between the ORGs.

Instead of comparing the usability of the tools between the ORGs, the controllers concentrated on the shortfalls of the system and tools, making no distinction between the ORGs. The resulting comments can appear to be negative at first glance. However, the PD/1++ system ran so much better and more smoothly than any other NATS conducted PHARE trial (as shown by the 85% run success rate) that the controllers were evaluating the software as pre-operational rather than research. This is borne out by the following controller comment:

- *"I think, to be fair, and it's a compliment, this simulation is running so much better in terms of its stability and functionality. I mean I was involved with PD/1+, including being a participant on one of the four weeks. We never* *at the end of PD/1+ got as close to being able to assess the real air traffic control issues as we have done in the first three or four days on PD/1++. It's that much better. I mean it's a compliment in some respects that this all coming out now, that we've actually got a simulation in which the real issues are not masked by an unreliable system".*

Planning

When planning an aircraft controllers commented on the lack of ability to be able to use the tools to plan across a sector boundary:

- *"You need to be able to manipulate HIPS across sector boundaries to do effective ATC";*
- *"You have also got the problem that you get a situation where you have got a potential conflict on the boundary and you think, well if I move mine, and the other controller moves theirs and we both move in the same direction, we still compound the problem".*

Conflict Detection

Controllers made the following comments with respect to the Conflict Risk Display (CRD):

- *"I found myself looking at it [the CRD] quite a lot to see what was going on";*
- *"…of all the tools that I could pay least attention to before this simulation, and the one that I came to trust most during the simulation, was the Conflict Risk Display. It actually didn't let me down when everything else did, most of the time";*
- *"The nice thing about the CRD is you can set it to 25 minutes or 15 minutes or whatever you want. You can do your essential entry tasks to make sure the aeroplane comes in safely and you know that sooner or later that little red sign is going to come rolling in on the right to remind you, if you have forgotten it, that there's still a separation task you've got to resolve. It's excellent for that, it's the only aide memoir that you've actually got on the whole system. Everything else is 'do it' 'done it' – that's the one thing that reminds you of outstanding tasks, and it also tends to be very reliable and accurate";*
- *"It's the only thing you've got to remind you of outstanding problems you haven't solved. If you're a planner, if you didn't have the CRD, you would really have to resolve everything at the time that it was offered to you because otherwise you've got no way of remembering what your outstanding tasks are".*

However the lack of consistency at times between the various tools led to the following comments:

- *"The tools behaved well, in terms of conflict detection and presentation. They were unreliable due to lack of consistency…on occasion the tools failed";*
- *"There were many instances where the CRD showed a potential loss of separation while the HIPS showed no red";*
- *"Short Term Conflict Alert (STCA), HIPS and CRD need to talk to each other and not present different or conflicting information";*

- *"The cross-correlation between the 3 tools [CRD , HIPS, ADFL] sometimes gives totally different pictures of the situation. That is intensely frustrating".*

Tactical Intervention

When required to give a tactical intervention controllers felt that the tools hindered their task. The following comments were made:

- *"As soon as you do your first thing tactically, you created an extra [controller] workload that's not there in today's world. The system has created work which then goes exponential because then you have more things to do tactically, because everything's fallen behind";*
- *"There's too much HMI involved in tactical interventions. It appears to me that there's more HMI involved than with planning".*

Control of aircraft without datalink

The principal of having to pass messages at a very specific time via the R/T to maintain aircraft without datalink on their trajectories was questioned. Even when the controllers issued the exact instructions listed in the CLW at the correct time the aircraft deviated. Tactical controllers made the following comments:

- *"...you're constantly watching the clock and trying to pair up the times to do the instruction";*
- *"…trying to tick off in your mind how many more minutes it is before you have to follow the instruction there, and in the end in fact I took those instructions as being merely a hint of what to do".*

SUMI Questionnaire

SUMI Questionnaires were used to measure quantitatively how usable the controllers found the PD/1++ system.

SUMI analysis is split into five different aspects: efficiency, affect, helpfulness, control, and learnability, as well as giving the global usability score, thus allowing diagnosis of any problematic aspects of usability in each ORG. See Appendix E for a brief definition of these categories.

The global scale is the most reliable scale in SUMI. It has a mean of 50 with a standard deviation of 10; therefore, 68% of the population will lie between 40 and 60. The global scale is a good measure for comparisons between ORGs and is a general usability benchmark. If an ORG is to be considered state-of-the-art, then the target for the global score should be greater than 60. ORGs scoring between 50 and 60 are by definition above average, ORGs scoring 50 and 40 are below average.

Any of the other sub-scales which are at or below 50 indicate that they are considered poor for that aspect. Sub-scales at or below 40 indicate the need for remedial action. Good software will achieve scores of 60 or more in most sub-scales. As a rule of thumb, reasonable acceptable commercial software rarely falls below 55 in most sub-scales.

Scores below 20 or above 70 for any SUMI scale indicate that the user has responded in an atypical fashion.

In a research environment, the above interpretation of the SUMI scores may be slightly relaxed. A definition of the SUMI score more relevant to the maturity of the software may be employed. For software of the PD/1++ maturity, above 40 is understood to be acceptable. Only the ‘learnabilty’ aspect of the SUMI analysis for PD/1++ was acceptable, see Figure 14.

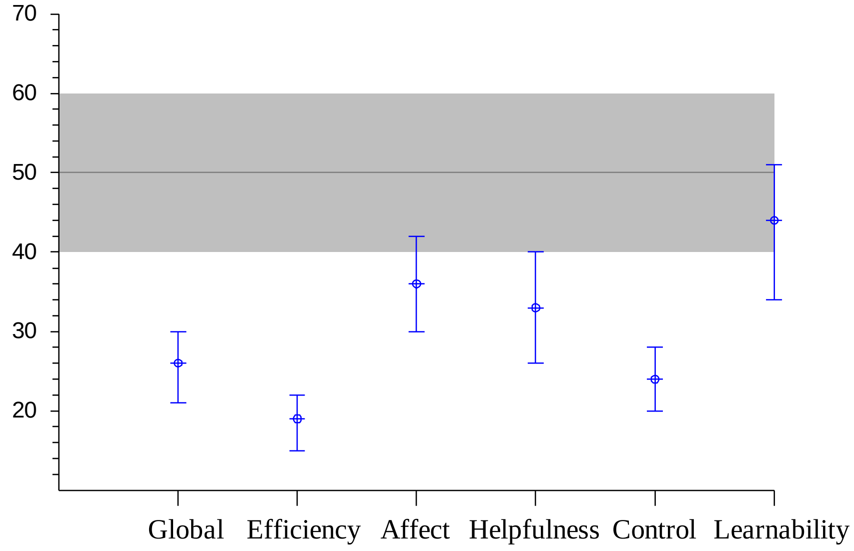

Figure 14 - Summary of the SUMI scores

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9. DISCUSSION

This section draws together the results of both the objective and subjective data and, in addition, the results from the usability study. The discussions relating to the usability of the PD/1++ system rely upon the subjective data gathered during debriefs, observations and from comments logged by the controllers themselves.

Within the overall PHARE concept of the introduction of computer assistance tools and advanced planning, separate subsections discuss the effects on airspace capacity, controller workload, and quality of service to aircraft of the introduction of direct routes and larger sectors. The design of the PD/1++ trial makes it impossible at times to discuss one without the other. In each discussion, consideration is given to the usability aspects of the system. Finally, subsections are devoted to a discussion on the usability of the PD/1++ system and software and the various aspects of the concept highlighted during the trial.

In drawing conclusions from this section, it should be noted that in all organisations simulated:

- RVSM was included above FL295;
- 70% of the aircraft had a 4D FMS and datalink capability;
- the PHARE Advanced Tools were available to the controllers.

It can therefore not be said with any certainty, that conclusions drawn from this section hold true if one or any combination of these were absent.

9.1. Airspace Capacity

When developing the PD/1++ analysis plan, the number of aircraft on frequency when ISA 3 scores were recorded was selected as an indication of the airspace capacity; the rational being that an ISA 3 score represents a busy, but sustainable, level of controller workload. This measure had been used in previous PHARE trials, (see Reference 2). Using this definition and considering the results obtained, see Figure 7 and Tables 8, 9 and 10, the conclusions drawn would be that:

- the airspace sector capacity was greater for Hornsea than either of sectors 10 and 11 separately;
- the airspace sector capacity was greater when direct routes were flown.

Certainly the controller comments would support the view that direct routes have the potential to increase sector capacity.

During the post-trial analysis phase, it became obvious that for a number of reasons this measure could not be used as a complete indication of sector capacity.

Detailed analysis of the PD/1++ trial has served to highlight the complexities of trying to measure and analyse airspace capacity or throughput where either the sectorisation or traffic routings differ markedly. Further work needs to be carried out to understand airspace capacity and throughput and in particular the effects that the introduction of the PHARE concept alongside direct routes and larger sectors may have. If, for example, it could be demonstrated that throughput of the entire airspace had at least been maintained with no increase in controller workload, the gain would be in the reduction in the number of controllers required to operate the airspace. Traditionally sectors have been split to increase throughput; the PHARE tools and concept may enable the reverse, but this can not be concluded from the PD/1++ trial. Neither can it be concluded that moving from structured to direct routes has increased throughput. It must also be noted that any conclusions drawn would only hold for the sectors simulated and could not necessarily be translated to other areas of airspace.

Therefore, it may be concluded that the PD/1++ trial has demonstrated a significant increase in the **controller's instantaneous capacity** through both the introduction of larger sectors and direct routes. With the PD/1++ tools and concept, the controllers can comfortably handle the increased traffic resulting from combining sectors or moving to direct routes. This conclusion supports the findings of previous PHARE trials that the PHARE tools may be better suited to use in larger sectors than examined hitherto and that they support the introduction of direct routes; however, the degree to which the tools and aircraft fit were alone responsible for any improvement in the controller's instantaneous capacity cannot be stated as there was no 'without tools baseline'. The trial did not examine whether the introduction of the PHARE tools could enable either sector 10 or 11 to handle significantly more traffic in either the structured or direct routing scenarios without affecting controller workload.

9.2. Controller Workload

9.2.1 Comparing sectors 10 and 11 with Hornsea when structured routes are flown

The results from the ISA responses show that controller workload increased for both the planning and tactical controllers when moving from sector 10 to Hornsea, but remained the same for the tactical controller when moving from sector 11 to Hornsea. These results are perhaps not surprising. Under structured routes all traffic that passed through sector 10 also passed through sector 11, but the converse was not true. For a controller moving from sector 10 to Hornsea it would appear that there was more traffic to control for the same exercise; however the difference in moving from sector 11 to Hornsea would not be as marked. To a certain extent this is borne out by the aircraft per hour figures presented in Figure 7, where the sector 11 results are very similar to Hornsea.

The results obtained for the amount of R/T communication – a well proven objective measure of some element controller workload – also support this argument, being greater for Hornsea compared to sector 10 but remaining the same between Hornsea and sector 11. Examination of tool usage shows that there was no evidence to suggest a difference in the number of times the ADFL was invoked by either controller in Hornsea when compared to sector 11 (see section 9.5.1). Since the ADFL is routinely invoked when planning an aircraft, this data supports the ease with which sector 11 controllers were able to move to Hornsea.

Although an increase in controller workload was recorded in moving from sector 10 to Hornsea, the ISA scores recorded by both the planning and tactical controllers suggested that, at no time, did either the planning or tactical controllers experience excessive levels of controller workload. High levels of controller workload (ISA 4) were occasionally recorded by the planning controllers, but only for short periods. For the majority of the time the controllers were working at either a busy but sustainable level of controller workload or less, whether working sector 10, sector 11 or Hornsea.

The controllers' perceived advantages of the Hornsea sector compared to sectors 10 and 11 were that the planning task became easier, there being less time pressure in Hornsea than in sectors 10 and 11. Comments made by the planning controllers suggested that the removal of the sector 10 and 11 boundary eased the planning task, the computer assistance tools being more suited to planning across a larger sector rather than being constrained by sector boundaries. This view is supported by the reduction in the level of frustration experienced by the planning controllers when working with the tools in the Hornsea sector.

9.2.2 Comparing sectors 10 and 11 with Hornsea when direct routes are flown

The ISA results obtained when comparing sectors 10 and 11 with Hornsea for direct routes are very similar to those obtained for structured routes. The controller workload was perceived to be higher in Hornsea than sector 10, but the same when comparing Hornsea with sector 11 for both roles. As before, the periods of high (ISA 4) and excessive (ISA 5) controller workload were extremely small over the 27 recorded runs.

R/T communications were also higher with Hornsea than sector 10 as before.

The argument that all traffic that passed through sector 10 also flew through sector 11 and vice versa can not be used when direct routes are flown; however, there are a number of reasons why similar results were seen in both the direct and structured route systems. First, it must be remembered that the direct route system also has a significant element of structured routes within the airspace. All 3D aircraft, 30% of the sample, were flying on an identical structured route in all ORGs. In addition, all 4D aircraft that descended below FL295 (approximately 70% of the 4D aircraft within the traffic sample) joined the structured system (however, they only flew on the structured routes for approximately 35% of the time that they were in sectors 10 and 11). Second, the aircraft per hour figures in Figure 7 show that the size and position of sector 11, it being closer to Amsterdam and Heathrow than sector 10, mean that, as with the purely structured route results, sector 11 controllers, within the context of the PD/1++ trial, will be used to handling a higher traffic load than sector 10 controllers.

The results from the questionnaires contradict those obtained from the ISA and R/T for both the planning and the tactical controllers. The tactical controllers stated that there was no difference in controller workload between sectors 10 and 11, and Hornsea with direct routes. The planning controllers indicated that their workload was high, but acceptable in all sectors. Despite this discrepancy, both the planning and tactical controllers indicated that their workload was 'never' or 'rarely' too high to cope.

9.2.3 Comparing structured routes with direct routes

The Temporary Operating Instructions issued to the controllers (see section 6 and Appendix B) revised the allocation of tasks between the planning and tactical controllers when moving from structured to direct routes. In practice, however, the controllers retained the same task allocation as used when structured routes were simulated; therefore, any differences between structured and direct routes can not be attributed to a difference in task allocation.

The move from structured to direct routes did, however, serve to highlight the inappropriateness of the traditional planning and tactical roles within the PHARE concept. This is discussed in more detail in section 9.5.1.

The ISA responses for the planning controllers indicate an increase in controller workload with direct routes when compared to structured routes, irrespective of the sectorisation. For the tactical controllers sector 11 and Hornsea showed a similar increase in controller workload for direct routes, but this was not the case for sector 10. The reason for sector 10 TCs' results being different from all the others is unclear; however, it is probably a function of the number of aircraft under control (see Figure 10) and the aforementioned size and location of sector 11 compared to sector 10.

An increase in R/T for all tactical controllers with direct routes when compared to structured routes, irrespective of the sectorisation, was recorded. This is to be expected since more aircraft fly through sectors 10 and 11 in the direct route scenario compared to the structured scenario.

Despite the apparent increase in controller workload, all controllers indicated that with direct routes their workload was 'never' or 'rarely' too high to cope – rating their average workload as either 'high but acceptable' or 'low but acceptable'.

Tactical controllers commented that their mental demand increased with direct routes. With a structured route system the pattern of traffic through the sector is known and concentrated along pre-determined routes through the sector. With direct routes it was not so obvious to the tactical controller where the aircraft would enter or leave the sector, the traffic being scattered throughout the sector. This made it harder to scan or monitor for deviations, which may partly account for the increased ISA scores.

9.2.4 Comparing structured routes and sectors 10 and 11 with direct routes and Hornsea – Controller Workload and Capacity

While it may be concluded that the PD/1++ trial has demonstrated a significant increase in the **controller's instantaneous capacity** through both the introduction of larger sectors and direct routes, it cannot be stated that the PD/1++ concept led to an increase in total airspace capacity. It is necessary to emphasise this point when concluding the controller workload results.

From the controller workload results obtained from the PD/1++ trial, it may be concluded that as the system progresses towards a direct route environment within a larger sector, the workload of the controllers – though increased – remains acceptable, while more traffic is handled. Certainly the ISA results for the comparison between ORG3 and ORG0, coupled with aircraft on frequency results, see Figure 7, would support this conclusion. Controller comments also suggest that direct routes through the Hornsea sector were easier to handle, though there seems to be some doubt about whether the tools contributed to this result.

However, as stated above such a conclusion cannot be drawn. The PD/1++ trial conditions were very specific and the discussion of sector capacity has already indicated that further work needs to be done to understand the implications on sector and airspace throughput of moving towards an ORG3 type scenario. However, it may be concluded from the results that introducing the PHARE concept alongside direct routes and larger sectors is an acceptable step to the controllers that warrants further, detailed investigation.

9.3. Service to aircraft

It is important that with any future system or concept the current levels of service to aircraft are either maintained or improved. Since PD/1++ did not simulate a current day baseline, it was not possible to ascertain whether this had been achieved. In addition, no statistically significant improvement or degradation in any of the quality of service measurements were recorded. Controller comment suggests, however, that in moving towards a direct route environment and larger sectors, aircraft are likely to receive a better service. Direct routes provide the airlines with the opportunity to save on flying time, the larger sectors enabling the controllers to plan improved profiles.

9.4. Usability

The results of the SUMI questionnaire, observations and controller comments suggest that the usability of the PD/1++ system was less than satisfactory. The controllers, though briefed that the system was not pre-operational, tended to treat it as such and this was reflected in the content of many of their comments. This may well have been due to the fact that the reliability and robustness of the PD/1++ system exceeded that experienced by the controllers in previous PHARE trials hosted by either NATS or the other PHARE partners.

PD/1++ highlighted three specific usability issues which are discussed in the following sub-sections.

9.4.1 Ability to plan across a sector boundary

Within the PHARE concept investigated under PD/1++ the planning controller gains planning authority on an aircraft some ten to twenty minutes before it is due to enter the sector. At this point a conflict free trajectory is planned for the aircraft through the sector to the point at which the aircraft leaves the sector. The controller is only able to plan out conflicts up to his or her sector boundary. As a consequence, the subsequent planning controller may immediately inherit a problem to resolve once the aircraft becomes plannable through the next sector. In PD/1++ the planning controllers requested that they be able to plan across sector boundaries; however, this poses problems with respect to the overlap of planning authority. The PD/3 versions of the PATs were designed to enable the planning controllers to plan across sector boundaries; however, this concept and the associated PATs had not been evaluated within the PHARE project prior to PD/1++ and were therefore not included.

9.4.2 Conflict detection

The conflict risk display (CRD) has been available to the controllers for use in all of the previous PHARE trials carried out by NATS; however, up to now it's usefulness has been very much overlooked by the participating controllers. In contrast to this experience, the planning controllers in PD/1++ found it indispensable as an aide memoir, enabling them to delay the resolution of potential conflicts if necessary. The lack of consistency between the CRD and the HIPS, ADFL and STCA, caused intense frustration for the controllers at times in all the ORGs simulated during PD/1++.

9.4.3 Tactical intervention

To give a tactical intervention requires the controller to pass a message via the R/T and update the relevant field in the aircraft label with the new height, heading or speed. Once the aircraft responds to the tactical intervention it deviates from its trajectory. Conflict monitoring by the system with respect to this aircraft is no longer correct, as it is still based upon the old trajectory, requiring the controller to manually separate the aircraft until a new trajectory can be established within the system. This requires the controller to either make use of the ADFL or HIPS when planning the new trajectory, validating it and finally registering it. The tactical controllers in PD/1++ commented that the usability of the system in these circumstances created controller workload, there being too many interactions required with the display. A simpler method of giving a tactical intervention was requested.

9.5. The PHARE Concept

The PD/1++ trial, and in particular the usability assessment, served to highlight two shortfalls within the PHARE concept. Although these were identified during a trial in which RVSM, direct routes, and larger sectors were simulated they are not considered to be necessarily a product of this specific environment, but fundamental to the PHARE concept as a whole. These shortfalls are discussed below.

9.5.1 Controller roles

When direct routes were simulated, the PD/1++ participants were asked to take on different tasks within their respective roles of either planning or tactical controller. However the fundamental aspects of the traditional planning and tactical roles remained. In attempting to measure the effect that the change in task allocation had had on controller workload, for example, the controllers were questioned about their particular roles. The appropriateness of the implementation of the traditional planning and tactical roles in conjunction with the PHARE concept was questioned as a result. Previous PHARE trials for example PD/1 and PD/1+ (see references 1 and 2) have highlighted the imbalance in controller workload for example between the planning controller and tactical controller when 70% of the aircraft have a 4D FMS and datalink capabilities. Within the PD/1++ trial it was not possible to explore alternative roles, nor was it possible to ascertain how these roles might need to change with the introduction of direct routes or larger sectors.

9.5.2 Control of aircraft without datalink

As in previous PHARE trials (see reference 2) the concept of controlling aircraft without datalink through the use of advisories was questioned during the PD/1++ trial by the tactical controllers. Although only 30% of the aircraft had no datalink capability, the tactical controllers questioned the principal of having to pass messages at a very specific time to maintain the aircraft on it's planned trajectory.

PHARE has explored a number of different methods for displaying advisories to the Tactical controller: the CLW during PD/1, PD/1+ and PD/1++; information in the aircraft label during PD/2 and PD/2+; and the Advisory Display (AAD) during PD/3. All have relied on the controller passing a message via the R/T at a specific time. If the tactical controller fails to pass a message at the correct time, or the aircraft fails to respond to the instruction promptly and correctly the aircraft deviates from it's planned trajectory. Any datalink equipped aircraft within the sector will be unaware that the aircraft has deviated and will continue to follow its planned trajectory previously agreed with ATC, even if this means turning, climbing or descending into conflict with the now deviating aircraft. Conflict detection tools will not consider the deviating aircraft until a new trajectory has been established within the ground system. Until this happens the deviating aircraft must be separated from all other aircraft by the tactical controller who will have been alerted to the deviation. However the tactical controller will have only a limited insight in to the previously agreed plans established for the datalink aircraft. When only 30% of the aircraft are without datalink it may be possible for the tactical controller to separate deviating aircraft from other aircraft in the sector. However, during the period in which aircraft will be encouraged to fit the equipment necessary to take advantage of the PHARE concept there will be a transition period during which the majority of aircraft will have no datalink capability.

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10. CONCLUSIONS

The Objective of the overall PHARE programme was to demonstrate the feasibility and merits of an air-ground system in all phases of flight. The success of the PD/1++ system with respect to the stability and performance of the NRF and the PD/1++ system as a whole enabled this objective to be met for the en-route phase flight. However, specific conclusions from the PD/1++ work programme can only be drawn from the statistical analysis carried out, coupled with the subjective views of the participants, against the trial aims. This is done with the measured trial variables in mind: the route structure; the sector size; and the controller operating practices.

The conclusions from the PD1++ work programme are as follows:

- Within the scenarios investigated, the PD/1++ operational concept enabled the controllers to handle the increased traffic that resulted from the introduction of larger sectors and direct routes;
- The increase in traffic from the introduction of larger sectors and direct routes, resulted in an increase in controller workload that was acceptable to the controllers;
- Whether flying structured or direct routes, removal of the boundary between the two small sectors simulated to create one large sector, eased the planning task;
- Whether flying structured or direct routes, removal of the boundary between the two small sectors simulated to create one large sector, reduced the frustration experienced by the planning controller when working with the PHARE PD/1++ tools;
- The introduction of the PHARE concept alongside direct routes and larger sectors, received controller approval and warrants further, detailed investigation (see recommendations in section 12);
- An environment in which direct routes are flown through larger sectors, implicitly improves the service provided to aircraft and was supported by controller comments;
- The PD/1++ trial reinforced the need for consistency between any set of computer assistance tools developed to aid the controller’s task;
- The traditional planning and tactical roles, with their associated tasks, are not appropriate within the PHARE concept;
- The control of aircraft without datalink within the PHARE concept needs refinement to account for the fact that the tactical controller is no longer able to keep ‘the picture’ with the levels of traffic forecast.

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11. RECOMMENDATIONS FOR FURTHER WORK

The recommendations have been broken down into two categories; those which relate specifically to the aims of the PD/1++ trial; and a number of broader recommendations relating to the overall PHARE concept and any future PHARE related work.

Recommendations relating to the PD/1++ trial:

- Further work must be done to understand the effect on controller workload and sector capacity of the introduction of either direct routes or larger sectors.

Recommendations relating to PHARE as a whole:

- Further work must be done to understand the relationship between controller workload and both sector capacity and total airspace capacity (ie groups of sectors);
- Further work must be done to establish appropriate controller roles for a PHARE type environment;
- Further work must be carried out to refine the method by which aircraft without datalink are controlled within a PHARE type concept.

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12. GLOSSARY

4D FMS	4D Flight Management System
ACC	Area Control Centre
ACPO	Aircraft Position Operator
ADFL	Augmented Dynamic Flight Leg
AHMI	Airborne Human Machine Interface
AL	Aircraft Label
AM	Arrival Manager
AMD	Arrival Manager Display
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATMDC	Air Traffic Management Development Centre
BADA	Base of Aircraft Data
CDR	Conditional Route
CLW	Communications List Window
CMS	Common Modular Simulator
CP	Conflict Probe
CRD	Conflict Risk Display
CZW	Conflict Zoom Window
DASR	Department of ATC Systems Research
DERA	Defence Evaluation and Research Agency
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
ELW	Extended Label Window
EFMS	Experimental Flight Management System
FL	Flight Level
FPM	Flight Path Monitor
GHMI	Ground-Human Machine Interface
GTB	General Tool Box
HAW	Horizontal Aid Window
HIPS	Highly Interactive Problem Solver
IOCP	Internal Operational Clarification Project
IAS	Indicated Air Speed
ISA	Instantaneous Self Assessment
LATCC	London Area and Terminal Control Centre
MIW	Message In Window
MOW	Message Out Window

NAS	National Airspace System
NATS	National Air Traffic Services Ltd
NERC	New En-Route Centre
nm	nautical miles
NRF	NATS Research Facility
ORG	Organisation
PATs	PHARE Advanced Tools
PC	Planner Controller
PD/1	PHARE Demonstration 1
PD/1+	PHARE Demonstration 1+
PD/1++	PHARE Demonstration 1++
PD/2	PHARE Demonstration 2
PD/2+	PHARE Demonstration 2+
PD/3	PHARE Demonstration 3
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
PRT	Preferences Tool
PUMA	Performance and Usability Modelling in Air Traffic Management
PVD	Plan View Display
R/T	Radio Telephony
RTB	Radar Tool Box
RVSM	Reduced Vertical Separation Minima
SID	Standard Instrument Departure
SILs	Sector Inbound Lists
SM	Stack Manager
STAR	Standard Arrival Route
SUMI	Software Usability Measurement Index
TAAM	Total Airspace and Airport Modeller
TC	Tactical Controller
TLX	Task Load Index
TMS	Tools Manager Server
TP	Trajectory Predictor
TPAS	Trajectory Predictor based Aircraft Simulator
TST	Trajectory Support Tool
UK FIR	United Kingdom Flight Information Region
VAW	Vertical Aid Window
VVD	Vertical View Display

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