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- the UK CAA (Civil Aviation Authority);
- the NATS (National Air Traffic Services);
- the DERA (Defence Evaluation and Research Agency)

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Executive Summary

This document is the final report for the CENA PHARE Demonstration 3 (PD/3). This Main Report section gives a broad overview of this experiment, and presents the major results, a discussion of these results and recommendations. Annex sections, provide a full detailed analysis of the results and all the relevant data which have been collected in order to enable anyone deeply involved in PHARE to grasp all the outcomes of this experiment.

PD/3 concludes the series of PHARE Demonstrations; 2 main Demonstrations took place before PD/3, devoted to a specific operational environment being En-Route for PD/1 (organised by the National Air Traffic Services Ltd - NATS - UK), and TMA for PD/2, (organised by the Deutsches Zentrum für Luft- und Raumfahrt - DLR - Germany).

The EUROCONTROL Experimental Center (EEC), the Centre d’Etudes de la Navigation Aérienne (CENA - France), the Nationaal Lucht- en Ruimtevaartlaboratorium (NLR - Netherlands) were the main participating research organisations that hosted the PD/3 demonstrations, assisted by NATS (for evaluation aspects notably). These concentrated on the air and ground systems which could be available in the 2005-2015 time-scale and addressed the influence of different controller working methods from the En-Route to the Terminal Area, extending the work to encompass a series of demonstrations defined in a plural-site environment.

The CENA PD/3 research programme took place in Athis-Mons - France involving 27 controllers from various nationalities (USA, Romania, Germany and France). It was applied in an operational environment gathering a TMA/DEPARTURE sector including CDG Airport, an ETMA/DEPARTURE sector and an En-Route sector, thereby covering areas left unexplored by previous PHARE Demonstrations. It allowed evaluating future ATM concepts, which combined Air/Ground integration, advanced tools to support the controllers and a transitional introduction of 4-Dimensional Flight Management System and Data-Link equipped aircraft. The aim was to explore the effectiveness of concepts in an environment where the man must stay in the process of decision-making following a « Human Centred Approach ».

The CENA evaluations included a successful Airborne demonstration with the DERA (Defence Evaluation and Research Agency - UK) BAC1-11 live aircraft equipped with an Experimental Flight Management System (EFMS). It showed the ability of an aircraft to establish an Air/Ground connection through the PATN network using the INMARSAT satellite, to use Data-Link applications before take-off and during the flight, and to use the EFMS capabilities to manage 4-Dimensional routes and to carry out Air/Ground 4-Dimensional trajectory negotiations.

The CENA PD/3 training programme met the training objectives. The controllers fully understood the underlying concepts of PD/3, and were able to participate intensively to discussions about the system. In addition to the instructors, having technical experts who were capable to answer in a competent manner all operational and technical questions of the controllers proved to be necessary and efficient. However, more training would have been profitable to some controllers and made them get used to the simulated airspace (traffic flows and rules).

The controllers generally well received the PD/3 concepts but emphasised that system performance problems resulting in long response times prevented them from fully evaluating the novel concepts and procedures that were proposed; some shortfalls limited the scope of the evaluation, among them:

- the absence of a suited Activity Predictor Display for the ETMA position;
• the absence of a Medium Term Conflict Probe for the Departure position.

Looking at the expected gain in airspace capacity, being the main purpose of the overall PHARE programme, results are mixed because the introduction of the computer assistance tools induced a direct increase in workload, especially at the Planning Controller positions. Controllers agreed that either advanced procedures or introduction of Data-Link equipped aircraft fitted better to planning activities and felt that optimising traffic and managing conflict in advance could be of strong interest.

However, they deplored the difficulties that the Tactical Controllers encountered when handling the non-equipped aircraft, as well as their possible feeling of being powerless when monitoring the Data-Link equipped aircraft (they reported difficulties to mentally integrate these aircraft within the overall traffic which they called «losing the picture»).

For the Tactical Controller, spared time for VHF communications was generally well appreciated as soon as the proportion of Data-Link aircraft reached a good level (70%). In fact, a common frustration to both Planning Controller and Tactical Controller was the clear cut between them that led to a real lack of co-operation setting into light a phenomenon, called the operational gap; it suggests that, as new sharing of task will lead both operator to work in different time frame hampering oral communications between them, the communication via the system did need to be improved.

As in PD/1 or PD/1+ (if we exclude for the last the optimal solution where 100% of the fleet is equipped), there is little evidence of a measurable change in airspace capacity. Though objectives measures of minimum safe separation infringements must be considered cautiously, they provided issues that deserve to be mentioned: whereas computer assistance and important level of equipped aircraft allow to bring some improvement in traffic throughput, they did provoke an increase in either the number of infringements or their duration. Though, this objectives measurement must be analysed with caution because of the too few level of collected data, it may suggest that the fact that the Tactical Controller could lose the mental picture of the traffic, could jeopardise the security in some occasions; some controller comments support this rational.

Quality of service results remains complex to analyse; although little improvement in traffic throughput could be observed resulting from computer assistance and proportion of equipped aircraft, these observations are only valid for the observed Departure to en-route phase and should rather be evaluated at the scale of an entire route from Departure to destination.

The principle of computer assistance was well received by the controller: especially the integration of tools like CO-OPERATIVE TOOLS and Highly Interactive Problem Solver on the En-Route Planning Controller position offered a powerful evaluation environment. On the Departure position, the first acquaintance of controllers with a DEPARTURE MANAGER created great interest. Though the functions of ground sequencing were not directly taken into account by the PHARE concepts, these ones were well received by the controllers. They also proved to be efficient for supporting functions of planning provided that aircraft sequence was considered rather than the precise take-off time. Some controllers stated they intend to ask for an in-depth evaluation of this tool in a more realistic and short-term environment.
Recommendations for future ATM projects utilising (part of) PHARE concepts are that they should:

- explore ways to simplify Air/Ground Trajectory Negotiation and propose at sector level, procedures which comply with time pressure (it could be derived from CPDLC or Formalised Clearance);
- explore ways to render management of non-equipped aircraft as flexible as it can be, while keeping the concept of advanced planning;
- explore ways to define a new role in the ATC picture concerned with Multi-Sector Planning capable to use efficient Air/Ground Trajectory Negotiation for rerouting, decomplexifying the traffic;
- do everything to obtain responses time as short as possible, a reliable overall system as well as logical and clear responses of the system;
- limit automation to what can be without any doubt trusted by controller and provide co-operative system functions allowing the controller to remain the master of the system;
- study new concepts and future systems taking into account significant non nominal events.

Recommendations on a broader point of view for all the ATM R&D community, which will continue the research through large scale ATC experimentation are that they could:

- benefit from the techniques used in the preparation of this experiment to teach controller trainees very futuristic concepts with a good level of mastering;
- adopt similar evaluation strategies mixing qualitative and quantitative observations and refine Workload, Security and Capacity analysis techniques;
- develop more detailed set of quality of service measurement and tools.

CENA PD/3 was the result of a major programme gathering the ideas, efforts and skill from dozens of ATM experts in Europe. On a technical point of view, having achieved the building of such a challenging experiment is a success. Though it would be pretentious to state that an implementation strategy can emerge at the light of this experiment, we can, at a minimum assess that it contributed to extract knowledge, which will be essential for the future of ATM. Indeed, it allowed developing technologies, 4-Dimensional-Flight Management Systems, computer assistance tools that will find application in any further ATM field.
DOC 99-70-01 has been produced in 4 volumes:

- PD/3 Synthesis report Volume 1 of 4
- CENA PD/3 Final report Volume 2 of 4 (this current volume).
- EEC PD/3 Final report Volume 3 of 4
- NLR PD/3 Final report Volume 4 of 4

This 2nd volume has been produced in 2 parts:

Part 1 - MAIN BODY
Part 2 - ANNEXES:

ANNEX A: Experimental design and methods
ANNEX B: Controller subjects and training
ANNEX C: Results
ANNEX D: Analysis of Questionnaire
ANNEX E: Airborne aspects
ANNEX F: Miscellaneous information about CENA PD/3 experiment
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1. INTRODUCTION

1.1 Scope
This document is the final report for the CENA PHARE Demonstration 3 (PD/3). This Main Report section gives a broad overview of this experiment, the major results, a discussion of these results and presents recommendations. A second section, the Annex section, provides a full detailed analysis of the results and all the relevant data, which have been collected in order to enable anyone deeply involved in the PHARE project to grasp all the outcomes of this experiment, namely:

- Annex A: Experimental design and methods,
- Annex B: Controller subjects and training,
- Annex C: Results,
- Annex D: Analysis of Questionnaire,
- Annex E: Airborne aspects,
- Annex F: Miscellaneous information about CENA PD/3 experiment,
- Annex G: Glossary and References (for the Annexes).

PD/3, as a plural-site experiment, has produced a four volume final report DOC 99-70-01 containing:

- PD/3 Synthesis report Volume 1 of 4,
- CENA PD/3 Final report Volume 2 of 4 (this current volume splitted in 2 parts),
- EEC PD/3 Final report Volume 3 of 4,
- NLR PD/3 Final report Volume 4 of 4.

1.2 Context
Today's ATC system is at times unable to handle the demands made upon it. Furthermore, EUROCONTROL traffic growth scenarios, based on a 1995 reference, consider, in attempting to establish strategic capacity objectives for EATMS, that an increase of 56% might be expected in 2005 and around 121% in 2020\(^1\). Restrictions imposed to safeguard the system from overload often lead to delays during peak periods. In less busy areas the required capacity goals can be achieved by the well-proven technology and procedures that represent "best current practice". However, in the busier areas the scope for increasing capacity through existing ATC methods and technology is limited. Although improvements in the existing methods and technologies must be pursued, changes in the technology and processes of ATC must also be envisaged if system capacity and productivity gains are to be secured.

One of the limiting factors in the present ATC system is the capacity of the controller. A means must be found which can improve the system significantly to meet this predicted demand. This will have to be achieved whilst maintaining or improving the safety of the system.

\(^1\) EATMS Operational Concept Document, Ref. EATCHIP Doc.: FCO.ET1.ST07.DEL01 Edition 1.1 January 1999, page 4
1.2.1 PHARE objective
To evaluate the performance of new concepts taking advantage of enhanced technologies, a series of real-time simulations, or PHARE demonstrations, was planned to evaluate the introduction of computer assistance tools and Data-Link in En-Route (PD/1), Terminal Movement Area (TMA) airspace (PD/2) and combined En-Route/TMA environment (PD/3), each demonstration being led by one or more PHARE partners.

These large scale validation activities, comprising integrated ground system, air system and Air/Ground Data-Link facilities are the last step in a validation process consisting of functional testing, basic evaluation of individual tools and partial validation of subsystems of increasing complexity.

1.2.2 PHARE Demonstrations « in a nutshell »
The first PHARE demonstration, PHARE Demonstration 1 (PD/1), was hosted by National Air Traffic Services Ltd. (NATS). The trial was conducted over a period of eight weeks towards the end of 1995 (see reference [9]). The primary aim of PD/1 was to investigate the introduction of computer assistance tools and aircraft equipped with Data-Link and a 4D Flight Management System (4D FMS) within En-Route airspace. The computer assistance tools were designed to assist controllers in planning, implementing, conflict-free trajectories through the airspace. It was envisaged that these tools, together with the Data-Link 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 workload following the introduction of the tools and Data-Link. While some preliminary assessment of this result was given in the PD/1 Final Report (see reference [9]), 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) so called PD/1+, within the overall PD/3 work programme, re-examined the outcome of the PD/1 trial, in particular addressing tool utilisation and controller workload (see reference [11]). The changes made to the Tools and the HMI, and also an increased familiarity with the system did succeed to reduce overall workload comparing a baseline system and an advanced one.

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

The second PHARE demonstration, PD/2, was hosted by the Deutsches Zentrum für Luft-und Raumfahrt (DLR) in Germany (reference [10]). The trial was conducted over a period of 8 weeks in late 1996, early 1997. The primary aim of PD/2 was to demonstrate the introduction of computer assistance tools and aircraft equipped with Data-Link and 4D Flight Management System in a TMA environment, using the Frankfurt TMA as the simulated airspace. The main computer assistance tool to be demonstrated during the trial was the Arrival Manager (AM), which, it was intended, would sequence arrival traffic into a conflict free stream at a designated point before the runway (the metering fix).

A follow-up of PD/2, a PD/2+ work programme was initiated in 1997 to complement results obtained by PD/2 with a demonstration performed by NATS.
1.3 PHARE DEMONSTRATION 3

1.3.1 In general

PD/3 concludes the series of PHARE Demonstrations; CENA, NLR and EEC are the main participating research organisations that hosted the PD/3 demonstrations, assisted by NATS (for evaluation aspects notably). This concentrates on the air and ground systems which, could be available in the 2005-2015 time-scale and addresses the influence of different controller working methods.

PD/3 should have provided a coherent evaluation, bringing together the En-Route and Extended TMA results, extending the work to encompass a series of demonstrations defined in a plural-site environment. However, due to problems with tools and platforms integration at the different partners, it was impossible to maintain complete coherence between the PD/3 partners’ demonstrations. The current report concentrates on the CENA PHARE demonstration 3.

1.3.2 CENA PHARE Demonstration 3

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

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

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

During the year 1997, a CENA Internal Operational Clarification Project (IOCP) focused on the «Human Centered Approach» allowed to foresee required improvements to integrate Air/Ground Integration Principles in a environment where the Controller remains a key element for safety.

The lesson learnt from this CENA/IOCP had effects on both the design of the tools, the Human Machine Interface (HMI) and especially on the necessity to strengthen working method and time resources to design and teach them; the major architecture and design principles for building the CENA -PD/3 platform were established at this occasion.

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

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

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

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

The process of evaluation was conducted in a comparative manner as it will be explained in chapter 4, an Advanced scenario supported by an Advanced system and a Baseline scenario supported by a Baseline System were defined; a Baseline system was settled in order to lead simulations in the same conditions as the ones led with the Advanced system, giving reliable reference measurements; this system did not mimic trustfully a real system since no paper strips were provided to the controllers; instead, the information was presented to the controllers through interactive track data blocks and lists displayed on the controller’s screens. Some simple computer assistance was also provided to the controllers.

1.4 REPORT STRUCTURE

Chapter 2 presents the CENA PD/3 system starting with operational concepts applicable to En-Route and TMA/DEPARTURE environment; then technical matter are summarised: PHARE Advanced Tools (PATS), Ground HMI, PHARE Aeronautical Telecommunication Network (PATN).

Technical platform, airspace and procedures, real aircraft technical environment are introduced in chapter 3.

Chapter 4 is devoted to experimental approach, measurements performed and controller who participated in the experiment. Chapter 5 addresses training topics.

Chapter 6 brings out major results providing a synthesis invaluable to those who wants to keep essential points of this experiment. A discussion of the results appears in chapter 7.

A conclusion is drawn in chapter 8 followed in chapter 9 by a synthesis of the most important recommendations for further work in ATM research.

A list of annexes as defined in 1.1 constitute part 2 of this report and give a deeper knowledge of what have been accomplished through this experiment.
2. THE PD/3 SYSTEM

This section gives a brief overview of the operational concepts, advanced tools, and HMI supporting the Advanced Scenario and thus the Advanced system; the Baseline system is not described in detail here; specifications of the Baseline HMI could be found in Ref. [1].

2.1 OPERATIONAL CONCEPT

The operational concept underlying PD/3 experiment was the result of a joint effort of the different ATM centres involved in PD/3; this huge definition work was performed by trying to take into account results from previous PHARE experiments (PD/1, PD/2), new available technology (PHARE Advanced Tools like NEGOTIATION MANAGER, CO-OPERATIVE TOOLS, DEPARTURE MANAGER had never been integrated before in a PHARE system) aiming to cover a “complete” part of Airspace i.e. from take-off runway to landing runway (gate-to-gate concept).

More detailed level of information concerning the concept are given in Ref. [3] and in the Task Logic Diagrams in Ref. [1].

The PD/3 main philosophy can be stated as follows:

- to strengthen the skill of the team of Air Traffic Controllers to analyse and anticipate in order to increase overall ATC capacity by:
  - using digital data transmission (Data-Link) between Air and Ground (and on the Ground) in an intensive manner, reducing VHF usage, and
  - providing sophisticated computer-aided tools at each phase of the process.

The PD/3 concept was based upon the existence of aircraft having new type of equipment allowing them to navigate on any desired track respecting 4-Dimensional constraints with high precision using 4-D Flight Management Systems and exchanging swiftly rather big volume of digital data with ATC systems over Data-Link.

The new digital Data-Link channel was used for 2 main purposes:

- making silent the Frequency Change between 2 sectors (ACM application as it is standardised by ICAO);
- exchanging “trajectory data” integrated in the Trajectory Negotiation application defined by PHARE.

To illustrate this, a typical scenario of an equipped aircraft in a PD/3 sector would be:

- 10 ' before the aircraft cross the sector boundary, the Planning Controller is warned of an incoming aircraft; at this stage, the last downlinked trajectory is known from the ground system;
- the Planning Controller, using computer assistance tools, would check for conflicts with other aircraft, and if any were found, find an alternative trajectory to solve the conflict;
- using the Data-Link facility, the Planning Controller would uplink the set of constraints suited to let the 4D-Flight Management System calculate the required trajectory to the aircraft;
- once the new trajectory calculated by the 4D-Flight Management System is agreed by the crew, it would be downlinked to the Controller, thus providing him with the best source of information about future aircraft behaviour;
after an acknowledgement by the Controller, this trajectory would be flown by the aircraft and closely monitored by the pilot;

after a silent switch on current sector frequency\(^1\), the aircraft’s path in the sector would also be monitored by the Tactical controller with assistance of a deviation surveillance system (Flight Path Monitoring).

At the boundaries of the targeted airspace, dedicated tools would be available either for sequencing of arriving aircraft or for sequencing aircraft in the Departure phase (Arrival Manager, DEPARTURE MANAGER).

PD/3 experiment took into account the required transition phase where probably aircraft with a variety of on-board equipment will share the same airspace. PD/3 simplified this, balancing the fleet in 2 parts: “equipped”, meaning aircraft with Data-Link and 4D-Flight Management Systems, and “non-equipped”, meaning aircraft without Data-Link and only 3D-Flight Management Systems.

However, the level of assistance for the Air Traffic Controllers to manage “equipped” and “non-equipped” aircraft was harmonised in order to integrate both type of aircraft in the same efficient process, as far as possible.

### 2.2 PHARE ADVANCED TOOLS

The overall efficiency of the PD/3 concepts depends highly on the controller having appropriate computer assistance tools. PD/3, on a technical and organisational point of view, set very high the level of complexity compared to previous PHARE Demonstration since, no less than 9 different PHARE Advanced Tools (PATs) designed by 5 ATM research centres had to be integrated on up to 3 different simulation platforms.

CENA PD/3 was the occasion to refine tools already designed for PD/1 as the Trajectory Predictor, the Flight Path Monitor, the Conflict Probe, and the Problem Solver. Brand new tools were created (Departure Manager) or adapted (Negotiation Manager\(^2\), Co-operative Tools) for this experiment.

2 tools (Arrival Manager and Tactical Load Smoother) were not integrated because of no use in CENA PD/3 experiment (no Arrival position neither MSP position).

The following chapters give an overview of the use of each of these Tools; detailed information about each of them can be found in Ref.[16].

---

\(^1\) In CENA-PD/3, the receiving controller still welcomed aircraft on frequency in order to check the VHF link with the aircraft.

\(^2\) The NEGOTIATION MANAGER appeared in PD/2 but was severely redefined for PD/3 purposes.
2.2.1 Trajectory Predictor (TP)

The role of the Trajectory Predictor is to predict the trajectory of an aircraft taking into account all known information; compared to tools already in use in ACC, this new one is far more accurate, using a database of aircraft performance characteristics and capable to be enriched by downlinked aircraft trajectory parameters. Obviously, it is of major help for non equipped aircraft since all assistance provided to the controller will depend on its outcome and it is a fundamental tool because a lot of the overall behaviour of the system relies on it.

A dedicated tool was designed in the framework of PHARE; the PHARE version of this tool developed by the PHARE Advanced Tools Group was not integrated on the CENA’s platform unfortunately; this version, faced some problems during very late integration phases jeopardising the CENA’s experiment; as a fallback solution, it was decided locally to use one of CENA’s in-house TP: the TICTAC algorithm was upgraded in order to make it compliant with the PHARE Trajectory Predictor.

2.2.2 Conflict Probe (CP)

The Conflict Probe in CENA PD/3 system was used for Departure positions in order to detect possible conflicts involving pre-Departure aircraft; this tool was in fact used internally by other tools as the Departure Manager in order to determine automatically the best SID trajectory, and as the Negotiation Manager to evaluate if a proposed trajectory, in case of a co-ordination, was conflict free or not. Contrary to what has been planned, no Medium Term Conflict Alert was displayed on the Departure Manager label; the Conflict Probe was not capable to update conflict information within a reasonable delay, thus it was decided to withdraw this function.

For En-Route, Medium Term Conflict Detection was in fact devoted to Co-operative Tools; this new tool allows to have a better view of problem at stake and their position in time.

For ETMA, it was not feasible to tune Co-operative Tools in order to provide a good level of Medium Term Conflict Detection; unfortunately, it was not feasible to link the Conflict Probe to the Activity Predictor Display in order to give to the controllers this kind of information.

The Conflict Probe was also used for basic assistance in the Baseline Organisation.

2.2.3 Flight Path Monitor (FPM)

This tool checks every new aircraft position against the stored system flight plan; if a significant deviation is detected in any dimension, the Flight Path Monitor (FPM) raises a deviation alert displayed on the GHMI.
2.2.4 Negotiation Manager (NM)

The role of this tool is to manage communications between the different actors sharing the same information, mainly trajectory of an aircraft: it receives either Pilot Request or ATC sets of constraints and decide, using underlying tools such as Conflict Probe and Trajectory Predictor, to warn the right people in the right manner. This tool encompasses threshold logic limiting the occasion where a controller should be warned by a change of trajectory.

2.2.5 Problem Solver (PS)

The Highly Interactive Problem Solver (HIPS) is a tool which allows the controller to assess different solutions for solving a conflict: this tools gives the controller an immediate feedback (yellow or red zone appearing directly on the radar image and the vertical profile window) of what would be the consequences of a new manoeuvre for an aircraft (notion of What-If facility).

The HIPS functions were made accessible at the HMI level in what PD/3 named the Trajectory Editor and Problem Solver tool (TEPS); the new design prioritised the access to information and limit switch of use between the radar image and another tool especially for the Tactical controller; thus, the lateral function of the HIPS was directly integrated in the main radar image imposing this image to be modal while in HIPS operation. This was a major difference with PD/1 GHMI where lateral modification via the HIPS took place in a dedicated window.

Technically, the Highly Interactive Problem Solver was coupled very tightly with the GHMI in order to obtain a reactive HMI.

2.2.6 Departure Manager (DM)

This tool was evaluated for the first time in the framework of CENA PD/3 experiment. The Departure Manager (DM) task is to manage the different constraints which influence Departure sequencing: CFMU slot constraint, operational rules which imposes delay between 2 take-off (because of wake vortex) and separation rules during climbing phases; it pursues the objectives to limit the delay between Scheduled Time of Departure and Estimated then Realised Time of Departure, and proposes to the controllers a sequence which makes the better use of available runways.

Coupled with Conflict Probe, it proposed automatically a conflict free SID procedure, if any, among the set of predefined SID and alternative SID trajectories registered by both ATC and companies.

2.2.7 Co-operative Tools (CT)

These tools encompass different functionalities: at first, predicted trajectory issued from Trajectory Predictor is reconsidered in order to match controller perception; second, “problem detection” is processed aiming at gathering conflicts in “Significant Traffic Unit” these problems are posted along the time axis of the Activity Predictor Display according to the priority of solving.

Subsequent functionality allows the controller to filter the radar image focusing on a specific problem and performing look-ahead for the set of aircraft involved in the problem.

Whilst the Co-operative Tools fulfilled their role for the En-Route position, they had to be withdrawn from the ETMA position because the quality of problem detection was too poor due to insufficient tuning.
2.3 LIMITATIONS OF PD/3 SYSTEM

2.3.1 General
The simulation limited its scope to nominal operations: i.e. no special event (as aircraft losing pressurisation and requiring an emergency descent) was included in the scenario. Meteo conditions were stable and normal. No activity of military zones was simulated.

2.3.2 TMA
On the Ground part: no true taxiing, no Local neither Ground neither Pre-Departure position were manned; the controller or System (Departure Manager) played the role of the pilot in some phases (take off) in order to simplify the simulation.

The Departure Planning Controller especially carried out the task currently performed by Pre-Departure, Ground and Co-ordinator in real environment.

2.3.3 ETMA
As already noted, the Co-operative Tools had to be withdrawn from the ETMA position, which severely limited the anticipation capability of controllers.

2.4 GROUND HUMAN-MACHINE INTERFACE (GHMI)

As established in PHARE, the GHMI was compliant with HMI specifications defined in the framework of the PD/3 GHMI design team. Refer to Ref. [1] for detailed information.

As a brief history, the PD/3 GHMI derived from the work initially performed by the EUROCONTROL ODID Group; the core definition of the HMI principles were established for PD/1 and then refined through PD/2 (issues specific to Approach especially); HMI principles derived from Co-operative Tools were integrated tactfully in order to cope with the overall philosophy defined by the GHMI group and the overall PHARE concepts.

Real prototypes of furniture of the future French Operational CWP have been used as it appears on Figure 3-1. Therefore, some adaptations have been made in order to cope with layout characteristics: average distance between main screen and ATCO's eyes imposed to enlarge size of the fonts, making complicated the display of all the windows on a unique screen. Fortunately, an ancillary screen (21 inches) is available on these CWP and its use can be combined with the main one offering a larger surface.

The following sub-sections give a short presentation of the Advanced GHMI.

NOTE 1: the Baseline GHMI is not described here.

NOTE 2: organisation of windows on the 2 screens was defined after having collected controller's filling during the Pilot Phase.
2.4.1 For ETMA and En-Route CWP

Figure 2-1 and Figure 2-2 show the set-up for the ETMA\(^3\) and En-Route Controller Working Position for the Advanced Configuration with the main screen displaying Radar Image and Activity Predictor Display and the ancillary screen displaying Message In/Out Windows and Profile Window. This choice was made after having collected ATCO’s filling during the Pilot Phase.

\(^3\) Note that the figure 2.1 shows an illustration of PROSIT whereas it did not exist in ETMA positions.
2.4.2 Detailed presentation of main screen

- Radar Image:

A major part of the main screen is devoted to Radar Image: it displays the current position of the aircraft, and flight plan information through label or extended label; Sector Inbound List displays incoming aircraft at the border of the screen.

Menus allow the controller to change flight state, to input instructions. Main Menu allowing to change flight state (ASSUME, TRANSFER, etc.) is in fact offered in any window where the callsign of an aircraft is displayed.

This Radar Image is modal: i.e. filtering modes either Problem oriented (selectable with Activity Predictor Display) either aircraft oriented (selectable through the Trajectory Editor and Problem Solver facility) are offered.
Highly Interactive Problem Solver facilities were integrated at the HMI level through the Trajectory Editor and Problem Solver tool (TEPS): lateral editing was available directly in the main Radar Image; vertical editing was available in the dedicated Profile Window; time editing was possible either in the main Radar Image either in the Profile Window through a Time menu; aiming at reducing the number of dedicated window, this philosophy differs from the one proposed in PD/1 or PD/1+ where lateral editing and speed/time editing were proposed in separated windows.

- **Activity Predictor Display (APD):**

  The APD provides a time axis; on the left side, ATC problems to be solved by the ATCOs are posted to the ultimate time of resolution; on the right side, advisory (ATC instruction) for non-equipped aircraft are posted to be issued just-on-time to Pilot.

  The APD was fully compliant with GHMI specifications except no global Look Ahead facilities were implemented.

- **Additional windows:**

  Radar toolbox and Clock window complete the main screen allowing the configuration of the radar image (e.g. map, space layers, etc.)

### 2.4.3 Detailed presentation of ancillary screen

- **Message In / Out windows:**

  The Message In Window collects the request for co-ordination issued by the neighbouring controllers and important system messages. The Message Out Window is a log of sent messages.

- **Profile Window:**

  The Trajectory Editor and Problem Solver facility once activated displays the vertical profile of the aircraft in a dedicated window: the Profile Window. Interaction zones are displayed by the Problem Solver; the controller may draw a new working trajectory combining vertical constraint (in this window), lateral constraints (in the Radar Image) and time constraint via Time Menu facility.
2.5 **FOR TMA DEPARTURE CWP**

As shown in Figure 2.3, the right part of Departure CWP GHMI was used for the Departure Manager Display; this window figures out a double time axis in the middle and two columns each for the two banalized runway available at Roissy / CDG ("27" and "28").

As for En-Route and ETMA position, Message In/Out Windows and Profile Window were set on the ancillary screen (as shown by Figure 2-2).
2.5.1 Detailed presentation of main screen

- Radar Image:

A major part of the main screen is devoted to Radar Image: it displays the current position of the aircraft, and flight plan information through label or extended label; Sector Inbound List displays incoming aircraft at the border of the screen.

Menus, Flight Leg allow the controller to change flight state, to input instructions, to display route. Main Menu allowing to change flight state (ASSUME, TRANSFER, etc.) is in fact offered in any window where the callsign of an aircraft is displayed.

This Radar Image is modal: an aircraft oriented filtered mode is offered (selectable through the Trajectory Editor and Problem Solver facility).

As for the ENROUTE/ETMA position, Highly Interactive Problem Solver facilities were integrated at the HMI level through the Trajectory Editor and Problem Solver tool (TEPS); conflict information were displayed only through red zones; this was decided in order to prevent from cluttering the radar image with useless information.

- Departure Manager Window:

This window figures out a double time axis in the middle and two columns each for the two banalized runway available at Roissy / CDG (“27” and “28”). On each axis are presented label for arriving aircraft (dark label) and departing aircraft (coloured label). Each label is posted at time of either take-off or landing. A yellow horizontal bar marks current time.

This tools allow to organise take-off sequences, pick-up additional flight plan information, CFMU time slot information, delays and all information related to sequence management.

- Additional windows:

Radar toolbox and Clock window complete the main screen allowing the configuration of the radar image (e.g. map, space layers, etc.)

2.5.2 Detailed presentation of ancillary screen

- Message In / Out windows:

The Message In Window collects the request for co-ordination issued by neighbouring controllers or important system messages. The Message Out Window is a log of sent messages.

- Profile Window:

The Trajectory Editor and Problem Solver facility once activated displayed the vertical profile of the aircraft in a dedicated window: the Profile Window. Interaction zones are displayed by the Problem Solver; the controller may draw a new working trajectory combining vertical constraint (in this window), lateral constraints (in the Radar Image) and time constraint via Time Menu facility.
3. SIMULATION ENVIRONMENT AND TECHNICAL PLATFORM

The CENA PD/3 trial was conducted on CENA Athis-Mons facilities hosted near French North ACC. This section gives an overview of the facilities used for this experiment.

3.1 HARDWARE COMPONENTS AND CONFIGURATION

The simulation platform gathered different pieces of hardware:

- 6 complete Controller Working Positions made of Dec workstation, Thomson X Generator, and Sony 2k by 2k raster screen;
- a network of Sun, Digital, Nec workstations or X terminals supporting simulation, supervision and basic functions;
- Sun workstations for the Air Traffic Generator and cockpit simulator;

1 Each CWP was equipped of a main 2kx2k screen plus an ancillary standard 21 inches screen compliant with the French CWP hardware configuration and suiting PHARE recommendations.
• a standalone system for Instantaneous Self Assessment (ISA) on loan from NATS \(^2\);
• a Matra/Thomson R/T system providing simulated R/T and telephone communication;
• a connection to the SITA network to exchange data with Real Aircraft;
• a connection to operational R/T channel in order to dialogue by voice with Real Aircraft.

6 complete Controller Working Positions as figured on Figure 3-1, were set up in the large simulation rooms of CENA Athis-Mons (2 of them were loaned by North ACC).

6 pseudo-pilots position were manned to pilot simulated aircraft according to Air Traffic Controllers request.

Real prototypes of furniture of the ODS France CWP have been used.

\(^2\) TLX software package customised by CENA used directly CWP hardware.
3.2 SOFTWARE COMPONENTS

The architecture and the various software components are briefly described below.

3.2.1 Overall architecture

The Figure 3-3 presents this overall architecture:

![Figure 3-3 Overall architecture](image)

3.2.2 Ground system

DAARWIN (Distributed ATM Architecture based on RNAV Workstations Intelligent tools and Networks) is a client-server environment encompassing an enhanced Flight Data Processing System; this open environment allow the use of its services by clients and the implementation of new ones via the Common Modular Simulator (CMS) Standard programming interface.

3.2.3 Algorithmic Tools

PATs: 6 PATs among the 9 defined in the framework of PHARE were implemented: Flight Path Monitor, Negotiation Manager, Conflict Probe, Departure Manager, Cooperative Tools and Problem Solver were implemented and linked with the Ground system or directly the GHMI (for the Problem Solver).
3.2.4 CWP/GHMI

Ourasie Toolkit: following on the same basis as the IOCP development, the CENA Ourasie toolkit was refined to offer new services as the HIPS features especially and to fulfil the GHMI specifications.

3.2.5 Data Link Communication

PATN: a complete stack compliant with ATN specifications as been designed and allowed Air side to exchange digital data with the Ground side.

3.2.6 Aircraft simulators and real aircraft

2 simulators plus one real aircraft constituted the air part of the simulation; a dedicated DAARWIN server, the Air Context server, integrated 3 sources of information.

♦ Multi-Aircraft Simplified Simulator

The MASS traffic generator: capable to navigate up to 250 flights at the same time, it allowed the 6 pseudo-pilot positions to exchange data through PATN and reported information to the Ground System through DIS protocol.

![Figure 3-4: MASS radar display and trajectory editor](image)

A special effort was made to implement HMI facility for the Pseudo-Pilot allowing them to intervene in the negotiation process; either in order to answer to controller’s input, either to perform themselves a Pilot Request. It should be highlighted that pseudo-aircraft were not under control of an automatic process but with pseudo-pilot in the loop.
♦ **Real aircraft**

The CENA PHARE Airborne demonstration with the DERA **BAC1-11** live aircraft took place between the 2nd and the 5th of June 98. It was a specific exercise within the whole CENA PD/3 demonstration. Its objective was to show to the visitors the capabilities of the PHARE Air/Ground integration. With two flights per day, the visitors attended the BAC1-11 onboard demonstration on a half-day and the CENA ground system on the other half day. Around 50 visitors of the ATM community were taken onboard during three demonstration days. Controllers involved in the first session of CENA PD/3 experiment had the opportunity to evaluate “true Data-Link communication” and also to exchange experience with some visitors.

The demonstration is fully described in Annex E: Real aircraft.

The main points presented during the airborne demonstration were:

- the establishment of an Air/Ground connection through the PATN network using the INMARSAT satellite;
- the use of Data-Link applications before take-off and during the flight:
  - CPDLC-PR for the position reporting;
  - CPDLC-FC for the frequency change;
- Trajectory Negotiation for the negotiation of 4D trajectories;
- the use of EFMS capabilities to manage 4D routes and to carry out Air/Ground 4D trajectory negotiations.

The configuration of the simulation facility during the trial is shown schematically in Figure 3-5.
Multi-aircraft-Cockpit Simulator

The Multi-aircraft Cockpit Simulator was used during the week devoted to the tests with the real aircraft. At a technical level, the MCS was equipped with the same EFMS software as the Real aircraft.

The cockpit simulator platform consisted at:

- The MCS simulator;
- The PHARE EFMS software;
- The Navigation Display and CDU from the PHARE/AHMI project.

The simulator was linked to the ground system via PATN.

The cockpit simulator was also very useful in the integration phase in CENA. Since it was equipped with the EFMS, several tests could be done to prepare the real aircraft trials. Several configurations were tried concerning PATN at that stage: X25 and satellite.

Still with the aim of preparing the ground for the demonstrations, it was decided to fly the same route as the real aircraft.

It involved a take-off from Paris-CDG, the BNE8A SID, and then several waypoints northbound to London. The route stopped 35 Nm after the VOR BNE since the rest of the route was out of the airspace involved in PD3.

The MCS was operated for each demonstration day in June, and even performed several flights during each run.

During each flight:

- Several trajectories were negotiated with the ATC, which involved all 3 ATC positions;
- Frequency changes were made via Data-Link;
- Position reports were sent via the PR application.
3.3 **LESSON LEARNT ABOUT PLATFORMS SET-UP**

The fact that the PATS project was not able to deliver a set of functionally consistent and pre-tested tools impeded the progress of the integration phase.

3.4 **AIRSPACE AND PROCEDURES**

To conduct CENA PD/3 experiment, an airspace involving subparts of REIMS ACC, PARIS ACC and Roissy Charles de Gaulle TMA, plus surrounding airspace has been set up; the Table 3-1 below shows the different ACC and simulated sectors:

<table>
<thead>
<tr>
<th>ACC / Area</th>
<th>Simulated sector</th>
<th>Feeder sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris/Roissy CDG</td>
<td>TMA (Departure)</td>
<td>No</td>
</tr>
<tr>
<td>PARIS ACC</td>
<td>Lower En-Route (TN/TB)</td>
<td>Lower En-Route (TE)</td>
</tr>
<tr>
<td>REIMS ACC</td>
<td>Upper En-Route (UN/XN)</td>
<td>Upper En-Route (UR/UY), Upper En-Route (UZ/ZU)</td>
</tr>
</tbody>
</table>

**Table 3-1 CENA PD/3 sectors**

Paris/Roissy CDG area was completed by traffic issued to/from Paris ORLY (LFPO), Paris Le Bourget (LFPB), Paris Villacoublay (LFPV), Toussus Le Noble (LFPN).

Others airports Lille (LFLL), Brussels (EBBR) were included in airspace structure; incoming or outgoing traffic flows from these airports had a direct influence on the simulation.

An in-depth explanation of airspace rule and characteristics is provided in annex F; the Figure 3-7 and Figure 3-8 show an overview of the CENA PD/3 simulated airspace.

![Figure 3-7 Upper airspace Map](image-url)
Figure 3-8 Lower airspace Map
4. METHOD

This section briefly describes the design of the PD/3 trial. Full details are in Annex A.

4.1 EXPERIMENTAL DESIGN

The PD/3 main phase demonstration took place over six weeks in May and June 1998.

For system organisations were defined: the Baseline close to today’s operational with limited planning aids; the Advanced organisation with 0% Data-Link equipped aircraft (A0) which examined the effect of the introduction of PHARE Advanced Tools and a new GHMI; and the Advanced organisations 30% and 70% DL (A30 and A70) which examined the effect of introducing aircraft equipped with 4-D FMS and Data-Link. The objectives of the trial, namely to measure the impact of the PATs, 4-D FMS and Data-Link, were met by comparing the results from the various organisations whilst keeping other factors, e.g. controller rotation, system organisation and traffic volume, the same. Table below summarises the organisations.

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

Table 4-1 Summary of organisations
The traffic samples elaborated for the experiments were generated from data corresponding to the 21st June 1996 which was the summer peak for French ACCs. The samples were generated by building up a reference one from which the others were derived respecting the increasing ratio recommended for PD/3 trials. Initially, before the PD/3 experiment, the low traffic samples corresponded to the traffic existing in June 1996; the medium traffic samples corresponded to this traffic \( \times 1.5 \); and the high traffic samples corresponded to the traffic in June \( \times 2.25 \). In order to prevent learning effects, data processed procedures have been set up allowing to modify the callsign information sticking to a plausible company and the hours. Weather was not simulated.

However, the proposed ratios could not be maintained. For the Departure and Arrival sequences, the flight counting in the extracted slot (ref. Low Traffic) had allowed us to notice that the given capacity was near the top value of June 96 in terms of movements number. By keeping two runways in Charles de Gaulle, it seemed difficult to go beyond this capacity. On the other hand, to admit the possibility of one or two additional runways in Charles de Gaulle, involved a change in the space model of PD/3, with the coming of new SID(s) and STAR(s), knowing that the extracted flight plans could not be applied to the space model anymore. This process being hardly achievable, it has only been decided to try to increase the Departure flights, maintaining acceptable standards. The decision made for the Departure position had consequences on the resulting traffic load in the ETMA and the En-Route sectors.

During the Pilot Phase, the first resulting samples have been proposed to the controllers. Following controllers many requests and actions, the systems encountered some difficulties, the latter being mostly linked to the important planeload. Then the intervention on the samples consisted in:

- eliminating a number of flights, mainly those which had not to cross any measured sector;
- and, as it proved not to be sufficient, reducing the traffic load on the measured sectors (ETMA and En-Route).

The resulting increases were then less important than expected and led to an acceptable system load during the experiment.

Each controller participated in two weeks of measured runs and performed alternate role (either as Planning or Tactical controller) on the same sector for each run. Controller rotation has been chosen so that statistical tests could be run by reducing the effect of variability between controllers (refer to Annex A for further details).

In each first week, Monday was used for refresher training, and during the other eight days a total of twenty simulation runs were carried out. Full details of the timetable are provided in Annex A.

### 4.2 Measurements

For each of the measured runs a complete set of system data was recorded for subsequent analysis. This data can be broadly split into subjective and objective measurements.

**Subjective measurements** consisted of some form of self assessment performed by the controllers. A large number of subjective measurements were taken during the trial. Measuring the effect of the PD/3 operational concept on controller workload was one of the main aims of PD/3. Two major subjective measures of workload were used to record and analyse controller workload: the Instantaneous Self Assessment (ISA) and the NASA developed Task Load Index (TLX).
ISA is a method to assess workload in real time. Every two minutes during the simulations, controllers had to give their estimates of perceived workload by pushing one of the five buttons corresponding to the level of workload experienced: 1 corresponding to under-utilised, 2 for relaxed, 3 for comfortable, 4 for high and 5 for excessive. ISA gives a measure of the controller’s workload throughout every run, as well as an indication to each run’s average workload.

NASA TLX is a questionnaire providing a summary workload estimate. TLX is administered immediately after completion of each run. The controller has first to determine the relative importance of six factors (Mental demand, Physical demand, Time pressure, Own performance, Effort expended and Frustration) by pairwise comparison of the factors, and then has to rate his/her workload for each factor on a 20-point scale from ‘low’ to ‘high’. An overall score is calculated from the combination of weights and ratings in order to estimate the controller’s workload.

Questionnaires were administered at the end of each trial to collect the controllers opinions and comments. The questionnaires were designed in order to make possible the quantitative analysis and significance testing of the controller responses.

Finally, in order to allow the thorough debriefing of the controller just after a run, the video and audio recording provided the specialist observers with an efficient means for in depth investigation the overall strategy for using one specific HMI object or to better interpret the reason why a specific event occurred.

Objective measurements were automatically recorded by the ground system. During the PD/3 trial a large account of objective data was collected which contributed to the assessment of the PD/3 main topics (workload, sector capacity and quality of service). Full details of the measurements are given in Annex A.
4.3 CONTROLLERS

The controllers selected for the PD/3 trial covered a range of ages, nationalities and backgrounds. Most of them were familiar with computer management. Only two controllers had never used a mouse.

The two Main Phase trials for PD/3 were carried out over 6 week period with 9 controllers participating per session of three weeks. The 18 controllers for the PD/3 trials were made available by the following organisations:

<table>
<thead>
<tr>
<th>Country</th>
<th>Organisation</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>ADP Roissy</td>
<td>2</td>
</tr>
<tr>
<td>France</td>
<td>ADP Orly</td>
<td>2</td>
</tr>
<tr>
<td>France</td>
<td>CRNA/East</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>CRNA/South West</td>
<td>2</td>
</tr>
<tr>
<td>France</td>
<td>CRNA/South East</td>
<td>4</td>
</tr>
<tr>
<td>France</td>
<td>CRNA/North</td>
<td>3</td>
</tr>
<tr>
<td>USA</td>
<td>FAA</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>DFS</td>
<td>1</td>
</tr>
<tr>
<td>Romania</td>
<td>ROMATSA</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4-2 Summary of participants
5. TRAINING

The aim of the training period was to provide the controllers with sufficient expertise, as far as time permitted, so that they could attain a level of confidence and proficiency in the use of the PD/3 system, and thus allow them to participate fully in the PD/3 experiment. The training focused on providing the controllers with a full understanding of the system handling and philosophy. Full details of the training are given in Annex B.

5.1 THE COURSE

The controllers were trained using a full six days course, entailing a mixture of theoretical lessons and practical training on the full system. The day before the measured runs began, all controllers undertook two refresher runs.

In preparing and conducting this training course, a number of lessons were learned. In first instance, it was found necessary to have instructors who were capable to answer in a competent manner all operational and technical questions and concerns of the controllers. Secondly, it was found essential to have as much as possible a very limited set of controllers for one instructor during the practical sessions so as to ensure an efficient training. Two controllers per instructor should be the maximum. Finally, whilst the training programme was shown to provide a comprehensive course, it proved to be important that courses propose to the controllers a combination of operational and technical expertise.

5.2 CONCLUSIONS FROM THE TRAINING

The CENA PD/3 training programme succeeded in meeting the training objectives. It appeared that all controllers fully understood the underlying concepts of PD/3. The assimilation of all facets of both the new facility and the new concepts allowed them to greatly participate to discussions about the system and to bring their own knowledge about these specific subjects.

For training in future experimental system trials, the CENA PD/3 Training Team offers the following recommendations:

- plan and design the training course as soon as possible within the project plan;
- ensure a close matching between training tools and the targeted system (i.e. standalone using the same software components as in the linked system);
- work closely with the technical team to establish a complete and continually updated knowledge of the system;
- emphasise on practical differences between current CWP, tools and method compared to the PD3 system;
- quickly switch to practice and organise small courses on purpose when questions raised about specific points of the new concepts;
- give a precise goal to each lesson so that controllers could know whether they caught the essential point;
- ensure a good management of the practical training so that controllers have precise tasks to accomplish;
- check that controllers are familiar enough with Personal Computer handling.
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6. RESULTS

6.1 INTRODUCTION

CENA PD/3 was designed in the same ways as PD/1 and PD/2 to be an experimental system used to evaluate the PD/3 concepts and associated procedures and methods of control, but was not a pre-operational system. Obviously, such a programme provided various results that could not be investigated independently. Indeed, results from objective measures had to be interpreted under the light of subjective measures and conversely. In the same way, cross-checking between results from the three main topics (controller Workload, Quality of service and sector Capacity) was essential for drawing reliable conclusions.

This section summarises the results presented in Annex C1 - the effect of the PHARE Advanced tools (PATs) and Data-Link on controller Workload (see section 6.2), Quality of service to airlines (see section 6.3) and Capacity of sectors (see section 6.4) - and in Annex D - the controllers’ questionnaires answers on many aspects of the advanced system (see section 6.5).

These results are discussed in section 7.

6.2 CONTROLLER WORKLOAD

This section gathers the results of subjective indicators - the Instantaneous Self Assessment (ISA) and the Task Load index (TLX) - of perceived workload to compare the operational organisations (ORGs), sectors and controllers roles. Hypotheses were tested (H0 stating there is no significant difference between the compared organisations - H1 referring to the alternative hypothesis) using a number of non-parametric tests which were most suitable for the recorded data (see hereafter and more details in Annex A, section « Statistical tests-used » and Annex C1).

The analysis concentrated on identifying whether the change in results between the different ORGs was « statistically significant », i.e. the observed difference in the result was unlikely to have occurred by chance. A five percent level was used to identify a statistically significant difference in results, and a ten percent level used to identify a trend. This section concentrates on those results, which were statistically significant. The complete results obtained from the statistical analysis are given in Annex C1.

The Table 6-1 to Table 6-6 summarise the main figures extracted from statistical comparisons (Wilcoxon and Friedman tests) between ORGs (of ISA scores, TLX scores and TLX unweighted factors, for all sectors merged. The ‘=’ indicates that there was no statistically change in instantaneous perceived workload for that controller role and traffic volume. The ‘↑’ (Wilcoxon) and ‘<’ (Friedman) symbols indicate statistically significant increase. The ‘↓’ (Wilcoxon) symbols would have indicated statistically significant decrease. The ‘(‘)’ symbols indicates that a trend exists but acceptance of the alternative hypothesis cannot be concluded. Only Medium and High traffics were included in the picture, since A30 and A70 were not evaluated against Low volume traffic.
Tables that present results for each controller role and sector taken separately must be considered with high care since the number of observations is reduced (population of 8 vs. population of 24 when all the sectors are taken together). However they are of interest since they provide a general picture of each sectors specificity and explain how they contributed on the overall results.

Tables, which integrated all the sectors together, are much more reliable under a statistical point of view (population of 24). Moreover, they provide really relevant information on the general impact of the PD/3 concepts and the new sharing of tasks on the planning responsibilities on the one hand, on the tactical responsibilities on the other hand.

Obviously, the best configuration of simulation should be the one where three completely separated analyses on TMA, ETMA and En-Route sectors could be carried-out in parallel. Consistent results could be get independently on each sector, taking into account their operational and geographical particularities and suitable comparisons between these results could so be obtained. Now, the available number of runs and size of population in each sector was not considered as being sufficient in order to lead the CENA team to these three completely separated analysis.

**Note:** Meaning of L, M, and H abbreviations is respectively Low, Medium and Heavy traffic. A0, A30 and A70 abbreviations refer to Advanced ORGs with different percentage of Data-Link equipped aircraft (0%, 30% or 70%).

<table>
<thead>
<tr>
<th>Workload evolution</th>
<th>Planner</th>
<th>Tactical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>From Baseline to A0</td>
<td>=</td>
<td>↑</td>
</tr>
<tr>
<td>M</td>
<td>H</td>
<td>M + H</td>
</tr>
<tr>
<td>From A0 to A30 to A70</td>
<td>A0=A30=A70</td>
<td>A0=A30=A70</td>
</tr>
</tbody>
</table>

**Table 6-1 Synthesis of the results for the comparison of ISA means**
### Table 6-2 Synthesis of the results for the comparison of ISA means by sector

<table>
<thead>
<tr>
<th>Workload evolution</th>
<th>Planner</th>
<th>Tactical</th>
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<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>From Baseline to A0</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>From Baseline to A70</td>
<td>M</td>
<td>H</td>
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<tr>
<td>From A0 to A30 to A70</td>
<td>A0–A30–A70</td>
<td>A0–A30–A70</td>
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### Table 6-3 Synthesis of the results for the comparison of TLX score by sector

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<th>Tactical</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>From Baseline to A0</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>From Baseline to A70</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>From A0 to A30 to A70</td>
<td>=</td>
<td>=</td>
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</tbody>
</table>

### Table 6-4 Synthesis of the results for the comparison of TLX score by sector

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<th>Tactical</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>From Baseline to A0</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>From Baseline to A70</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>From A0 to A30 to A70</td>
<td>=</td>
<td>=</td>
</tr>
</tbody>
</table>

1 Terminal Manoeuvring Area associated to Roissy Charles de Gaulle airport
2 Extended Terminal Manoeuvring Area (TN/TB)
3 UNXN
<table>
<thead>
<tr>
<th>Workload evolution</th>
<th>Planner</th>
<th>Tactical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>from Baseline to A0</td>
<td></td>
<td></td>
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<tr>
<td>Mental_demand</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Physical_demand</td>
<td>↑</td>
<td>=</td>
</tr>
<tr>
<td>Time_pressure</td>
<td>=</td>
<td>(↑)</td>
</tr>
<tr>
<td>Effort</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Frustration</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Own_performance</td>
<td>=</td>
<td>=</td>
</tr>
</tbody>
</table>

from Baseline to A70

| Mental_demand      | = | ↑ | (↑) | = | = | = |
| Physical_demand    | = | = | = | = | = | = |
| Time_pressure      | ↑ | ↑ | ↑ | = | = | = |
| Effort             | ↑ | ↑ | ↑ | = | = | = |
| Frustration        | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| Own_performance    | ↑ | ↑ | ↑ | = | = | = |

Table 6-5 TLX unweighted Factors results
## Table 6-6 TLX unweighted Factors results by sector

<table>
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<tr>
<th></th>
<th>TMA Planner</th>
<th>TMA Tactical</th>
<th>ETMA Planner</th>
<th>ETMA Tactical</th>
<th>En-Route Planner</th>
<th>En-Route Tactical</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental_demand</td>
<td>=</td>
<td>=</td>
<td>(↑)</td>
<td>=</td>
<td>(↑)</td>
<td>=</td>
</tr>
<tr>
<td>Physical_demand</td>
<td>=</td>
<td>=</td>
<td>(↑)</td>
<td>=</td>
<td>↑</td>
<td>=</td>
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<td>Time_pressure</td>
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<td>=</td>
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</tr>
<tr>
<td>Effort</td>
<td>=</td>
<td>=</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Frustration</td>
<td>=</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>(↑)</td>
</tr>
<tr>
<td>Own_performance</td>
<td>=</td>
<td>=</td>
<td>(↑)</td>
<td>↑</td>
<td>↑</td>
<td>=</td>
</tr>
<tr>
<td><strong>medium and heavy traffic loads</strong></td>
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<td></td>
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</tr>
<tr>
<td>Mental_demand</td>
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<td>=</td>
<td>=</td>
<td>(↑)</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Physical_demand</td>
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</tr>
<tr>
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<td>=</td>
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<tr>
<td>Effort</td>
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<td>Own_performance</td>
<td>=</td>
<td>=</td>
<td>↑</td>
<td>=</td>
<td>↑</td>
<td>=</td>
</tr>
</tbody>
</table>
6.2.1 Workload comparison of Baseline and A0

Considering the ISA scores, for all sectors, traffic volumes and controller roles together, the controllers significantly scored the A0 ORG higher than the Baseline ORG. This result tends to show that the implementation of the advanced ORG, together with new working methods, immediately resulted in a feeling of heavier workload on the controllers' point of view.

The increase in workload perceived in A0 was more sensibly felt by the Planner Controller (PC).

In a compliant way with the overall results, the PC of each sector systematically scored the A0 organisation higher than the Baseline one.

For ETMA and En-Route sectors, the results of TLX measures completely fit the observations about ISA scores. The feeling of a heavier workload in A0 ORG than in Baseline was expressed in the TLX scores, as expected. However, no significant difference neither for the PC nor for the Tactical Controller (TC) is found when the TMA sector is considered alone.

As verified for the ISA scores, when all the sectors are considered together, the TLX score shows that the results are sharper for the PC (more consistent significant results through the different traffic loads). The clear change towards activities of early planning can once again explain the result.

Turning to the individual TLX factors, whichever the factors considered in PC position (mental demand, physical demand, time pressure, effort, frustration and own performance), the scores are higher for Baseline than for A0 (all sectors and traffic loads considered). All these results appeared as significant to the exception of the Mental demand factor. However, whichever the TLX factor considered again, the TMA sector has been the special case, as no significant difference was found there. These results comply perfectly to the overall (all factors, all roles) TLX scores.

The overall increase in workload for the PC positions exists in each related individual component. When considering the TC position, a significantly lower score characterises the Baseline ORG against the A0 ORG (all sectors, all traffic loads together) for the Frustration factor. This result is still valid for each sector taken individually as a significant result (except for the En-Route sector where a trend only was found). The Time Pressure factor shows the same result except for the TMA sector where no significant result is found. The factors Frustration and Time Pressure obviously had, for the TC position, a decisive influence to the overall feeling of workload felt in A0.

The TMA sector shows specific results for both the TC and PC. Firstly, only the Frustration factor has been felt as increasing for the TC when A0 was introduced. No difference was issued between the Baseline and the A0 organisations for the PC, whatever the workload factor.

Conversely, the ETMA sector showed for the TC a strong impact of the introduction of A0 organisation on most part of the TLX factors. Real difficulties met by the PC in preparing and de-complexifying the in-coming traffic (unsuitable environment for early display of aircraft) can explain this fact.
6.2.2 Workload comparison of Baseline and A70

As for A0, the A70 ORG was, in controller’s eyes, a source of a more important workload than the Baseline ORG. This increase in workload (significant result) was however not as important as for A0. First of all, as the En-Route sector is involved, no significant difference does turn up. Then, and this time whatever the sector, the contribution of the TC position is very low for the overall result.

The increase in workload perceived in A70 was more sensibly felt by the PC (more consistent significant results through the different traffic loads).

The results of TLX measures completely fit the observations about ISA scores. The feeling of a heavier workload in A70 ORG than in Baseline is expectedly expressed in the TLX scores.

Now, if each sector is considered separately for the analysis of ISA scores, the Planner controllers systematically scored the A70 organisation higher than the Baseline one, whereas regarding the Tactical controllers, only the ETMA sector showed the same result. For the TMA and En-Route sector no difference was found between the both organisations. For TMA and ETMA sectors, the results of TLX measures completely fit the results of ISA scores.

When considering the PC positions, the contribution of the various TLX factors in the global score seems dimmer in the comparison Baseline/A70 than in the comparison Baseline vs. A0. The factors Frustration and Time Pressure, besides ranked among the most influent (i.e. the more significant in the workload as expressed by the controllers) comply well to the results obtained in the global comparison.

The strong difference that comes in the TC position between comparisons Baseline vs. A0 and Baseline/A70 is related to the Time Pressure parameter. In effect, though it had little impact on the feeling of frustration felt by the TC, the massive introduction (70%) of Data-Link equipped aircraft in the advanced ORG seemed to influence the Time Pressure factor in a positive way.

The TMA sector shows specific results for both the TC and PC. Firstly, only the Frustration factor has been felt as increasing for the TC when A70 was introduced.

Conversely, the ETMA sector showed for the TC a strong impact of the introduction of A0 organisation on most part of the TLX factors. As it was for the A0 organisation, the real difficulties met by the PC in preparing and de-complexifying the in-coming traffic for the TC (unsuitable environment for early display of aircraft) can explain this fact.

6.2.3 Workload comparison of advanced organisations (A0, A30, A70)

It can be stated through ISA results that the introduction of Data-Link had obviously much less impact on the controller’s workload than the new ORG. Notice however from the overall results (all sectors included) that the TC position generated a significant answer. The A30 ORG was given the highest workload when compared to A0 and A70.

TLX results comply again with the ISA scores, as the influence of the ratio of equipped flights on the workload is harder to distinguish than that of the advanced ORG.

When each sector is considered separately for the analysis of both ISA and TLX scores, no difference can be stated between the three advanced organisation (A0, A30 and A70), whatever the controller position.
6.2.4 Workload comparison of controller roles

When comparing the workload between the tactical and planning controllers, the results may be summarised as:

- **ISA scores (see Table 6-1)** - Baseline vs. A0 and Baseline vs. A70 show no actual difference between the two roles, to the exception of the Medium traffic load. Indeed in the latter case PC scored both the A0 and the A70 significantly higher than the Baseline. TC did not. On the contrary, regarding comparisons between the advanced ORGs, differences appeared as trend (Medium traffic) or significant results (Medium + Heavy traffics) for the TC position only.

- **TLX scores (see Table 6-3)** - The results between PC and TC did not show any difference when all traffic loads are included. The only differences observed between PC and TC were relative to the comparison Baseline vs. A0, Low and Heavy traffic loads. For these cases, the differences quoted by the PC did not show up in TC’s scores. No influence from introduction of Data-Link equipped aircraft could be raised neither for the PC nor for the TC.

- **TLX unweighted factors (see Table 6-5)** - The TLX factor **Frustration** has undergone the most general increase (for both the PC and TC position, and for all traffic conditions) from Baseline to A0 ORG, with the **Time pressure** being second.

  The differences between scores in Baseline and A70 show once again the greatest differences in favour of the Baseline ORG for frustration and time pressure. For all other factors, the TC scores undergo no variation whereas the PC scores rise for all factors but the physical demand. For the TC positions, the massive introduction (70%) of Data-Link equipped aircraft in the advanced ORG seemed to influence the Time Pressure factor in a positive way.

  For both comparisons (Baseline vs. A0 and Baseline vs. A70), the consequences of the Heavy traffic load were strongly noticed by the PC position and hardly noticed by TC, for whom the frustration only rises.

- **Results relating to the ISA scores are similar for the ETMA whatever the controller role. However, for the TMA sector and even in a clearer way for the En-Route sector, the TC reported less difference in their perceived workload in the advanced organisations (A0 and A70) when compared with the Baseline organisation. It’s really of interest to note that the pattern of results is quite similar for the TLX scores.**
6.2.5 Workload summary

The workload results presented in sections 6.2.1 to 6.2.4 may be summarised as follows:

- Whatever the Workload measure (ISA, TLX), converging results show an increasing perceived workload on both PC and TC positions due to the introduction of advanced ORG.
- Nevertheless, these results proved to be more obvious for the PC as an effect of transferred workload to PC (planning activities).
- Frustration and Time pressure factors proved to be of great influence on the overall feeling of perceived workload for PC and TC.
- Though introduction of Data-Link equipped aircraft did not prove to really influence the perceived workload, when introduced in a massive way, it seemed to have more positive impact on the TC positions.

6.3 Traffic Throughput / Quality of Service

This section summarises the results of the statistical analysis of the Quality of Service data recorded during PD/3. The quality of service to airlines which constitutes a consistent measure of the effectiveness of any ATC system has been addressed through two objective measures: «time at or near the Preferred Cruise Flight Level (PCFL)» and «time spent in sector».

The TMA sector is only concerned by the measure «time spent in sectors». In addition to this measure, Quality of service was considered by examining conditions of take-off (delays and ground constraints violations).

Contrary to what has been reported from PD/1, except the En-Route sector where no variation was found, the introduction of advanced ORG alone (A0 ORG) causes the aircraft to spend less time in the others sectors (TMA and ETMA). However, no increase in time spent at the PCFL was observed for ETMA. Time spent at and 2000 ft about the PCFL decreased for the En-Route sector whereas time spent within 2000 ft of the PCFL increased from Baseline to A0 ORG when considering ETMA. No satisfying operational explanation has been found for the last issue.

When all the sectors are considered together, the joint introduction of advanced ORG and Data-Link equipped aircraft showed a significant diminution of the time spent per aircraft in these sectors (but only the TMA sector produces a significant result with an average amount of 5.5% of saved time compared with Baseline when the sectors are considered independently). However the percentage of Data-Link equipped aircraft did not show any influence.

Regarding Departure sector (TMA), no influence from the introduction of Data-Link on take-off delays (number of delayed aircraft and delays values) has been raised. However it can be mentioned that going to heavy traffic samples means increasing the average Departure delay from 4 to 6 minutes in case of 0% or 30% of equipped aircraft and to only 5 minutes in case of 70% of equipped aircraft. No operational factor really explained this fact but it should be further investigated so as to check if this trend is only attributable to random.

The conditions of the simulations did not allow detailed analysis for CFMU (Central Flow Management Unit)/non CFMU aircraft comparison and ground sequencing constraints violations.
6.4 AIRSPACE CAPACITY / SAFETY OF CONTROL

The capacity of sectors was recorded directly as an objective measure but should rather be considered as an input data for calibrating the «traffic volumes». Objective measures of safety were chosen as an indication of whether a capacity increase may be possible by implementation of advanced ORG and Data-Link equipped aircraft. These measures were number of occurrences and duration of Short Term Conflict Alerts (STCAs) and minimum safe separation infringements.

The relevance of STCAs data was of limited warranty. Indeed, the values obtained within the framework of the analysis revealed numerous abnormal results (unrelevant alerts notably). Therefore, it was decided to give up the investigation of STCAs.

The comparison between Baseline and A0 does not give rise to significant differences when considering the number of safe separation infringements. However, if all the advanced ORG are compared, the results seem much marked and thus show a real influence of Data-Link equipped aircraft (increasing of number of infringements). Comparison between Baseline vs. A70 reinforced this statement (significant increase in A70).

The measures devoted to the duration of safe separation infringements show quite different tendencies since no influence neither from the percentage of Data-Link equipped aircraft nor from the Baseline / A70 comparison was found. Moreover, when all sectors and traffics loads are considered together, Baseline vs. A0 comparison gives rise to a significant increase in A0.

The notion of capacity is tightly coupled to that of the controllers’ Workload and the resulting Quality of service that the ATC users may expect. Now, the results reported from the Sector Capacity and Perceived Workload topics counter-balanced a part of results from the Quality of Service.

No increase in capacity can be achieved in moving from the Baseline to the advanced ORGs if, considering the same traffic level (Heavy one above all), no decreasing of perceived workload is stated for the advanced ORGs. Overall results devoted to the perceived Workload even show the opposite.

In others respects, aircraft spent less time in TMA and ETMA sectors in A0 compared with Baseline, but it is unlikely to be interpreted as a clue of an improvement in Sector Capacity since the safety condition seemed not to be met. Indeed, regarding the duration of safe separation infringements, a comparison between Baseline vs. A0 showed in parallel a significant increase for A0 (all sectors and volumes together).

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

6.5 CONTROLLER ACCEPTANCE

This section summarises the results presented in Annex D (controllers final questionnaires). The controllers were asked to answer a number of questions by ticking the following responses: 'strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree'. In addition, an entry was left available for the controllers to add any comments they felt applicable. The results are summarised below based on the different sections of the questionnaires. In each case, the main comparison was between the number of controllers recording one of the three ‘agree’ categories versus those recording one of the three ‘disagree’ categories.
6.5.1 Simulation Environment and Training

These questions covered the Training, traffic samples, feed sectors, simulation room, use of ISA. In general, the majority of controllers agreed with the way these items were implemented by the PD/3 team, although only a few of the results were statistically significant.

All training aspects (airspace and route structure, GHMI and tools functions, sharing of tasks, feeder positions, TLX questionnaire) have been positively received by a majority of controllers. **Questions relating to feeder positions and TLX questionnaires presented significant results.**

Controllers have been less convinced by the suitability of traffic samples and the working environment (balanced positive and negative responses). A reason that prevented the controllers from fully accepting the traffic sample related in fact to the aircraft performances that were considered as sometimes unrealistic. Notably due to the impact on speed and rate of climb, controllers of TMA and ETMA sectors were particularly critical on this point. Regarding the working environment, comments indicated that too cold a temperature in the simulation room was a really disturbing element.

A little majority of controllers reported that answering the ISA was not distracting. However the trend is at the opposite for the En-Route controllers. Conversely, whatever the simulated sector, a majority of controllers indicated that the ISA prompt was not noticeable enough.

**A strong majority of controllers (significant result) reported that other activities in the simulation room induced disturbances.** They clearly indicated that number of visitors was the most hampering factor.

6.5.2 Operational aspects

- **PD/3 concepts**

  A majority of controllers (although not statistically significant) considered that the PD/3 concepts were positive for future ATC environment. Nevertheless they clearly advised that their feeling had to be received with precautions since some simulation limitations (responses time of the system mostly) prevented them from fully evaluating the system.

  The PD/3 concepts have received a better acceptance for the PC position than for the TC. Indeed, controllers globally felt that optimising traffic and managing conflict in advance could be of strong interest (under condition of strong improvements for the Trajectory Editor and Problem Solver tool (TEPS)) but deplored the difficulties encountered by the TC when handling non equipped aircraft (advisories not adapted) and their feeling powerless when monitoring the equipped aircraft (feeling of silent and independent behaviour of those aircraft).

  The En-Route sector controllers reported a higher number of positive opinions. Their sector actually had the most suitable characteristics for applying and testing negotiation and early planning concepts.

  On the other side, results from ETMA controllers showed a negative tendency. Comments indicated notably that the lack of early display of Departure aircraft was strongly penalising. The very short time they had for carrying out the Planning and Negotiation processes made them feel they were somewhat ‘jostling’ between PC and TC while accomplishing these actions.
Opinions from Departure controllers (TMA) were quite mixed. Some of them expressed clear reservations about the trajectory function of the DEPARTURE MANAGER (incertitude of take-off time).

♦ Traffic Handling Procedures

By comparing with today’s situation, the controllers generally reported that the means for ATC have been improved for Baseline ORG whereas the trend of answers was inverted for all the Advanced ORGs (A0, A30, A70). No one was really disturbed by the stripless environment whatever the ORG. Comments indicated that facilities for issuing instructions of Direct route were highly appreciated in baseline ORG. It corresponds precisely to a common criticism that has been addressed to the Advanced ORGs: giving a direct is one of the best solution for traffic optimisation but it was proved to be too much complicated to issue it through the TEPS tool. Rigidity of the system (co-ordination, trajectory edition, etc.) has not been counter-balanced by concrete benefits on R/T workload, which has been however recognised by a majority of controllers.

Moreover, when asked about handling more comfortably peaks of traffic, keeping aircraft separated and how well the system helped to ‘maintain the picture’, Advanced ORGs received significantly negative results.

In a general point of view, what has been deplored regarding Advanced ORGs can be summarised by a controller comment: « I had sometimes to work too hard to obtain too little ». A significant number of negative responses regarding the suitability of the advanced system to allow more handled traffic or to increase control efficiency constitutes illustrations of this statement.

A significant majority of controllers agreed that it was difficult in the Advanced ORGs to handle the traffic with the given task partitioning whereas no real trend was emphasised for this question regarding the Baseline ORG. Comments clearly indicated that lack of communication (oral and through the system) and radar assistance (see notion of ‘operational gap’ in discussion of co-operation aspects) hampered activities of control.

Concerning matters of Workload, the controllers relative view of the ORGs revealed once again some considerable differences. Although the responses were not statistically significant, the majority of controllers reported that their workload would have been lower with the today’s system compared to the Advanced ORGs whereas the trend was inverted when comparing the Baseline ORG with the today’s system. Comments brought to light that planning activities greatly increased the PC’s workload (the difficulties in using TEPS also frustrated them a lot) meanwhile stress and insecurity feelings more contributed to the TC’s workload.

When the controllers were asked if they would prefer all aircraft to be 4D FMS equipped for a better traffic throughput, two groups of controllers had opposite opinions. The first group tended to emphasise the significant benefits brought by the decreased exchanges on frequency (notably for the transfer function) while the second group strongly worried about the difficulties they met for integrating equipped aircraft which might cross and behave within the sector (change of level notably) in a totally silent way.

However a clearer trend showed that a majority of controller were doubtful regarding the safety aspects in case of a 100% equipped aircraft traffic. According to them, the conditions to well intervene in emergency on these aircraft were not fully met (problems for re-planning a trajectory, pilot who could pay less attention to the frequency, etc.)
When asked about the way they experienced the co-ordination aspects, the controllers reported really mixed opinions. No clear trend could be raised regarding the benefits in overall traffic optimisation compared to Baseline ORG whereas a significant majority of them expressed negative opinions regarding benefits in control safety.

6.5.3 GHMI: Displays, Interaction

Very few questions regarding the set of displays presented significant results. However two general and opposite trends were reported.

On the one hand a majority of controllers considered as insufficient and not obvious enough the way display of priority information was managed (common criticism was that some factors like Sector Inbound Lists (SILs), labels overlapping and filtered views might hide sometimes important radar image information).

On the other hand, a majority of controllers reported a positive feeling about the coding of many GHMI objects when considered independently. For instance, a significant majority of controllers thought that coding of radar labels were quite efficient (logic and comprehensible) and allowed status of each aircraft to be clearly identified. However a common criticism was that aircraft track and speed vector were scarcely visible.

The Short Term conflict Alert (STCA) presentation was rejected by a majority of controllers. They justified it by the too many false alarms and the chosen coding (too slow flashing notably).

Material orientations for the screen have been very well received by the participants. Indeed, questions regarding the central screen size and the choice of a second screen (19 inches) led to significant positive answers (controllers particularly appreciated presentation of the Profile Window in the second screen).

Interacting with the system through the mouse has been generally considered as a suitable solution. However a general comment highlighted limits of this device when devoted to the use of menus. Many controllers experienced real problems particularly with the level menus (significant majority of them expressed that selecting option in this menu was really uneasy) and strongly wished improvements on it and introduction of parallel input devices such as a mini-keyboard.

6.5.4 Individuals Tools and Functions

♦ The Trajectory Editor and Problem Solver (TEPS) / Trajectory Support Tool (TST)

No significant results have been raised regarding frequency of use of TEPS in DISPLAY MODE neither for the PC nor the TC. Nevertheless, comments indicated that controllers agreed it allowed a quick way to consult a specific trajectory or compare several ones. In other respects, a controller reminded that he would have appreciated a lot having the possibility to display several trajectories while editing one.

A significant majority of controllers reported that they frequently used the TEPS in EDIT MODE as PC. Comments indicated that they performed as much as possible their planning activities and were de facto obliged to use the TEPS. It was logical to state an opposite trend for TC position since controllers instructions given during the training specified that TEPS in EDIT MODE was much more devoted to planning activities.
Results were similar when controllers were asked if they used frequently the Profile Window. Trend was negative when considering TC position whereas a significant majority of controllers reported they frequently used the Profile Window in PC position.

Opinions regarding the helpfulness of TEPS for avoiding conflicts diverged depending on the sector. Indeed, all the controllers from En-Route sector reported that they agreed or slightly agreed with this statement while TEPS was not seen in this light by a majority of controllers from ETMA and TMA sectors. Negative answers have been triggered by the feeling of too many irrelevant ‘bubbles’ (interactions zones).

A significant majority of controllers judged that the TEPS was not useful for reducing workload. Common criticism was that even though the way conflicts were presented (bubbles) was globally well received, trajectory edition was far too long and complicated.

En-Route controllers clearly expressed that TEPS and TST facilities provided good conditions to well manage planning activities with non equipped aircraft and de-complexify the traffic. However the trend was opposite for ETMA controllers. Answers from Departure controllers were quite mixed. Comments indicated that positive feelings were mainly due to the possibility of resolving conflicts in advance while negative feelings were due to the lack of co-operation PC/TC, which hampered the efficiency of planning actions. In others respects, a significant majority of controllers raised that TEPS facilities are useful in PC/TC co-operation only when supported by oral communication.

Opinions were quite mixed regarding the way TEPS and TST helped controllers to manage Data-Link exchanges with equipped aircraft. The excessive time demand (validation step or crew reaction) was, according to the controllers, the main factor to be improved. However, a significant majority of controllers reported that, in this context, their workload due to the VHF communication was reduced.

A majority of controllers (though not statistically significant) reported that, as PC, their workload due to telephone could be reduced by TEPS and TST facilities. It can be noticed that all the En-Route controllers positively answered to this question. However, opinions were quite mixed regarding the way the co-ordination with entry and exit sectors could be managed through the TEPS and TST facilities. Comments indicated that the principle of exchanging a trajectory can be full of promises but some incertitude - Is someone currently working on this aircraft? Has something been changed on this trajectory by someone else? Can this facility substitute the telephone in case of emergency? ... - might strongly disturb the controllers.
The Message In Window (MIW) / Message Out Window (MOW)

In Baseline ORG, a majority of controllers (statistically significant for TC and trend for the PC) reported that they did not frequently used the MIW/MOW. Negative responses were all statistically significant (PC and TC positions) when considering the Advanced ORGs. Whatever the ORG, a majority of them rejected the statement that the MIW/MOW were helpful for optimising co-ordination. Common comment raised that they were not enough alerted by an in-coming message and they did not really integrate the MIW/MOW in their visual checking. Some controllers added that just a sound signal would have correctly drawn their attention on those windows. Other comments also indicated that messages were not enough explicit and often forced them to use the phone.

A significant majority of controllers thought that improvement in the MIW/MOW would be desirable for all the ORGs. Some of them suggested to display the MIW/MOW on the main screen and to add a sound signal in order to intensify the events of in-coming messages.

The Conflict Risk Display (CRD)

A significant majority of controllers reported that they did not use the CRD frequently in TC position. A majority of them (trend) also reported negative answers for PC positions. They appreciated the idea of providing a synthetic and dynamic view of conflicts but clearly criticised the fact that conflicts were most of the time non pertinent or affected another sector. They consequently estimated that the CRD was not useful for reducing their workload (statistically significant result). A majority of them (trend) justified it by the fact that information displayed in the CRD was not helpful for avoiding conflicts. Associated comments indicated that the display was quickly cluttered by obsolete conflicts that could not be removed from it and thus prevented them from efficiently check the CRD content.

All the controllers thought that improvement in the CRD would be desirable for all the ORGs.

The Sector Inbound Lists (SILs)

A majority of controllers stated (trend for TC and not significant result for PC) they did not use the SILs frequently. However, controllers of en-Route and ETMA sectors expressed it could be useful for planning controllers rather than for tactical controllers. Comments indicated that information in SIL might be of interest for managing conflict in sector entry. However a significant majority of controllers reported that SIL was not highly relevant for their work and they all stated that improvement as follow could change their point of view: when presented on radar display, SIL should not in any way hide other information (e.g. radar labels) and present complete information on request like route details (the destination notably); when automatic removal event occurs, it should come with the explicit fact that the associated aircraft has been fully integrated by the controller.

4 The CRD was used only in the Baseline environment
5 Departure positions were not provided with SIL
The Advisories labels in the APD

Advisory labels in the APD aimed at helping TC to organise his control activity and to give prepared instructions just in time. Feeling about this depended on the sector. Indeed negative and positive opinions were balanced in En-route sector whereas all the ETMA controllers gave a negative one.

A common criticism was that advisories messages were often without operational sense (incorrect or concerning an other sector) and it led the controllers to mistrust those messages. Hence, a significant majority of them wished improvements in the advisory labels information.

6.6 ISSUES FROM THE CENA PD/3 TEAM EVALUATION

The CENA team who has been directly involved in assessment process was composed of three ergonomist experts, an ATC expert, advanced tools specialists (DEPARTURE MANAGER (DM) and Activity Predictor Display (APD)), and CENA experiment managers for PD/3.

Each ergonomist expert was responsible for one of the three simulated sectors (TMA, ETMA and En-route). Analysis methodology was applied accordingly to the experimental protocol (see reference [5]). Continuous observations carried out by the mean of analysis charts and post run debriefings have greatly contributed to raise significant issues of interest for interpreting overall analytic results.

Detailed issues relating to the Trajectory Editor and Problem Solver (TEPS), APD and DM tools are given in Annex C2.

Overall issues are summarised here.

6.6.1 Issues regarding PD/3 concepts

Advanced planning

Advanced Planning, which aimed at de-complexifying the traffic in sector by early taking it into account appeared as a positive concept since it showed great potential for trajectories optimisation and conflicts resolution in comfortable conditions (in this sense a specific PD1 trend is enforced). Trajectory support which is strongly linked to this concept might be really advantageous for tuning and enriching operational exchanges between controllers as well as optimising co-operation and co-ordination aspects.

Nevertheless, some strong conditions that has been issued had to be respected so that all the perceived potential of advanced planning concept can be fully exploited.

First of all, a clear sharing of tasks has to be ensured between PC, who is in charge of the planning activities, and TC, who must gain direct benefits from the planning results within the frame of tactical control. Both PC and TC were provided with the planning tool (TEPS in EDIT mode), thus if a suitable co-operation PC/TC is wished, it is fundamental to ensure a clear and mutual awareness of who invokes TEPS in EDIT mode and when.

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6 Departure positions were not provided with APD
• **The shared planning authority** is notably to be introduced with care. Indeed, it is a real complementary notion to the advanced planning concept. Having the possibility for both controllers to exchange data with the same aircraft in the same time (when they shared the planning authority) represented a very new operational logic for the controllers’ activity and so appeared as very fragile as regards controllers’ acceptance (some controllers in ETMA and En-Route sectors were strongly disturbed by the simple fact that two controllers could work in the same time on the same aircraft trajectory).

• Then, the **early display of incoming traffic** has to be effective so that the early handling by the planning authority can be of real interest. It clearly appeared that this sine qua non condition was not met in an equivalent way in the three simulated sectors (ETMA sector was particularly disadvantaged on this point of view).

• Last but not least a **suitable system for conflict detection** has to be provided in order to perfectly conciliate both objectives of advanced planning as optimisation of traffic throughput and early conflict resolution. Though the « bubbles » principle of HIPS has been perceived in a positive way, its operational potential has been only partially assessed. Indeed for all simulated sectors some system insufficiencies in detecting real conflicts or well sorting problems (APD) induces difficulties for controllers to reconcile their own views with those reported by the tools.

♦ **Trajectory negotiation (introduction of Data-Link and 4D FMS equipped aircraft)**

Trajectory negotiation which aimed at building a common and contracted trajectory with the aircraft appeared as a positive concept since it could lead to a much more accuracy in the forecast of trajectory (based on aircraft trajectory) and a significant decrease in VHF occupation (mostly for transfers action). In parallel of this concept, trajectory support has shown a great potential since it could allow tuned and enriched operational exchanges with pilot.

6.6.2 **Issues regarding operational aspects**

♦ **Handling traffic on positions (PC and TC):**

• **Planning activities:**

Concerning the PC position all controllers well integrated the quite enhanced Planner role they had to play compared to the Baseline ORG. They actually played the game by fully using the TEPS tool and perfectly understood the real benefits they could gain from Trajectory support. Moreover contracted trajectories (4D FMS equipped aircraft) increased the feeling of potential efficiency their planning activities could have.
The figure 6-1 shows that PC of ETMA and En-Route sectors regularly used the TEPS for trajectory editions (mean numbers of 25 times per run for ETMA and 21 times for En-Route). The high level of standard deviation shows that the frequency of TEPS using for edition was also dependent on the controller (the maximum value measured for ETMA sector shows that one of them used the TEPS for edition 58 times in a run). It was logical to observe through these figures that the TC used the TEPS in EDIT MODE much less (about 5 times per run), whatever the sector. This activity was indeed strongly limited to the absolute needs for re-planning.

### Figure 6-1: Number of trajectory edition per run (all traffic volumes and advanced ORGs)

Unfortunately some simulation limitations like the use of TEPS for trajectory edition or conditions of aircraft early display prevented them from fully exploiting this potential. Such limitations had a direct negative impact on co-operation with the TC and thus enforced the ‘Operational gap’ between PC and TC.

When a need for re-planning occurred after a tactical intervention from the TC, the PC or the pilot contribution did not succeed in helping the TC in an efficient way. Indeed the PC was rarely free to help the TC and the system did not work efficiency to allow new trajectory up-dating with a trajectory designed and down-linked by the aircraft.

Despite the supplementary time demand required by the negotiation procedure, the introduction of equipped aircraft did not really disrupt the way PC carried out planning activities.

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7 The PC of the TMA sector (DEP PC) is not concerned since he never used the TEPS through the radar image (his planning activities were centred on the DM tool).
• Traffic monitoring:
  Possibility to quickly consult the trajectory (TEPS in DISPLAY mode) was of strong interest for both PC and TC positions since it allowed instantaneous and dynamic knowledge (design, conflicts) of each forecast trajectory. Figure 6-2 shows that the average number of TEPS activation in DISPLAY mode are on the one hand little higher for En-Route sector (between 15 and 20 per run) than for ETMA sector (about 8), and on the other hand are very closed for the PC and the TC positions whatever the secto. No concrete explanation could be raised for the small difference observed between both sectors. However closed values that came out regarding PC/TC comparison clearly showed the suitability of this facility whatever the controller position. In fact, and as it was for the trajectory edition, the high level of standard deviation underlines that the frequency (and so the need) of TEPS using for trajectory display was strongly dependent on the controller.

![Figure 6-2: Number of TEPS activation in DISPLAY mode per run in (all traffic volumes and advanced ORGs)](image)

Integration of horizontal and vertical displays of trajectory proved to be useful (notably by identifying the Top Of Climb (TOC) or the Top Of Descent (TOD) through associated cursors on radar image and profile window).

Although numerous inadequate triggering really hampered their operational support, the principle of FLIGHT PATH MONITOR (FPM) has been positively received as a suitable help in real time and so deserves to be kept in the overall process of traffic monitoring.

Introduction of advanced tools demonstrated how the potential of advanced information and trajectory support could enhance traffic monitoring. However, the lack of immediate or suitable information of conflicts (e.g. via the DEPARTURE MANAGER for TMA or the Activity Predictor Display for ETMA) or other trajectory status (e.g. a specific change that has been performed few time earlier by a previous controller in the process) could not allow a real exploitation of this potential.

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8 When positioning the cursor on the vertical (the horizontal) trajectory, the associated geographical point on the horizontal (the vertical) trajectory was highlighted by another cursor.
It clearly appeared within PD/3 framework that a large part of tactical controllers (whatever the simulated sectors) felt their activity becoming impoverished. TC was sometimes reduced to either fully trust the tools or continually scan what could go wrong instead of really building an operational mental picture of the traffic.

It has been noticed that the “Silent behaviour” of equipped aircraft in front of which TC sometimes felt themselves passive and powerless was in a large part responsible of the here above statement. Some controllers reported that they were obliged to often consult planned trajectories of Data-Link equipped aircraft so as to keep a mental picture of this traffic as much as possible. Nevertheless, figures 2-5 (En-Route) and 2-6 (ETMA) in Annex C2 can not emphasise this last statement since no real influence of percentage of Data-Link equipped aircraft is observed.

- **System / GHMI up-dating:**

  The principle of providing the TC with an **advisories display** could be of interest since it represented a concrete help for the TC to maintain a clear awareness of what the PC had prepared. Intuitive and synthetic view (through the trajectory consultation or the Activity Predictor Display) of the instructions to be issued and the quick associated action to acknowledge each of them should have been helpful in the frame of TC activities. However, besides a lack of relevance of some advisory displays, controllers have been disturbed by the rigidity of the system that compromised all the PC preparation when an advisory was not acknowledged precisely at the time it was forecast to be.

  The necessity to update the system with a new registered trajectory each time an aircraft has deviated from its forecast trajectory was perfectly clear in all controllers mind. **Re-planning** due to unforeseen tactical instructions or advisory not given in time was in fact quite frequent during trials. However even though controllers seemed comfortable with interface mastering, they did not like the way the re-planning actions had to be performed under time pressure.

  To help them reminding tactical instructions they had to give by VHF, a majority of tactical controllers used the **dialogues in the radar labels** to input data like Level or Heading (**Aide-memoire** function). This up-dating activity significantly decreased when traffic level increased. Indeed the way the level menus (which was the most utilised) have been implemented strongly limited its use under time pressure.

  The possibility to optimise or ensure a safe traffic through the use of **time constraints** was not really used. When applied, it proved to work, but one has to realise that meteorological conditions were not simulated. The controllers seemed to think that the pilot would be unable to meet the time constraints in practice, because of meteorological conditions (e.g. wind, turbulence areas) that would be unpredictable in reality.

  The second argument was that with the use of time constraints, the controllers could not ensure that the aircraft would not catch up. They found it was not possible because not realistic to work that way. Therefore, they rarely used this option when choosing the type of conflict resolution.

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9 This issue has also been reported by PD/1 team for En-Route context, « Some tactical controllers saw their role as merely monitoring and passing clearances according to the planner’s plan ».
Co-operation aspects

Though its entire potential could not be fully exploited during the trials runs, support of trajectory planning combined with the concept of shared planning authority showed concrete advantages for both co-operation (PC / TC exchanges) and co-ordination (adjacent sectors exchanges) aspects since it provided controllers with enriched communication and decreased risks of misunderstanding. Therefore it should be an efficient complement to the early planning concept in an improved configuration.

A major drawback that has been raised while observing co-operation activities is the appearance of an 'Operational gap' between PC and TC for all simulated sectors. It means that PC and TC felt they were working on two separated sets of traffic, one not knowing what the other was doing. On the other hand, when traffic increased the PC could not provide tactical assistance because the planning tasks he was in charge of were taking more and more attention and were time demanding.

Co-operation aspects are discussed in more details in section 7.2.3.

Co-ordination aspects

The majority of the co-ordination activities have been performed through the telephone whatever was the ORG or the traffic level as electronic co-ordination sometimes was too time demanding or unsuitable according to the controller’s logic.

The simulation did not provide a sufficiently mature environment to promote the real potential of co-ordination by exchanging trajectory information. On the one hand some GHMI imperfections (e.g. MIW/MOW limitations - see section 6.5.4) strongly deteriorated a quick awareness of each in-coming co-ordination. On the other hand, controllers felt a strong frustration for being dependent on the system’s decisions about needs for co-ordination. Indeed electronic co-ordination was limited to the sole system proposals. As a consequence a controller did not have the ability to trigger a co-ordination he/she considered as necessary if the system had not initially detected a need for it. At the opposite some controllers felt irritated when system imposed them an electronic co-ordination (in case of conflict) when they would have preferred to use solely the telephone.

Some controllers strongly reacted against it. They were much more in favour of the following general principle: «The system has to show us quickly and clearly all information we need in each operational situation so that we are able to build a suitable picture of the situation and thus react in our own fashion in an efficient way». Of course this statement deserves to be deeper investigated.
6.6.3 Issues regarding use of Advanced tools

- The Trajectory Editor and Problem Solver (TEPS)

The TEPS tool clearly appeared to the controllers as a fundamental element in the framework of the Advanced Planning. They really could use it in an efficient way for quick trajectory invocation (except for the first trajectory activation via the DEPARTURE MANAGER label in which the mechanism of comparisons of alternative Standard Instrument Departure trajectories (SID) was too long). However the controllers failed more often to manage quick and precise trajectory edition. Those difficulties were especially penalising when they used the TEPS through the Profile Window.

Table 6-7 presents average numbers of trajectory edition duration per sector and traffic volume. Those values were obviously much too high and did not fit with the controller’s operational needs (minimum value is equal to 21.2s for En-Route sector and Medium traffic / maximum value is equal to 46.5s for the Departure sector and Low traffic). It is also of interest to note that whatever the traffic volume, greater values was systematically found in the Departure sector. A cross-checking made with qualitative data (observations and debriefings) clearly indicated that a more frequent use of the Profile window (instead of the radar image) for editing profiles in the TMA sector compared to ETMA and En-Route was at the origin of these increases of duration.

Moreover an incompressible response delay of the system is shown in Table 6-7. It is due to the system reaction after the controller validates a new edited trajectory. Those delays can be considered as important (minimum value is equal to 5s and maximum value is equal to 9s) since Human Factors data generally recommend that a delay for getting an answer from a system should not exceed 2s...

<table>
<thead>
<tr>
<th>Sector</th>
<th>Traffic Volume</th>
<th>Edition mean length</th>
<th>Validate mean length</th>
<th>Validate Max length</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEP</td>
<td>L</td>
<td>46.5s</td>
<td>6s</td>
<td>7s</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>36.9s</td>
<td>7s</td>
<td>9s</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>33.7s</td>
<td>7s</td>
<td>9s</td>
</tr>
<tr>
<td>ETMA</td>
<td>L</td>
<td>28.2s</td>
<td>7s</td>
<td>8s</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>29.6s</td>
<td>8s</td>
<td>10s</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>27.6s</td>
<td>9s</td>
<td>11s</td>
</tr>
<tr>
<td>ER</td>
<td>L</td>
<td>30.2s</td>
<td>5s</td>
<td>7s</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>21.2s</td>
<td>7s</td>
<td>9s</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>23.4s</td>
<td>8s</td>
<td>12s</td>
</tr>
</tbody>
</table>

Table 6-7: Details of duration of trajectory edition per run (all advanced ORGs and PC)

Considering trajectory negotiation, the use of TEPS greatly benefited from the overall convenient environment provided by the TST (Trajectory Support Tool) support in all trajectory exchanges (including ground-ground exchanges between controllers or controller and system).
Nevertheless it must be reported that the negotiation procedure was not always carried out in optimal conditions since the exchange protocol which involved human reaction (controller and crew) demanded an excessive time. Therefore when under time pressure (evolving aircraft appearing late or re-planning necessity) the overall negotiation protocol, plus the difficulties in trajectory edition, showed important limitations for the way negotiation was mechanised in the PD/3 simulation.

Use of TEPS for conflict resolution (« No Go Zones » erasure) really appeared as an attractive solution\(^\text{10}\). Nevertheless further investigations have to be done in order to be sure that identified pitfalls can really be avoided. First of all, duration of trajectories editions must imperatively be shortened (it could be done for instance the way short-cuts for instruction of Direct routes are). Then, even if it had been clearly observed that many times controllers mentally elaborated solution for conflict resolution before using the TEPS (it was notably the case in En-Route sectors), a tendency to reduce conflict resolution by simply erasing the ‘bubbles’ may exist. Such a tendency could lead to a real lack in traffic optimisation (each resolution laying more on the bubble erasing than on a minimum and sufficient separation) and a damage in mental integration of traffic (each conflict resolution being considered as a single pair aircraft-bubble instead of a subset strongly correlated to the overall traffic).

Due to some simulation limitations\(^\text{11}\), the anticipation of conflict events were not shown at a first level in the Departure positions (it was forecast to display it through the Departure Manager Display) nor the ETMA positions (it was forecast to display it through the PROSIT (PROblem SITuations) in the Activity Predictor Display). Display of trajectory through the TEPS tool was then the only way to access this kind of information. Nevertheless, it added a significant time to controller’s intervention and sometimes did not cope with control activity. In other respects and though its principle appeared as useful, systematic triggering of filtered view mode made sometimes the controller be disconnected from the whole traffic\(^\text{12}\) and so might induce supplementary stress (e.g. TC had more difficulties to find any aircraft which was calling).

Moreover, both PC and TC sometimes met some difficulties to build a clear awareness of each trajectory status. The following questions did not always give rise to a quick answer. Is it a conflict free trajectory? Is it a foreseen trajectory? Has something specific been changed by the PC? Is someone currently working on the trajectory of this aircraft or intending to?

\(^{10}\) The PROBLEM SOLVER (associated to the TEPS tool) was explicitly initially not for use in the TMA. However the principle appeared to good effect and so deserves to be deeper investigated in such sectors.

\(^{11}\) APD: lack of time for tuning and implementing suitable algorithms devoted to the detection of problem situations (PROSIT) in the ETMA sector (high percentage of evolving flights).

DM: the principle to up-date conflicts for pre-Departure aircraft was not applied since it led to a major risk of CP overload, thus it was decided not to present any conflict at all on the DMD rather than possibly present not relevant ones (not up-dated).

\(^{12}\) Filtered view of radar image was triggered through TEPS activation and highlighted aircraft, which were involved in problems while the rest of the traffic was shadowed.
♦ The Departure Manager (DM)

A positive issue can also be raised regarding overall information that was provided by the DM display. DEP PC appreciated the clear and synthetic view of pre-Departure traffic pattern: the overall ground sequence on each runway, the occupation balance between both runways and the precise configuration of aircraft that were about to take-off (this last one was also appreciated by DEP TC).

In association with the Advanced Planning concept it appeared a priori that combining sequencing functions and trajectory functions in DM was a really interesting orientation. However it must be raised that planning actions on pre-Departure aircraft proved much less credible in the point of view of controllers. Indeed even if some simulation limitations like the lack of conflict information devoted to pre-Departure aircraft hampered evaluation process, problem of take-off time precision appeared as a stumbling block in context of SID optimisation...

Algorithm of ground sequencing proved to be quite satisfactory according to the TMA controllers and it opens the way to optimistic perspectives. Besides specific improvements that were identified (notably softening the DM rigidity towards the controller’s interactions), DM performances deserve to be further investigated in a more complete and realistic environment. It means that various configurations must be checked (facing east and west, runways in single or mixed-up mode, etc.) in the framework of complete ground positions (including Tower manager, ground controller, Local, neighbouring airport, etc.) including a reliable ground event monitoring.

It would notably allow a better assessment of consequence of time Departure incertitude. Regarding this specific point several questions have to be investigated in the frame of DM tool introduction. Will we be able to ensure an improved precision of take-off time? If not, shall we find new concepts or a new system logic in order to make up for a persistent rough estimation of take-off time?

Detailed results are given in Annex C2.

♦ The Activity Predictor Display (APD)

The APD tool showed some potential for completing the Advanced Planning activities. By support of PROSIT (PROblem SITuations) labels, PC was clearly encouraged to consult and solve problems in advance. Moreover the use of the ‘Extrapolation’ function could provide concrete help for verifying conflict occurrence and choosing aircraft to be manipulated. Finally advisory labels appeared as an efficient link with the TEPS tool since it displayed synthetic view of what PC prepared for non equipped aircraft trajectories.

However, other reasons kept the En-Route controllers from fully trusting the system. First of all, discrepancies between the notion of a problem (PROSIT from CO-OPERATIVE TOOLS) and the notion of a conflict (Bubbles from PROBLEM SOLVER) were quite uneasy for controller to integrate. Then, according to them, PROSIT labels, which showed problem events were not systematically sorted in an relevant way with regard to resolution priority (see APD in annex C2). Thus they could not fully rely on the system to optimise their activity.

These APD limitations hampered a deep evaluation process but they highlighted an illustration of the ‘operational gap’ between PC and TC, which was generally identified in all the simulated sectors.
It must be emphasised that the implementation of the CO-OPERATIVE TOOLS in PHARE environment differs significantly from their implementation in ERATO environment\(^{13}\). Thus the results concerning the lack of co-operation between PC and TC are only valid in the frame of PD/3 environment. In ERATO environment, the PC has the responsibility to analyse new conflicts through PROSIT labels, to filter and classify them in order to transfer to the TC pertinent and well-sorted conflicts.

In such a context, the Agenda is a suitable support to enrich discussions between PC and TC. What is new and different with PD/3 environment, is that the PC also had the responsibility to resolve conflicts for incoming traffic in the framework of his planning activities. Observed results in trial runs were that a major part of remaining problems presented in TC’s APD concerned those that PC had no time to resolve. These ones often had to be resolved in emergency, and TC was then focusing exclusively on radar image to take them into account. Thus, PC worked on the traffic upstream, whereas TC focused on the traffic in the sector. No real co-operation could be supported by the APD.

Detailed results are given in Annex C2.

\(^{13}\) The APD is derived from the Agenda in ERATO, integrated in the PHARE operational scenario. To realise this integration, the Agenda had to be adapted according to the PD/3 concepts (notably the trajectory negotiation and the advanced planning) and facilities.
7. DISCUSSION

7.1 INTRODUCTION

The philosophy of «keeping the man in the loop» obviously makes us consider the problem of the Human Factor intervention.

During the trial runs, the future control environment (clearly presented as not being a pre-operational mock-up) proved to be suitable to the controllers cognitive characteristics under the following conditions only:

- responses time of the system coping with the time pressure;
- an overall system all controller can trust;
- an overall system relevant to the controller logic.

It means responses time as short as possible, a reliable overall system as well as logical and clear responses of the system.

If those conditions are not met, the shortcoming of the man becoming ‘slave to the system’ cannot be avoided. Therefore, negative impact on controller Workload, Quality of Service and sectors Capacity might be expected.

The following discussions gather results of the statistical analysis, controller questionnaires and the CENA PD/3 team’s observations and attempt to illustrate the generic considerations above by reporting them respectively throughout the CENA PD/3 Trial three main topics (controller Workload, Quality of Service and sectors Capacity).

7.2 CONTROLLER WORKLOAD

The general analysis of controllers’ workload had to be carried out by identifying the part of the workload coming from the activity of controlling in the CENA PD/3 environment (the «real» workload caused by introduction of advanced planning concept, advanced tools and Data-Link equipped aircraft) and the part of the workload coming from the effects of the simulation environment (that could be called «parasite» workload). The example of response times highlights this purpose since two strong distinct sources can be distinguished. Excessive response time could directly involve human factor intervention (crew and controllers) within a negotiation or co-ordination procedure, but it could also be assigned to the system performances when for instance the Departure Manager invoked the contribution of other tools (Trajectory Predictor and Conflict Probe) for complex operation (search of an optimised conflict free SID (Standard Instrument Departure) trajectory among several alternatives).
7.2.1 Introduction of advanced planning and advanced tools

♦ About specific PC workload

When considering the PC position, a change from Baseline to A0 ORG led to a common feeling of an increase in the perceived workload. Indeed, ISA (Instantaneous Self Assessment) and TLX (Task Load Index) scores (see section 6.2.1) as well as questionnaires responses (see section 6.5.2) converged to such a result. Regarding planning activities controllers might feel highly discouraged because of some concrete problems they met. First of all, limitations in trajectory edition (through both profile window and radar image) sometimes made this procedure complicated and unsuitable under time pressure (see section 6.6.3 and section 6.6.3). The time spent on trajectory editing (20-40s per aircraft) and the fact that an average of 20 edits were made per run means that this has taken a considerable percentage of the time of the PC.

Especially the time required to validate (6-9s) have also been a source of frustration (see Table 6-7 section 6.6.3.). Consequently a significant level of «parasite» workload was generated.

The introduction of planning activities had a strong impact on the perceived workload whatever the sector. Nevertheless some slight differences occurred for the TMA sector in which TLX scores seemed to smooth the ISA scores. The following analysis aims at identifying, what could lead to this statement.

First of all, lack of clear awareness of who had to handle the traffic and when, led the ETMA and En-Route PC to trouble.

On the contrary, due to the very clear separation of handled traffic (DEP PC was in charge of the pre-Departure traffic while the DEP TC specifically focused on the traffic in TMA), Departure controllers did not meet any problem to know who had to perform planning activities and when: these activities were exclusively devoted to the DEP PC for pre-Departure aircraft (TMA configuration is not adapted at all for planning activity on post-Departure aircraft). Moreover DM display provided TMA controllers with an efficient information about pre-Departure traffic.

Unfortunately, due notably to some limitations of the simulations like the lack of relevant viewing of flights in the different altitude layers (more details are given in the Annex C1 - section « Minimum separation infringement events »), the controllers of ETMA, who handled major traffic from CDG (Charles De Gaulle airport), was particularly penalised. Indeed, they encountered lot of difficulties to gain benefices from optimised trajectories that could be performed by the controllers of the TMA since they were not provided with an early and reliable display of the incoming aircraft.

Moreover, the impossibility to perform early co-ordination with the TMA (no co-ordination allowable for pre-Departure aircraft) might have kept the PC of ETMA from performing planning activities in optimal conditions (maybe such a scenario deserves to be further investigated).

Besides, and it's clearly expressed through the ISA scores, all the PC from all the sectors blamed the lack of opportunities to cope with an efficient sharing of tasks with the TC and it negatively influenced their feelings concerning their own performances in accomplishing their planning activities (see sections 6.5.2 and ?). Section 7.2.3. gives more details regarding the co-operation aspects.
About specific TC workload

When considering the TC position, even though the results were not as clear as for PC position, a change from Baseline to A0 ORG also led to a common feeling of an increased perceived workload. Once again, ISA and TLX scores (see section 6.2.1) as well as questionnaires responses (see section 6.5.2) converged to such a result.

Following deeper analysis aims at identifying, for the TC position, what contributed to this perceived workload increase when introducing A0 ORG.

Stress and feeling of lack of safety were expressed in priority by TC (see section 6.5.2) while Frustration and Time Pressure appeared as the more influent among the unweighted TLX factors. With the introduction of the advanced ORG without Data-Link equipped aircraft (A0), observations from ergonomist experts (see section 6.6.2) as well as controllers comments in final questionnaire (see sections 6.5.2 and 6.5.4) clearly reported that advisories display, which principle was quite accepted by the controllers, highly contributed to the TC perceived workload however. Indeed, they felt annoyed by being dependent on (or «slave to» as reported some controllers) the advisories mechanism they sometimes considered as irrelevant or too ‘rigid' (see section 6.6.2). Such a situation significantly increased TC’s workload since PC’s prepared trajectories could not be applied.

It had notably a strong impact on the time pressure the TC of ETMA and En-Route sectors felt. Conversely, the TC of the TMA sector who preferred to completely give up the use of advisories did not undergo as much the time pressure.

Several factors enforced the effect of both time pressure and frustration since they sometimes prevented the controller from quickly performing specific actions. For instance TC strongly regretted they were not provided with optimised facilities for Direct instruction update as they were in the Baseline organisation and felt really frustrated for that. Generally a lack of quick dialogues for tactical instructions update (level menus notably) discouraged them to perform this action (see section 6.5.2).

In the same way TC met difficulties for re-planning actions since no efficient mechanism allowed quick tactical updates to be converted into a complete re-planning (see section 6.6.2).

‘Doubt removal’ process which constitutes a large part of controller cognitive activity was partially hampered by a lack of relevant conflicts or alerts information (inopportune FPM (FLIGHT PATH MONITOR) alerts or conflict events which display was not always obvious (see ‘Traffic monitoring’ in section 6.6.2). Moreover controllers (from TMA and ETMA sectors above all) progressively lost their full confidence in the system since they did not agree with some conflicts shown while conversely conflicts they considered as real were sometimes not detected.

Therefore, a specific workload can be correlated to such an issue insofar as controllers felt a real frustration due to the lack of a strong system assistance. As direct consequence, the main feeling of frustration (for both PC and TC roles and in most situations simulated in the advanced ORGs), could be directly attributable to the occurrences of infringements.

Besides, it must also be mentioned that a part of the feeling of frustration was due to the aircraft performances that were considered as sometimes unrealistic. It had notably negative impacts on reliability of speed and rate of climb aspects. Therefore it wasted a part of the trajectories support contribution.
So, all the TC of all the sectors logically scored higher the factor of frustration in the advanced organisations. Condition of PC/TC co-operation was not optimised and therefore could not provide the TC with opportunities to get direct assistance from the PC and then to make up for the problems reported before. Section 7.2.3. gives more details regarding the co-operation aspects.

7.2.2 Introduction of advanced planning, advanced tools 4D FMS and data-link

It can be stated through ISA and TLX results (see section 6.2.3) that the influence of the introduction and the percentage of Data-Link equipped aircraft (A30, A70) was harder to distinguish than that of the advanced ORG (A0). Though it does not appear through each sector when considered separately (no difference in perceived workload is noticed neither with the ISA scores nor the TLX scores), it can be observed however that the introduction of Data-Link equipped aircraft had a more significant impact on TC's workload than it had on PC's. It also appears that runs with 30% of equipped aircraft (A30) seemed to be the most critical for TC whereas TLX unweighted factors show that the A70 ORG had a positive influence on the Time Pressure factor.

Through the debriefings with the controllers, it can be reported that the period of simulation was obviously too short for TC to really build new references as regards to the equipped aircraft behaviour. Hence it induced difficulties in mental integration of each equipped aircraft in the overall traffic (notably due to a lack of regular VHF contact) and difficulties in keeping confident with the entire trajectory. Some controllers reported (see section 6.5.2) that they felt a strong frustration because they often felt passive and powerless in front of equipped aircraft trajectories they considered as ‘black boxes’.

Strong feeling of insecurity has also been noticed since no efficient Ground Human Machine Interface (GHMI) facilities were proposed to the TC in order to get immediate information on status of incoming aircraft trajectories (see section ?). Such a situation was particularly critical in the context of Data-Link equipped aircraft. Persistence of ‘operational gap’ severely worsted the situation since the lack of oral communication prevented the controllers from counter-balancing these encountered difficulties.

Moreover, when asked about a 100% Data-Link equipped aircraft, a majority of controllers presented clear reservations (see section 6.5.2). Thus it should be understood that a major part of the controllers felt much more comfortable with non equipped aircraft since they mastered their trajectories and were much better aware of their behaviour.

So how can it be explained that A30 runs seemed sometimes to be handled by the TC with more difficulties than the A70 runs? The explanation which was proposed in the framework of the detailed analysis of Workload (see Annex C1 - section «TLX unweighed factors for TC») can be reported here: the massive introduction of Data-Link equipped aircraft had a positive impact on the Time Pressure factor (and only on this one) mainly due to the significant time spared in the VHF communications with pilots.
7.2.3 Specific issues for PC/TC Co-operation: appearance of an ‘Operational gap’

Comparison with Baseline organisation had a strong impact on controllers frustration regarding the lack of co-operation. Indeed, without advanced tools like the DEPARTURE MANAGER (DM), the Activity Predictor Display (APD) or the Trajectory Editor and Problem Solver (TEPS) they worked in Baseline organisation as they do in today configuration. It means that PC and TC shared the same space-time environment regarding traffic awareness. PC kept a close overview on traffic dynamic and tactical actions of TC and thus if needed was able to help him on critical situations (e.g. conflicts resolutions) or to perform complementary actions like anticipating co-ordination.

The situation was really different in Advanced Organisations whatever the percentage of Data-Link equipped aircraft (0%, 30% or 70%) in the traffic sample. Feeling of insecurity in TC’s mind was largely induced by the lack of efficient support from the PC. The latter was too busy upstream in the process to ensure neither a function of radar assistance nor a surveillance of his own planning consequences for TC activities.

Even when PC sometimes had the possibility to focus his attention back on the current traffic within the sector, it seemed it represented each time a huge mental demand to build again and update his knowledge of the traffic. In an other side most of the time he had forgotten what he had prepared on a trajectory 10 min earlier and felt unable to orally advise the TC on any trajectory. Therefore he was rarely in an optimised receptive mind to adequately assist the TC.

It has also been noticed, as significant clue of lack of co-operation, that Oral communications between them were quite rare compared to what happened within Baseline organisation. This should be seen as a success since it seemed to cope with the PHARE medium term scenario that stated « The routine communication between the PC and TC will be formalised and done via the computer system...Normally the explicit communication will be silent and unidirectional ... and which generally needs no additional explanation... ». However, the observations clearly brought into light that the controllers were sometimes in trouble, emphasising that the communication via the system should support more complete information. Unfortunately, due to their workload, they were unable to have any discussion (as a fallback solution) that should have helped them to make-up for some GHMI or system limitations. Thus this phenomenon which has been named ‘operational gap’ also induced strong feeling of frustration for the PC.

The following statement can be stressed here. Although in an automated system the TC does not need to maintain the same mental picture, it is important that the system gives him all the information that is required on the trajectories of aircraft in the sector. Trusted and complete trajectory information on all trajectories must be made available to all controllers as it is fundamental part of co-operation (and co-ordination) between the controllers. The results from the experiment show that where this is reduced or breaks down, the automation becomes a hindrance.
7.3 **Capacity of sector and safety**

The capacity of the sectors was recorded directly as an objective measure but has to be considered as an input data rather than a data which could be interpreted as a result of the simulation. These data aimed at calibrating the "traffic volume" variable (Low, Medium and Heavy traffic) so as to measure (in a qualitative and a quantitative way) the conditions of integration of these traffic volumes by the team of controllers according to the ORG (Baseline, A0, A30 and A70) and the sector (TMA, ETMA, En-Route).

As STCAs (Short Term Conflict Alerts) measures could not be exploited (STCA alerts revealed some abnormal results), the criteria targeted so as to measure the consequences induced by the increase in the number of aircraft was limited to the number of safe separation infringements observed and their duration:

Those measures are of interest since could the controllers not handle the number of aircraft ‘safely’ in one organisation, as may be indicated by an increase in the number of safe separation infringements, the traffic sample under consideration might be too high for that sector and should be reduced. Could the same traffic be handled in a different ORG, there might be a change in capacity.

For the same capacity (traffic load), the introduction of PD/3 concepts in the framework of an advanced Organisation (A0), compared to a Baseline Organisation, does not do significantly better in the number of infringement events, and moreover seems to slightly increase their duration.

For the same capacity (traffic load) again, the introduction of Data-Link, together with advanced Organisations, seems to induce a rise in the number of infringements, their duration being kept about the same.

It may then be assumed that the TC was not provided with an environment meeting the required conditions to let him calmly handle the remaining infringements. In addition with the limitations that are to be attributable to the experimental environment, remarks from ATCO (see section 6.5) and the observation of the PD/3 team (see section 6.6) allowed to better interpret such a statement:

- the system does not let the TC build his own mental image of the traffic, since everything he sees on his screen has been planned and decided by the PC;
- the increasing traffic load reduces dramatically the communication PC/TC, hence a handicapped planning efficiency and a lack of efficient help in an emergency. The TC lost the interesting part of his role which turned into mere monitoring actions and if necessary advisories delivering according to PC planning;
- traffic handling procedures due to the new tools are complex, and the reduction of the workload resulting from the decrease in VHF communication did not have a sufficient impact;
- the concepts introduced in PD/3 fit a PC role much better than a TC. They seem more adequate to an En-Route sector.
In a general point of view, results devoted to the infringements are to be considered with care. Indeed, even if the infringements that were not directly attributable to the controllers have been identified and removed from the analysis, the fact that the system did not always give conflict information to the controllers or provided sometimes ambiguous and contradictory conflict information, induced 'parasite' controllers' behaviour. It reduced their trust in the system and they tended to revert to practice they would use without the automation support (behaviour which now became a hindrance). This demonstrates that automated systems can only work if they achieve controllers trust and anything that detracts from that trust can and will increase workload and decrease safety.

7.4 TRAFFIC THROUGHPUT / QUALITY OF SERVICE

First of all, the interpretation of the two main objective measures (time spent in the sector and time spent at or near the Preferred Cruise Flight Level (PCFL)) is not easy since the results, as reminded here after, can disagree (see section 6.3.). The introduction of advanced ORG alone (A0) causes the aircraft to spend less time in the TMA and ETMA sectors. However, an opposite result might be expected insofar as general comments of controllers (see section 6.5.2) reported that they were not provided, in Advanced ORG, with suitable facilities for giving instructions of direct routes (efficient way for traffic optimisation). Moreover, no increase in time spent at the PCFL was observed for the ETMA sector. The introduction of A0 did not induce any significant variation regarding the time spent in the En-Route sector but causes the aircraft to spend less time at or near the PCFL.

No clear influence from introduction of Data-Link equipped aircraft was observed and it copes quite well with the controllers feelings. Their opinions were indeed shared when they were asked the effects of a 100% Data-Link equipped aircraft traffic on the traffic throughput (see section 6.5.2).

The apparent contradictions regarding the effects of A0 introduction can be alleviated by the precautions that must be taken regarding the relevance of statistical results (see Annex C1 - section «Summary and discussion of results »). In others respects, even though some explanation could be provided, objective measures that were initially forecast like number of levels off, number of heading instructions are really missing for a deeper investigation and a better understanding of the results. Following considerations aim at reminding some facts that also must be taken into account when considering the notion of Quality of Service.

The results as a whole should be taken with care as the number of elements was not high. First of all, some statistically significant different measures cannot be considered as relevant in their amount: the top ratio of time saved in a comparison involving the Baseline remains below 6%. It means a few seconds only for some streams and could be considered as derisory in an operational point of view.

Moreover, in the framework of the PD/3 experiments, probably as well as in all ATC simulation environments, numerous factors which can be called 'experimental noises' may interfere with clues of traffic throughput optimisation and make very difficult the assessment of Quality of service. It also led us to consider results with high care. Some of these factors that could be observed were as follows:

- simulated performances of aircraft that can lead to significant discrepancies with the actual performances (unrealistic rates of climbs were notably noticed);
- a lack of flexibility for determination of ATC constraints (based on static space description) led to «precaution scenario» where all a priori constraints were applied (potential increase of route length);
• insufficient sector knowledge for some controllers, at least during the first part of the simulations;

• a lack of confidence in the advanced tools that could lead controllers to work with larger safety margin than they would have used in today's organisation (for instance the controllers considered that the equipped aircraft were flying within a tube, they tended to separate the tubes instead of separating precise nominal trajectories - it might then increase the length of routes) or, on the contrary, an artificial controller relaxation when facing to a simulated traffic that could lead us to intentionally underestimate crossing distances (potential decrease of routes length).

All these factors had interfered one way or another (and more or less depending on the sector and the controller) during the trials.

Finally, at a higher level, further investigation devoted to the Quality of service should involve entire trajectories from the Departure to the arrival so as to really assess impacts of the new concepts and tools. In fact, gate to gate flights were initially forecast in the framework of PD/3. Unfortunately these objectives were not achieved. Main factors of satisfaction for airlines like respect of arrival time was notably missing. Therefore, conclusions about the overall Quality of Service cannot be drawn with high confidence.

7.5 CONTROLLER APPROVAL

It is of interest to focus on the general profile of controllers attitudes that could emerge from the overall PD/3 experiments. Controllers opinion regarding the Simulation Environment (see section 6.5.1) was quite mixed but no real criticisms (maybe except concerning aircraft performance) tended to call the global relevance of simulations into question. In other respects, the training aspects that could really hamper all the further assessments, have been positively received by a majority of controllers. However, some discrepancies between controllers were observed during the first trials. Insufficient knowledge of simulated sectors has particularly disadvantaged some controllers.

In fact, the strongest reservations that controllers raised concerned directly the 'technical environment' rather than the overall experimental environment. They perfectly understood they were not in front of a pre-operational system but however insisted on the fact that the slow performance of the system prevented them from fully evaluating the PD/3 concepts (see section 6.5.2) and the operational procedures (see section 6.5.2). The consequence was as follows: the controllers globally well received the concepts and advanced tools proposed in PD/3, but could not have a clear opinion or could not justify with high relevance when assessing the conditions of control and facilities they were provided with. However, they could raise very interesting discussions about future operational conditions that should promote or conversely strongly hamper the introduction of the PD/3 environment in a future ATC system.

Integration process of the PD/3 environment by the controllers mostly emerged throughout the use of individuals advanced tools and interaction with the GHMI and the way they reacted (positively or negatively) in real time (ISA scores, comments, etc.). By this way, a large part of information could be extracted by the specialist observers and related to detailed GHMI aspects as well as higher considerations like the induced methods of control.
8. CONCLUSION

8.1 OVERVIEW
PD/3 concludes the series of PHARE Demonstrations. CENA, EEC and NLR are the main participating research organisations that hosted the PD/3 demonstrations, assisted by the NATS (for evaluation aspects notably). PD/3 concentrates on the air and ground systems, which could be available in the 2005-2015 time-scale and addresses the influence of different controller working methods.

The CENA PD/3 research programme culminated in the participation of 27 different controllers from various nationalities (USA, Romania, Germany, and France). Three sectors were simulated (TMA including CDG airport, ETMA and En-Route) in order to evaluate future ATM concepts which combined Air/Ground integration, advanced tools to support the controllers and a transitional introduction of 4D FMS and Data-Link equipped aircraft. Another main concept of PD/3 was to keep the man in the loop by following a « Human Centred Approach ». The controllers were assisted by the provision of a set of PHARE Advanced Tools (PATs) designed to help the decision making process, to permit the timely exchange of data and to improve the aircraft role in the flight planning process.

The general objectives of the PD/3 trial were to determine the effects of the future ATM concepts on the controller’s workload and the Quality of service provided to the airline companies. Thus, relevant information regarding the gain in Sector Capacity could be obtained.

8.2 ABOUT THE RESULTS
The CENA PHARE Airborne demonstration with the DERA BAC1-11 live aircraft was successful. It showed the ability of an aircraft to establish an Air/Ground connection through the PATN network using the INMARSAT satellite, to use Data-Link applications before take-off and during the flight, and to use EFMS capabilities to manage 4D routes and to carry out Air/Ground 4D trajectory negotiations. The demonstration is fully described in Annex E: Real aircraft.

The CENA PD/3 training programme succeeded in meeting the training objectives. The controllers fully understood the underlying concepts of PD/3, and were able to participate intensively to discussions about the system and to bring their own knowledge about these specific subjects. In addition to the instructors, having technical experts who were capable to answer in a competent manner all the operational and technical questions and concerns of the controllers proved to be necessary and efficient. However, more training would have been profitable to some controllers and made them get used to the simulated airspace (traffic flows and rules).

The controllers generally well received the PD/3 concepts but insisted on the fact that some limitations inherent to the system performances prevented them from fully evaluating the novel concepts and procedures that were proposed.
Even if the introduction of the advanced ORG induced a direct increase in workload that was much more discernible on PC positions (TLX scores showed that all the components of workload was higher scored compared to the baseline ORG), controllers agreed that either advanced procedures or introduction of Data-Link equipped aircraft coped better with planning activities. Indeed, they felt that optimising traffic and managing conflict in advance could be of strong interest but deplored the difficulties that TC encountered when handling the non equipped aircraft (problems of advisories) and their possibly feeling powerless when monitoring the Data-Link equipped aircraft (difficulties to mentally integrate these aircraft within the overall traffic).

Hence, the TC scored Time Pressure and Frustration factors higher in the advanced ORGs (A0, A30, A70) when compared to the Baseline ORG. However, spared time for VHF communications was generally well appreciated in A70. In fact, a common frustration to both PC and TC was the clear cut between them that led to a real lack of co-operation (it was called the ‘operational gap’).

The full picture of Quality of service results is complex to analyse. No relevant conclusion can be drawn without on the one hand a deep analysis of specific data (that can highlight detailed behaviours of aircraft within each sector), on the other hand without consideration of the Quality of service provided on the entire route of an aircraft (from the Departure to the destination).

As it was in PD/1 and PD1+ (if we exclude for the last the optimal solution where 100% of the fleet is equipped), there is little evidence of a measurable change in airspace capacity. Though objectives measures of minimum safe separation infringements must be considered cautiously, they provided issues that deserve to be mentioned. They notably counter-balanced some results of Quality of service by bringing to light that the little improvement in traffic throughput that could be observed in A0 and A70 compared to Baseline (in TMA and ETMA) also came with an increase in either the number of infringements or their duration.

8.3 ABOUT THE EVALUATION METHODOLOGY

The experimental approach as proposed by the VAL Group and set up for PD/3 turned out perfectly adequate as regards to the principles used. The experiments led by the CENA team have in fact highlighted that some very complex subjects such as the Controller’s Workload, the Quality of Service and at last the Sector Capacity, cannot be grasped in a simple way. Therefore the will to go for evaluations based on both quantitative data (automatic data recordings devoted to the activities being studied) and qualitative data (observations, questionnaires) results is definitely justified. Only the strengthening of these various sources of results could provide reliable, or at least possible, interpretations.

As suggested by the VAL Group, the qualitative data had to hold a major role. The CENA team, according to its experience in this field, went a step further in this logic by granting real-time observations a prime importance (each sector was permanently monitored by an ergonomist expert). Such an organisation enabled every observer to get used to one of the three simulated sectors (e.g. a better knowledge of the geographical configuration and specific rules). Therefore, the richness of information obtained through post-run debriefings and the final questionnaire was all the more increased than the ergonomist experts could regularly cross-check with their own observations, and thus feed and help the verbalisation process.
The set of qualitative data thus obtained was used secondly as a support to the interpretation of quantitative results. The PD/3 experience strengthened the CENA team’s choices since some quantitative (and mainly statistical) results could have led to false or incorrect results. At last, a precise study of qualitative data enabled to compensate, at least partially, for the limits of statistical tests when the latter are applied to very few elements. It was notably so for processing the part of the questionnaires dedicated to the DM (the TMA alone was concerned) or to the PROSITs labels in the APD (En-Route only).

Considering the major topics such an experiment tries to address, i.e. ATCO workload, capacity and safety, quality of service, differences rise: whereas capacity and safety, quality of service and at a lower level ATCO’s workload seem to be well defined, ATCO workload could not be fully seized through the applied measures. At a higher range, drawing conclusions about quality of service was severely handicapped by the measurement conditions.

*ATC Workload* - As far as workload is concerned, the contribution of the ISA and TLX techniques was efficient, but the biggest obstacle they face is the big inter-controllers difference about the representation of the meaning of the “workload” notion, even though the TLX factors could limit its effects. More systematic approaches such as occurrences of mistakes and recovery conditions, or the impact of a new organisation on the controller’s mental picture (is it still efficient? does it require an evolution?) were lacking.

*Quality of Service* - This factor can be reliably appreciated in the context of gate-to-gate flights, to the exception of all others. In fact, the consequences of the new organisation on quality of service need to be considered at a global level, insofar as for example, delays measured in a single sector can well be counterbalanced by the shortenings in others, resulting in a flight arriving on time - the key data for airlines.
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9. RECOMMENDATIONS

9.1 ABOUT THE PD/3 CONCEPTS

The concepts of advanced planning and trajectory negotiation are proven interesting but deeper investigations, with an enhanced simulation environment, deserve to be done. First of all it has been clearly shown that the involvement of Human factor implied advantages but also some limitations regarding new tools or concepts approvals. Following considerations intend to summarise some outcomes of PD/3 experiments extracted from various observed situations of control and which could open research and thus, axis for the future.

9.1.1 Advanced planning

Two basic conditions should be required to allow the opportunity of shared planning authority. Firstly, it might be introduced within the frame of a very clear and stabilised sharing of tasks and responsibilities between PC and TC. Secondly, controllers who were sharing planning authority had to keep a high level of mutual awareness regarding the activity of each other in order to avoid an anarchic use of the Trajectory Editor and Problem Solver (TEPS). Improved GHMI solutions have to be applied so as firstly, to avoid simultaneous trajectory edition on the same aircraft and secondly, to clearly inform the following or previous controller in the control process that some trajectory changes have been performed for a specific aircraft.

Advisories aimed at concretely support TC by easy application of planned trajectory of non-equipped aircraft. Regarding logic of advisories it can be issued that actions of control which are performed via the TEPS or the Activity Predictor Display (advisories acknowledgements) are not exact substitute of tactical actions programmed in advance. Therefore a much more flexible mechanism should be proposed so as to allow the TC to by-pass or modify a single forecast advisory without losing the overall planned trajectories. In other respects the notion of proposed advisories, instead of imposed ones, should be investigated...

Whatever the improvements that could be made, a fundamental question is now whether it is possible to reconcile, even in the future, planning activities with radar assistance ability ('Operational gap' bringing down). It would mean that PC would be able to constantly keep a mental picture of the current traffic handled by TC. However it is clear that an enhanced planning activity leading PC to focus on the traffic 10 min before entering the sector obviously moved him away from TC activities. The corollary question may be whether the potential of co-operation support (trajectories exchanges, advisories...) can be exploited without a direct radar assistance...
9.1.2 Trajectory negotiation

Besides the fact that trial runs have strongly confirmed that the use of data-link procedures do not cope with tactical activities, one of the major outcome highlights that negotiation procedure will always require a minimum delay to be accomplished because of human implication (controllers and crew) and consequently must be carefully implemented in some control contexts. Exchanges between controllers and crew should be optimised in such a way that crew reaction time will not constitute an obstacle in the exchange protocol. For instance procedure of ‘Formalised clearances’ (that was already implemented for the experiments) could be enhanced with a kind of CPDLC board acknowledgement that would allow temporarily a system update without having to wait for an immediate down-linked trajectory.

In other respects improvements in general system response times as well as GHMI dialogues optimisations like horizontal and vertical trajectory editions should allow much more precise and consistent assessments.

PD/3 did not go through the use of trajectory negotiation by strategic operators as it was intended by the Multi-Sector Planning concept: this area seems promising because trajectory negotiation could be better integrated in an environment less urgency-prone.

9.2 ABOUT THE ASSOCIATED OPERATIONAL ASPECTS

9.2.1 Traffic monitoring

A suitable environment should be offered to the TC (but also the PC) so that he can keep a dynamic and continuous traffic awareness. Whatever the aircraft equipment, a quick and reliable knowledge of each trajectory status is absolutely necessary for the controller (mostly in case of time pressure). This trajectory status covers notions like trajectory display (clear and precise design of the trajectory including more realistic design of turns as it was proposed for instance in the frame of PD/2 experiments), trajectory characteristics (conflict free or not) and trajectory history (clear awareness of what has been previously changed and by whom).

9.2.2 Re-planning activities

Re-planning activity could be devoted to the TC under the strict condition that the mechanism perfectly copes with a high time pressure. It means that a quick update close to the logic of the tactical update and aiming at re-connecting the deviating aircraft to its previous trajectory should be privileged (e.g. dialogue for Direct instruction in Baseline organisation).

External assistance allowing efficient aircraft re-planning (i.e. pilot by the mean of down-linked trajectory and PC through an enhanced availability of radar assistance) has to be further and much deeper investigated.
9.2.3 Co-ordination with adjacent sectors

Question must be raised about the way system (NEGOTIATION MANAGER (NM) tool in this case) and controller responsibilities can be balanced: in this matter, PD/3 philosophy attempted to reach maximum level of automation, i.e., NM was in charge of detecting if a change of trajectory needed to be co-ordinated and did not let the opportunity to the ATCO to force co-ordination, neither to avoid it (in case of eventual conflict in the next sector or when parameterised entry or exit thresholds were exceeded, NM forced co-ordination).

This direction imposed to obtain a nearly perfect algorithm embedded in the NM; yet, defining suitable thresholds for triggering co-ordination is quite difficult since many factors have to be taken into account: kind of sectors boundaries, evolving Letters Of Agreement (LOA), etc. Thus, we can consider than obtaining a nearly perfect algorithm is out of reach. Furthermore, in most cases, a controller is perfectly aware of possible consequences of a change of trajectory in the neighbouring sectors; providing him with such a feature is «overkill».

This choice has 2 major drawbacks: first of all, on an operational point of view, it has been assessed that electronic co-ordination limited to the sole system proposals were not acceptable; a controller must have the ability to trigger such a co-ordination even if the system had not initially detected a need for it. At second, NM overall processing had serious consequences on the Response Time for the end-user during any submission of a new trajectory (software specialists asserted that «validation» transaction could have been reduced drastically without this sophisticated feature) ; this last consequence is not the least since it had a global effect on all the behaviour of the couple «controller-system».

This is why, we enforce the general idea to carefully design sharing of task between the controller and the system; too much automation (in this case, imperfect and non-efficient) leads to unsuited system.

9.3 ABOUT THE AIRSPACE ENVIRONMENT

The whole airspace and sectorisation (simulated sectors and feeder sectors) can be mentioned too as, more or less, a limiting factor in the frame of the analysis: the impact of early planning in limited-sized sectors (TN/TB and UN/XN) could not be really assessed, the quality of co-ordination was hampered by the important limitation of traffic in feeder sectors\(^1\) (it resulted negatively on the interest of controllers towards these positions) as well as by the absence of feeder sectors to simulate the way out the simulated sectors. It can be also stated regarding the co-ordination that they are quite limited and most of the time can be characterised by a very unusual configuration (for instance exit conditions that can not be met for any reason). Therefore, by keeping the existing sectors and LOA, strong limitations were a priori induced for evaluating co-ordination aspects.

Routes - Measures devoted to the Quality of services must be applied within a complete gate to gate flow environment. Moreover, more flexible (with less a priori constraints like LOA) routes should be provided so as to really assess contribution of advanced planning concept on traffic optimisation.

Size of sector - Despite all above proposed improvements or orientations which greatly deserve to be assessed, it can be wondered today if the scale of today control sector is really relevant for integration of the PD/3 concepts. Maybe solutions like the multi-sectors activities (re-planning or re-routing) should be in fact the research axis to be privileged. Probably outcomes from PD/1++ may bring some interesting first assessment of such a strategy.

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\(^1\) It was due to small-sized screens and the maximum load acceptable for the whole system.
9.4 **ABOUT THE EXPERIMENTAL AND TECHNICAL ENVIRONMENTS**

9.4.1 *Data recordings*

Other facts deserve mention, such as some initially forecast data collection which could not be implemented or analysed because of lack of time: detailed tactical instructions given to aircraft, contents and duration of VHF and telephone communications.

Probably this is a commonplace that, building an evaluation system should start as soon as the overall project start and this is true for all the bit of software or hardware involved: measurement tools must be designed in the same time as the core functionality rather than appearing as an additional layer designed late in the process, in a hurry.

9.4.2 *Baseline environment*

The main conclusion of PD/2+ was that reintroducing paper strips for the baseline eased the workload of the controller and therefore any baseline would need to be fully representative of current-day operations if meaningful comparisons are to be made with any advanced concept. This statement has been verified in the framework of PD/3 and notably for the DEPARTURE MANAGER. Therefore, further experiments should really cope with it.

9.4.3 *Simulation environment*

The negative impact of non-mastered environmental conditions (temperature, occurrences of visits, etc.) should not be under-estimated either. The controller’s concentration as well as ergonomist experts’ work might have been affected.

The implementation of an access control system should be investigated.
10. ACKNOWLEDGEMENTS

PD/3 was by nature a collaborative venture, gathering efforts from many participants from the ATM R&D community. CENA PD/3 could not have taken place without the cooperation of the PHARE partners: DERA of the UK, DLR of Germany, EEC (the Eurocontrol Experimental Centre), NATS of the UK, NLR in Netherlands. Everyone from these research centres who deeply care about PD/3 matters shares the results of these experiments.

A special thought to the CENA’s staff; 30 persons very deeply committed themselves in the project, often at the expense of their private life.

We do not forget initiators of the PD/3 project at CENA: Mr Pascal Huet, who launched the basis of the overall project, and especially, Marc Le Guillou who was Project Leader for the PHARE Demonstration 3 for one year and was a major contributor to the settling of PD/3 Operational Concepts (PD/3 Operational Scenario Document).

Marc died on 8 September 1996. This report is dedicated to him.
11. GLOSSARY

3D Three Dimensional
4D Four Dimensional
4D FMS 4D Flight Management System
a/c Aircraft
A0 Advanced ORG with 0% DL a/c
A30 Advanced ORG with 30% DL a/c
A70 Advanced ORG with 70% DL a/c
ACC Area Control Centre
ACM ATC Communication Management (Data-Link application: change of VHF frequency and change of Data-Link communication)
ADFL Augmented Dynamic Flight Leg
AHMI Airborne Human Machine Interface
AM Arrival Manager
AMD Arrival Manager Display (PATs)
APD Activity Predictor Display
API Application Programming Interface
ASP Arrival Sequence Planner
ATC Air Traffic Control
ATCO Air Traffic Control Officer
ATM Air Traffic Management
ATN Aeronautical Telecommunication Network
BADA Base of Aircraft Data
CDG Roissy Charles-de-Gaulle Airport
CDR Conditional Route
CENA Centre d'Etude de la Navigation Aérienne (France)
CFL Cleared Flight Level
CFMU Central Flow Management Unit
CMS Common Modular Simulator
CNS Communication, Navigation and Surveillance
CP Conflict Probe (PATs)
CPDLC Controller Pilot Data Link Communication
CRD Conflict Risk Display
CT Co-operative Tools
CWP Controller Working Position
CZW Conflict Zoom Window
DAARWIN Distributed ATM Architecture based on RNAV Workstations Intelligent tools and Networks
DASR Department of ATC Systems Research
DEP Departure
DERA Defence Evaluation and Research Agency
DIS Distributed Interactive Simulation
DL Data-Link
DLR Deutsche Forschungsanstalt für Luft- und Raumfahrt
DM Departure Manager
DMD Departure Manager Display
EATCHIP European ATC Harmonisation and Integration Programme
EATMS European Air Traffic Management System
ECM Extended Callsign Menu
EEC EUROCONTROL Experimental Centre
EFMS Experimental Flight Management System
ELW Extended Label Window
ERATO En Route Air Traffic Organiser
ETMA Extended Terminal Manoeuvring Area
FC Formalised Clearances
FL Flight Level
FMS Flight Management System
<table>
<thead>
<tr>
<th>Glossary</th>
<th>CENA PD/3 Final Report, Main Body</th>
</tr>
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<tbody>
<tr>
<td>FPM</td>
<td>Flight Path Monitor (PATs)</td>
</tr>
<tr>
<td>GHMI</td>
<td>Ground-Human Machine Interface</td>
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<tr>
<td>GTB</td>
<td>General Tool Box</td>
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<tr>
<td>H</td>
<td>Heavy (traffic)</td>
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<tr>
<td>HAW</td>
<td>Horizontal Aid Window</td>
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<tr>
<td>HIPS</td>
<td>Highly Interactive Problem Solver</td>
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<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
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<tr>
<td>IAS</td>
<td>Indicated Air Speed</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation</td>
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<tr>
<td>INI</td>
<td>IINitial approach controller</td>
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<tr>
<td>INSTILUX</td>
<td>EUROCONTROL Institute (Luxembourg)</td>
</tr>
<tr>
<td>IOCP</td>
<td>Internal Operational</td>
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<tr>
<td>ISA</td>
<td>Instantaneous Self Assessment</td>
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<tr>
<td>ITM</td>
<td>InTerMediate approach controller</td>
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<tr>
<td>L</td>
<td>Low (traffic)</td>
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<tr>
<td>LAD</td>
<td>Look Ahead Display</td>
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<tr>
<td>LOA</td>
<td>Letter Of Agreement</td>
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<tr>
<td>MASS</td>
<td>Multi Aircraft Simplified</td>
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<tr>
<td>MCS</td>
<td>Multi-aircraft Cockpit Simulator</td>
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<tr>
<td>MIW</td>
<td>Message In Window</td>
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<tr>
<td>MOW</td>
<td>Message Out Window</td>
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<tr>
<td>MSA</td>
<td>Multi-Sector Area</td>
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<tr>
<td>MSP</td>
<td>Multi-Sector Planner</td>
</tr>
<tr>
<td>NAS</td>
<td>National Airspace System</td>
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<tr>
<td>NATS</td>
<td>National Air Traffic Services</td>
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<tr>
<td>NLR</td>
<td>Nationaal Lucht- en Ruimtevaartlaboratorium (Netherlands)</td>
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<tr>
<td>nm</td>
<td>nautical miles</td>
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<td>NM</td>
<td>Negotiation Manager (PATs)</td>
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<tr>
<td>ODS</td>
<td>Operational and Display System</td>
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<tr>
<td>ORG</td>
<td>Operational Organisation</td>
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<td>OSD</td>
<td>Operational Scenarios Document</td>
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<td>OTF</td>
<td>Operational Task Force (PD/3)</td>
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<tr>
<td>OURASIE</td>
<td>Oursasie Toolkit : software Xwindow toolkit built above Xt Intrinsics layer (CENA in-house product)</td>
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<tr>
<td>PATN</td>
<td>PHARE ATN</td>
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<td>PATs</td>
<td>PHARE Advanced Tools</td>
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<tr>
<td>PC</td>
<td>Planning Controller</td>
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<td>PCFL</td>
<td>Preferred Cruise Flight Level</td>
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<td>PD/1</td>
<td>PHARE Demonstration 1</td>
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<td>PD/1+</td>
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<td>PD/1++</td>
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<tr>
<td>PEL</td>
<td>Planned Entry Level</td>
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<tr>
<td>PHARE</td>
<td>Program for Harmonised ATM Research in EUROCONTROL</td>
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<tr>
<td>PROSIT</td>
<td>PROblem STuation</td>
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<tr>
<td>PS</td>
<td>Problem Solver (PATs)</td>
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<tr>
<td>PUMA</td>
<td>Performance and Usability</td>
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<td>PUMA</td>
<td>Modelling in Air Traffic</td>
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<tr>
<td>PVD</td>
<td>Plan View Display</td>
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<tr>
<td>R/T</td>
<td>Radio / Telephony</td>
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<tr>
<td>RFL</td>
<td>Requested Flight Level</td>
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<td>RPVCD</td>
<td>Radar Plan View Display</td>
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<td>RTB</td>
<td>Radar Tool Box</td>
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<tr>
<td>RVSM</td>
<td>Reduced Vertical Separation</td>
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<td>SID</td>
<td>Standard Instrument</td>
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<td>SID</td>
<td>Departure route</td>
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<tr>
<td>SILs</td>
<td>Sector Inbound Lists</td>
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<tr>
<td>SITA</td>
<td>Société Internationale de Télécom. Aéronautiques</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>SM</td>
<td>Stack Manager</td>
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<td>STAR</td>
<td>Standard Arrival Route</td>
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<td>STCA</td>
<td>Short Term Conflict Alert</td>
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<td>STRANGE</td>
<td>Simplified TRAjectory Generator</td>
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<tr>
<td>TC</td>
<td>Tactical Controller</td>
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<td>TEPS</td>
<td>Trajectory Editor and Problem Solver</td>
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<tr>
<td>TICTAC</td>
<td>Time Constrained TrAjectory Computation : Trajectory Predictor</td>
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<td>TLX</td>
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<td>Terminal Manoeuvring Area</td>
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<td>Tools Manager Server</td>
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<td>Trajectory Negotiation</td>
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<td>TOC</td>
<td>Top Of Climb</td>
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<td>TOD</td>
<td>Top Of Descent</td>
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<tr>
<td>TP</td>
<td>Trajectory Predictor (PATs)</td>
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<td>TPAS</td>
<td>Trajectory Predictor based Aircraft Simulator</td>
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<tr>
<td>TST</td>
<td>Trajectory Support Tool</td>
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<td>VAL</td>
<td>PHARE Validation Project</td>
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<td>VAW</td>
<td>Vertical Aid Window</td>
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<tr>
<td>VHF</td>
<td>Very High Frequency</td>
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<td>VVD</td>
<td>Vertical View Display</td>
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<tr>
<td>vs.</td>
<td>Versus</td>
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<td>XFL</td>
<td>Exit Flight Level</td>
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