



NLR-TP-2000-004

**The PHARE Concept of  
Conflict Detection and Resolution  
and the NLR experience  
in PHARE Demonstration 3**

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This report is based on a presentation held at the FAA/EUROCONTROL Technical Interchange Meeting on Ground Based Decision Support for Conflict Detection and Resolution, Memphis, Tennessee on 19-21 October 1999.

The contents of this report may be cited on condition that full credit is given to NLR and the authors.

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## **Summary**

This report contains a paper that has been presented at the fourth Technical Interchange Meeting (TIM) on Ground-Based Decision Support for Conflict Detection and Resolution that was organised from 19-21 October in Memphis, Tennessee, by the Federal Aviation Administration (FAA) and the European Organisation for the Safety of Air Navigation (EUROCONTROL). The paper represents the conceptual developments in the field of ground based conflict detection and resolution that have taken place in the Programme for Harmonised Air Traffic Management Research in EUROCONTROL (PHARE) and in particular the practical experience that was gained at NLR when preparing and running the PHARE Demonstration (PD) 3 trials. The conclusion of the paper can be summarised by saying that the provision of appropriate automated conflict detection and resolution support to air traffic controllers can result in a reduction of the involved controller workload per flight, which can lead to an increase in system capacity. The application of an appropriate operational concept is an essential requirement to achieve this.

The slides that were presented at the conference are included in the appendix.



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## The PHARE Concept of Conflict Detection and Resolution and the NLR experience in PHARE Demonstration 3



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### Abstract

This paper highlights the purpose of Air Traffic Management (ATM) in simple terms and then describes the concepts as applied in the Programme for Harmonised ATM Research in EUROCONTROL (PHARE). It details the use of 4-dimensional trajectories and the 'closed-loop system' approach to guidance and its importance for deconfliction. The PHARE methodologies and concepts for conflict detection and conflict resolution, and the problems associated with their combined use are then discussed. The PHARE Advanced Tools involved with conflict detection and resolution are briefly described and the issues raised by their integration into a real-time simulation are detailed. Finally, the NLR experience of running a large real-time PHARE simulation utilising the PHARE Advanced Tools is covered in detail with particular attention to the lessons learnt from using advanced ATM decision support tools for conflict detection and resolution.

### 1 Introduction

Air Traffic Management (ATM) is based around one major issue: keeping aircraft apart. To this 'anti-collision' function an ideal ATM system will add, in the learnt by rote phrase, the "safe, economic, orderly

and expeditious" operation of the aircraft<sup>1</sup>. The aircraft should be safe, although there is no real definition of what 'safe' means, there are only standard separation definitions. The economic operation of the aircraft should mean giving the aircraft operator or pilot the flight-path that has

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<sup>1</sup> Note the addition of "economic" for which we must thank the Eurocontrol " Strategy for ATM2000+

been requested as far as is possible. However, to be 'orderly' the separation should not be achieved with a flight-path made up of repeated short term deconfliction manoeuvres and as far as is possible there should be no delays to the aircraft's flight to its destination<sup>2</sup>.

Of course, to keep aircraft apart it is necessary to know where they are going in sufficient detail to be able to forecast future positions. This means that the aircraft have to indicate where they are going to whoever or whatever it is that has the task of separating them and, if they change where they are going, they should ensure that the change is also indicated. Then it is possible by comparison of the aircraft flight-paths to see if they will miss each other by a sufficient margin to be safe from collision. This flight-path has to extend far enough into the future to meet the requirement for orderliness and avoid panic measures. The accepted names for this flight-path are either the 'trajectory' or its synonym the 'intent' of the aircraft. Both of these are often qualified with the term "4D" meaning a trajectory or an intent that is defined in terms of lateral, 2D; plus altitude, 3D; and longitudinal - or time - 4D. The aircraft are then expected to follow their 4D intents, otherwise the exercise of deconflicting them would be futile.

It is the expectation or trust that the aircraft will follow the agreed 4D intent, and the actions that are taken if it deviates, that

differ between the various methods of ATM.

This paper discusses those aspects of the PHARE concept that influenced the approach to conflict detection and resolution.

## **2 PHARE Concept development**

In current (1999) ATC Systems, the limiting factor in airspace capacity is usually quoted in terms of controller workload. In the context of a sector team of two controllers, aircraft separation is usually assured by the radar controller, with the planner controller co-ordinating sector entry and exit conditions with adjacent sectors. The controller with the highest workload in this workload share is the tactical or radar controller. In the development of the PHARE Operational Concept, the central issue was to reduce the tactical controller workload per aircraft by moving separation tasks to the planner controller thereby increasing the capacity of the sector. When the workload of a controller is analysed, a number of contributing factors quickly become visible. A significant amount of work is spent on the detection of possible conflicting situations and on subsequently resolving them. With the current operations, accurate planning over more than a few minutes is not possible since flight execution is an open-loop process without feedback from trajectory planning and with little feedback from flight path monitoring. Radio and telephone communications are significant

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<sup>2</sup> All concepts and methods of ATM should be exposed to scrutiny under these headings



contributors to controller workload. These two aspects in particular influenced the direction in which the PHARE operational concept developed.

## 2.1 PHARE Concepts

The intention of PHARE was to provide the controllers as far as possible with a 'known trajectory environment'. All aircraft, regardless of avionics equipage and phase of flight, have an active 4D trajectory. The best place for the *generation* of the trajectory is the aircraft Flight Management System. The generation of the trajectory only in three dimensions is of little use for deconfliction. A 4D trajectory provides accurate time information for all points. Datalink allows the reliable *transmission* of complex trajectory data that could not be transmitted by the pilot on radio. It was the integration of the aircraft and ground systems using datalink that was the basic objective of PHARE.

The trajectory generation is based on a set of 'constraints' on the trajectory. These constraints are 4-dimensional windows through which the generated trajectory must pass. On receipt of the initial trajectory from the aircraft, the ground system and controller assess the trajectory for conflicts and pass deconfliction constraints to the aircraft to be added to the constraint list used to generate the original trajectory. The aircraft Flight Management System then regenerates a trajectory to meet the deconfliction constraints and, after approval from the pilot, datalinks it to the ground system. The datalink negotiation process

for the exchange of constraints and the resulting trajectories is managed by the Negotiation Manager tool [1]. Once negotiated, the trajectory is 'active' both in the ground system and in the 4D Flight Management System that will accurately guide the aircraft along the planned trajectory.

If any change of trajectory is required, the new 'active' trajectory will replace the old. This ensures that the ground systems<sup>3</sup> are always working on valid data generated by, and active in, the aircraft Flight Management System. Aircraft not equipped with a Flight Management System or datalink will have trajectories generated on their behalf in the ground system based on a generic aircraft-performance model using specific aircraft type data. The effect is that the 4D trajectories are known for all aircraft being managed.

The aircraft must implement the trajectory that has been transmitted and on which deconfliction will be based. This requires accurate *guidance* by the Flight Management System. To ensure that the aircraft does actually follow the trajectory it is *monitored* by the ground systems and if necessary corrected back to the trajectory or the trajectory is amended to take into account the deviation. This known trajectory environment allows the ground system to identify conflicts between the trajectories reliably and well in advance.

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<sup>3</sup> The ATC Ground System will be referred to as the 'ground system'.

## 2.2 Closed planning loop

The basis of the PHARE concept is closed loop guidance. There are two feedback loops operating in the PHARE concept: the internal aircraft guidance within the Flight Management System and the external flight-path monitoring by the ground systems. These two feedback loops ensure that the generated trajectory is what is flown. There may be guidance errors but these are allowed for by providing a 4D bubble of airspace for the aircraft, and deviations outside the bubble are detected by monitoring [2]. However, as long as the trajectory generated is achievable within the flight envelope of the aircraft, *there are no 'trajectory prediction errors' affecting deconfliction*<sup>4</sup>, as the aircraft will fly the generated 4D trajectory. This is a major conceptual change that was *not* always fully accepted.

The separation of trajectories requires the definition of what separation is required. The intention is to prevent aircraft colliding and to ensure that a safety margin 'standard separation' has been set around the actual position of aircraft. The conceptual issues that arose here were to do with the actual definition of the separation standards and with differing separation standards for adjacent pieces of airspace.

It was possible to use the probability of an aircraft leaving its trajectory and colliding with another as a method of assessing the safety of a trajectory. This could be done by creating probability maps of the aircraft

positions, and likely guidance errors, and overlaying them to assess the collision risk. A parameter probability could then be used to highlight areas where the risk was unacceptable. However, the *legal* requirement is for certain separation standards rather than low risks of collision to be maintained.

Unfortunately, these separation standards are sometimes illogical. Firstly, the standards appear to have been arbitrarily set rather than based on reasoning. Secondly, the standards are different for adjacent airspaces such as Terminal Manoeuvring Areas (TMA) and En-route sectors<sup>5</sup>. This is acceptable for a controller working in one airspace, but for automatic systems it makes assessing the separation between aircraft flying either side of an airspace boundary more difficult. This led in PHARE to some arbitrary decisions being made. If implemented such decisions would need to be legally supported.

Using the PHARE 4D concepts it is possible for aircraft to fly their own user-preferred trajectories as they are being separated from each other in 4D, each within their own 4D bubble of airspace which allows some latitude for smooth guidance<sup>6</sup>[2] [3]. It is important to realise that a user-preferred trajectory does not

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<sup>4</sup> The trajectory may be inefficient but it will be safe.

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<sup>5</sup> It is claimed that these differences are based on better radar cover in the TMA despite TMAs often being served by remoted en-route radars.

<sup>6</sup> Typically in PHARE this bubble was: en-route: +/-100ft vertical +/- 0.5NM and +/-30secs longitudinally. In the TMA these were reduced to +/-5secs and +/-0.25NM. The PHARE trials aircraft were all able to remain within such parameters.



*Figure 1: PD/3 at NLR*

have to be a 'free' or direct route, but could be a trajectory from beacon to beacon along a fixed route. The 4D separation methods would be applied in the same way.

### **2.3 PHARE Sub-projects and Concepts**

The PHARE Medium Term Scenario description was completed in 1990. It described the proposed PHARE concepts at a very high level. It was intended that advanced software tools would be developed over time and that at points in the development their capabilities would be demonstrated in 'PHARE Demonstrations'. The tools that were identified were to be based on tools being developed or planned to be developed by the PHARE Partners. Some of these tools were based on slightly

differing concepts although superficially appearing to be part of a functionally integrated set of services.

The split of concept setting between the Medium Term Scenario, the PHARE Advanced Tools Project and the Demonstrations caused some difficulties in the integration of the various approaches.

Within the structure of PHARE programme, the internal consistency of the tools and the integration of the tool concepts into the demonstration operational concepts remained a problem until the end of the programme. Not only were the PHARE Demonstration projects more or less independently responsible to run a valid demonstration of parts of the operational concept which they had refined

themselves, but also, initially, the development of the PHARE tools was not very much co-ordinated. The latter resulted in tools that were not very well implemented to co-operate with each other. By the time this became visible during the integration of the first and second PHARE Demonstration platforms in 1994, it was probably already too late to fully recover. The fact that there was not a single, stable, integration platform available continued to aggravate the situation up to the last integration of the PHARE tools in the PHARE Demonstration 3 (PD/3) platforms. A detailed description of the operational scenario that was implemented in the NLR PD/3 exercises can be found in [5], which will be published shortly. This Operational Scenario took the PHARE concept at a '2015' level and removed some of the limitations that had been envisaged for PD/3 trials aimed more at controller transition.<sup>7</sup>

### 3 Tools development

Nine advanced ATC support tools were developed within the PHARE Advanced Tools (PATs, [8]) project. These tools were:

Trajectory Predictor	(TP)
Conflict Probe	(CP)
Flight Path Monitor	(FPM)
Problem Solver	(PS)

Negotiation Manager	(NM)
Arrival Manager	(AM)
Departure Manager	(DM)
Co-operative Tools	(CT)
Tactical Load Smoother	(TLS).

To some extent, *all* the tools are involved in conflict detection and deconfliction. The Arrival Manager and Departure Manager are sequencing tools that deconflict runway usage in time. The Tactical Load Smoother identifies areas in which conflicts occur and allows the Multi-Sector Planner to move trajectories to reduce conflicts. The Negotiation Manager provides protocol links between air and ground, and controller to controller, to allow the implementation of deconfliction actions. However, the tools that have a direct relationship with conflict detection and resolution are Conflict Probe, Problem Solver and Co-operative Tools.

The Conflict Probe probes all active trajectories and client nominated 'what-if' trajectories to detect separation infringements between trajectories and between a trajectory and volumes of airspace (e.g. a Temporary Reserved Airspace, or even SIGMETs). Separation infringement can either be detected on a geometric basis or by using a probabilistic approach. Some filtering of the output needs to be carried out by the client tools. For example, where aircraft are on final approach to parallel runways they can be within the separation criteria for the Conflict Probe but legally separated. The National Aerospace Laboratory NLR of the Netherlands developed both types for the PHARE Conflict Probe.

<sup>7</sup> Despite this 'advanced' approach a traffic sample was run which initially had all aircraft flying fixed route without datalink then over the course of the 90 minutes transitioned to 70% datalink and all off route. This showed that an advanced system is suitable for transition.

The initial intent was that the Problem Solver would provide deconfliction *solutions* to the problems detected by the Conflict Probe. However, after preliminary prototyping with controllers, it was instead developed as a tool that provides an interactive capability to modify an aircraft's planned trajectory by dragging it on screen until the Problem Solver shows that conflicts have been resolved. The graphical interface allows the controller to manipulate constraints points that are applied to the trajectory.

These constraints can be just lateral, or in combination with altitude and/or time constraints. One of the issues raised by this graphical approach was the mismatch with the basic concept of applying constraints to the trajectory. Controllers initially tried to 'edit the trajectory' and expected the system to 'join up the dots'. However the Trajectory Predictor generates trajectories that meet the constraints but these do not necessarily match the trajectories designed on the Problem Solver display. To allow for this the trajectory generation has two steps, the first being to 'validate' the Problem Solver solution with the Trajectory Predictor and only then a second step of Registration instigating negotiation with the aircraft.

The use of the Problem Solver's interactive graphical interface for deconfliction was a huge step forward in decision support for controllers who immediately grasped its

capabilities<sup>8</sup>. The subsequent graphical display of the Flight Management System generated trajectory to the pilot, based on the constraints generated by the Problem Solver, allowed the controller and pilot to communicate using pictures. Thus, the Problem Solver not only increased controller capabilities, but also led to a far more efficient use of datalink and better, less error prone information exchange between ground and air.

The EUROCONTROL Experimental Centre (EEC) developed the Problem Solver tool.

The 'Co-operative Tools' comprise a set of tools developed to support the cognitive processes of air traffic controllers. First, they include a filtering function that selects groups of aircraft that are involved in or related to a possible separation infringement. These groups, which are called PROblem SITuations (PROSIT), are selected using functions that aim to reflect the conflict detection reasoning of the human operator.

In simple terms this involves using geometric parameters larger than those used for conflict detection to identify aircraft sufficiently close to a conflict to 'interfere' with any resolution action. The aircraft in conflict and the set of those interfering in its solution are then added to a PROSIT which is then graded in severity.

The various PROSITs are presented to the controller using another function called the

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<sup>8</sup> Indeed the HIPS has almost become the standard 'display tool' of PHARE

Agenda. This function generates a graphical presentation of the types of the PROSITs and the moment in time at which they should be addressed at the latest. It also allows the planning controller to add conflict resolution information that can be picked up by the tactical controller to actually resolve the problem.

A final function that is included in the Co-operative Tools is the look-ahead tool. It allows a controller to drag an aircraft involved in a PROSIT along its trajectory and shifts the Radar Plan View Display forward in time at the same rate, allowing the controller to assess a predicted future situation.

The Co-operative Tools were based largely around more current controller methods and unlike the other tools expected a degree of trajectory error widening the scope of the search for interfering aircraft with time. Within the PATs project the Co-operative Tools have been developed by the Centre d'Etudes de la Navigation Aérienne (CENA) of France.

## **4 Tools Integration**

In this section, the integration of the tools will be discussed from the NLR PD/3 point of view. The other PD/3 partners will have had partly similar, but sometimes also very different experiences.

Integration of the PHARE advanced tools in the NLR ATC Research Simulator (NARSIM) began as early as 1995 in preparation for the Internal Operational Clarification Project (IOCP), to run in

1997. This first integration was planned to develop into the final system configuration by integrating updates or first versions of tools as they became available.

The focus of the NLR PD/3 experiments was the integration between arrival management and en-route traffic handling; it was not planned to integrate all the PHARE tools. There was no need to integrate the Tactical Load Smoother and Departure Manager tools without a multi-sector planning position or specific departure planning controller.

### Trajectory Predictor integration

The tool that was first integrated was the Trajectory Predictor, the heart of the system. It was derived from the trajectory prediction function of the PHARE Experimental Flight Management System (EFMS). With the EFMS designed for actual operation in research aircraft, it was implemented in ADA and it used some very complex data structures. The performance was designed for use onboard the aircraft, where trajectory predictions are made infrequently and a delay of a few seconds is acceptable. The predicted trajectories contained a lot of detail required for the accurate guidance of the real aircraft.

The ground Trajectory Predictor inherited many of these characteristics as it used the same trajectory prediction kernel. This was based on the reasoning that there should be no large mismatch between the ground 'what-if' modelling and the aircraft generated trajectories. However, instead of detail for aircraft guidance the ground

system required fast performance capable of generating trajectories for many flights in a short time (e.g. to support arrival rescheduling). Although there were some problems in PD/2, the impact of these requirements mismatches only became fully apparent with the integration of the large-scale PD/3 platforms. Therefore, NLR and NATS, who had developed the Trajectory Predictor, expended significant effort integrating the PATS Trajectory Predictor and optimising its performance. This led to reductions in the trajectory prediction time and in the system resources required (mainly memory and CPU-time) by up to a factor of five. Additionally, due to the way the Trajectory Predictor was implemented in the NARSIM platform, it became possible to run up to ten instances of the Trajectory Predictor across the network to provide the various controllers with predicted 'what-if' trajectories.

#### Conflict Probe integration

Although the Conflict Probe was developed by NLR, the simulation platform was developed by a different team. However, close co-operation was achieved easily and the integration of the Conflict Probe caused few problems. Nevertheless, as with the Trajectory Predictor, performance became a problem in the full scale PD/3 platform. With a large number of concurrently active flight plans in the system, 14 air traffic controllers and some other PATS tools requiring conflict information, the Conflict Probe could become a bottleneck in the system. Again, this was solved by using

several instances of the Conflict Probe to serve particular clients.

#### Problem Solver integration

Due to its interactive nature, the Problem Solver needed to be closely integrated with the Ground Human Machine Interface (GHMI). To achieve this in PHARE Demonstration 1 (PD/1), every instance of the GHMI had its own integrated Highly Interactive Problem Solver (the combination of Problem Solver and its GHMI elements).

For PHARE Demonstration 3 (PD/3), a design problem arose with the integration of all PHARE tools and a suitable advanced GHMI. In particular the display and management of conflict information coming from several tools (Conflict Probe, Problem Solver and Co-operative Tools) resulted in complex discussions between the teams involved. This highlighted that the design and development process from concept to implementation was far from optimal (see also [5]). The team that designed the PD/3 GHMI eventually produced a specification for the "Trajectory Editor and Problem Solver" (TEPS), a GHMI function that would use data from all conflict detection tools. [6]

During the tools integration it was assessed that the integration of the Co-operative Tools within the NARSIM platform would be too difficult and time consuming (see next section). Although this made it difficult to maintain the TEPS as specified, it was decided to implement it mimicking the Co-operative Tools functions. However,

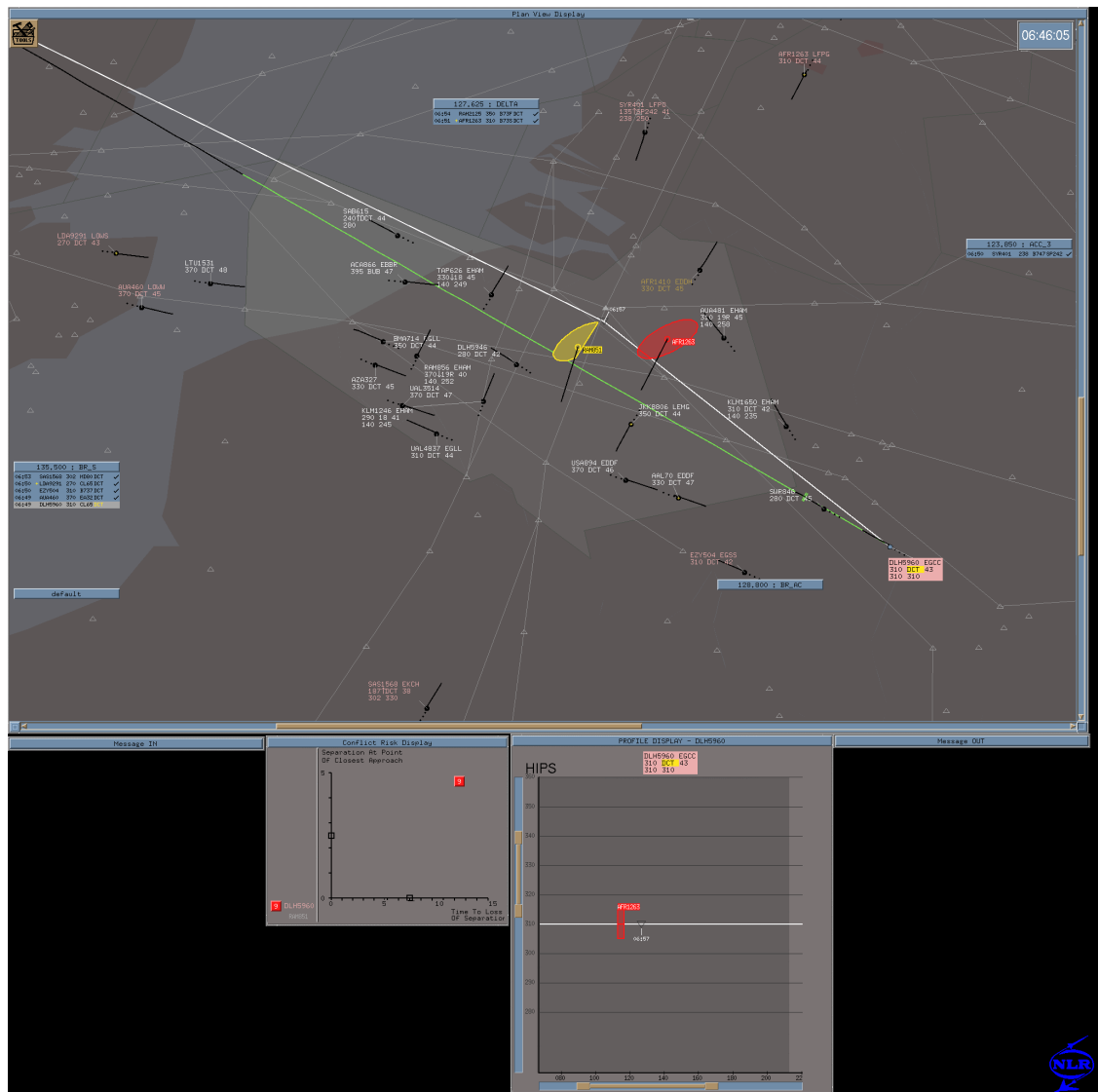


Figure 2: Typical planner controller GHMI

the first PD/3 GHMI software development failed in 1998. This left NLR with no option other than to fall back on the PD/1 GHMI software that had already been integrated with the PD/3 platform and to extend it for PD/3 functionality. Thus, eventually the GHMI still had an integrated HIPS, but, unlike PD/1 the GHMI elements were further integrated in the synthetic radar display.

The TEPS specification led to a major alteration from the PD/1 HIPS, in that the HIPS 'Horizontal Aid Window' (a kind of separate PVD for problem solving) was integrated with the main PVD, reducing window clutter. However, this integration meant that the PVD needed to be operated in two modes: PVD or Problem Solver.<sup>9</sup>

<sup>9</sup> This was necessary since the HAW requires GHMI functionality that conflicts with the RPVD itself (see operational experience).



The main problem that arose with the integration and use of the Problem Solver was the consistency of conflict detection with the Conflict Probe. Initial lack of consistency was due not only to the different method of conflict detection in the Problem Solver, but also to the different behaviour of the Problem Solver trajectory prediction function compared to the Trajectory Predictor tool. Given a certain set of constraints, the Trajectory Predictor and the Problem Solver could generate significantly different trajectories, especially in the vertical plane.

With support from the EUROCONTROL Experimental Centre, where the Problem Solver had been developed, the Problem Solver internal prediction was amended to follow the Trajectory Predictor rule base, making the trajectories predicted by each tool almost identical. The differing conflict detection algorithms that could also cause mismatches were more easily fixed (although not completely cured) by parameter changes. These changes resulted in greater consistency of conflict prediction between the Conflict Probe and the Problem Solver.

#### Co-operative Tools integration

It was decided not to integrate the Co-operative Tools into NARSIM. The GHMI design problems had already led to the identification of some subtle differences in philosophy between the Co-operative Tools and the rest of the PHARE tools. These were the Co-operative Tools' routine expectation of errors in guidance for

aircraft following their trajectories, and the implicit sharing of workload across the temporal split between Planner Controller and Tactical Controller. This operational difference, together with the very tight integration of the Co-operative Tools with the Common Modular Simulator (CMS) platform made integration in the NARSIM environment a significant risk. This was a pity, since the conflict management functionality represented by the Agenda would probably have been very useful.

#### Overall integration issues

From the integration experience of PD/3 it can be concluded that in a multiple-partner project a stable integration platform, which acts as a reference, is essential. Nevertheless, it can also be concluded that any integration of a tools set in an ATC simulation platform requires separate and iterative tuning and adjustment.

The fact that many of the elements of the final NLR PD/3 platform had been programmed in different languages meant that the middle-ware had to be able to cope with all of these. In addition, wider expertise was required from the system integration team in the field of programming languages. This ranged from Fortran, through C and C++ up to Ada.

Probably the most important experience from the system integration is that it must result in a simulation platform that actually works. During the concept and system specification phase, it is quite common that not everything is specified. It is almost impossible to see all the consequences

related to the introduction of a new operational concept. The people involved in this are usually very capable of continuing their work while certain details are missing. When it comes to building a working system this changes. The system forces one to think of every detail. Unfortunately, by the time the system is ready for a 'full system test', the functionality has become so complex that it is nearly impossible to design all the test cases that could be used to verify the system. This is especially true for novel and experimental systems such as those in PHARE. The best option is then to try using the system according to the operational concept. This not only allows the identification of missing or incorrect functionality, but it may also lead to new insights in the operational concept.

## 5 System Operation

In the final NLR PD/3 Demonstration in November 1998, fourteen air traffic controllers operated the system simultaneously, simulating five lower airspace sectors and three upper sectors. The whole simulation area was centred on the Amsterdam Schiphol TMA and its surrounding sectors.

The controllers, of whom only a few had previous experience with the PHARE concept, were trained for seven days. The training used a combination of classroom instruction, Computer Based Training (CBT) and hands-on training.

Of course, the amount of training was not enough to give the controllers a thorough

understanding of the concept and the operation of the system. Nevertheless, it allowed them to understand the ideas behind the system and to control a significant amount of simulated traffic. It also gave them time to learn to trust the conflict detection capability of the system. They only started to appreciate this capability when the system detected all the conflicts that they had found themselves. During the learning phase, the benefit of the system is low as the controllers do not yet trust it and continue to work in parallel with it.

### Conflict detection

If the ATC system is to reduce the controller workload with respect to conflict detection, the system must detect *all* conflicts. If the controller is aware that not all conflicts will be detected by the system, he will not trust or use the system and instead will perform his own conflict detection. Conversely, once the controller *can* trust the system to detect the conflicts, he will use it as a trigger to take appropriate action. In the NLR PD/3 demonstration, the planning controllers (D-Side) were therefore instructed only to re-plan traffic when the system indicated a trajectory conflict. This reduced the planner controller task and allowed more workload to be transferred from conflict detection towards conflict resolution.

***In NLR's final PD/3 system, the geometric Conflict Probe tool was used to detect all conflicts. With every update of an active trajectory, it would check for***

**conflicts against all the other active trajectories. When a conflict was found, an event would be generated that resulted in the presentation of a conflict indication on the appropriate controllers' GHMI. There was a general impression that probably all conflicts were detected.**

However, since the conflict detection and deconfliction has been carried out on the active trajectory in the ground system it is essential that the controller is alerted to any deviations by the aircraft from that trajectory. The role of the Flight Path Monitor tool to signal deviations from the active trajectory, is therefore very important. Any deviation should lead either to a re-planning action that takes into account amending the trajectory to the actual flight position or to a tactical controller action to recover the aircraft to the agreed conflict free trajectory. It depends on the situation and the co-operation between the planning and tactical controller which action is applied.

One special function of the Conflict Probe in the NLR PD/3 system is to support the Negotiation manager tool in identifying whether co-ordination between sectors is required. It had been decided that in the PD/3 user preferred routing environment the only reason to co-ordinate changes in a trajectory would be if a controller's action created a conflict in the next or previous sector. Therefore, every re-planned trajectory is assessed by the Conflict Probe for conflicts in adjacent sectors. If there is a conflict the Negotiation Manager indicates the need to co-ordinate the new plan with

the relevant sector. The Negotiation Manager follows the same procedure with trajectories down-linked from the aircraft. If they do not result in any conflict then there is no strict need for the controller to modify them and they are accepted. Thus predicted trajectories can only be activated if they do not create any conflicts in the near future.

### Conflict Management

With the conflicts driving the activities of the planning controller, it would have been useful to provide a conflict management function. All that was offered in the NLR PD/3 system was a Conflict Risk Display (CRD). Although this allows controllers to discern between urgent and less urgent conflicts, more advanced conflict management functionality might have improved the time management of the planning controller.

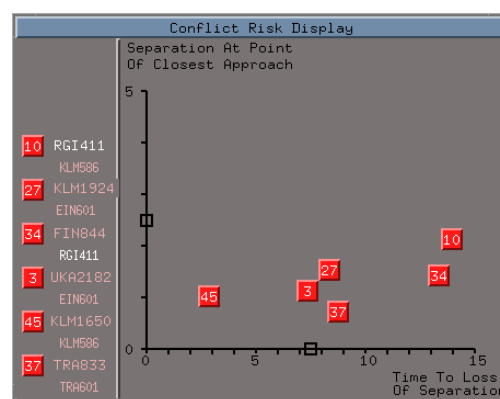


Figure 3: CRD indicating six potential conflicts

One aspect that certainly needs further research is the co-operation between planner and tactical controller within the sector to resolve conflicts. A range of

options is possible. In the current operational situation, it is normally the tactical controller that solves nearly all the conflicts 'just-in-time' using radar; whereas, with the PD/3 system the planner controller could resolve all conflicts strategically. It has been postulated that in order to transition between these extremes, some of the conflicts would be resolved strategically, while others would be left for resolution or implementation of the resolution by the tactical controller. The experience gained by CENA in their PD/3 trials has shown that such a transitional case is by no means straightforward.

#### Conflict resolution

Once a conflict was indicated by the system, the planning controller could assess the conflict configuration by several means (for example: Conflict Zone Window, Advanced Dynamic Flight Leg, Highly Interactive Problem Solver). In principle, the controller would be required to select one of the conflicting flights to resolve the conflict (although the system will allow him to subsequently modify more than one flight-plan). The selected flight would be 'loaded' into the HIPS, which would then display the conflict area or areas and possibly 'no-go' zones (Figure 4). The latter are areas where, if the trajectory were modified to go through them, a conflict would occur. The controller can now 'drag-and-drop' constraints related to the trajectory in such a way that the conflict is

resolved. He will get immediate and continual feedback from the system through changes in the conflict no-go zones.

This advanced method of conflict resolution has a number of specific features that should be highlighted:

- The graphical representation of the trajectories and the conflict zones allows the potential conflict situation to be identified easily. The dynamic feedback gives immediate insight into the consequences of a certain solution and even helps to identify directly whether new conflicts will be created. The displayed information even allows the controller to apply minimal resolutions, which results in higher flight efficiency and less disturbance to the future flight plan.
- Graphical editing also allows controllers to design solutions which would otherwise not have been selected. These may be valid solutions, but sometimes go against the controller's 'instinct'.
- With the very accurate trajectory representation, a problem of perception arises. Controllers can easily begin to think that an exact route and profile for the flight can be 'designed'. They often forgot that they were editing 'constraints' and that the trajectory generation function of the ground system, or the aircraft Flight Management System, determines the final trajectory. If maximum freedom is to be given to the aircraft to optimise its trajectory, then controllers should make very careful use of the constraint editing capabilities.

- The interactive conflict resolution function critically depends on the capability to accurately predict the effect on changing constraints on the trajectory prediction. This has to be done in real time. In addition, the conflict information has to be updated with the same refresh rate. This places high demands on both functions. The current PATS Trajectory Predictor and Conflict Probe are not designed to do this. On the other hand, the Problem Solver cannot do it with the same accuracy as the Trajectory Predictor and Conflict Probe. The result is a 'quick and dirty' conflict resolution that needs to be verified by the Trajectory Predictor and Conflict Probe. For the controller this leads to an unnatural situation of first using the system to design

a solution, and then instructing the system to verify itself.

#### Short Term Conflict Alert consistency

It is a safety requirement that there is no direct link between the conflict detection function, which works on medium-term trajectory predictions, and the Short Term Conflict Alert (STCA), which uses tracking data to identify more immediate conflicts.

Nevertheless, consistency between both functions must be achieved as display of an STCA when the Conflict Probe does not indicate a conflict can destroy the controllers' trust. The experience from PD/3 at NLR showed that considerable effort is required to achieve uniformity between the STCA and Conflict Probe.

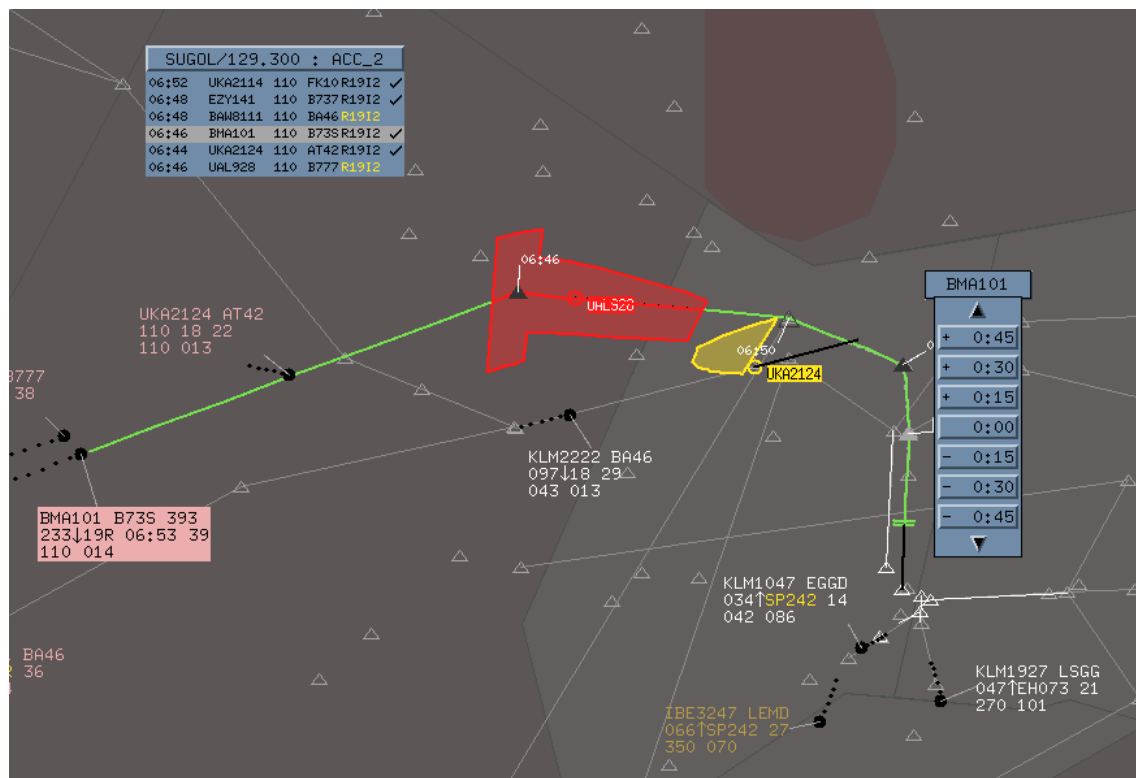


Figure 4: The HIPS showing conflict and no-go zones (Note the change in separation criteria shown by the no-go zone as the trajectory enters the TMA)

## 6 Conclusions and recommendations

PHARE and PD/3 have provided many insights into conflict detection and resolution and much has been learnt. Although many issues remain to be resolved, the following conclusions can be drawn:

- System supported conflict detection requires equivalent trajectory generation for all flights. The least accurate trajectory generation determines the effectiveness of medium-term conflict detection. A mismatch between trajectory generation and flight execution (i.e. a guidance failure) renders medium-term conflict detection useless.
- Conflict detection is only a part of the puzzle. Trajectory generation is probably even more important. If the generated trajectory is *not* used for the guidance and control of the flight, then it becomes merely a predicted trajectory and the system is 'open loop'. The resulting inaccuracy will make medium-term conflict detection support less useful.
- Controller trust must be obtained if the introduction of conflict detection tools is meant to reduce workload. Otherwise tools are ignored or double-checked continuously.
- Performance (response times) of trajectory prediction and of conflict detection are important issues for the usability of interactive conflict detection and resolution tools.

The following recommendations are made:

- When a novel system is developed, a 'rapid application development' approach should be taken with a *fully functional* prototype being used as soon as possible. This allows the functionality to be better assessed and can lead to an improved understanding of the operational concept or concepts.
- Research should be continued on the benefits of medium-term conflict detection and resolution. In particular the interactive conflict resolution capability requires further study.

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- [2] "PHARE: Definition and Use of Tubes", I. Wilson, EUROCONTROL DOC 96-70-18, July 1996
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- [4] "PHARE Medium Term Scenario 2000 to 2015", Issue 1 (Draft), EUROCONTROL, July 1990
- [5] "NLR PHARE Demonstration 3 Final Report", W. Post, DOC 99-70-01 (Volume 4 of 4), December 1999.
- [6] "PD/3 Ground Human Machine Interface Specification" Version 2.2, CENA/EEC/NLR, DOC 98-70-07, January 1998
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## Acronyms and Definitions

4D	4 Dimensional
ADFL	Augmented Dynamic Flight Leg
AM	Arrival Manager
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
CBT	Computer Based Training
CENA	Centre d'Etudes de la Navigation Aérienne
CMS	Common Modular Simulator
CP	Conflict Probe
CRD	Conflict Risk Display
CZW	Conflict Zoom Window
CT	Co-operative Tools
DM	Departure Manager
EEC	EUROCONTROL Experimental Centre
EFMS	Experimental Flight Management System
FAA	Federal Aviation Administration
FMS	Flight Management System
FPM	Flight Path Monitor
GHMI	Ground Human Machine Interface
HAW	Horizontal Assistance Window
HIPS	Highly Interactive Problem Solver
IOCP	Internal Operational Clarification Project
MSP	Multi Sector Planner
NARSIM	NLR Air Traffic Control Research Simulator
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NM	Negotiation Manager
PATS	PHARE Advanced Tools
PD	PHARE Demonstration
PD/1	PHARE Demonstration 1

PD/3	PHARE Demonstration 3
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
PROSIT	PROblem SITuation
PS	Problem Solver
R/T	Radio Telephony
RPVD	Radar Plan View Display
STCA	Short Term Conflict Alert
TLS	Tactical Load Smoother
TMA	Terminal Manoeuvring Area
TP	Trajectory Predictor

### Planner Controller (D-Side):

The controller that is responsible to **plan** flights safely and expeditiously through a sector. He normally performs planing before the aircraft actually enters the sector.

### Tactical Controller (R-Side):

The controller that is responsible for the safe and expeditious flights through a sector. He controls the aircraft that are in the sector and maintains R/T contact.

## Biography

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

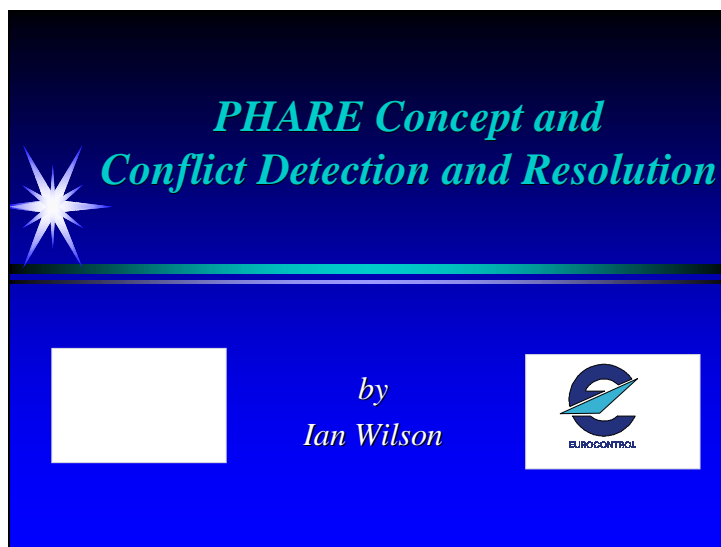
Mr Ian Wilson joined the UK Royal Air Force in 1968 graduating as a pilot from RAF College Cranwell in 1970. Subsequently he worked as an Air Traffic Controller at military airfields in UK and Germany and then as an area controller with UK NATS at Scottish and Oceanic Air Traffic Control Centre. In 1981 he became an analyst/programmer team leader in the Flight Data Processing support group for NAS Host at London Centre; then in 1984 the Project Leader on the Tandem based Flight Data and Support Information Systems. In 1986, he moved to UK CAA HQ as Project Officer and System Acceptance Manager on the Electronic Strip systems for London Centre ENE Operations Room. From 1989 until 1994 Ian Wilson was the Network Systems and Installation Manager for a distributed low flying notification and flight-information workstation system. In 1994 he joined EUROCONTROL as a member of the PHARE Cell and became Project Leader for the PHARE Advanced Tools project. Currently, he is working on ATM Research on 4D decision support tools within EUROCONTROL Air Traffic and Data Processing domain and as Project Leader of the INTEGRA project within the Co-operative Actions for R&D in EUROCONTROL (CARE).



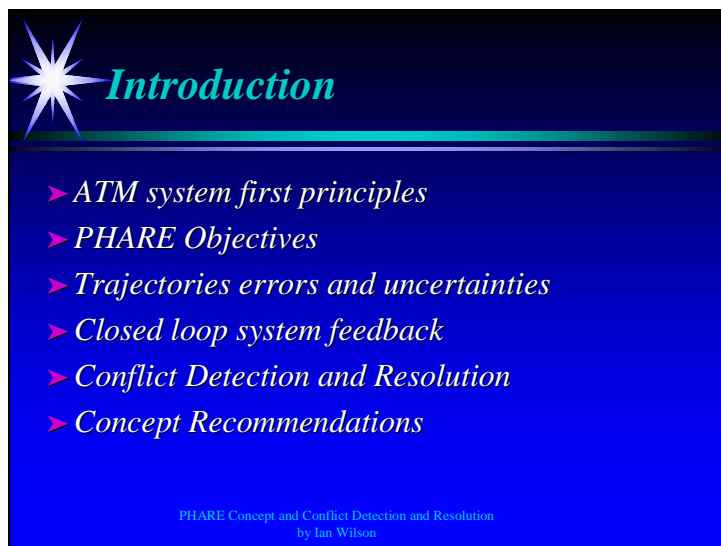
## Appendix A Slides presented at the conference

Part I: Presented by I. Wilson.


Slide 1



Slide 2



Slide 3




## *ATM Functions*

- *Safe, economic, orderly and expeditious flow of air traffic*
- *'Safe' not fully defined apart from 'tombstone count'*
- *Orderly means a flight should not be a series of short term deconflictions*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 4




## *PHARE Objective:*

“....to organise, co-ordinate and conduct on a collaborative basis, experiments and trials aiming at proving and demonstrating the **feasibility and merits** of a future **air ground integrated air traffic management system** in all phases of flight.”

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 5




## *Advantages of Datalink*

- *Replaces error prone R/T*
- *Allows*
  - *transmission of complex data*
  - *transmission of trajectories*
  - *transmission of deconfliction constraints*
- *Enables control by pictures*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 6




## *ATM Problem lack of Capacity*

- *Capacity traditionally equated to Controller workload*
- *Tactical Controller workload limiting factor*
- *Therefore, move tasks to Planner Controller and increase capacity, or.....*
- *“Re-empower the planner controller”*
- *Use datalink to ‘negotiate’ conflict free trajectories prior to sector entry*
- *Planning and deconfliction with a long look-ahead*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 7




## *What is a Trajectory ?*

- *4D* - "The precise description of the flight path of an aircraft as a 4 dimensional continuum from take-off point on the departure runway to touchdown on the arrival runway."  
(Note: Ground track, Ground Speed, Ground Radius turns)
- *3D* - Same as the 4D but no time
- *3½D* - Same as the 3D but with reporting point times - multiple Requested Time of Arrival
- Need the time at all points on the trajectory for accurate deconfliction

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 8




## *What is modelled ?*

- *Model of the gate-to-gate trajectory of every aircraft in the system*
- *Use the model:*
  - *to identify the conflicts*
  - *for what-if amendments of solutions to deconfliction*
  - *as a basis for tracking the real world*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

## Slide 9




## *Trajectory 'Prediction'*

- *Trajectory 'prediction' is or should be a misnomer*
- *If an aircraft is cleared to fly a certain trajectory even in today's system they will fly it within the bounds of the accuracy of the clearance.*
- *Cannot be called a 'prediction' unless there is no tracking and no feedback loop*
- *Trajectory predictors that have 'error tubes' or 'areas of uncertainty' inevitably lead to similar error tubes and uncertainties in conflict detection / resolution*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

## Slide 10




## *Open vs Closed Loop Systems*

- **Open Loop** - *no attempt to correct deviations in flight track but periodically correct the ground ATM model*
- **Closed Loop** - *aircraft are corrected to the agreed '4D intent' or 'contracted trajectory' - either using internal guidance and/or by flight path monitoring and ground command or the aircraft intent is renegotiated*
- *If deconfliction action has been taken which of these approaches is the safest ?*
- *If the trajectory is **not** for deconfliction what is it for ?*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 11




## *Trajectories 'How Accurate'*

- *More important on ground to have speed of generation for what-if modelling (spurious trajectory accuracy led to performance problems in PHARE)*
- *In the air accurate as needed for FMS and pass trajectory to ground where it replaces ground generated trajectory that was used for deconfliction*
- *Guidance is far more important for safety than accuracy of trajectory generation*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 12




## *Trajectory 'Prediction' Errors*

- *Prediction errors ?*
  - *if trajectory is flyable there is no such thing in a **closed loop** system*
- *Generation errors -*
  - Loss of efficiency but are safe if generated in the air then it is an airline business case to be efficient*
- *Guidance errors -*
  - Mean Loss of implementation accuracy and reduce safety*
- *Close the system feedback loop to ensure safety*
- *PHARE had guidance feedback in Flight Management System and monitoring by ground Flight Path Monitor*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 13



## *Safety means Model Must Match Reality*

- *What to do if it doesn't ?*
- *Change model*
- *Change real world*
- *Must end up matching*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 14




## *Safety - Do what has been agreed*

- *Contracted trajectory = Agreed 4D intent*
- *Responsibilities:*
  - *Ground - keep trajectory conflict free*
  - *Air - fly the trajectory until agreement is modified*
  - *Ground and Air - Monitor the flight to ensure trajectory is maintained - if not, correct model or trajectory*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 15




## *Safety - Look where you are going*

- *Trajectories mean no open ended instructions (e.g. headings)*
- *Entails always considering the longer term effect of trajectory changes*
- *Gate-to-gate continuum must not pass through the ground - likely to reduce CFIT*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 17




## *Procedures to use Trajectories*

- *Current procedures are based on 'old innovations' - trajectories modelled by use of ground navigation aids and estimates - Radar control with Procedural fall back*
- *PHARE trajectories accurate in 4D long look-ahead ahead - trajectories management with radar fall back*
- *User preferred trajectories are stable and simple - easy to plan ahead*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson



Slide 18




## *What is a conflict ?*

- *Separation less than laid down criteria*
  - *These have no logical support*
  - *If a safety zone to allow avoidance then by making it a 'hard' standard another safety zone is generated around it wasting capacity*
- *Alternative is 'unacceptable risk of collision'*
  - *Probability that aircraft will collide*
  - *Either on trajectory on likely guidance failures*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 19




## *Conflict Probe*

### *Conflict Detection 1*

- *Geometric Conflict detection based on standard separation criteria.*
- *Rule base allowing different separations at different altitudes/levels*
- *Required client tool to filter spurious conflicts (e.g. aircraft approaching parallel runways)*
- *Also reported conflicts with 'airspace' volumes (e.g. SIGMET, Holds, potentially CFIT detection)*
- *Stop searching after <time> parameter from client to reduce reports*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 20



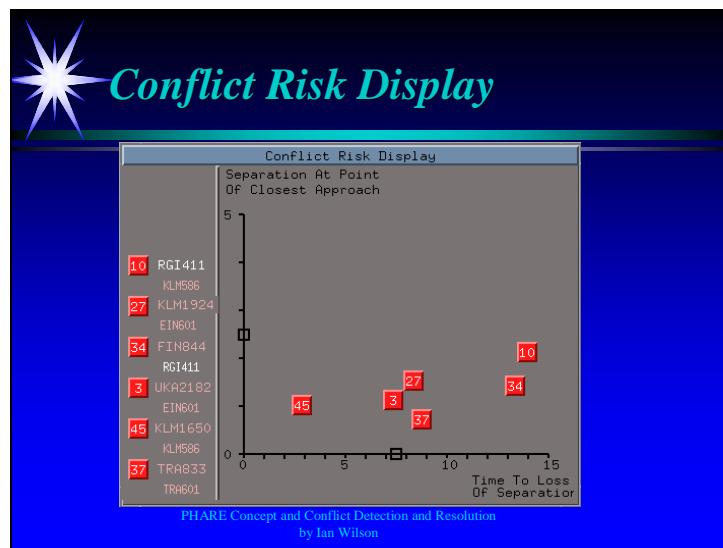
## Conflict Probe

### Conflict Detection 2

- Probabilistic conflict detection based on trajectories
- Map skewed probability of guidance failures (e.g. more likely to level bust than to stop climb or descent early)
- Overlay / combine probability volume maps
- Use collision risk parameter to indicate acceptability or presence of conflict

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 21



Slide 22

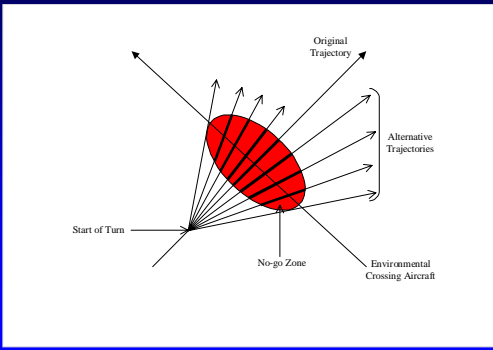
## Co-operative Tools Conflict Detection

- Geometric conflict probe but including rule base of 'controller logic' and 'continually widening cone of uncertainty'
- Search area adjusted where known errors occur (e.g. in the climb)
- Detects aircraft close enough to be a 'problem to watch'
- Larger search area including 'interfering aircraft set'
- Allowed interactive drag forward of aircraft to examine conflict
- Expected sharing of conflict resolution across the temporal boundary

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 24

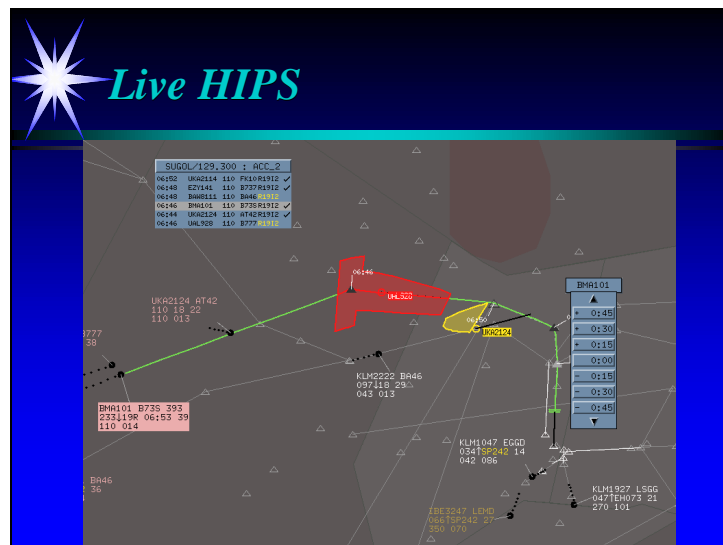
## HIPS Conflict Detection



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by Ian Wilson



Slide 25




Slide 26

**Deconfliction**

- *Used the HIPS as a what if modelling device*
- *Drag constraints on the trajectory either existing or new constraints*
- *Led to discussions on allowing out of sector changes by planner controllers*

PHARE Concept and Conflict Detection and Resolution  
by Ian Wilson

Slide 27



## *Amending Trajectories*

- *Conflicting Objectives - freedom vs control*
  - *retain the Aircraft freedom to produce a UPT*
  - *allow realistic what if modelling of the likely aircraft performance*
- *This was a problem in HIPS vs Trajectory Predictor*
- *Solution was a 2 stage process*
  - *fast less accurate HIPS model for what-if*
  - *Validated by ground Trajectory Predictor emulating the aircraft Flight Management System*
  - *Lack of 'control' seen as a problem by some 'controllers'*

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by Ian Wilson

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## *Concept mismatches*

- *Trajectory 'prediction error' used by Co-operative Tools although twin feedback loops assured there was no error*
- *Problem Solver seen as 'trajectory editing' but was in fact 'constraint editing' initial mismatch with Trajectory Predictor rule base.*
- *Underlying confusion of 'trajectory prediction error' with uncertainty of trajectory implementation*
- *Temporal confusion - planner is working in the future and cannot 'share' workload simply with the tactical*

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by Ian Wilson

Slide 29




### *Merits of PHARE Concept*

- *Each aircraft flies inside a bubble of allocated airspace that is following a conflict free trajectory*
- *This provides the capability to control aircraft in 4D inside or outside the normal 3D route structures*
- *The aircraft generates a trajectory that best meets the ground constraints that ideally are only provided for deconfliction*
- *This allows 'user preferred trajectories' to be flown but with Ground Separation Assurance*


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### *Concept recommendations*

- *Define and Agree on the concept*
- *Ensure that everyone understands what is meant - avoid the homonym / synonym trap*
- *Ensure that the concept is operationally acceptable*
- *Define tools that meet the concept without unnecessary overlap*
- *Ensure that performance requirements are feasible*



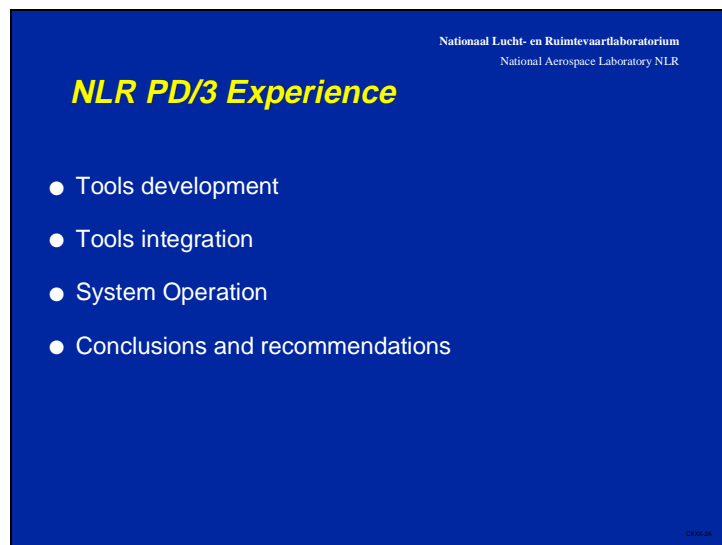
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Part II: presentation presented by W. Post

Slide 1



Slide 2



Slide 3

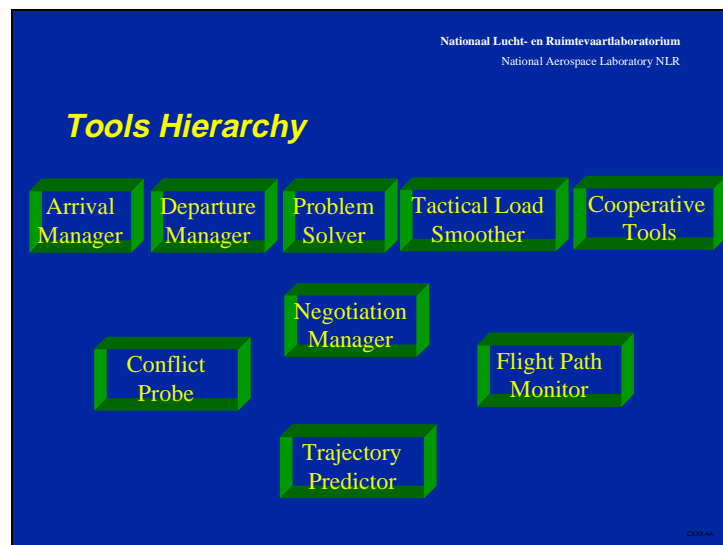
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### *NLR PD/3 Experience*

- Tools development
- Tools integration
- System Operation
- Conclusions and recommendations

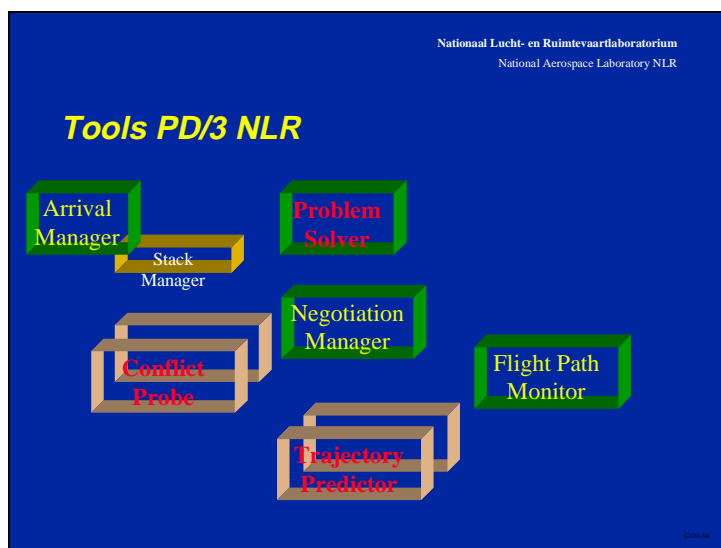
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Slide 4





Slide 5



Slide 6

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### *CD&R Related Tools: CP*

- ✧ Medium Term Conflict Detection between:
  - ✧ All active trajectories
  - ✧ One alternate trajectory and all active trajectories
  - ✧ One alternate trajectory and all restricted airspace volumes
- ✧ Uses planned trajectory data
- ✧ Geometric or Probabilistic

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***CD&R Related Tools: CT***

- \* Filtering of sets of aircraft involved in a PROblem SITUation (PROSIT)
- \* Cognitive Rules
- \* Agenda for PROSIT management
- \* Sharing of sector information between sector controllers
- \* Dragged 'look ahead' or conflict preview

CD&R-04

Slide 8

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***CD&R Related Tools: PS***

- \* Drag and Drop constraints on an alternate trajectory
- \* Immediate visual feedback on conflict resolution
- \* Works vertically, horizontally and longitudinally
- \* Simple fast trajectory prediction

CD&R-04

Slide 9

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### *Development Issues*

- ✦ Agree on standard interfaces between tools
- ✦ Make sure all tools follow the same operational concept
- ✦ This is also true for the rest of the platform
- ✦ Ensure all demonstrations/simulations follow the operational concept of the tools and the platform

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### *NLR PD/3 Experience*

- Tools development
- **Tools integration**
- System Operation
- Conclusions and recommendations

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### *Tools Integration*

- ✦ NLR Perspective !!
- ✦ Not all tools were integrated
- ✦ Integration started in late 1995 for the first trials in mid-1996
- ✦ Several versions of the tools were delivered up to early 1998 for trial in May 1998
- ✦ But with no development platform, the tools had not been run together prior to delivery

0200011A

Slide 12

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### *Tools integration: TP*

- ✦ Core of the platform
- ✦ Tool is based on the prediction kernel of the PHARE Experimental FMS
- ✦ Mismatch in accuracy and performance requirements with ATC System requirements
- ✦ Possibly unnecessarily complex data structures causing significant integration effort
- ✦ Final system used up to 10 instances of TP

0200012A

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***Tools integration: CP***

- ✦ Was developed on the NARSIM NLR platform so little integration effort
- ✦ With 300 - 400 active trajectories and many system plan updates and what-if modelling, performance became a problem
- ✦ Final system used up to 7 instances of CP

CDR-13A

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***Tools integration: PS and CT***

- ✦ Interactive nature requires close integration with GHMI
- ✦ Intention to integrate PS, CP and CT through GHMI 'Trajectory Editor and Problem Solver' (TEPS)
- ✦ For NLR the integration of CT was seen as too much of a risk and so was not integrated
- ✦ GHMI problems forced fall back to HIPS developed for PD/1
- ✦ HIPS was further integrated into the radar PVD

CDR-14A

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### ***Tools integration: General***

- ✦ Every platform requires full integration cycle, yet pre-integration of tools on reference platform is very useful
- ✦ Use of several computer languages is possible but requires more data conversions reducing performance
- ✦ The full extent of the operational concept can only be understood once tools and GHMI have been integrated in the platform
- ✦ Testing is best performed by using the system in accordance with its operational concept

CSW-ISA

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### ***NLR PD/3 Experience***

- Tools development
- Tools integration
- **System Operation**
- Conclusions and recommendations

CSW-ISA

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### ***System Operation Experience***

- ✦ 2 weeks demonstration with 14 ATCOs using full system for the first time
- ✦ 7 days of training - CBT, Class Room, Hands-on
- ✦ It takes time to build up trust in the system capabilities and to understand how it will help manage the traffic

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### ***System operation Experience: Conflict Detection***

- ✦ To gain ATCO trust and to reduce ATCO workload **all** trajectory conflicts need to be detected.
- ✦ The conflicts drive the deconfliction action
- ✦ Resolving trajectory conflicts only makes sense if the trajectory is actually flown  
- Flight Path Monitor tool
- ✦ Conflict detection also used by the system to identify need for co-ordination with adjacent sectors
- ✦ Consistency Issues !

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### ***Conflict Management***

- ✦ Only simple support was offered through the conflict risk display
- ✦ The more advanced support from the agenda like function of the Co-operative Tools would have been useful
- ✦ Sharing of conflict resolution activities in the sector team needs further research

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### ***Conflict Resolution***

- ✦ Several GHMI functions available to assess conflict configurations
- ✦ HIPS allows easy re-planning to resolve conflicts
- ✦ Graphical editing can cause perceptual problems
- ✦ New solutions possible
- ✦ Strong performance requirements
- ✦ STCA consistency - should planning data be used ?

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### ***NLR PD/3 Experience***

- Tools development
- Tools integration
- System Operation
- **Conclusions and recommendations**

CSX/KTA

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### ***Conclusions***

- ✧ The basis is an accurate match between flight planning and flight execution
- ✧ Trajectory prediction is essential
- ✧ Trust in the system
- ✧ Good performance is essential for interactive work

CSX/KTA

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### ***Recommendations***

- ✧ Close the planning loop
- ✧ Research into
  - ✧ **Fast but accurate trajectory prediction**
  - ✧ **Further development of conflict resolution support**
  - ✧ **Conflict management functionality**
  - ✧ **Visualisation of conflict risk**

02/06/2004