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ATM SUPPORT TOOLS IN PHARE – THE IMPORTANCE OF MATCHING THE CONCEPTS OF MANAGEMENT OR CONTROL

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ABSTRACT

The Programme for Harmonised Air traffic Management Research in EUROCONTROL (PHARE) carried out research into the feasibility and merits of the integration of airborne and ground systems.

The PHARE concept is based on closed loop guidance of aircraft along a trajectory generated by the aircraft and deconflicted by the imposition of ground constraints.

The Automated support tools were all advanced tools but they were based on differing concepts.

- Some tools were advanced extensions of existing controller methods providing automated support to the controller and based more on flight plan deconfliction and thus geared towards imprecise trajectories.
- Other tools made full use of the 4-dimensional closed loop control and were based more on exception management.

The paper discusses and contrasts the 2 approaches and shows how the differing views on ownership of both the aircraft trajectory and deconfliction solution affected the use and efficacy of the tools.

The Integration of the tools is discussed with particular emphasis on the problems the differing concepts caused and how those problems were overcome. The paper concludes with some of the lessons learnt within PHARE Advanced Tools project and gives recommendations for the transition to future operational systems.

INTRODUCTION

Automated (decision) support tools for ATM are being introduced in many areas. As the pressures increase there is a tendency to put these tools in piecemeal to solve local problems and to provide improvements. Thus there are conflict probes (or Medium Term Conflict Detectors) being introduced in several places in Europe and in the US User Request Evaluation Tool is being used operationally at 2 centers. Problem Solvers or conflict resolution aids are also appearing such as the Oceanic HIPS. There are arrival and departure managers that have been in use now for decades such as MAESTRO and COMPAS in Europe and CTAS/FAST in the US.

Nevertheless, the current operational support tools all tend to have one thing in common: they automate the current Air Traffic Control procedures and working methods of the controllers. In many areas in Europe the Tactical Controller workload has become the limiting factor of the ATM systems imposing capacity restrictions on the use of the airspace.

The intention of PHARE philosophy was to move the deconfliction workload from the tactical controller to the planner controller. Use of aircraft derived data over datalink and closed loop guidance of the aircraft provided the required certainty of trajectories allowing deconfliction action to be taken several minutes prior to sector entry. To assist the planner and tactical controller a set of Advanced Tools were developed. These tools allowed the early identification and resolution of conflicts and the sequencing of runway usage times for arrivals and departures. The tools were based on the use of the 4-dimensional trajectory generated by the aircraft modified if necessary for deconfliction by the imposition of ‘constraints’.

Nevertheless, the tools were each based on concepts that reflected slightly differing future views. The mismatch in operational and philosophical concepts made the tool integration in PHARE a complex process requiring changes both to the tools and to operational concepts.

However, it should be noted that, with the exception of surface management, the 9 PHARE tools in the advanced tool set successfully covered all the necessary functional automation areas for an advanced ATM System.

PURPOSE OF PAPER

This paper highlights the conceptual and practical issues that were raised by integration of the 9 automated support tools developed for PHARE. First it highlights the paradigm shift that is occurring globally in ATM, as there is a more general move towards ‘free-flight’ or User Preferred Trajectories. Then having discussed, the individual PHARE tools are compared with these concepts to show how some were rooted more in the current ATM system concepts than in those of the future 4-dimensional systems. The paper then suggests a transition path to future systems.

INTRODUCTION TO 3 AND 4-DIMENSIONAL ATM CONCEPTS

The current airspace structure is based on a systemic 3-dimensional separation by the imposition of a fixed route structure. Aircraft are routed to avoid opposite direction traffic and vertically separated based on their direction of flight. The systemic 3D structures whilst protecting the aircraft are inefficient in airspace usage, as they exist regardless of the presence of an aircraft. However, this systemic separation is necessary in current systems as there is considerable uncertainty on the future position of aircraft. Tools to assist the controller in this environment take this uncertainty into account and are based on sequencing rather than on accurate times.

In a 4-dimensional concept the aircraft are separated by their actual trajectories, which need not be constrained to the 3-dimensional structures this permits more efficient use of the available airspace. The 4-dimensional philosophy also allows the aircraft to follow their 'user preferred trajectories' potentially leading to more efficient and less polluting flight paths. A 4-dimensional system may only really be feasible in high traffic loads with the provision of automated support tools for the controllers that highlight conflicts, aid their resolution and that retain the detail of the individual aircraft. If the controllers trust these automated support tools then they need only be involved with exceptions, potentially greatly reducing their workload.

OVERVIEW OF THE PHARE CONCEPT

The underlying basis of the entire PHARE concept was that all aircraft regardless of their avionics fit have an active 4-dimensional trajectory. A trajectory that is only defined in 3 dimensions is of little use for deconfliction whereas a 4-dimensional trajectory is accurate in time along the trajectory continuum.

The aircraft flight management systems generated the 4-dimensional User Preferred Trajectory to meet constraints of any procedures and the operator's requirements. The aircraft trajectory was then data-linked to the ground system ensuring that identical accurate trajectory information was available to the controller. The ground system checked the down-linked trajectory for conflicts and any necessary deconfliction was carried out by the controller setting 4-dimensional constraints on the trajectory and data-linking them to the aircraft which added the constraints to its constraint list and regenerated a new trajectory to meet the constraints. After pilot approval the new deconflicted trajectory was data-linked to the ground. The ground system then had a precise copy of the trajectory in the aircraft flight management system. [Reference 1]

This basic negotiation was followed whenever either the pilot or the controller required a trajectory change. The intent was that the active trajectories in the aircraft and in the ground system remained identical. The aircraft flight guidance then ensured that the aircraft accurately followed the negotiated trajectory. As an external check the flight progress was monitored by the ground system and any unacceptable deviations caused an alert to the controller.

Aircraft without datalink had a 4-dimensional trajectory generated on their behalf in the ground system, which was then deconflicted in the same way as for an aircraft generated trajectory. The non-equipped aircraft was then guided along its trajectory by the tactical controller using 'advisories' or radio commands, generated by the ground system.

Thus the PHARE concept resulted in a 'known 4-dimensional trajectory environment' in which aircraft were deconflicted by the planner controllers using conflict resolution tools up to 10 minutes prior to sector entry. Such an environment allows freedom to the aircraft to generate a User Preferred Trajectory that can be amended at any time by the pilot subject to controller imposed sequencing and deconfliction constraints. The philosophy is seamless and applicable to all phases of flight and all airspace traffic densities.

THE PHARE TOOLS

Trajectory Predictor

[Reference 2]
A 4-dimensional Trajectory 'predictor' generated the aircraft trajectories. Guidance within the Experimental Flight Management System (EFMS) ensured that the aircraft follows the trajectory in all 4 dimensions within a parameterised 'bubble' allowing efficient recovery from minor deviations.

The ground trajectory predictor used aircraft performance models to tailor the output to particular aircraft types. The ground Trajectory Predictor was used to generate trajectories on behalf of unequipped aircraft and for what-if modelling of deconfliction and sequencing by tools and controllers.

Wherever possible the active trajectories were based on the trajectory in the Flight Management System, which was down-linked to the ground. Most importantly this meant that:

- the aircraft systems generated the trajectory to meet deconfliction and time constraints *and did not necessarily follow* the what-if trajectory on the ground
- There were no 'trajectory prediction errors' as the aircraft will fly the negotiated trajectory to the accuracy of its guidance or within the accuracy of the ground controller.

The accuracy of the closed loop trajectory guidance allowed long 'look-ahead' planning as the only reason that an aircraft would *not* follow the trajectory would be due to pilot or controller action and not 'errors'.[1] However, contrary to the PHARE philosophy, there were some tools such as the Problem Solver and Cooperative tools that assumed the existence of an 'error tube' around the predicted trajectory to account for 'trajectory prediction errors'.

The Trajectory Predictor used a set of simple rules based on flight phases with trajectories generated for the aircraft to climb as early as possible at best climb rate and descend as late as possible at just above flight idle. This set of rules was to lead to some 'operational' problems in the use of the Problem Solver and deconfliction.

Conflict Probe

[Reference 3]
The PHARE Conflict Probe operated on all active trajectories and on request from 'client tools' on what-if[2] trajectories. It provided full details of conflicts to other tools and to the sector controller display. The Conflict Probe was also capable of detecting conflicts with volumes of airspace such as restricted areas. The Conflict Probe was based mainly on geometric conflict detection although there was also a probabilistic capability.

The extra 'trust' that could be placed in the PHARE closed loop trajectories meant that conflicts reported can be deconflicted by the Planner Controller several minutes prior to the entry of the aircraft into the sector rather than waiting for 'just in time' deconfliction by the Tactical Controller within the sector. This also allowed the use of agenda functions such as the 'Conflict Risk Display' and the Cooperative Tools Agenda, by the Planner Controller as a way of prioritising workload.

Co-operative Tools

[Reference 4]
The Co-operative Tools were a set of tools bound together that provided a 'human centred approach' filtering information to the controllers' to allow rapid assimilation of the air traffic situation. The Co-operative Tools provided a conflict display and added to the conflicts found 'interfering aircraft' which could be affected by deconfliction action. The Co-operative Tools expected trajectory inaccuracy and trajectories were treated as becoming more inaccurate with time and therefore would include more aircraft as 'interfering' if the conflict was further in the future.

The Co-operative Tools also envisaged a concept of controller task sharing that was not completely consistent with long look-ahead deconfliction. The PHARE concept envisaged that the Planner Controller would deconflict trajectories prior to the aircraft entering the sector. The involvement of the Tactical Controller was expected to be limited to guidance of non-datalink aircraft, using the generated advisories and exception handling. However, there was a counter philosophy that was to adopt a 'wait and see' approach to deconfliction due to trajectory 'uncertainties' with the Planner only partially deconflicting or suggesting a deconfliction solution then using the agenda display of PROSITs as an aide-memoire for the Tactical Controller to carry out deconfliction in the sector if necessary. This sharing of an individual task meant that the Planner had to work in 2 temporal problem areas: current time with the Tactical Controller and planning and deconfliction of aircraft up to 10 minutes prior to sector entry. This led to what was called an 'operational gap' where the Planner was not always able to revert from future time to current time to assist and advise with a problem that had been 'solved' up to 20 minutes previously. This problem could be exacerbated by a lack of information on the vector changes on trajectories.

Problem Solver

[Reference 5]
The Problem solver was one of the main controller tools in PHARE. It relied on interactive GHMI display of conflict zones or no-go areas (called blobs by the controllers) and was initially called the Highly Interactive Problem Solver (HIPS). The HIPS provided controllers with an intuitive interface for solving conflicts in all 4 dimensions and they rapidly grasped its capabilities.

The Problem Solver needed to interactively display the new no-go regions as controllers used the mouse to drag the trajectory of a conflicting aircraft. This requires very explicit and interactive what-if modelling. To be fast enough for

[1] The aircraft equipped with the EFMS demonstrated that this was true 'in real life' by flying many sorties where there were no appreciable deviations despite being based on normal forecast meteorological information.

[2] Known within PHARE as Alternate Trajectories.

interactive use the Problem Solver was closely integrated with the GHMI[3] and had its own internal trajectory generation and conflict mapping algorithms. One of the problems of integration was to achieve a match between the interactively generated trajectories and those produced by the Trajectory Predictor. The no-go zones were based on different algorithms to those used by the Conflict Probe and initially there were mismatches with conflicts that were shown not being visible in the Problem Solver or vice versa. These issues were largely solved by parameter changes in the Problem Solver and by closer matching of the trajectory generation rules and parameters.

The Problem Solver display led the controllers to believe that they were editing the trajectory whereas what the Problem Solver was doing was putting constraints on the trajectory. But these were not 4-dimensional 'windows' but were point constraints that reduced the freedom of the trajectory predictor to optimise the trajectory and forced controllers into a join-up-the-dots approach.

For the Problem Solver that required interactive trajectory generation the Trajectory Predictor was too slow so a 2-step process was used with interactive what-if modelling using an internal trajectory generation and the Trajectory Predictor only being called as a validation step at the end of the deconfliction process.

The stability of the trajectories in the system allowed the planner controllers to take effective conflict resolution action up to 10 minutes before the aircraft entered their sector for conflicts more than 20 minutes flying time away. Although the Problem Solver initially was designed to a prescriptive control concept, the amendments of PD/3 altered it toward the 4D management concepts.

Negotiation Manager

[Reference 6]

The Negotiation Manager was a tool that managed the communication between the air and the ground for trajectory negotiation and the ground-ground links for co-ordination. The Negotiation Manager was the tool that activated trajectories after successful trajectory negotiation down-link or, in the case of non-datalink aircraft, on the request to negotiate after what if modelling.

The Negotiation Manager could enforce the transfer of planning and control authority; coordination with the adjacent sectors; and, explicit acceptance or rejection of either every down-linked trajectory or only in certain cases such as constraints not met or a conflict.

In the initial PD/3 exercises to assess coordination requirements it was found that the controllers did not appreciate the Negotiation Manager forcing them to coordinate with adjacent sectors and would take an option to 'force' the trajectory effectively discarding the ground-ground coordination option.

In PD/3 at NLR the Negotiation Manager software could, automatically accept an aircraft originated trajectory amendment that caused no conflicts, *without recourse to controller acceptance* even if it violated constraints imposed by the controller. This can be seen to be the equivalent of free-flight but with ground separation assurance. Whilst the controllers in the unmeasured NLR PD/3 trial were content to try this approach, and it appeared to greatly reduce their workload, it remains to be quantified and assessed for acceptability in a more realistic scenario.

The Negotiation Manager could therefore be used restrictively, in a fixed and highly controlled environment or extremely flexibly automating the ground system acceptance of any trajectory that did not cause an exception.

Flight Path Monitor

[Reference 7]

The Flight Path Monitor provided alerts on aircraft that deviated from their 4-dimensional trajectory. The deviation was identified by comparing the aircraft reported 'radar' position against the expected position on the 4-dimensional trajectory. A certain amount of deviation is expected in flight, this was allowed for by the Trajectory Predictor generating a 'contract tube' around the negotiated trajectory [Reference 8]. This was more correctly a 4-dimensional contract bubble in which the aircraft had a degree of freedom for optimal FMS guidance recovery to the trajectory from minor deviations.

If the Flight Path Monitor detected a deviation it was possible for a new trajectory negotiation to be automatically triggered. However, this was discarded as an option in PD/2 as the controllers felt that the it was their decision if a new trajectory was required rather than recovery to the existing trajectory.

Departure Manager

[Reference 9]

The Departure Manager was a sequencing and runway load-balancing tool that allocated aircraft departure times and Standard Departure Routes from a catalogue of available departure routes. This was following more of a fixed route philosophy.

[3] Ground Human Machine Interface

The major concern was the requirement for an accurate departure time to fit with the PHARE known 4-Dimensional trajectory concept. Controllers found the idea of aircraft departing with a +/- 30-second accuracy difficult to accept. However, the fact that the current system does not require any accuracy does not mean that it is infeasible. It is probable that in the initial noise abatement climb there is sufficient time to renegotiate a trajectory.

The Departure Manager disallowed the re-sequencing of departures after push-back. Controllers found this constraint unwelcome, although it was unlikely that such re-sequencing would take place normally. This was another indication of controllers disliking automation restricting their actions.

Arrival Manager

[Reference 10]
The PHARE Arrival Manager is a ground based planning tool that automatically planned, and re-planned the optimal arrival sequence at an airport smoothing peaks in arrivals by balancing runway usage and / or applying small delays to a number of arrivals. If there was a significant delay, the Trajectory Predictor would generate a holding pattern at the Metering Fix[4]. The Arrival Manager would check new trajectories for holds and if necessary impose altitude and time constraints to automate stack separation of holding aircraft. This was a relatively contentious issue with controllers who were unhappy about aircraft automatically descending on times without the need for explicit clearance from a stack controller.

The major difference between the PHARE Arrival Manager and other arrival managers is the use of 4-dimensional trajectories. In this philosophy aircraft are given precise landing times rather than a landing sequence. This limits the propagation of errors back up the arrival stream as aircraft are all correcting to a landing time.

There was concern that the affect of the Arrival Manager resequencing trajectories could cause aircraft to alter their speed in the en-route phase and cause conflicts. The subsequent deconfliction action in the en-route sector could force a resequence of the arrivals and this in turn cause more conflicts. Thus the system in theory could become exponentially unstable. This was avoided by damping the system with parameter limits on the time constraints set on aircraft and their negotiation. Also in a free-routed environment there was less chance of conflicts being caused by minor speed changes.

Tactical Load Smoother

[Reference 11]
The Tactical Load Smoother was a tool that was to be used by the Multi-Sector Planner to reduce sector workload to an acceptable level. In a 4-dimensional free-route system the workload of the sector is linked to the number of exceptions. The Tactical Load Smoother assessed traffic complexity and highlighted areas that were above normal levels to a multi-sector planner some 30 – 40 minutes in the future. The multi-sector planner could then amend the trajectories of the aircraft involved to reduce the complexity and thus the potential workload for the sector controllers[5].

A tool such as the Tactical Load Smoother, that allows long look ahead alerting to exceptions and provides means of intervention to reduce their number or complexity, will be essential in all free-routed environments where workload is driven by exceptions.

TEMPORAL SPLIT OR OPERATIONAL GAP

The ability for planner controllers to solve problems with a long look ahead meant that when they were busy they were working on traffic up to 10 minutes prior to sector entry. With large sectors and slow aircraft this could mean conflict resolutions 20 – 30 minutes in advance. The tactical controller on handling a problem could often not ask the planner to clarify what was done as the planner had solved that problem such a considerable time before. However, those controllers that were used to the cooperative sharing of workload such as that which was expected with the Co-operative Tools, found that the lack of GHMI information and the planner being temporally separated led to what was called an Operational Gap. This caused extra workload as the Tactical Controller attempted to repeat the work of the Planner Controller. [Reference 12]

RESTRICTIVE AUTOMATION OR PERMISSIVE AUTOMATION

Initially many of the current controller restrictions were implemented in software, for example: enforced co-ordination of minor alterations to trajectories changing entry and exit conditions. But entry and exit conditions are only required to be precise in the absence of an accurate trajectory. Where there is a full display of trajectory information these conditions are redundant. These

[4] Note that the Trajectory Predictor was set up such that holds would only be generated at the 'metering fix' that was the entry fix into the TMA.

[5] The multi-sector planner position can be considered to be a kind of real time flow management position.

restrictions were in general a hang-over from the positive control concept.

Permissive automation where the system provided information but left decision to the controller, such as conflict risk displays and the Problem Solver, was far more welcome. However, where the automation tended to take over the controller roles such as the Negotiation Manager acceptance of negotiated trajectories, or automated stack management the controllers became more wary.

CONSISTENT UNDERSTANDING AND IMPLEMENTATION OF CONCEPTS

The major conceptual problems were associated with trajectories. All aircraft have trajectories regardless of their avionics. The closed loop guidance in PHARE was intended to ensure that the negotiated trajectory was always flown accurately.

Constraints were meant to be 4 dimensional windows not 'points'. Control instructions such as "climb to and maintain flight level 240" are closed as there is no time or position limit on the maintenance of flight level 240. An instruction such as "cross RKN not below flight level 240" is an open constraint as the altitude window at RKN has a bottom level but that is all. The Trajectory Predictor could accept these constraint types and other closed/open and open/closed constraints but they were difficult if not impossible to implement in the Problem Solver, which had to carry out interactive generation of a what-if trajectory. The final version of the Problem Solver followed the constraint matching rules of the Trajectory Predictor but due to GHMI restrictions was unable to provide the windows in altitude.

A final issue with trajectories is the use of ground track, ground radius turns and ground speed. Aircraft fitted with FMS even 3 dimensional FMS, follow a ground track within the bounds of their navigation accuracy. In Europe all aircraft are expected to be B-RNAV equipped. This means that the effect of wind on the aircraft is to change its ground speed but *not make it deviate in track* as the aircraft will correct its heading to make good the FMS set ground track. There was a tendency in PHARE to expect the 3 dimensional FMS aircraft to be less accurate in track whereas the inaccuracy would only be in time.

TRAJECTORY AND DECONFLICTION OWNERSHIP

Ownership of data is an important information system issue. One of the main changes in PHARE was that the aircraft 'owned' the trajectory amending it as required. This was along the lines of the free-flight paradigm of 'here is my intent is it safe'. This philosophy is acceptable to controllers until there is a conflict. Then the real ownership issues arise, as the controllers tend to feel they must own the solution to the conflict. The pilot must be told the constraints to avoid the conflict, as it is obviously not acceptable or efficient for the pilot to iterate through a series of guesses at acceptable deconfliction solutions. However, if the controller explicitly amends the trajectory of the aircraft for deconfliction the controller has taken back trajectory ownership.

What is possible is for the controller to indicate with 4-dimensional constraint windows a 'solution space' within that constrained freedom the aircraft generates a best possible trajectory. In this way the controller does not assume ownership of the trajectory but retains some 'control' of the solution. In busy areas the solution space is more constrained than in sparse areas. Thus there is a seamless tendency toward more managed flight as the airspace becomes busier. Eventually in crowded TMA the controller can issue formalised negotiation that allows very little freedom to the aircraft.

TRUST IN TOOLS

An automated system will only be used if it has the controllers' trust. There were 2 major issues here. The first more obvious one was the occasional mismatch in conflict detection due to differing algorithms. So a conflict would be highlighted by the Conflict Probe and shown in the Conflict Risk Display, but when the aircraft was loaded into the Problem Solver no conflict was shown. Although these problems were cured by PD/3, there is a general lesson to be learnt that any tools that use different algorithms for a closely allied function are going to occasionally provide different results. If this is in a safety related area trust in the system could be greatly reduced.

Secondly, management must take responsibility for the systems introduced if controllers are to trust the system. That means that if controllers **do** trust the system and it goes wrong – management will need to take responsibility. Controllers think that this is unlikely and are therefore likely to continually second-guess the automated systems 'just-in-case'. This would increase controller workload and devalue the capability of the system.

TRANSITION TO 4D CONCEPTS

Contrary to popular belief, transition from the current system to 4-dimensional control is easy. A 4-dimensional control system can support the requirements of a fixed route 3-dimensional system. If the ground tools are put in place for a 4-dimensional system, aircraft can alter to the free route system at any time. Or to put it another way: a trajectory that follows a fixed beacon-to-beacon route can be treated as a user preferred trajectory by the advanced tools. To demonstrate this, in the unmeasured PD/3 demonstration at NLR, a traffic sample was run which started with all aircraft unequipped with datalink flying fixed route and during the 90 minutes of simulation the traffic altered to become 70% datalink equipped and all flying User Preferred Trajectories. The same ground tools and procedures could cope with both fixed and free-routes.

TRANSITION FROM UNMANAGED TO MANAGED AIRSPACE

The PHARE philosophy of ground separation assurance of negotiated User Preferred Trajectories is seamless gate-to-gate. Unlike transition from free-flight to managed airspace, the PHARE approach would be identical regardless of the density of traffic. All that would change is the degree of freedom in 'solution space' that would be allowed to the aircraft.

FURTHER RESEARCH

There are several areas that merit further research:

- The PHARE 4-dimensional trajectory philosophy is seamless and does not require the 3 dimensional airspace structures. An integrated airspace management approach should be assessed where there is no need for virtual airspace boundaries. The level of management and ownership of the solution space could vary dynamically with traffic density.
- Temporal Issues and controller roles need to be addressed. In the PHARE concept the Multi-Sector Planner could be working 40 minutes in the future and the Planner Controller could be deconflicting up to 10 minutes prior to sector entry. Only the Tactical controller would be working in current time. This leads to a large temporal split between controllers. Specifics that need to be addressed are task sharing; sufficient display of flight and intent information on the trajectory; handover and handling of overlapping control and planning authority.
- One of the concerns of the controllers was that the automated tools would deskill them. However the use of the tools required a different set of skills. So controllers would need to be reskilled. Misuse of automated support tools can often cause considerable disruption. Therefore, there is a need for controller procedures and techniques for the use of these tools to be developed and refined.
- PHARE made use of datalink from the FMS to the ground system. This allowed the accurate transmission of trajectory data. However, there will be many non-datalink equipped aircraft and CPDLC equipped aircraft for the foreseeable future. Transmission of trajectories to these aircraft could be made more precise and efficient. Advisories could be issued automatically over datalink as CPDLC commands to those aircraft that were appropriately equipped. The advisories for non-equipped aircraft could be concatenated into a clearance instead of being passed as individual commands. However, the automated generation of a clearance that can be passed safely over R/T from a series of vector changes is not simple.
- There is concern among aircrew that the use of datalink reduces their awareness of traffic in the airspace. The same issues arise with controllers with automated trajectory acceptance and filtered displays. However, the need for a controller to maintain a continual accurate 'big picture' is currently one of the limiting factors in ATM capacity in Europe. It should not be accepted as necessary without testing of alternate concepts.
- This paper has been addressing the issue of 'automated tools'. In fact many of these tools could be considered as methods of objects. With a true object oriented approach some of the scalability problems of the client server architecture could be avoided. There are many potential benefits of object-oriented architectures from more consistent flight planning through to fault tolerance. Some efforts are being made in this area but a pure top-down object-oriented approach is needed.
- One of the major issues at the end of PHARE was the lack of quantification of the results. As the system moved more towards exception management the old methods of assessing capacity as equivalent to controller workload became less reliable. There is an urgent need for abstract performance metrics to quantify simulated novel ATM systems.

LESSONS LEARNT

Trajectories are fundamental to ATM. However, there was initially little understanding of what a gate-to-gate 4D trajectory was and the benefits that were available from it.

- Accurate guidance is more important than accurate generation of the trajectory.
- All tools that use the trajectory should have the same data-definition and semantic understanding of the trajectory information.
- Amendments of a gate-to-gate trajectory are always closed, with the complete trajectory leading to the destination.

Automation support to the controllers raised some issues:

- automated tool concepts and airspace and controller procedures must be compatible.
- Mishandled or mistrusted tools can greatly increase the controllers' workload.
- Permissive automated support is more likely to be accepted than restrictive or prescriptive automated support.

CONCLUSIONS

The PHARE concept was based on the use of accurate 4-dimensional trajectory information generated by the aircraft and held in the ground system. The tools that were developed had differing views of the accuracy and ownership of trajectories. Both the Problem Solver and the Cooperative Tools expected errors in trajectories. However, there was a double feedback loop, FMS guidance and Flight Path Monitoring to ensure that there was no inaccuracy.

The ownership of deconfliction solutions was unclear as controllers could accept user preferred trajectories but were less willing to allow freedom of trajectory generation for deconfliction. When such freedom was provided by the Negotiation Manager settings in the NLR PD/3 demonstration it appeared to reduce controller workload without causing problems.

The change to airspace management by exception makes the use of flow assessment and control tools such as the Tactical Load Smoother essential to ensure that the future exception loading and complexity is acceptable for the sector controllers. The change to exception management is also making assessment of sector capacity difficult as it can no longer be directly associated with controller workload.

The layered planning approach with multi-sector planners, planner controllers and tactical controllers working split temporally entails different levels of coordination and information passing and requires more research.

Controllers will accept automated assistance but dislike restrictive automation. If controllers are required to use automated support tools they will not fully use them unless they are consistent and supported by management. Controllers will require training in new procedures and techniques to make best use of the tools. However, if there is any doubt with the tools the controllers will revert to normal control practices as well as using the tools and their workload will increase.

Transition to a 4-dimensional environment should be easy if the ground system is equipped before the aircraft. Then as aircraft become capable of free-routing the system can support them immediately. A PHARE type 4-dimensional trajectory system can provide the benefits of 'free-flight' but with ground separation assurance in a seamless environment from sparsely flown areas to dense traffic areas.

If the users understand the concepts and the concepts of the tools match then the system will work consistently and gain the trust of the users.

ACRONYMS

ATM	Air Traffic Management
CENA	Centre d'Etudes de la Navigation Aerienne
CPDLC	Controller Pilot DataLink Communications
EFMS	Experimental FMS
FMS	Flight Management System
GHMI	Ground HMI
HIPS	Highly Interactive Problem Solver
HMI	Human Machine Interface
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium
PD/n	PHARE Demonstration
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
TEPS	Trajectory Editor and Problem Solver

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