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PHARE Advanced Tools
Flight Path Monitor

Final Report

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EXECUTIVE SUMMARY

This document is part of the final report for the PHARE Advanced Tools (PATs). Within the PATs project, decision support tools for Air Traffic Controllers (ATCos) were developed for reasons of Air Traffic Management (ATM) research purposes. One tool out of the PATs set is the Flight Path Monitor (FPM). The FPM provides the following four functions:

- The detection of deviations of aircraft from their planned trajectories.
- The provision of ground supported navigation advisories for aircraft in their unequipped directions[1] if necessary.
- The signalling of the passing of significant points.
- The reporting of progression of aircraft along their planned trajectories.

This document focuses on all relevant aspects of the development of the PATs FPM.[2]

The detection of differences between the actual and planned positions of an aircraft in all directions (longitudinal, transversal and vertical) is achieved by comparing its track (position report) with its correlated system plan (SPL). For each available pair of correlated track and SPL, the following is calculated: the size of the deviation (longitudinal in time, transversal and vertical in meters), the relative size of the deviation (insignificant, medium, or large) and the trend of the deviation (increasing, steady, or decreasing).

Ground supported navigation advisories for an aircraft in its unequipped directions are provided when it appears that the aircraft is moving out of its tube or when significant changes in the meteorological conditions are expected. For example, if a non-4D equipped aircraft has a medium deviation in the longitudinal direction, the FPM predicts the times at which this aircraft will reach certain 3D points. If the longitudinal deviation is predicted to be not too large at these 3D points the FPM will not send an advisory. If, however, the longitudinal deviations are predicted to be too large and the FPM has calculated a feasible (speed) advisory, this advisory is sent out by this function of the FPM.

These are the two basic functions of the FPM. Besides these functions, the current version of the FPM has two more functions. These functions are the signalling of significant point passing and the reporting of progression. These functions have been developed after being requested by the developers of other tools and/or simulation platforms.

The development of the FPM was by means of a stepwise progression through a series of PHARE Demonstrations (PDs). PD/1 took place in late 1995, PD/2 took place in June 1996 and PD/3 took place in 1998.

[1] With unequipped directions, those directions are meant for which the aircraft has no guidance system in its FMS. For example, 3D equipped aircraft are unequipped in the longitudinal direction: these aircraft are able to fly a 3D planned trajectory using their FMS but are not always able to meet the planned time.

[2] In this document, the terms PATs FPM and FPM are both used for the same developed flight path monitoring tool.

PD/1, hosted by NATS, was based on an en-route scenario. An initial version of the FPM was developed and integrated with other tools within a framework called the Common Modular Simulator (CMS). The scope of this version of the FPM was to detect deviations from planned trajectories in the en-route sector. This version of the FPM was developed at NLR before the beginning of PD/1.

PD/2, hosted by DLR, was based on a Terminal Manoeuvring Area (TMA) scenario. Adding the signalling of the passing of significant points extended the PD/1 version of the FPM. This function was developed after being requested by the developers of other tools like the Arrival Manager. An example of a significant point is a TMA entry point.

PD/3, hosted by NLR, EEC, and CENA, was based on a multi-sector scenario. This scenario included the full route of aircraft from take off to touch down. For PD/3, two additional functions were added to the PD/2 version of the FPM. The first of these functions was the provision of ground supported navigation advisories, if necessary, to aircraft in their unequipped directions. The second of the functions that were developed specifically for PD/3 is the reporting of progression. Further, the PD/2 versions of the deviation detection and the signalling of significant point passing functions were modified.

Every FPM function was well tested technically. It may therefore be assumed that the algorithms of the FPM work correctly.

The deviation detection function was used in the Internal Operational Clarification Project (IOCP) and in every PD. The significant point passed signalling function was used in the IOCP, PD/2, and PD/3. The reporting of progression function was only used in PD/3 at EEC and CENA. No comments were received about any of these three functions, which implies that these FPM functions are functionally correct. The ground supported navigation function was not used in any PD or IOCP. The main reasons for this are explained next.

The ground supported navigation function of the FPM was developed by NLR. However, this function has not been used to date in any real-time demonstration experiment. The main reasons for this are that inconsistencies exist between the aircraft performance models used by the PATs Trajectory Predictor (TP), which generates SPLs, the Air Traffic Server, which simulates the flights of different kinds of aircraft, and the FPM. These inconsistencies are so relevant in the handling of navigation advisories that it is not useful to incorporate FPM navigation advisories.

Another main reason for not using FPM advisories is the fact that the same kinds of navigation advisories are also generated by the TP. The presentation of both TP and FPM advisories (which might be inconsistent) to the ATCo can lead to a large amount of advisories that cannot be handled efficiently by the controller. Unfortunately, within the PATs project there was no time and budget left to solve these problems.

Both ATCos and other PATs use (parts of) the outputs of the FPM functions. The interaction between the FPM and the ATCo takes place through a Human Machine Interface (HMI). This HMI was not developed within the PATs project, but by the Ground Human Machine Interface (GHMI) project. The interface between the FPM and the other PATs was developed within the PATs project.

With respect to the development path of the FPM within the PATs project, the following can be concluded.

The purpose of the PATs project was that the tools would be developed in a simulation environment called the CMS. If all the tools had been integrated on the same simulation platform, test runs could have been made and the PATs cluster could have been evaluated and validated. However, the development of the simulation environment CMS was planned parallel to the development of the tools. The result of this parallel approach was that a lot of time was needed for the tool developers to integrate the tools in successive CMS versions. A lesson learnt is that the development of the simulation environment, in which Air Traffic Control (ATC) tools can be evaluated and validated, should be done before the development of the tools themselves start.

It turned out that the approach followed by the PATs project was a tool driven approach rather than a concept driven approach. With a tool driven approach, the tools are developed almost independently of each other. Only after some development work was finished it was noticed that some tools had incorporated conflicting or overlapping functions. For a successful development of an ATC tools cluster, a concept driven approach would have been better. All the tools should have been developed according to common concepts, which everybody had agreed upon, and the various activities should have been geared to one another to a much greater extent than was done within this project.

The main conclusions that can be drawn after the development of the PAT FPM are the following: the FPM has originally been developed in accordance with PHARE's 4D ATM philosophy. After being requested by the developers of other PATs and/or simulation platforms, additional FPM functions were developed. Although further research on the development on the FPM is required, the results obtained to date with the FPM are, in general, satisfactory.

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LIST OF CONTENTS

1. INTRODUCTION

1.1. SCOPE

This document is the final report of the Flight Path Monitor (FPM) that was developed during the Programme for Harmonised Air Traffic Management Research in EUROCONTROL (PHARE).

One of the projects within PHARE was the PATs project. The scope of the PATs project is to develop decision supporting tools for ATM research purposes. More detailed descriptions of the PATs project can be found in refs. [1], [2], [3], [4] and [5]. Within the PATs, the FPM provides an advanced flight path monitoring function.

This document has been produced as part of the PATs project.

1.2. DOCUMENT CONTEXT

The FPM is one of nine types of advanced tools that are known collectively as the PATs. The other eight types of tools are:

- The Arrival Manager (AM, ref. [6]);
- The Conflict Probe (CP, ref. [7]);
- The Co-operative Tools (CT, ref. [8]);
- The Departure Manager (DM, ref. [9]);
- The Negotiation Manager (NM, ref. [10]);
- The Problem Solver (PS, ref. [11]), also known as Highly Interactive Problem Solver (HIPS);
- The Tactical Load Smoother (TLS, ref. [12]);
- The Trajectory Predictor (TP, ref. [13]).

As well as the final reports, an overall document of the PATs provides all the additional and background information that is needed in ref. [14].

1.3. OVERVIEW

The subject of this document is the PAT known as the FPM. The FPM is one of the ground based decision supporting tools to support Air Traffic Controllers in their job. A detailed description of the FPM can be found in ref. [15].

The FPM compares the 4D tracked positions of aircraft against their 4D planned positions so as to detect deviations between them. Deviations are calculated in three dimensions; laterally, longitudinally and vertically. For each direction, deviations are characterised as being insignificant, medium, or large. The thresholds for detecting insignificant, medium and large deviations are determined by the TP (in terms of the dimensions of the contract tube and the large deviation tube). The contract tube defines the boundaries of a volume of airspace around the contracted trajectory, which is the trajectory along which the aircraft is contracted to fly. The large deviation tube defines the boundaries of a volume of airspace around the airspace defined by the contract tube, which defines the boundaries of ‘recoverable errors’ (see refs. [4] and [5]).

A deviation is classed as insignificant if the aircraft is within its contract tube. A deviation is classed as medium if the aircraft is outside its contract tube but within its large deviation tube. Finally, a deviation is classed as large if the aircraft is outside its large deviation tube.

The FPM provides corrective (calibrated) airspeed advisories to non-4D equipped aircraft when

1. Such an aircraft has left its contract tube and is expected to leave its large deviation tube in longitudinal direction.
2. Updated nowcast/forecast meteorological information is received that indicates that such an aircraft will leave its large deviation tube in longitudinal direction due to the changed weather conditions.

Corrective navigation advisories (airspeed advisories) will only be provided when the aircraft is still able to stay within its large deviation tube for a given segment of the trajectory. The airspeed advisories will be such that the change in (calibrated) airspeed is minimal.

If the performance characteristics of an aircraft are such that it is no longer able to follow the original planned trajectory, the aircraft is said to have a large deviation and the planned trajectory has become infeasible. When an aircraft has a large deviation, a new planned trajectory has to be generated for it by the ground system.

The FPM can notify an interested entity whenever an aircraft passes a significant point (specified by the entity).

The FPM can notify interested entities about the progression of an aircraft with respect to its planned trajectory. Progression information contains, amongst other items, the identity of the last overflown waypoint.

1.4. DOCUMENT STRUCTURE

The structure of the remainder of this document is as follows.

Section 2 describes the operational concept of the PATs Flight Path Monitor.

Section 3 describes the requirements for the PATs Flight Path Monitor.

Section 4 describes the implementation of the PATs Flight Path Monitor.

Section 5 describes the usage of the PATs Flight Path Monitor.

Section 6 describes and interprets the results of real time trials relative to the PATs Flight Path Monitor.

Section 7 provides conclusions and makes recommendations for future work utilising the PATs Flight Path Monitor.

Section 8 contains a list of abbreviations and acronyms. For an extended list of abbreviations and acronyms, the reader is referred to ref. [4].

Section 9 contains the list of references cited in this document.

2. OPERATIONAL CONCEPTS

In this section, the operational concepts of the PATs FPM will be described. It will be explained how the FPM works and how it fits within the PATs cluster. The development process of the FPM will be given, where it will be made clear how and why the FPM was developed the way it is.

2.1. OPERATIONAL CONCEPT

2.1.1. Overview of operation

The operational concept that all PATs are based on is the 4D ATM philosophy. In a few words, the 4D ATM philosophy can be described as follows:

If the 4D planned flight paths of different airframes are conflict-free and the actual positions and the evolution of the positions of these airframes comply within certain monitor limits with their planned flight paths, then the actual positions and their evolutions are conflict-free also.

The FPM has been developed in order to support the above 4D philosophy. The purpose of the FPM is to aid the Air Traffic Controller to keep aircraft on schedule. On schedule means that the actual positions and the evolution of the positions of aircraft comply within certain monitor limits with their planned flight paths.

The role of the FPM is to monitor the actual positions of aircraft with respect to their planned flight paths and, if necessary, to provide ground supported navigation to aircraft in their unequipped directions. Additional explicit functions of the FPM are to signal when aircraft pass predefined significant points and to report the progression of aircraft along their planned flight path. These functions will be described in the next section.

2.1.2. Key operational concepts

In accordance with the 4D ATM philosophy, the purpose of the FPM is to support non-4D equipped aircraft in realising their 4D planned trajectories and to signal both the deviations of the actual positions of all aircraft from the corresponding 4D planned flight paths and the trends of those deviations. In order to fulfil this purpose, the FPM performs the following two functions:

- The detection of differences between actual aircraft positions and planned 4D flight paths.
- The provision of ground supported navigation in unequipped directions.

Following requests made by the developers of other PATs and/or ATC simulation platforms, the following two functions were also developed within the FPM:

- The signalling of the passing of predefined significant points by aircraft.
- The reporting of the progression of aircraft along their planned flight paths.

Each of these four FPM functions will be described in this section.

Detection of Deviations

The purpose of the deviation detection function of the FPM is to alert the human controller, the pilot, and other tools whenever the deviation of the actual path of an aircraft from its planned 4D flight path is significant. For a detailed description of the algorithm for the calculation of deviations between tracks and a correlated SPL, see ref. [16]. With tracks we mean the information that is received from the tracker server (for example position and speed information).

The calculation of the deviations starts when a new track (the first one in the row) is received and this new track can be correlated with an SPL that is already known to the FPM. The correlation between tracks and a SPL is generally done by means of flight IDs. When a received track has been correlated with an SPL, the deviation between the track and the relevant SPL point is calculated. This process is repeated every time that a correlated update of the track is received by the FPM. If it is clear to the FPM that the track is the last one in the row for that flight, then the last deviation for this flight is calculated. When no SPL that is known to the FPM can be correlated with a track, no deviation calculations are performed.

Deviation data contains the following information: the size, the relative size, and the trend of the deviation for each direction. The directions considered are the longitudinal direction, transversal direction and the vertical direction.

The size of the deviation is the distance between the track position and the corresponding point as determined from the SPL (the point where the aircraft should be at that time on its flight). For the longitudinal direction, the size is expressed in seconds. Positive values for the longitudinal deviation mean that the aircraft is early. For the transversal direction, the size of the deviation is expressed in meters. Positive values for the transversal deviation mean that the aircraft is to the right (as opposed to the left) of the planned trajectory. For the vertical direction, the size of the deviation is also expressed in meters. Positive values for the vertical deviation mean that the aircraft is above its planned trajectory.

The sizes of the deviations are classified with respect to the dimensions of the large deviation tube. There are three classes, namely

1. ‘Insignificant’, meaning that the aircraft has almost no deviations.
2. ‘Medium’, meaning that the aircraft deviates but is still able to return to its planned trajectory.
3. ‘Large’, meaning that the aircraft deviates so far from its planned trajectory that it is no longer able to return to its planned trajectory.

This classification is made for each of the directions.

For the trend of the deviation, a distinction is made between an increasing, a steady, and a decreasing deviation. The interpretation of these trends is evident.

Other PATs and/or entities that use the deviation information that is calculated by the FPM are the TP and the GHMI. The TP needs to be informed of large deviations because new feasible trajectories have to be generated for these aircraft. The GHMI presents large deviations to the ATCo to draw his/her attention to the problem situations.

The use of the FPM deviation detection function is illustrated in Figure 1. This figure shows that large deviations are presented by the NLR ATC simulation platform, NARSIM, by means of yellow circles around aircraft that have a large deviation in one or more directions.

For the calculations of deviations, the FPM can be set to use one of two kinds of algorithms. The outputs of the two algorithms are the same: both calculate the longitudinal, transversal and vertical distances between the tracked position of an aircraft and its planned 4D position each time that track data are received. The differences between the two methods are the following.

With the first method, the accuracy of the deviations decreases when

1. the tracks surround a turn in the planned flight path and
2. the longitudinal distance between tracked and planned position grows.

The second method does not have this accuracy problem but it is computationally more expensive than the first method. In general the second method is to be preferred for its higher accuracy.

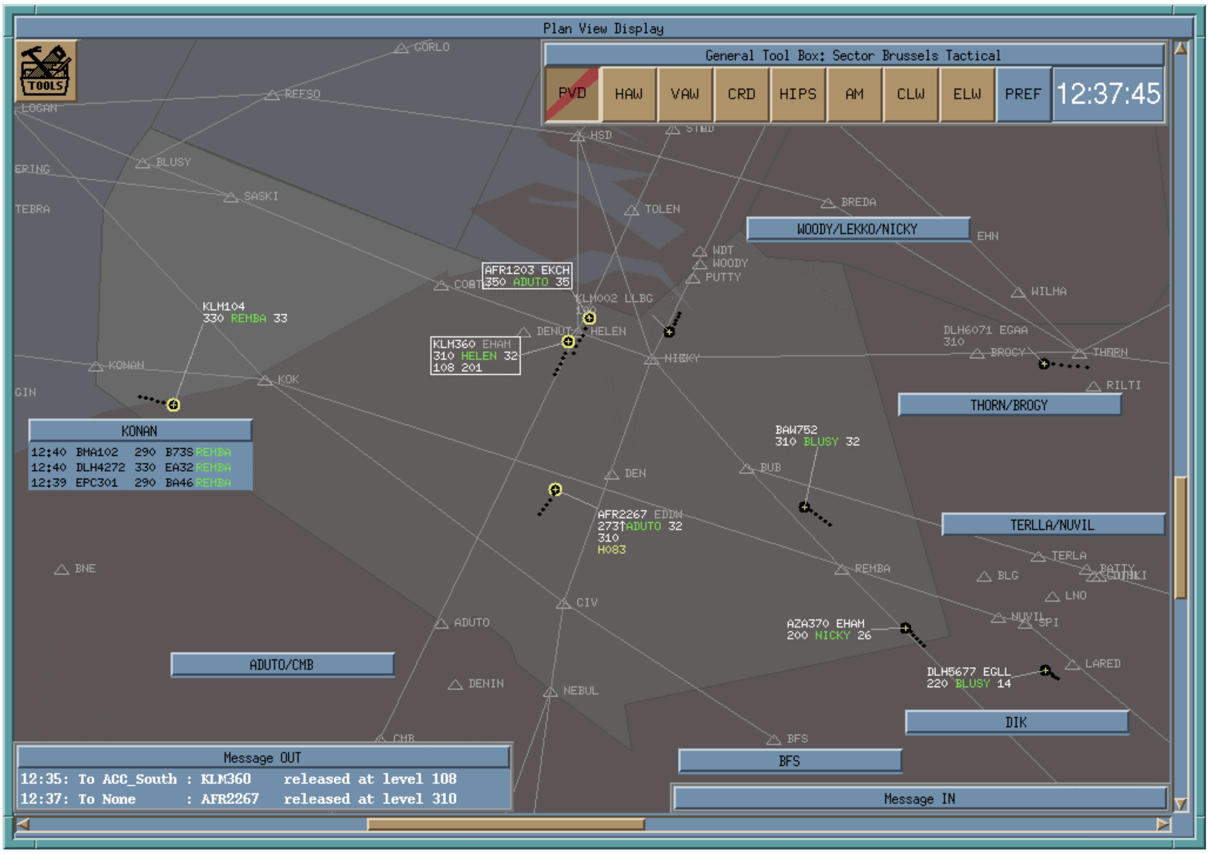

Figure 1 The working of the FPM deviation detection function in NARSIM

Providing Ground Supported Navigation

For the 4D ATM philosophy to be successful in practice, it was foreseen that it is necessary to support non-4D equipped aircraft in their navigation. Where 4D equipped aircraft are generally able to cope with deviations from their planned trajectories that are due to modelling errors in their Flight Management System (FMS) or unexpected meteorological conditions, non-4D equipped aircraft are not. Together with the fact that a significant part of the total fleet of aircraft will not be equipped with 4D FMSs between now and the year 2015, a ground supported navigation function to support aircraft that are not equipped with 4D FMSs in their unequipped directions is desirable.

The PD/3 FPM is able to provide ground supported navigation for non-4D equipped aircraft in the longitudinal direction, by providing calibrated airspeed (CAS) advisories. For a detailed description of this algorithm, see ref. [16]. By a non-4D equipped aircraft, we mean an aircraft that is able to fly its planned trajectory in 3D space but is not always able to meet the time constraints on these points.

The FPM Ground Supported Navigation (GSN) function is explained below.

The FPM GSN function is initiated either when medium longitudinal deviations occur or when meteorological information has been received that shows that significant changes have occurred in the meteorological conditions along the considered trajectories. Once the GSN function is initiated, a number of checks are done in order to evaluate whether it is useful to start the calculation of an advisory. Checks are made on:

- The availability of meteorological information.
- The aircraft equipment.
- The feasibility of the segment for which the advisory will be calculated.
- The utility of advisories for that flight.
- The existence of a previous advisory for that flight and segment.

A segment is a part of the SPL for which there is a constant CAS regime. Its first and last SPL point, the (constant) flight mode, and the CAS value define a segment. A segment is deemed not feasible if, for example, the time difference between the start point and the end point of the segment is too short to calculate a corrective advisory.

The outcome of the FPM GSN function is either no advisory, a CAS advisory, or a replan advisory. No advisory is returned when the FPM predicts that the longitudinal deviation will not become too large for the considered segment assuming that the aircraft maintains its original CAS during that segment. A CAS advisory is returned when a feasible CAS value (other than the original CAS value) has been calculated. Such a feasible CAS implies that the FPM has predicted that the aircraft will not deviate too much in the longitudinal direction for the considered segment, if the calculated CAS advisory is followed up. From all possible values for the desired CAS, the one that is chosen is the one that differs the least from the original CAS value. Besides the value for the new CAS, some other information is also returned. This information includes the flight ID and the segment where the CAS advisory is to be followed, the time and position that the CAS advisory has to be given by the ATCo, and the point until which the advisory yields. A replan advisory is returned when the FPM predicts that, at the end point of the segment, the deviation of the aircraft will be so large in at least one direction that no feasible corrective CAS value can be determined.

Both the TP and the GHMI can use the output of the FPM GSN function. The GHMI can present the advisory to the ATCo (at least when the advisory is a CAS advisory) and the TP can generate a new feasible SPL in response to a replan advisory.

Significant Point Pass Signalling

The first function of the FPM that was developed that was not directly relevant to the 4D ATM philosophy, was the signalling of the passing of significant points. The purpose of the significant point passing function of the FPM is to inform the human controller, or other tools, whenever an aircraft is going to pass a significant point a certain specified time ahead.

As for the calculation of deviations, for significant point passed calculations, the FPM can be set to use one of two available methods. The characteristics of these two methods are the same as the characteristics described for the deviation calculation methods. Therefore, they are not further described here. The relation between the calculation of deviations and the signalling of the passing of significant points is easily explained. A significant point is deemed to have been passed when the calculated longitudinal distance between track and that significant point becomes negative.

For the signalling of significant point passing related calculations, a number of points of the SPL can be characterised as a significant point (SP). These points are specified either by the PATs or by some other entity when the subscriptions are made to this FPM function. For example, an SP can be a TMA entry point, marked by the AM. Additionally, the flights for which the SP passing messages have to be calculated have to be specified. Furthermore, in most cases, the PATs or other entities that have subscribed to SP messages want to be informed if a certain flight is going to pass a significant point within a certain time period. This time period is called the "time before" period and its value also has to be specified.

When the FPM has determined that an aircraft has passed the time before period of a significant point that is marked for that specific flight, the FPM generates an SP passing message. This message contains information about the significant point concerned (position co-ordinates), the flight considered, and the time before period.

One way of using this function of the FPM is illustrated in Figure 2. In this illustration, a flight (KLM441) is due to enter the TMA in 24 seconds. The time before period is set to 30 seconds. The message 'KLM441 enters TMA' appeared when the flight was less than 30 seconds away from the TMA entry point.

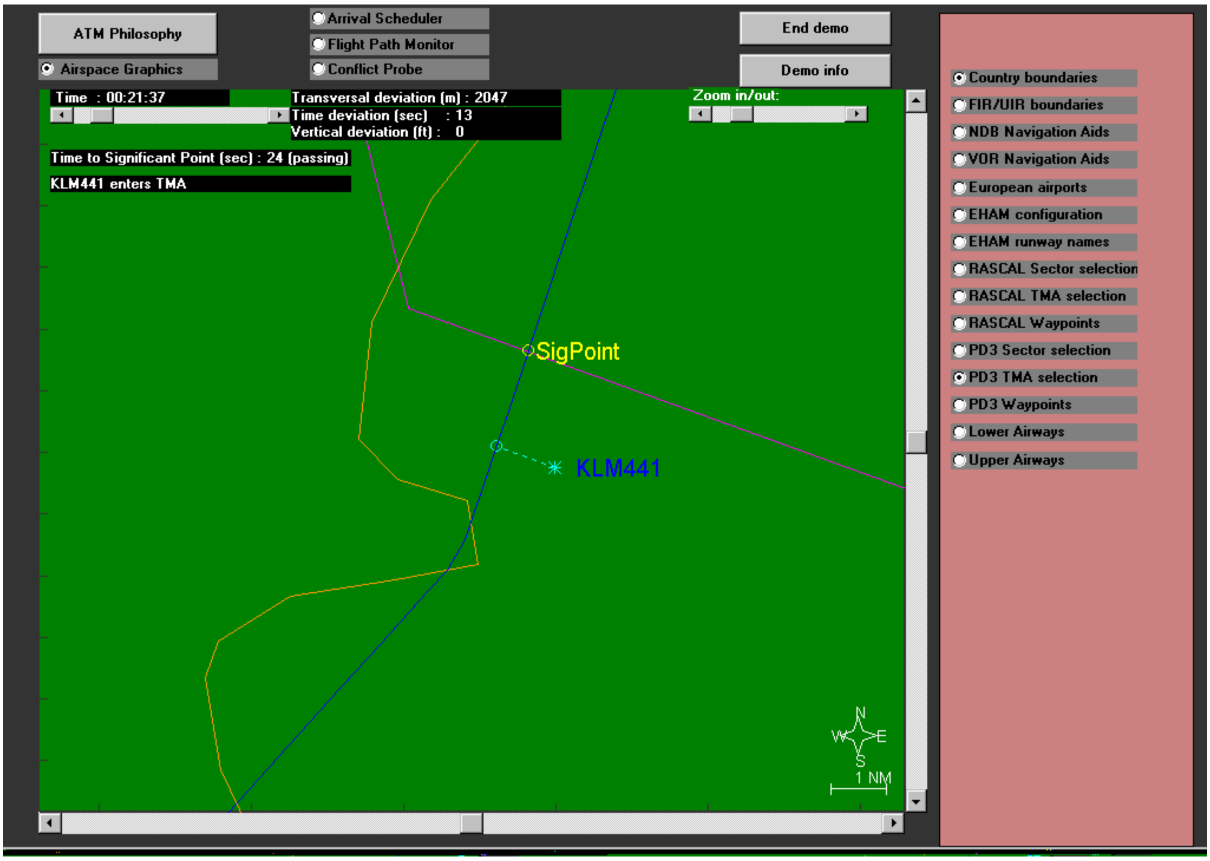

Figure 2 Illustration of the significant point pass signalling using an experimental HMI

Specific PATs that can use these SP pass messages are the AM and the DM.

Progression Reporting

The second function of the FPM that was developed that was not directly necessary for the 4D ATM philosophy, is the reporting of progression. The purpose of the progression reporting function is to inform either the human controller or other tools where aircraft are flying with respect to their planned flight path.

For the calculation of progression information, a track has to be compared with the correlated SPL. The progression reporting function works as follows. First, it is determined if the flight has started or not. This is done in the FPM by determining if the first SPL point has been overflown or not. If the flight has started, the following progression information is returned: the time at which the last overflown SPL point was passed, the details of the last received track, and the details of the last SPL point that was passed.

The TP can use progression information if it has to generate a new feasible SPL. The progression information is then used to optimise the calculation process by causing all SPL points that have already been overflown to be ignored. Also, the simulation platforms at CENA (DAARWIN) and EEC (ESCAPE) can use the progression information.

2.2. CONTEXT DESCRIPTION

This section describes both the external entities that are relevant to the FPM and their interfaces.

The basic functions of the FPM were explained in section 2.1. To achieve these, the FPM uses System Plans (SPLs) and tracks.

Depending on the outcome of the FPM functions, the server side of the FPM undertakes some actions. When a SPL has become infeasible or the FPM has predicted that a SPL will become infeasible (either because the aircraft is outside its large deviation tube or because the aircraft does not have the performance capabilities to comply with the SPL), the FPM requests that the planned trajectory be re-planned. Before an SPL becomes infeasible, it may be helpful to give the aircraft some corrective navigation advisories; this procedure is called ground supported navigation. Moreover, the FPM signals each time that an aircraft has passed pre-defined significant points, which, generally, are either waypoints or constraint points (such as Top of Descent) on the SPL. Finally, the FPM reports the progression of aircraft relative to the SPLs. Progression information contains, amongst other items, the last overflown SPL point.

Which of the PATs or other ATC entities are informed or signalled is scenario dependent.

Following the client-server paradigm, the FPM performs its task autonomously. To perform its functions, the FPM acts as a Client that calls different ATC simulation platform services and PAT services. Clients use the information of the FPM, either by accessing the FPM data area (an action initiated by the client) or by being informed by the FPM (an action initiated by the FPM). In both cases, the FPM acts as a Server.

2.2.1. Sub-system Terminators

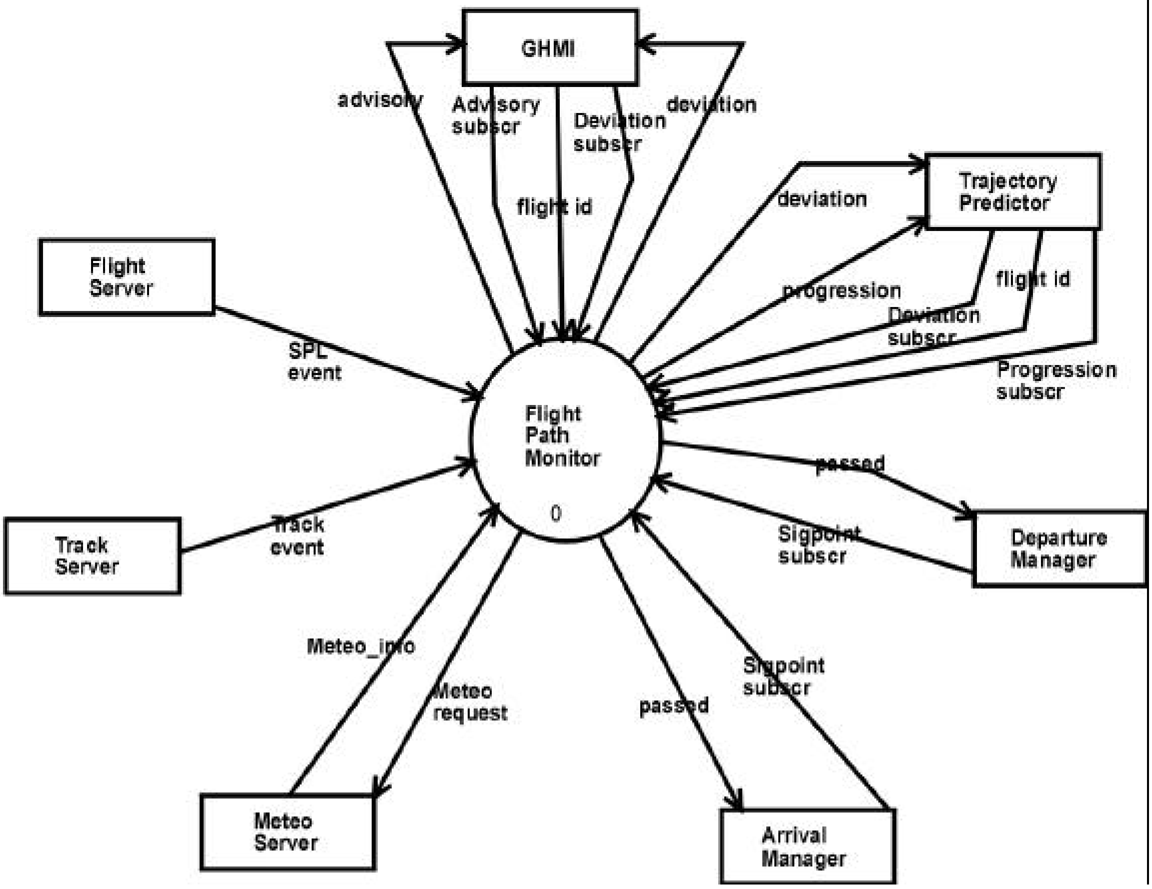

Figure 3 Context diagram of the FPM

For the description of the context of the FPM, the Yourdon environmental model is used (see ref. [17]). Figure 3 indicates the entities that are external to the FPM. The FPM itself is drawn as a circle (Yourdon: process 0). External entities that communicate with the FPM are drawn as boxes (Yourdon: terminators); they must be regarded as fixed entities in the environment of the FPM. Data flowing to and from the FPM are shown as arrows that indicate the direction of data flow.

For detailed descriptions of the architecture and the interfaces of the FPM, see refs. [18] and [19].

The list of external entities and external interfaces is a generic one. On different ATC simulation platforms, the functionality of the servers may differ slightly. The external entities that are identified with tools in the PATs cluster are the TP, AM and DM.

The following sections describe the entities that provide input to the FPM (the servers) and the entities that use the outputs provided by the FPM (the clients) respectively.

One external entity has been left out of the description. Input data may be supplied by, and output data may be supplied to, the researcher or supervisor of the simulator, e.g. parameters to examine different settings will be of interest to the researcher. However, since these parameters do not influence the functional behaviour of the system, it was decided to represent them internally in the FPM and to avoid communication to external observers to the system in this phase of the design.

2.2.2. Sub-system Inputs

The FPM has to be provided with the data that is needed to generate information on possible deviations, to provide navigation support, to signal significant point passing, and to report progression. All input information is obtained from the ATC simulation platform. The following ATC simulation platform servers are identified: the System Plan server, the Radar server, and the Meteo server.

- The *System Plan Server* deals with all the system plans of the ground system. It maintains all 4D-tube data for the system. It provides the FPM with all the SPLs within the simulator that are within the area of interest.
- The *Track Server* deals with tracks. It provides the FPM with track information on all the aircraft of interest.
- The *Meteo Server* deals with the meteorological information (such as wind speed and direction, and temperature). It provides the FPM with the best estimates of the current (nowcast) and future (forecast) meteorological conditions.

2.2.3. Sub-system Outputs

Output from the FPM is deviation information on SPLs, of which the most interesting is the message that an SPL has become infeasible (i.e. that there is a large deviation in at least one direction). Additionally, the FPM provides navigation support to aircraft that are non-4D equipped. Furthermore, the FPM signals when an aircraft passes pre-defined significant SPL points and reports the progression of each aircraft with respect to its SPL.

It is believed that the following entities could benefit from FPM information:

- The *GHMI* of the Air Traffic Controller.
- The *TP,* producing predictions of aircraft trajectories and information about the reliability of the predicted trajectory.
- The *AM,* providing assistance to the controller in handling approaching traffic.
- The *DM,* providing optimised departure schedules and advisories to the departure controllers.

2.3. DEVELOPMENT PROCESS

2.3.1. History of Tool Development.

The development of the Flight Path Monitor was by means of a stepwise progression through a series of PDs. PD/1 took place in late 1995; PD/2 took place in June 1996 and PD/3 took place in 1998.

PD/1, hosted by NATS, was an en-route scenario. An initial version of the FPM was developed and integrated with other tools within a framework called CMS. The scope of the FPM was to detect deviations of aircraft from their planned trajectories. An initial algorithm for this deviation detection function was developed by NLR. The algorithm and the implementation of this algorithm were tested for one scenario.

PD/2, hosted by DLR, was a TMA scenario. The algorithm of the initial deviation detection function of the FPM was used in the development of a second FPM function, namely signalling when predefined significant points have been overflown. This function was developed at the request of the developers of the Arrival Manager. The TMA entry points are defined as significant points by the AM.

PD/3 was a multi-sector scenario that was hosted by NLR, EEC, and CENA. This scenario included full route of aircraft from take off to touch down. In addition to the existing PD/2 FPM algorithms and functions, a reporting mechanism for the progression of aircraft along their trajectories was added. This third FPM function was developed at the request of CENA and EEC.

Also, compliant with the role of the FPM within the 4D ATM philosophy, a fourth FPM function was integrated, namely the ground supported navigation function. This FPM function has been developed at NLR to support non 4D equipped aircraft in flying their planned 4D trajectories.

Further, for PD/3, the deviation detection and significant point passed reporting functions were improved significantly after the analysis of the results of several tests that had been executed.

2.3.2. Why it was developed that way

There are two reasons why the four FPM functions were developed as they were. The deviation detection and the ground supported navigation functions were developed so that the FPM would be compliant with the PHARE 4D ATM concept. The significant point passed and progression reporting functions were developed and integrated because they were asked for by the developers of either other tools within PATs and/or simulation platforms.

For each of the FPM functions, new algorithms were developed by NLR, because no algorithms were available before PD/1 that performed sufficiently well the FPM functions that were required to meet the requirements imposed by the PHARE 4D ATM concept. These newly developed FPM algorithms were made in such a way that the forecast benefits of using probabilistic, advanced tracker output from, for example, the ATM Surveillance Tracker and Server (ARTAS) could fully be exploited. As the performance of the FPM is highly dependent on the quality and the amount of tracker output, it is expected that, as the tracker output improves, so the performance of the FPM will increase. The numbers of false and missed deviation alerts and the number of correct navigation advisories could be used to measure this performance.

2.3.3. Dropped ideas and concepts

Initially it was the intention to investigate how a (constant) tube around a planned trajectory can be modified as function of, for example, the traffic density, the meteorological conditions and the distance to the final point of a segment of the planned trajectory. During this project however, the time and budget were not sufficient to execute this investigation besides the development and integration of the FPM.

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3. REQUIREMENTS DESCRIPTION

In this section an overview of the requirements of the PATs FPM as described in ref. [20] is given.

3.1. USER REQUIREMENTS

The human end user of the FPM is the ATCo. The ATCos role is to interpret the data that is provided by the FPM. Output from the FPM to the ATCo shall be displayed by means of the HMI. The HMI of the ATCo shall be developed in the GHMI project.

The HMI of the ATCo shall provide the possibility to present for each flight information about deviations, navigation support, messages on significant points, and progression. The ATCo shall have the possibility of selecting specific information on each flight.

Since the FPM is also used as a research tool, a separate interface for research purposes shall be provided. The HMI of the researcher shall be developed in the FPM project. The HMI of the researcher shall not interfere with the HMI of the ATCo.

The FPM shall provide a "message"-file that contains information about the cases where the FPM was not able to perform its function properly, such as after incomplete information had been received.

3.1.1. Detect deviations

The FPM shall compare the tracked 4D aircraft positions with the planned 4D aircraft positions and calculate deviations. The FPM shall make available the following deviation information (the exact details being determined by the developers of the GHMI) to the Air Traffic Controller:

a. All deviation information on aircraft with medium deviations;

b. All deviation information on aircraft with large deviations (infeasible SPLs);

c. A notification when an SPL becomes infeasible.

d. The trends of the deviations.

3.1.2. Ground supported navigation

The FPM shall provide airspeed advisories for non-4D equipped aircraft that deviate. The FPM shall send the advisories to the ATCo/HMI rather than directly to the aircraft.

3.1.3. Signal significant point pass

The FPM shall notify the Air Traffic Controller, and other entities that have indicated their interest, whenever an aircraft passes a significant point.

3.1.4. Report progression

The FPM shall report the progress of aircraft along their 4D planned flight path. The FPM shall send the progress reporting messages to the ATCo/HMI.

3.2. FUNCTIONAL REQUIREMENTS

In this section, the requirements for the PATs FPM needed to support the user requirements are given. Four "high level" functions are identified, which are used to give a breakdown structure for this section: these are detect deviations, provide navigation support, signal significant points passed, and report progression.

3.2.1. Detect deviations

The FPM shall detect deviations of the actual aircraft track with that planned by the corresponding SPL.

The FPM shall detect deviations in each of the following directions:

a. Deviations transversal to the ground path covered by the aircraft.

b. Deviations longitudinal (in distance and/or time) to the ground path covered by the aircraft.

c. Deviations in altitude.

A distinction between insignificant, medium, and large deviations shall be made. An SPL that contains a large deviation is deemed an infeasible SPL.

The FPM shall determine the thresholds for detecting medium and large deviations. Thresholds between each class of deviation will be set or calculated individually per aircraft and may be changed as a function of time. Initially, the contract tube and large deviation tube defined by the TP will be used.

The FPM shall determine the trends of deviations. The trend may be increasing, steady, or decreasing.

3.2.2. Ground supported navigation

The FPM shall provide ground supported navigation advisories to non-4D equipped aircraft in the longitudinal direction if necessary. Only the en route flight phase is to be considered.

3.2.3. Signal significant point passed

The FPM shall determine when a significant point has been passed.

3.2.4. Report progression

The FPM shall report the progression of aircraft along their planned 4D flight paths. The FPM shall send the progression reporting messages to the ATCo/HMI and to other entities that have indicated their interest in the progression messages.

3.2.5. Other functions

The FPM shall provide a message whenever the FPM is not able to perform its expected function because some information has been received that is not complete.

The FPM shall provide a message when the information that is received does not conform to that that is expected, such as the case when a radar track is received even though there is no corresponding SPL available.

The FPM shall start monitoring the position of an aircraft when the first radar track has been received, provided that an SPL is available for the flight.

The FPM shall stop monitoring the position of an aircraft when the last radar track has been received, or when no SPL is available.

3.3. IMPLEMENTATION DEPENDENT REQUIREMENTS

3.3.1. Integration

The FPM shall be capable of being integrated as a tool in each of the following ATC simulator environments:

- PARADISE, available at every site (the integration is responsibility of FPM/PARADISE developers);
- PD/3 (PHARE Demonstration/3) at NLR, Amsterdam, CENA, Athis-Mons and EEC, Brétigny (integration is PD/3 responsibility).

The FPM shall be implemented in such a way that transportation to any of the above mentioned systems can be performed with a minimum of effort. To enable this, a client/server architecture will be used as far as possible. Also, the use of an ISO/ANSI specified programming language has a strong preference.

3.3.2. Client/server architecture

The FPM shall be developed according to a client/server architecture. The tool shall be developed in a manner that allows communications to take place either synchronously or asynchronously. In this way, delayed responses to requests for data made by the tool shall not cause the processing of other inputs to be delayed.

3.3.3. Platform independent

The tool shall be developed in a platform independent manner, such that there is no reliance on any underlying operating system. The developed software shall not make references to platform-specific functions.

3.3.4. Configuration data source

The tool shall be capable of accepting configuration data from servers within the simulation platform and / or a configuration file. The tool shall be developed with an Application Programming Interface (API) that allows configuration data to be passed in during initialisation. Additionally, the tool shall provide suitable routines for reading all required configuration data from a file. These routines shall be used by default. This provides the integrator with the option of reprogramming part or all of the configuration data interface so that configuration data can be obtained from other servers within the integrated system, rather than the file provided with the tool.

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4. IMPLEMENTATION

In this section it will be explained how the PATs FPM was developed and implemented. The environment in which the FPM was developed will be described. Problems that were encountered during the development as well as the reasoning behind solving the problems will be given. Finally some lessons learnt will be given.

4.1. HOW DEVELOPED

The development of the FPM was aimed at providing

- A tool box function in composition with other PATs.
- A research tool in the area of flight path monitoring.
- A tool that can be easily adapted to meet new (research) requirements.
- A tool that can be easily integrated in several ATC environments.

In order to reach the above goals, the interfaces to other PATs and servers are event based. Other entities are given the opportunity to use the FPM as a server that provides information on request. To support structured programming techniques, the tool has been implemented in Ada. Furthermore, the tool has been developed using client/server techniques.

The tool algorithms were first implemented and tested in a mathematical programming environment, called MATLAB. After verification, the algorithms were implemented in Ada. The shell around the algorithms was directly implemented in Ada.

Early in 1996, all PATs project participants received a workstation from EUROCONTROL that was to be used for PATs development. The intention was that all PHARE partners would use the same development hardware and software, making integration and software exchange between the partners easier.

To increase the possibilities to test the FPM at NLR, a mechanism was implemented that enables the FPM to be run stand-alone. This mechanism is referred to as the Fast Time Environment (FTE). In this FTE, the tool can process defined scenarios without running them in PARADISE or other specific platform.

Test scenarios can be defined and prepared either using a specific platform such as NARSIM or PARADISE, or by hand. The tool can directly read those scenarios by means of the Event Generator. Using this mechanism, scenarios can be processed at high speed since no intervention from other tools or time synchronisation is needed. This way, the tool can be tested as a stand-alone process. It is not necessary to start PARADISE or any other PATs tools. This reduces both the amount of time needed to start up the FPM as well as the amount of computer resources needed. As a result, test runs can be done in significantly less time than would otherwise be needed when testing in PARADISE or NARSIM. Representative FTE test runs could be finished within 1 minute, as opposed to similar test runs in PARADISE which would take 20 minutes or more. Still, test runs using PARADISE or another simulation platform had to be executed in order to test the correct behaviour of the tool with respect to interfaces and client/server connections.

4.2. TECHNICAL ENVIRONMENT

By using a 'remote login' or a 'telnet' session, the PATs development workstation (‘Paradise’) can be connected to from any NLR workstation or PC that is connected to the NLR computer network. The Paradise operating system is Solaris.

On the Paradise workstation, two Ada compilers were available. The Ada development environment used by all PHARE partners for their tool development was the VERDIX Ada development environment, version number 2.1. It consists of a complete set of software development tools, including a compiler, linker, and debugger. A drawback is that there was only one licence available for this compiler, so only one developer could compile his or her code at the same time. To overcome this drawback, the freely available GNU Ada compiler (gnat) was installed on the platform. This compiler could be used by an unlimited number of users at the same time. However, no debugging tools for this compiler were installed on the platform.

Other tools installed on the platform include a source code Revision Control System (RCS), a C++ development environment, and several GNU tools (such as GNU ‘make’ and ‘gzip’). Also installed on the platform was the PATs simulation platform PARADISE, which was used for testing and evaluating the PATs tools.

Since the beginning of the development of the PATs, PARADISE has been developed in parallel. The development of PARADISE progressed through various versions. Each new version of PARADISE demanded a lot of integration effort from the tools. The goal was to obtain a version of PARADISE where all tools were integrated on such that the tools could be tested and evaluated as a cluster. This goal was never reached, because of the continual changes to PARADISE.

The FPM tool was successfully integrated into different simulation platforms. These simulation platforms are NARSIM at NLR, ESCAPE at EEC, and DAARWIN at CENA.

4.3. PERFORMANCE ISSUES

During the development of the FPM, several performance tests have been executed using the facility to run the FPM stand alone (FTE). The results of these tests were such that, apart from the ground supported navigation advisory generation, no performance problems are expected for the FPM, when run in real-time systems. The performance of the ground supported navigation advisory generation proved to be a problem. It is discussed in the unsolved problems section below.

During the further development of the FPM, performance issues had lower priority than the fulfilling of the functional requirements. Until now, there have been no messages from the PDs and IOCPs that the FPM showed performance problems.

4.4. PROBLEMS FOUND AND SOLVED

Detection of deviation algorithm

A series of tests was carried out to verify the behaviour of the initial deviation detection and significant point passed algorithms. It turned out that both initial algorithms mis-behaved in situations where an aircraft with a large deviation in time combined with the presence of a turn in the planned trajectory. This was a common problem for both of these FPM functions. Modified algorithms were developed to solve this problem. Subsequently, the same series of test was executed and this problem was solved.

4.5. UNSOLVED PROBLEMS

Ground supported navigation

The ground supported navigation algorithm has been tested technically with all kinds of trajectories. These technical tests looked very promising. Also, first functional tests of this FPM function have been executed, although no proper operational HMI was available. From these functional tests, a number of important issues that have to be fulfilled for successful usage of this FPM function became clear. One of the issues is the fact that consistent aircraft performance models have to be used by the TP (to generate SPLs), the Air Traffic Server (to simulate the motion of different kinds of aircraft), and the FPM (for the calculation of ground supported navigation).

Another issue concerning the ground supported navigation, which was not been solved during PD/3, is the interaction of the FPM with the TP. This issue is important because both tools present navigation advisories to the ATCo for aircraft that are non-4D equipped. The TP presents navigation advisories at a number of SPL points, while the FPM presents navigation advisories when an aircraft deviates in time from its planned trajectory. This might lead to a (too) large number of advisories being presented to the ATCo. Also, the question then arises as to which advisory the priority should be given if two advisories are presented at the same time? Although effort has been expended in ensuring that the same format is used for the presentation of navigation advisories, no effort has been put into optimising this process.

It is forecast that the calculation of a navigation advisory may require more processing time than is available. Anticipating this, a parallel processing system was implemented. However, to improve the performance of the navigation advisories, the parallel processing mechanism should be elaborated more.

Dynamic tube determination

One of the main unsolved problems that is related to the PHARE 4D ATM concept is the determination of the dimensions of the tubes. The size of the tubes around the planned trajectories can be a function of, for example, the following:

- The Figure of merit of the SPL.
- The traffic density.
- The meteorological conditions.
- The distance to the final point of segments of the planned trajectory.

As the FPM uses the tube sizes to determine whether deviations are significant or not and, subsequently, whether to issue a deviation alert or not, this is an FPM research issue. However, no research within this area is done yet.

4.6. LESSONS LEARNT

Planning issue

The purpose of the PATs project was that the tools would be developed in a simulation environment called the CMS. If all tools had been integrated on the same simulation platform (referred to as PARADISE), test runs could have been made and the PATs cluster could have been evaluated and validated. However, the development of the simulation environment CMS was planned parallel to the development of the tools. The result of this parallel approach was that a lot of time was needed for the tool developers to integrate the tools in successive CMS versions. A lesson learnt is that the development of the simulation environment, in which ATC tools can be evaluated and validated, should be done before the development of the tools themselves start.

Consistency issue

At several places within the ATC simulation environment, aircraft performance models are used (see section 4.5). For successful development of an ATC tools cluster, these aircraft performance models have to be consistent.

Development approach

It turned out that the approach followed by PATs was a tool driven approach rather than a concept driven approach. With a tool driven approach, the tools are developed almost independently of each other. Only after some development work was finished was it noticed that some tools had incorporated conflicting functions or had overlap in functions. In general, the tools were not fully consistent with each other.

For a successful development of an ATC tools cluster, a concept driven approach would have been better. All the tools should have been developed according to common concepts, which everybody had agreed upon, and the various activities should have been geared to one another to a much greater extent than was done within this project.

5. USAGE OF TOOL

In this section, it will be explained how the PATs FPM has been used. The expected users of the FPM are Air Traffic Controllers, other PATs and the technical people who are responsible for integrating and maintaining the tool in their system.

5.1. OPERATIONAL USAGE

In this section, the operational usage of the FPM is considered, the users are considered to be a number of the other PATs and the controllers. The usage of the FPM as described in the final reports of PD/1 (see ref. [21]) and PD/2 (see ref. [22]) are given as well as the usage that is envisaged for PD/3. More information with respect to the FPM usage can be found in refs. [23] and [24].

Besides the three mentioned PD's, there have been performed a number of additional trials wherein the FPM participated. These trials were named PD/1+ (see ref. [25]), PD/1++ (see ref. [26]), PD/2+ (see ref. [27]) and PD/3 Continuation. In this section, the purposes of these additional trials and the usage of the FPM within these trials is briefly described. It has to be noted that re-integration of the FPM in PD/2+ was straightforward, as they had been used in PD/1, and their external interfaces were fairly simple (see ref.[27]).

PD/1, hosted by NATS, was an en-route scenario. The PATs that were used in PD/1 were the TP, the CP, the FPM, and the HIPS.

In PD/1, the FPM checked every radar reported aircraft position against the stored 4D trajectory for the aircraft. If an aircraft had deviated significantly in any dimension from the planned 4D trajectory, the FPM raised a deviation alert for the GHMI to display to the controller. The deviation alert provided full information on the deviation in all dimensions. However, in the PD/1 system, not all information was displayed to the controller by the GHMI.

The tactical controller was warned by the FPM (by means of a yellow circle being drawn around the radar plot on the Plan View Display (PVD)) when significant deviations were detected The controller could then intervene tactically to prevent any conflicts from occurring. However, the vertical deviation information generated by the FPM was not used in this demonstration to alert the controller. The main reason for this was that the FPM generated a large amount of (vertical) deviation alerts. The underlying reason for this large amount of deviation alerts was that there were significant differences in trajectories predicted by means of the TP and trajectories actually flown by simulated aircraft in the vertical plane. Consequently, the deviation alerts generated by the FPM were justified, however they were not feasible.

The **PD/1+** trial took place in January and February 1997 at the Air Traffic Management Development Centre, Hurn. The main aim of the PD/1+ trial was to compare workload and tool use between PD/1 and a modified PD/1 system. The trial was the culmination of the NATS PD/3 IOCP Project. The PATs used during the PD/1+ trial were the TP, the CP, the FPM and the HIPS.

The NATS **PD/1++** project was a continuation of the previously conducted PD/1 and PD/1+ trials and was specifically designed to begin the process of exploring the introduction of the PHARE tools and operational concept within alternative en-route airspace structures. The PD/1++ trial took place in late August 1998 at NATS' Air Traffic Management Development Centre, Hurn. The main aim of the PD/1++ trial was to examine the effects on controller workload, airspace capacity, quality of service and the usability of the ATC system of the introduction of alternative airspace structures and alternative operating practices. The PATs used during the PD/1++ trial were the CP, the FPM, the HIPS and the TP.

The usage of the FPM within PD/1+ and PD/1++ is the same as the usage of the FPM in PD/1.

PD/2, hosted by DLR, was a TMA scenario. The PATs that were used in PD/2 were the TP, the CP, the FPM, the NM, and the AM.

In PD/2, the FPM compared each radar position of an aircraft against the 4D position taken from the active trajectory stored in the ground system. Deviations in terms of distance in space and time were produced, at the surveillance update rate, both for further processing by the supporting tools like the Arrival Manager, and for being displayed to the controllers. Deviation messages were given regularly to the 4D Descent Manager (function to support implementation each scheduled trajectory) to decide whether the guidance mode of an aircraft had to be changed. In the PVD, a yellow circle appeared around the radar plot when a significant deviation was detected (i.e using the same mechanism as in PD/1).

In the Arrival Management Display (AMD), besides each label frame, the angle of the 'delay pointer' showed the deviation in time. A pointer pointing downwards indicated an aircraft that is early, a pointer pointing upwards indicated a delay, whereas a horizontal line indicated no delay.

The FPM also had the task of reporting when an aircraft had passed a significant point on its trajectory. Such a point was identified to the FPM by one of the other tools and the FPM alerted the relevant tool when the subject aircraft passed that point.

The NATS **PD/2+** project was designed to gain a more thorough understanding of arrival management concepts and interactions between controller positions, than had been possible during the PD/2 trial. Specifically, the aim of the project was to use the PD/2 PATs, primarily the AM, with further development to achieve full functionality. Additional enhancements included: staffed en route sectors; missed approaches; holds and arrival rates approaching runway capacity. These enhancements were to be evaluated through the ‘PD/2+ trial’, a real-time simulation on the NATS Research Facility.

The PD/2+ trial took place in September and early October 1997 at the Air Traffic Management Development Centre, Hurn. The PATs used during the PD/2+ trial were the TP, the CP, the FPM, the HIPS and the AM.

The usage of the FPM within PD/2+ is the same as the usage of the FPM in PD/2.

PD/3 was a multi-sector scenario that was hosted by NLR, EEC, and CENA. This scenario included the full route of aircraft from take off to touch down. The PATs that were used for the PD/3 trials at NLR, were the TP, the NM, the CP, the FPM, the AM, and the HIPS.

The operational usage of the FPM in PD/3 is described below:

- Detection of deviations from planned trajectory.

If a large deviation was detected by the FPM, indicating that the SPL had become unfeasible, the TP handled this information. The implication was that a new SPL had to be generated by the TP.

The executive ATCo was informed by the GHMI whenever an aircraft deviated largely from its planned trajectory. The executive ATCo handled this deviation information on his own insight.

- Ground supported navigation.

Ground supported navigation advisories generated by the FPM were not handled during PD/3.

- Signalling of a significant point passed.

If the FPM signalled that a given aircraft had passed a significant point (such as a sector boundary, a TMA entry point, or a Flight Information Region (FIR) entry point), the AM handled this information by, for example, scheduling this aircraft for a runway.

The executive ATCo was informed whenever an aircraft entered his sector.

- Reporting of progression.

The information concerning the progression of aircraft was used by the TP. This was the case when the TP had to generate a new SPL in case of a large deviation. The progression information (such as the last overflown SPL point) was then used to optimise the trajectory generation process.

5.2. TECHNICAL USAGE

The FPM tool is supplied as a set of Ada83 source files that are intended for integration into an air traffic control simulation system. To enable easy integration, a strict separation between platform specific packages and core function packages has been made. Integration teams need only change the platform dependent packages, which contain client/server mechanisms that are typical for the ATC simulation platform and conversion routines to convert platform dependent data to and from FPM internal data. The core functionality remains unchanged, thus ensuring a consistent working of the tool across all platforms.

The source code is provided with a number of Ada83 API packages that are used by system integrators as an interface between the tool and the software that the tool is being integrated into.

The source code is delivered as a single compressed file that is created using the 'gzip' and 'gtar' gnu programs, executed under the UNIX operating system. The source code should be uncompressed using the 'gunzip' program and unpacked using the 'gtar' program using a specific set of command line options. Alternatively, the standard UNIX 'tar' utility may be used.

The FPM tool is supplied with suitable 'make' files for each ATC simulation platform. It is intended that the tool should be built using the 'gmake' gnu program, running within the UNIX operating system.

The User Guide (see ref. [28]) provides a full description of the technical usage of the software.

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6. RESULTS

In this section, the results of the PDs and the trials and test runs that the PATs FPM was involved in will be shown. The results will be compared with what was expected from the original concept at the start of the PHARE Programme and the achievement of the tool will be discussed.

6.1. IOCP TRIALS AND TEST RUNS

The following FPM results were obtained during the NLR PD/3 IOCP on the integration of en-route and Extended TMA (ETMA) traffic handling in a 4D ATM environment. For an extended presentation of the IOCP results, the reader is referred to ref. [29].

The two available FPM functions that were tested during the IOCP trials were the deviation detection function and the significant point passed signalling function. The FPM was used to monitor the following:

- Deviations from planned trajectories. The start, update, and end of deviations were monitored by the FPM. Deviation information comprised the sizes and relative sizes for the transversal, longitudinal and vertical components.
- Significant point passed. The FPM signalled and reported whenever an aircraft had passed a pre-defined significant point. If an aircraft had passed a significant point, the information comprised the co-ordinates of significant point and time before period.

The FPM server subscribed to be notified of the occurrence of a number of NARSIM SPL and Track events so that it could perform the two functions mentioned above. Other servers were able to subscribe to the FPM server to receive these events.

Problem areas:

The following problems were encountered during the IOCP:

The display of deviation data by the GHMI was limited to a yellow deviation indicator around the aircraft symbol. The GHMI provided no further details, such as the relative size or trend of the deviations, thus leaving the user to assess the deviation by reference to the aircraft's ADFL or a trajectory in the HIPS.

The modelling of the flights of 4D equipped aircraft in the IOCP was not ideal, and so a greater number of significant deviations were detected than had been expected.

Comment FPM development team:

The trials indicated how much other parts of the system relied on the FPM. No problem that was indicated by these other parts of the system was determined to be due to the FPM.

6.2. PHARE DEMONSTRATIONS

In all PDs, the FPM activities could only be directly seen by means of the GHMI. In the background, the FPM delivered a lot of information to other tools that benefited from that information. The results that are available from the various demonstrations are based on the FPM information that was seen via the GHMI. Most comments that were received from the controllers concerned the way the information was shown via the GHMI. The GHMI project was a different project to the PATs project. Since no major problems concerning the FPM have been received from the PDs, it is assumed that the FPM functions adequately as it was used.

In PD/1, only the deviation information was shown by the GHMI. If a large deviation was detected by the FPM, a yellow circle around the track indicated this event. A tactical controller could then respond to this event. From the PD/1 Final Report, it is not clear whether and how the tactical controller reacted to this event.

In PD/2, the deviation information was made known by means of the GHMI as was done in PD/1. In addition, time deviations were shown in the AMD. In the final report of PD/2, there are no specific comments from controllers on the way in which the deviations were shown by the GHMI.

In PD/3, the main comment of the controllers comprised the deviation information that was generated by means of the FPM. It turned out that controllers do not handle large deviations (yellow circles) if the specific aircraft is not in a (predicted) conflict situation. In the second place, controllers find it annoying when, for one aircraft, alternately a yellow circle appears and disappears. Such situations occur when aircraft are moving closely to the large deviation tube. Finally, it became clear that the FPM deviation information is not correct for aircraft in a hold situation. The reason for this is that the SPL for an aircraft in the hold is not updated. Consequently, the FPM generates deviations in time.

In PD/2+, the FPM worked with no real problems, with the exception of the significant point functionality. This functionality was only used by the new missed approach handling code added into the AM. The significant point events appeared, on occasion, to be raised in advance of the aircraft passing the significant points referred to, and for this reason, the missed approach functionality could not be demonstrated consistently. This problem was not considered to be a high priority in PD/2+ and hence was not addressed fully during the PD/2+ project.

Comment FPM development team:

The reason why significant point passed messages appear in advance of the aircraft passing the significant is that a time before period is taken into account in the significant point pass functionality. The most likely solution for this specific PD/2+ problem is to set the time before period for the specific significant point to zero seconds.

6.3. ACHIEVEMENT OF CONCEPT

There are four key operational concepts described in section 2.1.2. In this section, it will be explained which of the operational concepts have been fully achieved and which of the operational concepts have not been fully achieved. The reasons why an operational concept has not been fully achieved will be given.

6.3.1. Areas achieved

During the three PDs, namely PD/1, PD/2 and PD/3, the FPM made use of various operational concepts, listed in section 2.1.2.

If the output of the deviation detection function was a large deviation, this was indicated by means of a yellow circle being drawn around the label of the aircraft concerned. There were no comments or questions on this from controllers. Therefore, the concept as in the context of deviations detection has been fully achieved.

If the output of the significant point passed signalling function showed that a significant point had been passed, other tools that had subscribed to this event used this. There were no comments or questions on this from controllers. Therefore, the concept as in the context of signalling when significant points are passed has been fully achieved.

Other tools that had subscribed to this function used the output of the progression reporting function. There were no comments or questions on this from controllers. Therefore, the concept as in the context of reporting progression has been fully achieved.

6.3.2. Areas not fully achieved

As it was decided not to use the ground supported navigation advisories of the FPM, this concept has not fully achieved. Reasons for not using these advisories are given in section 4.5.

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7. CONCLUSIONS AND RECOMMENDATIONS

In this section, the main conclusions are drawn and recommendations for further research are given.

7.1. CONCLUSIONS

The development of the Flight Path Monitor was by means of a stepwise progression through a series of three PDs. Since these three demonstrations had put the emphasis on different areas of ATC, the FPM development team have developed and integrated different algorithms.

The version of the FPM that participated in PD/1 consisted of algorithms and interfaces for the deviation detection function.

The version of the FPM that participated in PD/2 included, in addition to the functionality of the PD/1 version, the signalling of significant points function as this had been requested by the developers of the AM

The version of the FPM that participated in PD/3 included, in addition to the functionality of the PD/2 version, the function providing ground supported navigation. For this function, results from earlier NLR studies were used. Furthermore, at the request of the developers of other PATs and simulation platforms, the reporting of progression function was also added.

In all PDs and IOCPs, the FPM activities could only be seen via the GHMI. Underneath the GHMI, the FPM delivered a lot of information to other tools that benefited from that information. The results, that are available from the various demonstrations, are based on only FPM information that was seen through the GHMI.

In all PDs, PD/1 to PD/3, the FPM has had an important function without which the system would not have been complete. The latest version of the FPM has been integrated on three platforms, namely NARSIM at NLR, ESCAPE at EEC, and DAARWIN at CENA. Also, a stand-alone version of the FPM has been developed so that stand-alone tests can be done.

The development of the FPM was aimed at providing

- A tool box function in composition with other PATs.
- A research tool in the area of flight path monitoring and flight plan conformance monitoring.
- A tool that can easily be adapted to meet new (research) requirements.
- A tool that can easily be integrated in several ATC research simulators.

The above goals were set before the development of the FPM. Except for the first goal, every goal has fully been reached. For the first goal, it has to be mentioned that the provision of ground based navigation advisories by both the FPM and the TP is not the optimum solution. Using the current solution might lead to a too large number of navigation advisories. Examples of having realized the third goal are the integration of the functions reporting of progression and signalling significant point passing besides the two main FPM functions.

With respect to the development path of the FPM, the following can be concluded. The purpose of the PATs project was that the tools would be developed in a simulation environment called CMS. If all tools had been integrated on the same simulation platform (referred to as PARADISE), test runs could have been made and the PATs cluster could have been evaluated and validated. However, the development of the simulation environment CMS was planned parallel to the development of the tools. The result of this parallel approach was that a lot of time was needed for the tool developers to integrate the tools in successive CMS versions. A lesson learnt is that the development of the simulation environment, in which ATC tools can be evaluated and validated, should be done before the development of the tools themselves start.

It turned out that the approach followed by PATs was a tool driven approach rather than a concept driven approach. With a tool driven approach, the tools are developed almost independently of each other. Only after some development work was finished it was noticed that some tools had overlap in functions.

For a successful development of an ATC tools cluster, a concept driven approach would have been better. All the tools should have been developed according to common concepts, which everybody had agreed upon, and the various activities should have been geared to one another to a much greater extent than was done within this project.

7.2. RECOMMENDATIONS

The PHARE project has generated a lot of information that can be used as input to other projects in the field of ATC. Lessons can be learnt from the various development projects that were done in the PHARE project. For example, new tool developments should be done on a stable platform. Issues that are recommended for further research related to the development of the FPM mainly lie in the field of automatically generating ground supported navigation advisories.

Ideas in the field of corrective navigation support by ATC to aircraft that are non-4D equipped in a 4D ATM environment, have to be worked out further. To date, for the ground supported navigation a lot of technical tests have been performed. The results of these tests were very promising. Within the PATs project however, no functional tests in this area have been performed. It is strongly recommended that such functional tests be performed to get answers on the following questions. When are automatically generated navigation advisories desirable or even necessary? How should ATCos handle advisories? What is the (changed) role of the ATCo in the handling of advisories? What about the feasibility of advisories? These are just a number of interesting questions in this research area. Definitely, there are many more items with respect to this subject that have to be investigated.

Another research issue, that was not exploited to the full extent within the PATs project, is the concept of dynamic tubes. During the PATs project, only constant values for tubes have been considered. Although the values for the sizes of the tubes might differ for different flight phases, the sizes of the tubes were not adapted to such things as traffic density, meteorological conditions, or the figure of merit of the SPL. Research in this area is essential in further developing the 4D ATM concept.

8. MAIN ABBREVIATIONS AND ACRONYMS

3D	3 Dimensional
4D	4 Dimensional
AM	Arrival Manager
AMD	Arrival Manager Display
ANSI	American National Standardization Institute
API	Application Programming Interface
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ARTAS	ATM Surveillance Tracker and Server
ATM	Air Traffic Management
CAA	Civil Aviation Authority
CAS	Calibrate Airspeed
CENA	Centre d'Etudes de la Navigation Aérienne
CMS	Common Modular Simulator
CP	Conflict Probe
CT	Co-operative Tools
DAARWIN	Distributed ATM Architecture based on RNAV Workstations Intelligent tools and Networks
DFS	Deutsche Flugsicherung GmbH
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
DM	Departure Manager
DRA	Defence Research Agency
EEC	EUROCONTROL Experimental Centre
ESCAPE	EUROCONTROL Simulation Capability and Platform for Experimentation
ETMA	Extended Terminal Manoeuvring Area
EUROCONTROL	European Organisation for the Safety of Air Navigation
FIR	Flight Information Region
FPM	Flight Path Monitor
FMS	Flight Management System
FTE	Fast Time Environment
GHMI	Ground Human Machine Interface
GSN	Ground Supported Navigation
HIPS	Highly Interactive Problem Solver
HMI	Human Machine Interface

IOCP	Internal Operational Clarification Project
ISO	International Standardization Institute
LVB	Luchtverkeersbeveiliging (Air Traffic Control, The Netherlands)
NARSIM	NLR Air Traffic Control Research Simulator
NATS	National Air Traffic Services
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory, The Netherlands)
NM	Negotiation Manager
PARADISE	Prototype of an Adaptable and Reconfigurable ATM Demonstration and Integration Simulation Environment
PAT	PHARE Advanced Tool
PC	Personal Computer
PD	PHARE Demonstration
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
PVD	Plan View Display
RCS	Revision Control System
RLD	Rijksluchtvaartdienst (Department of Civil Aviation, The Netherlands)
RPC	Remote Procedure Call (also SPC: Synchronous Procedure Calls)
SP	Significant point
SPL	System Plan
STNA	Service technique de la navigation aérienne, France
TMA	Terminal Manoeuvring Area
TP	Trajectory Predictor

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