VITAL – AN ADVANCED TIME-BASED TOOL FOR THE FUTURE 4D ATM ENVIRONMENT

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Abstract

The number of aircrafts will increase in the future. It is commonly agreed that in several high density traffic areas like central Europe the capacity limits are nearly reached. A solution can be seen in 4-Dimensional (4D – x, y, z-coordinates, time) Air Traffic Management (ATM). As no revolution in ATC will take place, the close future 4D ATM system will be human centred. The human controller will still have to construct a mental picture of the air traffic for his own understanding. This mental picture is required for anticipating and predicting the movement of the aircrafts. The quality and speed of the construction of the mental picture depends largely how on the information is presented. Today, the presentation of the information is well adapted to the current working methods.

A future 4D ATM system requires more complex information. Presenting this information with current methods, will increase the mental load for controllers to create their mental traffic picture. Further mental demand for the controller will either decrease his quality and/or his speed and therefore the working capacity. To overcome these constraints for a future 4D ATM the EUROCONTROL Experimental Centre (EEC) searched a new method to present this information to the en-route controller. Therefore information from Radar and flight plans are correlated on the common time base and presented in a time-line. The concept, called ‘Vital’ represents the information in form of a table, the en-route MONitor (EMON). Each row of the EMON represents the artefact of an aircraft path related to the sector. The controller may place this artefact freely at any line of the EMON to support his mental representation of the sector. The innovation of this representation is the combination of digital and analogue information in the same artefact. The analogue information is presented on a time-line which is progressing in real-time. The size of the time-line window is common to all artefacts. The time-line information represents the past, actual and extrapolated future positions of an aircraft in the route network of the sector. The digital part of the artefact contains fix information from the flight plan and updated flight parameters. Future 4D concepts will include new features like route offsets, 4D rendezvous points, station keeping of two or more aircrafts, delayed or locally fixed climb/descend orders, including uncertainty. Furthermore displaying an envelope for possible speed variations are included in the analogue time-line representation without overloading the display and increasing the complexity significantly.

Introduction

The Problem

All current ATC systems are centred around the human controller. The technical equipment provide the human with all the required information to do the job. The information is based on flight plan data (mainly last update 2 hours prior to aircraft departure) and real-time information from technical sensors (Radar, Secondary Surveillance Radar - SSR, Direction Finder, …). There are some features to support the controller work. I.e. flight plan and Radar data are correlated for the Radar labels, or from actual and past Radar information a hypothetical aircraft behaviour for the near future is estimated to calculate Short Term Conflict Alert (STCA). Common to all actual tools is, they are based on past information. The technical systems have no knowledge of the future aircraft behaviour (climb, descend, turn, speed) caused by the pilot and the ATC instructions. Today in high density traffic areas, controller’s mental capacity limits the increasing traffic flow. It is commonly agreed that future ATM (Air Traffic Management) systems have to overcome this gap.

The current ATC traffic display permanently shows snapshots of the real traffic in a 2D (x, y - coordinates) picture. The represented aircraft symbols have a label attached with the identification and the flight level number (z -
coordinate). Mentally, the human controller has to scan permanently all these level numbers to create in his mind a virtual 3D picture. Therewith he predicts the movement of the aircrafts in time to anticipate future situations. This requires high mental effort. This is the reason why humans mental resources limit the number of aircrafts handled simultaneously in a sector. In our days, the controllers are mainly too busy to anticipate potential critical situations with in a reasonable time frame (~10-15 min.) and so they react on upcoming problems in a short time frame of some minutes.

The EUROCONTROL strategy paper ‘ATM Strategy for the Years 2000’ [1] and the MIRTE Corporation paper ‘Future Vision of Globally Harmonized National Airspace System with Concepts of Operations Beyond Year 2020’ [2] plan, beside others, to introduce 4D ATM systems to increase capacity. Avionic industries are conform with ATC as the 4D Flight Management Systems (FMS) for the cockpit are reality today. It is obvious that a future 4D ATM system requires more complex information. It includes control concepts with new features like station keeping of two or more aircrafts, route offsets, rendezvous points, delayed or locally fixed climb/descend order including uncertainty and so on.

A Proposed Solution

Up to now flight plan information was generally presented on separate paper strips on dedicated strip bays. The tendency in ATC is to go towards a stripless environment. In a stripless environment the flight plan information is mainly added to the Radar label, which is growing up from two lines to up to six lines. On some items in these lines the complete information is available by clicking, only. Therefore, conventional information displays of a controller working position become more and more crowded with information. In such a situation, the controllers need either more time to create their mental picture or they have to reduce the ‘focus’ of their picture.

R. Harper et al classified in their study ‘The Functionality of Flight Strips in ATC Work’ [3] the flight strips (flight plan) as the dynamic part and the Radar display as the static part of controllers mental traffic representation. In a stripless environment these dynamic parts of the control picture are reduced and are available through specific mouse clicks, only.

Vital proposes to support the controller in the en-route environment with a new concept for the presentation of the information. Vital represents flight plan information correlated with Radar information in form of a table, the EMON. Each row of the EMON represents the artefact of an aircraft path related to the sector. The innovation of this artefact is the combination of digital and analogue representation of information. Most of the digital information is coming from the flight plan. Others, like flight level and speed are dynamically updated from SSR data. The analogue information is time-based and is progressing in real-time. It is representing on a time-line the path of the aircraft through the sector. The representation of past, actual and future aircraft positions are based on extrapolated Radar information. The controller may place this artefact freely at any place of the EMON to support his mental representation of the sector. The advantages of an analogue information representation for humans are much simpler comprehension and quicker understanding of the situation.

Future 4D concepts including new features like 4D rendezvous, route offsets, station keeping of two or more aircrafts, delayed or locally fixed climb/descend order including uncertainty and displaying an envelope for possible speed variations are included in the analogue time-line representation without overloading the EMON and increasing the complexity significantly.

Vital’s Time-Line Technique

Vital’s innovative technique is based on the principle of presenting flight plan data on an analogue time-line. This technique was proposed in the early 1970s by Nobel and Sperandio [4] for en-route centres. In this approach the flight path information of an aircraft was no more represented in boxes with beacon names and its estimated time over this beacon on the strip. They presented the flight path as time-line calibrated in minutes. Figure 1 shows an example of a flight plan in time-line representation.
Figure 1. Flight Plan Information in Analogue Time-Line Representation

On the left hand side is the fix time reference line representing the actual time. The time-line is represented by dots for the minutes 1, 2, 3, 4, 6, 7, 8, 9 and rectangles for the minutes 5 and their multiples. This time-line is moving permanently in real-time to the left. When reaching the left edge of the time window, the information disappears and is filled with new upcoming information on the right edge of the window. The beacons and waypoints are shown in their chronological order of the flight plan. A black time spot, accompanied by the name, indicates the estimated time over this named navigation point.

The example from Figure 1 represents the following information for the sector controller: the time-window shows information 4 minutes in the past and 21 minutes in the future. Currently it is 10:08, the aircraft passed DOM (Dortmund) 2 minutes ago and is now halfway to OSN (Osnabruck) a major crossing point of the sector, it is estimated over HAM (Hamburg) at 10:23 and over TOSPA at 10:28. The controller knows from experience that the aircraft uses the route UM170 until Osnabruck and then strait on to the ‘one way’ route UP605 to the north, at Hamburg there are crossing several routes (sector knowledge).

The identification of conflicts with the Vital EMON will be done by the comparison of vertical alignments of current and extrapolated future aircraft positions over the navigation points represented on the time-line (Figure 2). Aircrafts flying the same level (or crossing) may conflict by:

- Opposite traffic; two flight plan artefacts contain the same beacon/waypoint names – one is in reverse order – and there is a vertical alignment/overlapping of a common segment (Figure 2, time-line 1, 2).
- Merging; the same single beacon/waypoint name is vertically aligned of crossing flight plan artefacts on the Vital tool (Figure 2, time-line 3, 4).
- Over speeding; flight plan artefacts with the same beacon/waypoint names of a route segment, but with different time intervals on the time-line and the vertically alignment of common segment (Figure 2, time-line 2, 3).

Figure 2. Conflict Identification by Vertical Alignment of Common Time-Line Information (Introducing Colour for Sector Boundaries)

The idea of Nobel & Sperandio [4] to use an in real-time updated time-line approach for en-route strips was picked up and realised from the ‘Innovative Business Unit’ of the EUROCONTROL Experimental Centre as the DynaStrips project. Early human factor evaluation results have been presented by Grau et al [5]. In conclusion they stated: ‘DynaStrips presents data to the controllers in a form which enables them to construct a more relevant mental image of the air traffic in a shorter time. By facilitating the controllers’ mental image, it allows them to work with greater anticipation, making it possible to manage heavy workloads more easily and safer.’

Hypothetically the EMON-Vital with its time-line approach will have similar benefit from the digital/analogue representation of data to the en-route controller. Vital could be an easy, natural, self-explaining interface for new ATC concepts like Controller Pilot Data Link Communication (CPDLC) and 4D ATM with new features like station keeping of two or more aircrafts, route offsets, delayed or locally fixed climb/descend including uncertainty, speed control and so on. Mouse clicks, ‘drag and drop’, recognition of simple gestures with the mouse, selection via menus are used by the interface.
**Vital’s Artefacts**

The EMON-Vital is representing in each line information from one aircraft only. This artefact represents the data in digital and analogue way. The data are extracted from flight plan information and Radar sensors (Remark: in the sense of this paper, Radar data means: aircraft’s position data, flight level information and the identification information, without regard to the technical source of the information). A generic aircraft data set is presented in Figure 3 and contents: the aircraft call-sign, airport of departure (D-AP), arrival airport (D-AP), aircraft type (AC-type), the actual speed, the actual flight level (AFL), the analogue time-line data, the exit flight level (XFL) and the exit way point (WP-ex).

The aircraft data sets are grouped in an EMON. The controller handles the data set in the monitor with the mouse. Moving a data set in the EMON, is done by a ‘handle field’ represented by the call-sign. Data displayed in digital form (call-sign, departure airport, arrival airport, aircraft-type, sector entering waypoint, exit waypoint and exit flight level) coming from flight plan are fix. The digital data of speed and current flight level (FL) are extracted/calculated from Radar sensor data. The call-sign field has a coloured diagonal bar in the background to indicate east-bound (right up; see Figure 3) and west-bound (left up) traffic. In the time-line window the pathway of an aircraft inside the sector boundaries is shown with a different colour (see Figure 3).

<table>
<thead>
<tr>
<th>Call-sign</th>
<th>D-AP</th>
<th>A-AP</th>
<th>AC-type</th>
<th>Speed</th>
<th>AFL</th>
<th>XFL</th>
<th>WP-ex</th>
</tr>
</thead>
</table>

**Figure 3. Vital Aircraft Data Set**

**Vital in a 4D Environment**

Current ATM research and developments are going towards 4D control of the aircraft trajectory. Actual aircraft FMS are able to support and execute exactly these 4D trajectories. Ground air data link communication will be one of the cornerstones of a future 4D ATM. The complexity of the 4D control will be a challenge for the controller. Vital with its time-line approach could help the controller to reduce the complexity of the 4D trajectories for human mental understanding and supporting his prediction. Due to its time-line, Vital is especially well adapted to support humans 4D medium/long term conflict detection and resolution in a graphical way. In a future 4D ATM environment Vital could support all innovative R&D concepts like route offsets, Airborne Separation Assurance System (ASAS), speed control, delayed or locally fixed climb/descend including an envelope of uncertainty. Vital could act as interface for the up linking of ATC instructions via CPDLC. Most of the examples in this paper show the time-line part of the aircraft data sets, only. The annex shows an example of an EMON–Vital. The example is constructed from traffic of the Munster-sector (MNHI) of the EUROCONTROL Upper Area Control (UAC) Maastricht.

**Route Offset**

Aircrafts on an offset fly on a line parallel to route with a fixed distance of i.e. 5 NM. The offset may be right hand or left hand of the route. Similar to aircraft position lights, red dots of the time-line indicates a left offset and green a right offset. Dragging a time-line dot or square slightly up or down, pops up a window to select the offset from this time on. Multiple offsets could be showed by their number in or instead the time-line squares. Figure 4 shows the different offset representations:

- (A) – flying left offset until half way OSN – HAM;
- (B) – flying right offset starting halfway DOM – OSN;
- (C) – popped up offset window, offset starts at time of top left window corner;
- (D) – aircraft is flying on second left (10NM) offset inside of the sector boundaries.
Climb/Descend

Known flight level change of the aircrafts are indicated by the Vital tool. A diagonal blue strip indicates the estimated level change area. The different time length of the strips are related to uncertainty of the manoeuvred execution. The angle of the strip is depending from the rate of climb/descend and the number of FL to move. The final CFL (Cleared Flight Level) is indicated at the right end of the strips.

Figure 5 shows two examples:

(A) – the aircraft will start at OSN with the descend to FL 330; to reach FL 330 will takes about 2 minutes from the actual FL indicated in the data set field AFL.

(B) – the aircraft will now climb to FL 250 from AFL; to reach it in one minute at the sector entry. Another climb is planed in the 4D trajectory of this aircraft to leave the sector at flight level 310. This climb will take about 4 minutes with another 3 minutes of uncertainty estimate for this operation.

Clicking on the AFL field of a aircraft data set pops up a selection window for the input of CFL changes. After selection of the level change direction climb or descend, relevant FL proposals appear. Thereafter a special rate of climb/descend may be specified. The input will be terminated by indicating the time or local area for the level change.

Station Keeping

Another future ATM concept is the transfer of responsibility from the ATC to aircrafts and is known with the name ASAS (Airborne Separation Assurance System). Therefore aircrafts flying at the same time, altitude, able to fly the same speed, on the same route (or segments of a route) may keep station behind another aircraft. Each aircraft following another will be instructed and get the responsibility to keep station with a fix safe distance to the previous aircraft. Several such station keeping aircrafts may fly in line.

Vital is able to indicate a station keeping ‘train’ of aircrafts in a natural way on the time-line (Figure 6). The red bar represents the time segment on the time-line which is attributed to the ‘train’ of aircrafts. In the example the 3 aircrafts occupy about 8 minutes of time space. The controller handles this ‘train’ as one unit which is represented for him by the first aircraft in line and its aircraft data set.

To create a train, a station keeping aircraft data set has to be connected to an aircraft data set flying at the first place of this new or existing train. The data set of the added aircraft is hidden from the EMON Vital for the lifetime of the train. If an aircraft leaves a ‘train’ its data set appears again on the EMON. To connect an aircraft to another the data set is picked up by its handle (call-sign field)
and released over the time-line field of the first aircraft in ‘train’. Vital creates now the bar or add the aircraft to an existing ‘train’. The call-signs of the added aircrafts appears in the bar representation in their time related order.

For extracting a station keeping aircraft, its call-sign inside of the red bar is picked up with the mouse and moved outside of the time-line field of the first aircraft in train and released. Now its hidden data set is shown again and may be placed accordingly.

**4D Rendezvous**

Advanced aircraft FMS have 4D navigation facilities. The FMS can give the time reaching a 3D navigation point on its way for the programmed flight path of the aircraft. This prediction is very exact as it is based on real flight parameters, like actual aircraft mass, air temperature, engine parameters, local air speed and so on. Future FMS will go a step further and accept reasonable 4D constraints on the flight path and will fulfill these constraints by modifying the aircraft speed. *Vital* shows these 4D constraints as 4D rendezvous points. The black time point of the time-line associated with the name of the navigation point is, in the case of a 4D rendezvous, replaced by a yellow diamond.

Creating a new 4D rendezvous point is done by a double mouse click on the black time point associated with the name of the waypoint (Figure 7). At this waypoint a small menu appears for the input of further data for the 4D rendezvous (Figure 7 for waypoint OSN). With a double click on a diamond the rendezvous data may be modified in a similar way (Figure 7 for waypoint HAM).

**Speed Envelope**

*Vital* gives the possibility to indicate possible time envelopes over the next waypoints of the timeline. These earlier or later arrival of the aircraft over future waypoints are based on estimated safe speed variations (related to aircraft type, flight level). Figure 8 shows an example when the speed field of the data set is clicked with the mouse.

![Figure 8. Time-Line Presenting Speed Envelope](image)

**Conclusion**

*Vital* proposes to improve the controllers’ mental image of the en-route traffic by the innovative combination of representing digital and analogue aircraft data in a single line of an EMON. The analogue data are extracted from Radar sensors, correlated with flight plan information and represented on a time-line.

An early evaluation of a time-line concept for strips showed benefit for the time needed to create the mental traffic picture. Hypothetically similar benefit could be expected by the concept of *Vital*.

Several new ATM concepts for the future complex 4D ATM can be supported by *Vital* with a, for humans, simple and natural representation of the information. If the EMON is sorted to blocks with the same AFL, only the time-line information of data sets in a block has to be checked for safe separation. Reading and evaluating time (i.e. how long is it to next full hour?) from an analogue watch is less demanding and quicker than from a digital one. Similar benefit can be expected from the analogue time-line representation of *Vital*.

The EEC will realise the proposed ideas of this paper as a demonstrator user interface of *Vital* with a graphical rapid prototyping tool. This paper describes its functionality for an early look and feel evaluation (see Appendix II).
References


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Appendix I

The Munster-sector (MN) of the EUROCONTROL UAC Maastricht on which the Vital – EMON sample under appendix II is based.
Appendix II

How an EMON - Vital could look like; an example constructed for the Munster-sector (MN) of the EUROCONTROL UAC Maastricht with mail- and recycling-box. The sector layout is shown in appendix I.