AUTOMATION IN AIR TRAFFIC CONTROL

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1. ABSTRACT

The introduction of automated support to the Controller working position, where routine tasks are transferred to a system component, is part of this approach to explore the possibility of introducing automation in today's Air traffic Control environment.

In contrast to the current Air Traffic Management (ATM) R&D strategy this automation approach is based on a reorganisation of Air Traffic Control (ATC) tasks, ATC roles and an ATC 4D trajectory, that is tailored to the needs of applications with enhanced accuracy in flight path prediction – the "ATC Intent Trajectory". This will lead to the development of new procedures concerning the man-machine interaction and the design of an HMI supporting the new system-operator task distribution. In consequence, a change from the well known paradigm of decision support in ATM towards a new paradigm of automation will evolve. In contrast to the estimated gains through the current support tool strategy of 2-4% each, this concept is addressing the anticipated increase in air traffic in the coming years, where a capacity gain is needed of at least 30 %. A first evaluation of a prototype was conducted early 2006, as a part of the GATE-TO-GATE project, funded by the European Commission [1].

2. INTRODCUCTION

Traditionally the business of Air Traffic Control (ATC) is considered as a highly automated area using very advanced technology. On first sight, there are some arguments to it: As early as 1976 analogue radar displays have been replaced with synthetic radar pictures. A more detailed look into the ATC world of today leads to a different conclusion. A classification of the current level of automation for today's ATC working procedures will result in level 1 as classified in Sheridan's level of automation hierarchy [2], i.e. "The Human does all planning, scheduling, optimizing etc. and turns tasks over to computer for merely deterministic execution".

Here a significant potential to compensate for the anticipated future increase in air traffic is given. The paper describes a new concept of automated support and System-Operator task sharing for Air Traffic Control Working Positions to facilitate this potential benefit. The approach chosen is the introduction of automated support for the Controller working position to exploit the potential of new technologies for ATC with the enhancement of safety and efficiency. The final implementation of the concept will enhance the level of automation up to level 5 "The Computer selects actions and carries out if the Human approves" (classified by Sheridan).

In ATC there is the widely accepted statement that the Executive Controller is in a critical load situation and is seen as a bottleneck for the needed capacity increase. The typical answer to this situation from the Air Traffic Management (ATM) community is to support the Controller with additional tools in order to lower the Controller workload. This approach has not lead to a significant change at the Controller working position, mainly due to the following reasons:

– The implementation of additional tools is accompanied by additional communication overhead and additional need for interaction. Every support tool has to be fed with input data by the controller and has to be monitored, which generates additional workload. This effect is contradictory to the needed relief at the Controller working position.
– The different tools that are foreseen for implementation will create at its best a few percent capacity increase each. This possible effect is not validated for most of those tools, especially where a combined implementation of different tools is foreseen.
– The basis for most of the Controller tools is the prediction of the 4D flight path, which is either updated through Controller input or updated through data link from the aircraft's flight management system (FMS). Prediction accuracy of 4D Profiles today is limited as Controller clearances as well as the time a clearance is given are not predictable. Even accurate FMS 4D Profiles will not lead to the necessary accuracy unless the intent of the controller is integrated into the prediction process.

3. REVIEW OF AUTOMATION IN THE EUROPEAN CONTEXT

On a European level, the approach to harmonise and introduce automation to ATM is dated back about 10-15 years. At that time, major European research initiatives for a harmonised approach towards automation were started. One example is the "program for harmonised ATM research and development in Eurocontrol (PHARE)" [3], triggered by the European organisation for the safety of air navigation (Eurocontrol). In parallel to these activities, but closely linked to them, the regulative part of Eurocontrol developed the "Eurocontrol air traffic management strategy for the years 2000+" [4]. This strategy was developed by Eurocontrol on initiative of the European conference of transport secretaries, the European civil aviation conference (ECAC).

The ATM2000+ strategy assumes a doubling of the number of flights in Europe in the year 2015 compared to 1997. Safety shall not be compromised, whereas capacity and efficiency shall be increased to fulfil the anticipated demand.

In 2005, a new European initiative, called Single European Sky ATM Research (SESAR) was launched. The SESAR programme is the European ATC infrastructure modernisation programme. It will combine technological, economic and regulatory aspects and will use the Single Sky legislation by synchronising the implementation of new equipment, from a geographical standpoint in all European Union member states, as well as an operational standpoint by ensuring that aircraft equipage is consistent with ground technological evolutions.

The first phase of SESAR, called the “definition phase” is being launched. This definition phase will end in 2007 and is undertaken by a consortium uniting forces from the whole aviation community. It will deliver an ATM Master Plan, which will define a common goal and vision for the development of the European air traffic control infrastructure. This programme will also rely in the technological domain on automated decision support tools for air traffic controllers [5].

Both European initiatives require as a major element enhanced controller support tools. As this is one possible way of introducing a higher level of automation, this approach seems to be reasonable. But a deeper analysis shows that the person in charge of all decision making processes with regard to safety – the executive controller – is already heavily loaded with tasks. If we add additional support tools to assist him, these tools come along with additional communication and interaction effort. If we shift the tool support towards the planning controller, indeed there may be an initial relief of the executive controller; but having the doubling of traffic up to 2015 in mind, this may not be sufficient.

A second critical issue is the need to investigate and demonstrate the associated benefits of these decision support tools. Although a lot of medium and large scale real time simulations tried to demonstrate and measure the benefits, it was not possible to gather statistically reliable data in that area. And even more, it was not possible to gather convincing data on the use of a combination of those tools.

A third critical issue is associated with the construct of a 4D trajectory. The ATM2000+ strategy proposes a combination of the ground based 4D trajectory which is supplemented by the more precise airborne 4D trajectory as available in modern flight management systems (FMS). These FMS trajectories already include the customer’s flight preferences. Thus airborne 4D trajectories can be used to update the ground based trajectories and increase the efficiency of advanced controller tools.

The airborne 4D trajectory only is precise if any surrounding traffic and ATC constraints are ignored and as long as no ATC clearance is given e.g. due other traffic. The controller intent is by far the largest source of error in flight profile prediction [6]. If the new clearance is implemented in the FMS 4D trajectory, the trajectory is precise again – up to the next interference. This leads to the conclusion that in the airborne 4D trajectory the necessary ATC related points or events are completely missing. However it has to be noted, that this is true vice versa for the ground 4D trajectory as well. Here aircraft related points and events like top of descent (TOD) or top of climb (TOC) are missing.

In the authors view, any 4D trajectory which does not integrate aircraft specific points and events as well as ATC related points and events into one single trajectory is useless with regard to the medium to long term development of an co-operative, world-wide ATM system.

Taken these critical issues seriously, a new automation concept evolves. This concept is based on a number of precise airborne trajectories in which the ATC instructions and constraints are integrated into a single 4D trajectory, thus allowing a stable planning and control process in a time frame of 10-20 minutes ahead. This concept is the basis for a revolutionary step in the European ATM system with regard to capacity enhancement.

4. THE DFS AUTOMATION APPROACH

As outlined before, a new paradigm of trajectory is needed. Based on this there are two major elements serving the concept: tools support and team roles in the human machine system. Both elements together in a well balanced interaction will guarantee the tremendous potential benefit of the concept.

4.1. 4D FMS Trajectory

In a modern glass cockpit the 4D trajectory is the basis for any planning process since years. In contrast to that, modern ATM systems are just undergoing an enhancement step towards relying on a ground 4D trajectory. However, almost any of the controller support tools rely on this ground trajectory. Examples are the medium term conflict detection (MTCD) [7] or the conflict resolution advisory (CORA) tool [8].

Most of the reports investigating on those tools in an operational environment stated that “if the trajectory would be precise, the tool could meet the expectations” or “a better trajectory input would enormously improve acceptance of the tool”. The conclusion from these findings is often to postulate data link and airborne trajectories as input data for improvements.

The FMS trajectory as a specific 4D trajectory is a projection into the future – with an uncertainty implied the more the projection points into the future. To decompose the problem, the 4D trajectory can be split into the lateral trajectory and the vertical trajectory (fig. 1). In this example, the trajectory is divided into 7 trajectory points (P1 to P7) with associated information for position (lat/long), altitude, speed and time. The trajectory points P4 and P6 indicate a turn manoeuvre, whereas trajectory point P2, P3 and P5 indicate a start of climb or start of descent manoeuvre.

The lateral and vertical trajectories are the estimates for the planned flight path. To evaluate the precision the projected trajectory, a comparison with the real flight path is necessary. Assuming there was no ATC clearance affecting the lateral trajectory (e.g. any heading instruction or direct instruction), the trajectory is fairly precise. So the estimates of the trajectory points for planned and real flight path are almost identically as long as no ATC clearances are given.

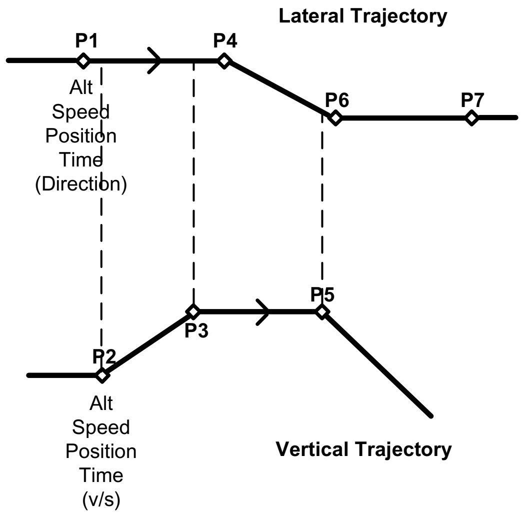

FIG 1. The 4D FMS trajectory (lateral and vertical)

The comparison for the vertical flight path with the real flight path shows a different result compared to the lateral flight path. In the aircraft FMS as well as in the ground system assumptions have to be made for the vertical manoeuvring points (P2, P3, P5). For example, the FMS or pilot has to define a point as top of descent (P5). Implicitly, he also defines the point in the trajectory, where the controller has to issue the associated clearance to him.

But the probability that the FMS or the pilot estimates correctly the type and the time of the controller's decision and implementation is rather low. As the real flight path is mainly determined by the controller clearances the probability that the 4D FMS trajectory is in accordance with the real flight path is very low.

For the ground based medium term conflict detection process the airborne 4D FMS trajectory – derived via data link –is used. An MTCD based on the 4D FMS trajectory would propagate the error probability discussed above into the results of the conflict detection process – or to state it clearly: the probability that the conflicts detected are valid is rather low.

This simple example demonstrates clearly that the today's ATM procedure supplemented by 4D FMS trajectories does not exploit the full potential of electronic data processing capabilities for ATM.

4.2. 4D ATC Trajectory

Due to the problem with the 4D FMS trajectory, we suggest a different approach. The 4D ATC trajectory is the basic and new paradigm, which integrates relevant information from already today existing trajectories (airborne and/or ground) and ATC specific information into one single construct.

The most important extension of the already known 4D trajectories is the ATC event. Each ATC event represents one ATC instruction with the associated influences on the 4D trajectory. Instruction may be initial calls, sector change messages, climb instructions or direct instructions. Figure 2 shows an example of a 4D ATC trajectory with integrated ATC events.

The 4D ATC trajectory overcomes the weakness of the 4D FMS trajectory and allows a stable planning and control horizon of 10-20 minutes. The full potential of the 4D ATC trajectory is developed with two further changes to today's system: a new system support and a new allocation of team roles and tasks.

4.3. System Support

Central element of the system support is the ATC message generator (AMG). It is based on the 4D trajectory and has four essential features:

– generating ATC events and establishing the 4D ATC trajectory
– continuous cross-check of 4D ATC trajectories
– generating ATC events for conflict resolution
– Rating and selecting ATC events for conflict resolution

In addition, an HMI component and an adaptive component to evaluate different levels of data interaction and communication are introduced.

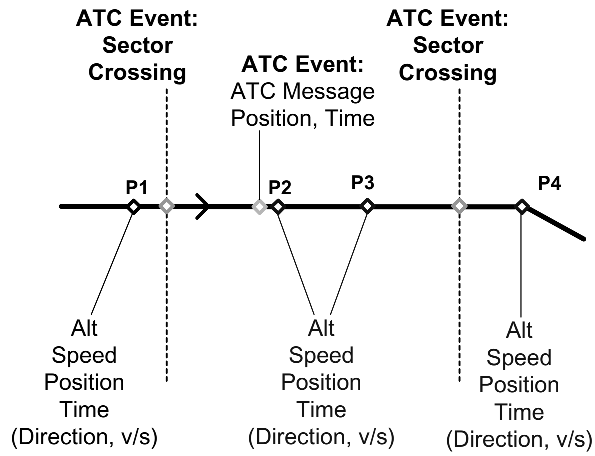

FIG 2. 4D ATC trajectory

4.3.1. Generating ATC Events

In the AMG ATC events are generated. All new trajectories are automatically passed through to the AMG. Sector entry and exit points are inserted. Moreover, predictable clearances like climb or descent are introduced. In contrast to a conventional 4D trajectory point, each ATC event comes along not only with position, altitude and time but also with the associated ATC clearance. By that, the new 4D ATC trajectory is established for each flight.

4.3.2. Continuous cross-check of 4D ATC trajectories

Modern ATM systems continuously update and cross-check the consistency between planned 4D trajectories and the real flight path. In addition to this, the AMG cross-checks also if the ATC clearances introduced into the 4D

ATC trajectory are issued on time to the pilot. This is done by monitoring the outgoing messages as well as by evaluating the result. If a clearance is not given in the expected time frame, an alarm can be triggered and the 4D trajectory can be updated.

4.3.3. Generating ATC events for conflict resolutions

The 4D ATC trajectories are passed to the MTCD component. The system continuously checks the whole set of data for potential conflicts. They are returned to the AMG, where conflict resolution proposals are generated systematically. The algorithm applies a limited number of possible manoeuvres and generates a small number of valid conflict resolution proposals. This is also a way of standardisation with the advantage of a reduction of the search space. They are re-evaluated in the MTCD module with regard to follow-up conflicts. All proposals are passed through to the rating and selection module.

4.3.4. Rating and selecting ATC events for conflict resolutions

The proposals already identified as potential solutions are now rated by a simple rating function. This function applies the following ideas:

– Deviation from the planned trajectory shall be minimised
– Conflict solutions shall be easy and avoid combined or follow-up clearances
– Conflict free solutions for the next two sectors have greater priority than “optimum” solutions for the current sector

After identifying one single solution to be implemented, this has to be included into the affected 4D ATC trajectory. For this purpose, again an ATC event is generated and inserted. From here on, the loop is closed to the other modules of the AMG.

4.3.5. HMI aspects

As HMI for the ATC events (ATC clearances to be issued at a specific time) a time line display is used, as it is known e.g. from sequencing tools in terminal areas. In addition, each ATC event included in a trajectory is displayed in the dynamic flight leg display on the air situation window.

Although most of the relevant ATC data is generated electronically in the AMG, data may be inserted into the system also manually which is an important aspect with regard to the transition aspects. On the other hand, the clearances can be communicated electronically as well. By that means, the approach is open towards today’s working procedures as well as for data link implementation.

4.4. Team role in the operational concept

All features explained so far serve as prerequisite for the most important change introduced: the change of roles and tasks of each individual actor in the human machine system ATC.

Based on the system support detailed above, this concept foresees that up to 10 minutes prior to an ATC event (clearance) the system generates and checks potential

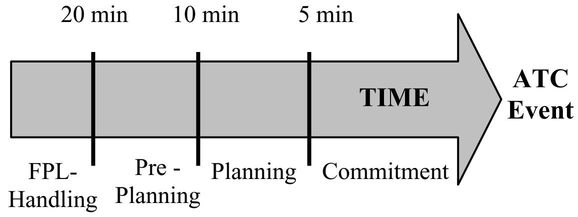

FIG 3. Time line of action

clearances and implements them into the 4D ATC trajectories. In a time horizon of 5-10 minutes prior to an ATC event (refer to figure 3), the planning controller evaluates future ATC events, optimises and adapts them. Objective of this procedure is to establish an obliging and stable plan well in advance to the ATC event itself. The role of the executive controller is limited to the implementation of an ATC event: To cross check safety and to communicate the clearance to the cockpit. By that, the executive controller’s workload decreases significantly, which gives him opportunity to concentrate on his role as a final safety net.

The processes flight plan handling and pre planning are taken over by the system, whereas the processes planning and commitment are covered by the controller team. Figure 4 shows the shift of controller tasks from the current environment towards the introduced Automation concept.

5. DEMONSTRATION OF FEASIBILITY

First validation exercises of the new Automation approach took place in winter 2005. DFS developed and integrated the tools (MTCD, ATC Message Generator, HMI with ATC Event Line) into a real time simulation environment.

Controller Tasks		Today	Automation
Conflict search	> 5 min.	PC	System / PC
	< 5 min.	EC	EC
Deviation from flight track		EC	System (EC to react to alerts)
Planning of solutions	Entry/exit conditions	PC	n/a
	Intra sector	EC	System
Implementation of solutions	Non time critical	EC	System (EC to implement)
	Time critical	EC	
Co-ordination tasks	Non time critical	PC	System
	Time critical	EC	EC
Handover procedures		EC	EC

TAB 1. Figure 4: Automation task shift (EC = Executive Controller, PC = Planning Controller)

The experimental design relies on iterative prototyping methodology. The basic idea behind iterative enhancement is to develop a software system incrementally, allowing the developer to take advantage of what was being learned during the development of earlier, incremental versions of the system. Key steps in the process were to start with a simple implementation of a subset of the software requirements and iteratively enhance the evolving sequence of versions At each iteration, design modifications were made and new functional capabilities were added [9].

The chosen airspace was the Karlsruhe Upper Information Region, ranging from flight level 285 to unlimited. The following sectors were simulated, each of them with a different level of automation in order to demonstrate the benefits of a higher degree of automation and to address possible transition issues from our current environment to the future:

– Tango (TGO) sector, automation level 5-6 [2], planning & conflict resolution by the system, clearances via data link in advance by the system
– Frankfurt (FFM) sector, automation level 4 [2], planning & conflict resolution by the system, clearances via data link in time by the human
– Würzburg (WUR) sector, automation level 2-3 [2], planning & conflict resolution by the system, clearances via voice by the human
– Söllingen (SLN) sector, automation level 0-1 [2], planning & conflict resolution by the human with system support, clearances via voice by the human (today's way of control).

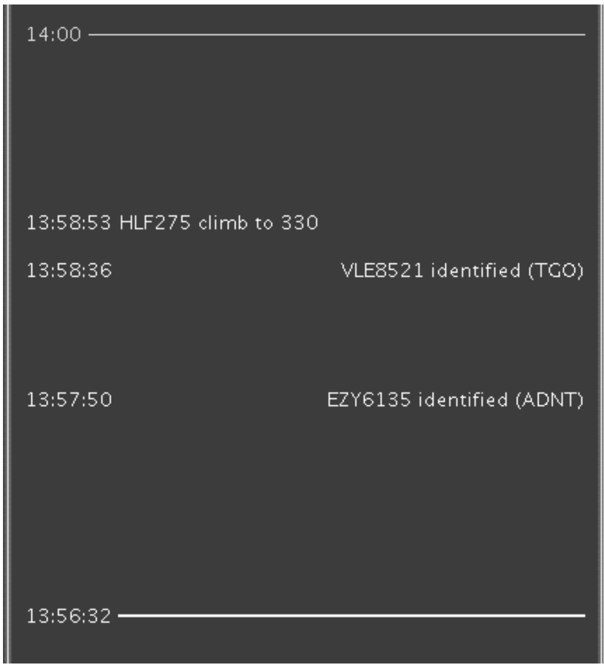

FIG 4. ATC event line

The sector load was about 80% of the maximum sector load, i.e. 30 to 40 aircraft entries per hour. Figure 5 depicts some detail from the implemented HMI with the ATC Event Line and the radar display. Current time is 13:56 UTC, and the system has generated three events. In one minute from now, at 13:57, flight EZY6135 will enter the sector, and at 13:58 flight VLE8521 will enter the sector. A few seconds later, a climb clearance to flight level 330 shall be given to flight HLF275.

In the radar display we can see flight VLE8521 which is still in the previous sector (here: Tango TGO). Flight HLF275 is already under control but still in flight level 290. This flight must be climbed in about 2 ½ minutes from now to its exit flight level of 330. This clearance has been generated by the AMG, and the controller must not climb the flight earlier because this may cause a conflict with another aircraft and it would definitely spoil the computed stable planning situation.

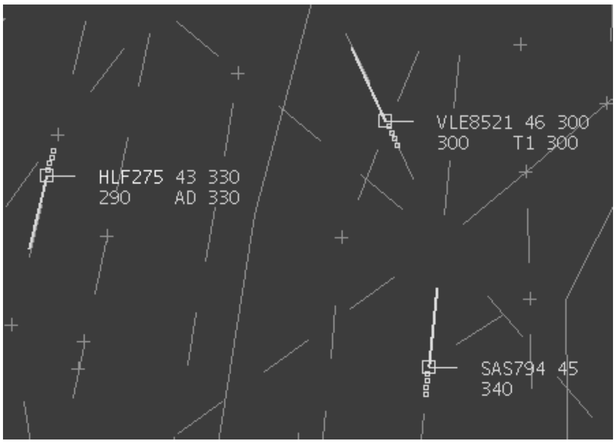

FIG 5. Radar display associated to the ATC event line displayed in FIG 4

A first analysis, based on the debriefing sessions with the controllers and on the simulation questionnaires, indicated that indeed the workload of the executive controller in the fully automated sector TGO was rather low in particular compared to the SLN sector. The system could always find solutions so that no intervention of the human was necessary. On the other hand, controller training may become an important issue because they stated that it was sometimes difficult to maintain situational awareness. This is due to the algorithm of the AMG which is not always transparent to the controllers. Further improvements in the algorithm and the HMI presentation are envisaged.

6. CONCLUSIONS

A prototype system has been developed, which is implemented into an ATM real time simulation infrastructure at DFS research and development laboratories. Investigations on the prototype were carried out in winter 2005. By hands-on evaluation together with experienced air traffic controllers, the prototype and the associated operational concept is tested and evaluated.

First evaluation shows promising results, and it seems quite realistic that the envisaged traffic increase can be handled with this new approach. Further improvements in the algorithm and the HMI design are planned in the next steps. In addition, the transfer of parts of the functionality in an airborne environment (comparable to Airborne Separation Assistance Systems ASAS) is foreseen. This will complete the revolutionary approach of re-designing the air traffic controller's tasks towards an air traffic management task. However, this step requires prove on applicability in ground based environments.

7. ABBREVIATIONS

4D	Four dimensional
AMG	ATC message generator
ASAS	Airborne separation assistance system
ATC	Air Traffic Control
ATM	Air Traffic Management
CORA	Conflict resolution advisory
EC	Executive controller
ECAC	European Civil Aviation Conference
FFM	Frankfurt sector
FMS	Flight Management System
HMI	Human machine interface
MTCD	Medium term conflict detection
PC	Planning controller
PHARE	Program for harmonised ATM research in Eurocontrol
SESAR	Single European Sky ATM Research
SLN	Söllingen sector
TGO	Tango sector
TOC	Top of climb
TOD	Top of descent
WUR	Würzburg sector

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