HUMAN MACHINE ASPECTS OF ARRIVALS MANAGEMENT IN FUTURE AIR NAVIGATION ENVIRONMENTS

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ABSTRACT

The air navigation environment of the future offers significant potential benefits in aircraft operations, but raises questions on how arriving traffic at future airports should be handled. Aircraft proceeding on their own optimal flight trajectories and heading towards the same airport will have to be transitioned to terminal airspace, in order to facilitate a safe, smooth and optimal arrival structure. This can be achieved by applying automated arrival transitioning systems, placing different demands on the performance of flight crews and air traffic controllers. This paper describes such an automated transitioning system, the interaction between human and machine and the use of a perspective interface for air traffic control purposes in such an environment.

KEYWORDS

Air traffic control, arrivals management, automation, human machine interaction, perspective displays.

INTRODUCTION

It is expected that the predicted doubling of the amount of air traffic in the next 20 years cannot be handled by the current air navigation system (Abbink,1996). For this reason, a lot of effort is put into updating and improving the traditional system. It will be necessary to use the available airspace more efficiently by integrating user-preferred four-dimensional flight trajectories with existing constraints, leading towards a concept that is usually referred to as Free Flight (IATA, 1996). In such a Free Flight environment aircraft operators are allowed to determine their own optimal flight paths in real time and user involvement will play a much more important role in decision making processes. Free Flight promises to be a highly feasible concept for en-route traffic, however it is expected that it might not be so suitable for use in very high-density airspace, like airport terminal areas. Not only is the traffic density in this area probably too high to make Free Flight applicable, the constraints in flight path determination are much more intense, since all aircraft are in the end all heading towards the same airport or even towards the same runway. So even though Free Flight offers a lot of potential benefits, the airports will still be the bottlenecks and prevent exploiting the benefits of Free Flight completely (Post & Jonge, 1997).

Increased air traffic density has made the need for automation in air traffic control apparent (Jensen, 1989) and has initiated a lot of research in the field of automated arrivals management. Especially the Center TRACON Automation System (CTAS), developed at NASA Ames Research Center and the Programme for Harmonized Air Traffic Management Research in Eurocontrol (PHARE), offer many automated planning and control tools, thereby enabling more efficient routing in approaching the runway. In Section 2 the most important characteristics of these two systems will be discussed briefly. Based on the considerations mentioned above, a research project was initiated at the Delft University of Technology to investigate and develop an Air Traffic Management (ATM) system capable of handling arriving Free Flight traffic efficiently. The main features of future arrivals management can be described as automatic scheduling of incoming Free Flight traffic, transitioning Free Flight traffic to controlled airspace and exploiting the benefits of high-precision four dimensional arrival routes. Application of these functions will result in curved approaches, reduced distances used for flying the traditional last straight part of the approach and therefore higher demands on the performance of pilots inside the aircraft as well as air traffic controllers on the ground. Future arrivals management and its consequences will be the topic of Section 3. In order to realize high-precision approaches, pilots will need improved tools to meet the higher required performance levels. Currently, a lot of research is being done into application of future cockpit displays, of which the Tunnel-in-the-Sky display is considered a promising candidate (Mulder, 1999). Apart from the airborne side, there will also be higher demands on the performance of air traffic controllers on the ground. The combination of more situation awareness in three dimensions with optimal airspace utilization and severe weather avoidance, has opened the door to research into three-dimensional or perspective air traffic control displays. Therefore, after implementing the automatic scheduling functions of the system that is being developed the outputs will be connected to a perspective Air Traffic Control (ATC) display, likely to be the main interface between aircraft and ground controllers in future environments. Generation of visual information in this way will enable the verification of the automated scheduling functions itself, the display interface and the interaction with the ground controller, as also discussed in Section 3. Finally, conclusions will be drawn in Section 4.

AUTOMATION IN ARRIVALS MANAGEMENT

The Center TRACON Automation System (CTAS)

The growing presence of delays and congestion, in combination with increasing air traffic density levels and demands on airspace utilization have led to the development of the Center TRACON Automation System (CTAS) at NASA Ames Research Center (Swenson et al., 1997). CTAS is an integrated collection of automation tools developed to assist air traffic controllers in handling arrival traffic. Currently, CTAS is installed at the Dallas/Fort Worth Terminal Radar Approach Control (TRACON), where it is being evaluated in an operational environment. CTAS consists of three tools: the Traffic Management Advisor (TMA), the Descent Advisor (DA) and the Final Approach Spacing Tool (FAST). The planning functions are implemented in the TMA, generating arrival sequences and schedules. The DA provides advisories to assist controllers in enabling descending aircraft to meet the schedules that have been determined by the TMA. FAST generates advisories in the terminal area, and assists controllers in managing arrival traffic once the terminal area is reached and the final part of the approach has been initiated.

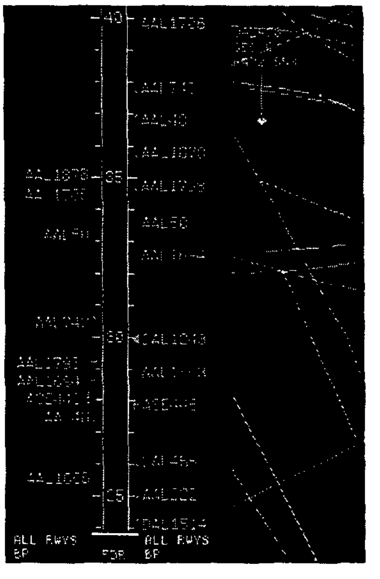

Fig. 1. *Timeline on the Planview Graphical User Interface (PGUI) in CTAS (Davis, 1999).*

After intensive simulations with controllers, the underlying algorithms in CTAS have been changed and the (graphical) user interfaces have been improved. Because CTAS has both planning and control functions, the user interfaces are designed to assist in planning and control tasks as well. The planning tasks are performed by traffic management coordinators, who are responsible for monitoring and balancing the flow of arriving traffic. The traffic in the area is shown to these coordinators by means of several graphical user interfaces. Both the TMA Graphical User Interface (TGUI) and the Planview Graphical Interface (PGUI), as shown in Figure 1, are used by traffic management coordinators, while air traffic controllers use primarily the PGUI to perform their control tasks (Davis, 1999). On these interfaces timelines, load graphs, sequence lists and alert messages are also displayed. Both coordinators and controllers are able to interact with the system through changing settings in control panels, pushing buttons and dragging items from one position to another. More analysis on human machine issues in CTAS can be found in (Harwood, 1993).

The Programme for Harmonized Air Traffic Management Research in Eurocontrol (PHARE)

At Eurocontrol, the PHARE project was started in 1989 and aims to investigate future ATM concepts based on air-ground integration. Experiments with developed tools have been conducted in 1995 in Malvern and in 1996/1997 at the DLR Braunschweig site in Germany. In these experiments high airborne navigation capability and performance has been assumed. PHARE has not been through the same process of extensive operational testing as CTAS, but a higher level of integration between airborne navigation capability and trajectory negotiation is investigated (Reichmuth, 1993). The tasks of all controllers consist of assuring safety, minimizing delays, fuel consumption and noise abatement and obtaining optimal situations for individual aircraft (Reichmuth, 1993). In PHARE, each workstation is equipped with a Plan View Display (PVD), simulating the traditional radar screen with labels identifying individual aircraft and indications of planned trajectories. In addition to this, a conflict risk display is shown if potential conflicts are detected. For air traffic managers a displays is available that shows the scheduled aircraft on a timeline, similar to the timeline displays in CTAS.

FUTURE ARRIVALS MANAGEMENT

The Air Traffic Transition System (ATTS)

With the Airport 2020 project the Delft University of Technology has recognized the need for a future ATM system in the terminal area. Based on the air navigation systems that will become available in approximately 10 to 15 years (IATA, 1996) and the automation of ATM as it is under development today, the Air Traffic Transition System (ATTS) has been designed. Baseline capability assumed is fully RNAV equipped aircraft. RNAV (Random or Area Navigation) equipped aircraft are able to maintain an optimal flight trajectory, without the need to pass traditional ground-based fixes. All airspace outside designated areas surrounding the airports is completely Free Flight airspace. The focus of ATTS is on transitioning Free Flight arrivals to controlled approaches to the runway, while optimizing the overall situation and meeting the preferences of individual aircraft to the best extent possible. More efficient use of available airspace, increased airport capacity and more flexibility are key design features.

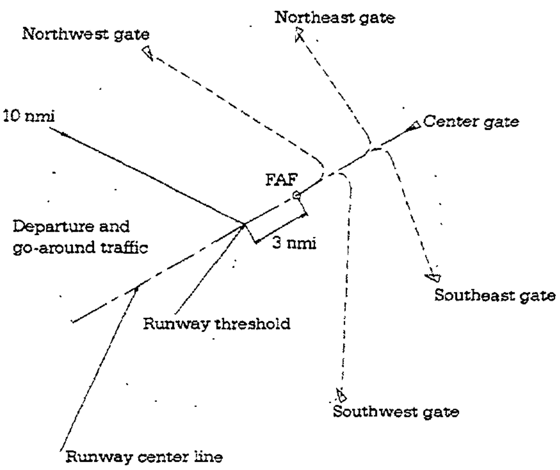

Fig. 2. *Example of the layout of the terminal area for runway 24 at Amsterdam Schiphol Airport. All approach gates through which aircraft can enter the terminal area are depicted. Five possible arrival routes are also illustrated.*

All aircraft outside the terminal area are assumed to operate in Free Flight conditions. Apart from operational constraints, the only constraint in flight path determination is a scheduled 4d position at one of the gates, fixed areas in space through which the terminal area can be entered. In the initial investigations, there are five different gates determining where the Free Flight area is left and the transition into the terminal area is initiated. An example of the layout of the terminal area is given in Figure 2 for runway 24 at Amsterdam Schiphol Airport. Based on investigations with a transition point at 10 nmi from the runway threshold (Reichmuth, 1993), the radius of the terminal area is initially set to 10 nmi. As can be seen in Figure 2, there is a curved approach path from each gate to the runway reducing the length of the final straight part of the approach to a minimum of only 3 nmi. Whether the 10 nmi range provides enough space for emergency handling and go-around procedures, is to be investigated during simulations. The scheduling algorithms for the transition system are derived from branch and bound methods as described in (Brinton, 1992) for determining optimal schedules at the gates. Using estimates of the times aircraft need to transition through the terminal area and calculating with individual aircraft performance data, the schedules at the Final Approach Fix (FAF) and at touch-down are constructed so that separation requirements are satisfied and also that the aircraft are indeed capable of meeting the assigned times. Furthermore, the concept incorporates a certain level of flexibility. The arrival routes inside the terminal area are not entirely fixed, but can be specified by aircraft operators. Another source of flexibility is constructing the schedules so, that if an aircraft is not able to meet its schedule (due to unexpected weather conditions for instance) the aircraft is still given the opportunity to change its final approach planning upon entering the terminal area slightly, so that the runway time is still met and other aircraft in the area do not have to suffer from a disrupted runway schedule.

The airborne perspective

From airborne perspective, applying an ATTS system places additional demands on airborne equipment and performance. More accurate navigation systems will enable high-precision approaches. Future primary flight displays (for example the Tunnel-in-the-Sky display) will be used to provide the necessary assistance to the flight crew in reaching the desired performance levels. To facilitate flying curved approaches, all turns implied by ATTS in the terminal area are rate one turns, where a complete reversal of flight direction (180 degrees) takes one minute. These are standard turns considered relatively easy to fly with sufficient precision. Additionally, the aircraft is always scheduled so, that the final straight part of the approach starts at least 3 nmi from the runway threshold, enabling the crew to prepare for landing.

Role of air traffic controllers

From human-machine issues point of view, one of the questions raised is what information should be made available to air traffic controllers on the ground and in what way this should be done. Since an ATTS-based environment offers a lot of new functionality and places different demands on monitoring and controlling tasks of ATC personnel, a good understanding of the new situation is necessary. First of all, similar to the traditional situation as well as in systems like CTAS and PHARE, a distinction between planning and control tasks can be made. However, in planning arrival traffic the focus of the controller's task will be more on monitoring system performance and intervening (in case a more optimal solution is apparent to the controller) than determining a planning himself. Controllers will have a direct leading role in case emergencies occur or aircraft do not stick to their planned trajectories.

Perspective air traffic control displays

Since weather is still a factor in a large number of accidents and in significant air traffic delays (Kayton & Fried, 1997), it is crucial to incorporate weather in the process of scheduling and controlling air traffic much more. This in combination with high demands on navigation performance, high levels of traffic density and increased amount of vertical movements in the terminal area, has led to research into the application of 3D or perspective ATC displays (Wickens, Campbell, Liang, & Merwin, 1995). In (Wickens, Mavor, & McGee, 1997) situation awareness is identified as a major stage in the process of events leading to actions. Furthermore, air traffic controllers base their actions on situation awareness of the current situation and especially on its prediction into the future. Apart from a better representation of weather, perspective displays potentially offer more situation awareness by displaying traffic in a three dimensional manner. Displaying available information in a format which is compatible with the mental model of the airspace maintained by the controller, results in more effective and easier perception (Wickens et al., 1997). Currently, the predictive part in obtaining situation awareness places extremely high demands on human working memory and usually suffers from the competitive aspect of the controller's attention (Wickens et al., 1997). Translating a two dimensional representation into situation awareness in a three dimensional world, challenges the controller to the extreme. A better representation of predicted aircraft positions and flight trajectories on a three dimensional display can facilitate the determination of expected future traffic situations by the controller and decrease his workload. In contrast to the promising advantages of perspective air traffic control displays, sceptic attitudes towards these displays have been based on the tendency to degrade perception of the lateral and longitudinal position of aircraft (Johnston, Horlitz, & Edmiston, 1993). Efforts to overcome this problem usually result in a distorted image when the traffic density is high. However, the controlled area in ATTS is rather small, and existing separation requirements limit the number of aircraft within the 10 nmi range significantly. Currently applied separation distances by air traffic controllers vary from about 3 to about 5 nmi, depending on the weight classes of the aircraft involved (Brinton, 1992). Since the quality of relative altitude perception is rather low except when aircraft are close together (Johnston et al., 1993), applying a perspective ATC display is especially attractive in a small area like the ATTS terminal area where separation is small but critical. In the vertical dimension, perspective displays offer the possibility of including 3D terrain maps which can lead to increased vertical situation awareness with respect to terrain as well. Previous investigations have shown that human performance is increased by integrating displayed information if it is to be integrated anyhow (Jensen, 1989). Where currently air traffic controllers have to integrate weather and traffic information manually, perspective displays can immediately integrate these two factors physically in three dimensions. There are still many issues in 3D displays subject to discussion. For ATC purposes, topic of discussion is especially the location of the viewpoint. Viewpoints can change the perception of the current situation by the controller significantly and influences the process of recognizing potential conflicts in a major way. Consequently, when a certain viewpoint shows one potential conflict to the controller very clearly, another conflict might be almost invisible. In accordance with the investigation carried out in (Wickens et al., 1995), it seems most promising to exploit the advantages of a 3D representation of air traffic and deal with its difficulties, by extending the traditional plan view display with perspective display functions.

The perspective ATC display in ATTS

Since all of the issues mentioned above play an important role in an ATTS-based environment as well, the human factors investigation in this research project focuses on connecting the ATTS system with a plan view ATC display extended with perspective viewing functions. To enable controllers to monitor the system performance, the display will have the ability to show incoming traffic on timelines, which is featured by most of the automated ATC systems (Petre, 1994). Traffic will be displayed with respect to any of the gates as well as the runway itself in time scale format. This enables controllers to check if sufficient separation is maintained, if the scheduling functions work correctly and, in general, if safety regulations are met. For controlling tasks, air traffic controllers require accurate and up to date flight data of all aircraft in the area in order to determine the state of the system and respond to conflicts, resulting in domain suitability (Harwood, 1993). The traditional summarizing of relevant data in aircraft labels can also be applied to perspective ATC displays, along with heading vectors and graphic altitude indications in the 3D mode. These labels typically contain aircraft identification code or call sign, altitude, ground speed, runway assignment and aircraft type. With the application of automated systems and given the higher demands on navigation performance in the terminal area, it is possible that adding flight path advisories to aircraft labels becomes necessary. In CTAS for example, speed and heading advisories as well as sequence numbers and advised runway assignments are added to the aircraft label (Davis, 1999). Especially in the terminal area where the traffic density is high, and it is most critical to show the controller accurate data in an intuitive way, the labels need to be small to avoid label overlap (Hopkin, 1982), resulting in technical usability. The ATTS display will also be equipped with extended aircraft labels containing primary aircraft data, planning information and parameters indicating to what degree plannings are met. This could mean displaying measured delays or using color coding to indicate aircraft running late. These extended labels will only be displayed inside the terminal area. Plotting planned trajectories in the perspective view will also enable controllers to verify if aircraft proceed as planned more intuitively and accurately.

CONCLUDING REMARKS

To cope with arriving Free Flight traffic in future air navigation environments the ATTS automatic transitioning system has been designed. Incoming traffic is automatically scheduled at fixed reference points in a way that optimizes the overall situation and meets the preferences of individual aircraft operators to the best extent possible. Improved cockpit displays and navigation equipment will enable the flight crew to meet the higher demands on navigation performance. Using perspective displays for air traffic control purposes offers many benefits, especially with respect to improved situation awareness and higher navigation performance in the terminal area. However, possible difficulties in perceiving information from these kind of displays in certain situations indicate that the most promising ATC display in future environments is a plan view display extended with perspective rotating functions. Such an improved perspective ATC display will enable air traffic controllers to monitor system performance of future automatic schedulers, allows controlling traffic if necessary, and will facilitate handling arriving Free Flight traffic at future airports in an efficient way.

REFERENCES

Abbink, F. (1996). Integrated Free Flight and 4-D Gate-to-gate Air Traffic Management, Possibilities, Promises and Problems (NLR Technical Paper No. TP 96239 U). Amsterdam: National Aerospace Laboratory.

Brinton, C. (1992). An implicit enumeration algorithm for arrival aircraft scheduling. 11th digital avionics systems conference proceedings.

Davis, T. (1999). CTAS - Project Desciption. NASA internet pages at http://www.arc.nasa.gov/ctas.

Harwood, K. (1993). Defining Human-Centered System Issues for Verifying and Validating Air Traffic Control Systems. In: J. Wise, V.D. Hopkin, and P. Stager (Eds.), Verification and validation of complex and integrated human machine systems. Berlin: Springer-Verlag (1993).

Hopkin, V. (1982). Human factors in air traffic control (Tech. Rep. No. AGARD-AG-275). Farnborough, Hampshire, UK: Royal Air Force Institute of Aviation Medicine.

IATA. (1996). FANS Manual Overview and Benefits (1st. ed.). Montreal Geneva.

Jensen, R. (1989). Aviation Psychology. Aldershot, England: Ashgate Publishing Limited.

Johnston, J., Horlitz, K., & Edmiston, R. (1993). Improving Situation Awareness Displays for Air Traffic Controllers. Proceedings of the Seventh International Symposium on Aviation Psychology, Ohio State University.

Kayton, M., & Fried, W. R. (1997). Avionics Navigation Systems (2nd. ed.). New York: John Wiley & Sons, Inc.

Mulder, M. (1999). Cybernetics of Tunnel-in-the-Sky Displays. Ph.D. dissertation, Faculty of Aerospace Engineering, Delft University of Technology.

Petre, E. (1994). Time Based Air Traffic Control in an Extended Terminal Area: A survey of such systems. On-line Handling of Air Traffic: Management-Guidance-Control, AGARDograph AG-321.

Post, W., & Jonge, H. de. (1997). Free flight in a ground controlled ATM environment (NLR Technical Paper No. TP 97594). National Aerospace Laboratory.

Reichmuth, J. (1993). PHARE Demonstration: Arrivals Management. Proceedings of the Mission System Panel Workshop on Air Traffic Management: Support for Decision Making Optimization - Automation(AGARD Report 825).

Swenson, H., Hoang, T., Engelland, S., Vincent, D., Sanders, T., Sanford, B., & Heere, K. (1997). Design and Operational Evaluation of the Traffic Management Advisor at the Fort Worth Air Route Traffic Control Center. 1st USA/Europe Air Traffic Management Research & Development Seminar.

Wickens, C., Campbell, M., Liang, C.-C., & Merwin, D. (1995). Weather displays for air traffic control: the effect of 3d perspective (Tech. Rep. No. ARL-95-1/FAA-95-1). Washington, D.C.: Federal Aviation Administration.

Wickens, C., Mavor, A., & McGee, J. (1997). Flight to the Future: Human Factors in Air Traffic Control. Washington, D.C.: National Academic Press.