

VertiDigi – A New Working Environment for E-TMA

Raïlane Benhacène

Centre d'Etudes de la Navigation Aérienne
7 av. Edouard Belin
31055 Toulouse, France
benhacene@cena.fr

Abstract

In this paper, we will describe a new working environment that has been designed in the framework of the ASTER project, Assistant for TERminal Sectors. The purpose of this project is to explore and propose new concepts for a working environment dedicated to Air Traffic Control in Terminal Sectors. An initial description of the characteristics of such sectors is given. An analysis of the tasks of controllers and their corresponding bottlenecks is given. The identification of these problems and difficulties opens the path to a tentative elaboration of a new interface, together with working methods. The first results described and illustrated is an interface, called VertiDigi, dedicated to arrival sectors. It consists of a vertical representation of traffic on a touch sensitive screen, which serves as a visualization and input device in lieu of the paper strips board. Discussion on the underlying concepts and advantages of the new interface follows. The possibility to even further augment the evocative and representative impact of this interface taking advantage of the touch screen possibilities, or connecting with other domains of the ATC research is evoked.

Introduction

E-TMA: Extended Terminal Maneuver Area

Terminal sectors are en-route sectors but mainly dealing with traffic inbound or outbound from a major or several major airports. These sectors are the intermediate buffer between classical en-route sectors and the final approach. Our study is currently focused on *arrival* sectors. Aircraft enter these sectors at high altitude and high speed. They must come out of the sector at lower flight level and lower speed, and must be sequenced. The traffic is therefore highly evolutive in nature (descending). Arrivals are characterised by important convergence towards a given point, the initial approach fix (IAF). At that point, aircraft are passed on to approach control, and must be delivered at an agreed flight level, speed, and with a given separation between aircraft.

Problems and Difficulties

Several problems can be listed, which are limiting the capacity of the arrival terminal sectors. We conducted a series of interviews, video and audio recordings of controllers at work on such sectors, and de-briefing post recording. The qualitative analysis of this material enabled the identification of three main issues that must be addressed in order to improve the situation.

Representation of traffic in vertical plane. The radar image controllers have is a horizontal view of aircraft positions. In the case of descending aircraft, the controllers extrapolate descent rates and vertical plane trajectories from flight level figures in the radar labels. Arrival sectors have a traffic that is in large majority made of aircraft descending, bound for the major airport involved. In addition, a minority of slow aircraft (called “transverse” aircraft) also cross such sectors at average altitude, and their trajectory sometimes conflicts with the main descending flow. For all these reasons, it seems that the vertical dimension is often a problem, or at least a consumer of mental resources and a difficulty for the building of an accurate mental image of the traffic.

Input and materializing traffic management. Currently, managing traffic is done making extensive use of the flight progress paper strips. The strip board, located below the radar image, accessible for the hands-on manipulation and writing, serves multiple purposes. Physically, to move and shift paper strips serves as a materialization of where aircraft are, or where they should be. Writing the clearances given to each specific aircraft helps remembering them, and enables cross checking conflicts with other aircraft and inside the controllers’ team. The main problem to move from this traditional way of working to a modern one incorporating decision aids, MTCD or other tools, is the need to have a host system informed and updated of all the clearances and actions on the traffic. In other words, the electronic stripping or input of clearances to a computerized system is needed. And for terminal sectors, the problem is very complicated because such traffic necessitates very numerous, multiple clearances at a very high tempo during peak hours of high traffic. It is not uncommon to hear an air traffic control giving the pilot three different clearances in one sentence on the frequency. (turn, descend

and reduce speed typically). Current attempts have failed, mainly because of this interface issue, and because of the need to have a reactive, natural and intuitive working environment.

Sequencing. Traffic must eventually be delivered to approach sectors that in turn feed the runways. Runways are the bottlenecks, and driving constraint for the whole system. So this constraint is managed with an arrival manager (AMAN), which calculates a sequence of acceptable aircraft, in a given order, and with a given spacing (Maestro). If demand is higher than runway capacity, delays are suggested for individual aircraft. Part of this delay is at best imposed in terminal sectors, when aircraft are high, spread apart and consume less fuel. The interface for visualizing these delays currently is shown on a separate screen. It consists of a timeline on which aircraft call signs are represented, associated to their delay in minutes. Terminal sectors' controllers find it difficult to use this screen during high workload periods: the AMAN screen distracts them from the radar image, and the interpretation of the delays is time consuming and not straightforward. In practice, the use of the AMAN is not systematic and not very satisfactory.

Directions for Improvement

Having identified the main problems of the arrival terminal sectors, we propose to describe in this paper a concept for the design of a new interface. This concept is an attempt to address the difficulties listed above, and yet preserve the advantages and the familiarity of the current environment. The philosophy is to design a human centered environment, and uses HMI techniques to render the new environment intuitive and natural to the users.

A New Working Environment: VertiDigi

Vertical Representation of Traffic

A vertical view of traffic is often felt necessary, either in cockpit or on the ground. Generally, such views are generated for a given flight, to give relative positions of neighboring aircraft. This, we believe, is not satisfactory, because it induces heavy cognitive cost on the user to switch to an ever changing reference in the vertical plane. A global vertical view seems more promising, to help build strong perceptive clues and reliable, dependable references. However, the difficult issue is: which perspective to take on traffic? The advantage of arrival terminal sectors is that they are in nature strongly oriented: the main flow is directed towards an exit point, the Initial Approach Fix (IAF), beginning the Standard Terminal Arrival Route (STAR). We chose to implement a vertical view of the sector positioning the aircraft according to their Flight Level on the y-axis, and their distance to the IAF on the x-axis.

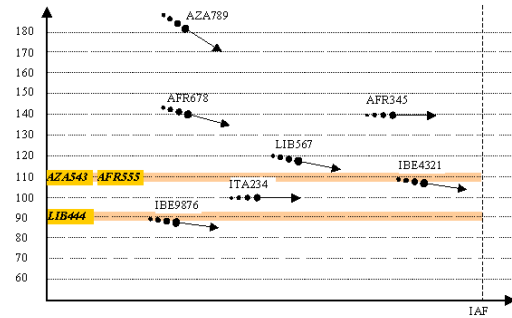


Figure 1- Vertical view of an arrival sector

Immediate benefit can be seen in using such a view. As can be seen in fig 1 above, the historical markers of past aircraft positions give an intuitive perception of the aircraft descent trajectory. Further, by selecting a different representation of “transverse” aircraft, any descent through one occupied flight level is more evident and if any conflict is induced, it is easier to detect. In this version for example, we chose to entirely highlight any occupied flight level. Other options can be chosen.

Touch Screen Input

Many attempts were made to try and tackle the issue of input. Clearly, in the context of terminal sectors, the rhythm and pace of clearances precluded the use of traditional scroll-menus: operators could simply not make input while they spoke on the frequency, like they do when writing on paper strips. We therefore elected to adopt a design already successful for similar issue, and developed by a team of interface specialist at the CENA: the DigiStrips interface (Mertz et al 2000). The use of touch screens combined with gesture recognition, animations, and graphical design was utilized in that project to achieve a very intuitive and natural, efficient interface. The change we made with respect to the original design is that we elected to combine input and the former mentioned vertical view. Thus we make the vertical view more than a simple visualization, but also as a means to designate aircraft by hand and make manual intuitive entries of clearances on the very view. The notion of paper strip is no longer necessary here, and the aircraft labels are the entry point for an aircraft designation, followed by manual entry of clearances. The use of an already proven technique insured a good efficiency of the clearance input, and saved development time. As an example to illustrate how input is made, a simple gesture recognition menu permits dragging an aircraft downwards to open a ‘descend to lower Flight Level’ menu, while a lateral dragging movement backwards opens a ‘reduce speed’ menu (see fig 2). All clearances can thus be entered into the system very naturally, and even beginners took only seconds to be able to use all menus and give directions to aircraft with no loss of time and at a pace close to speech on the frequency.

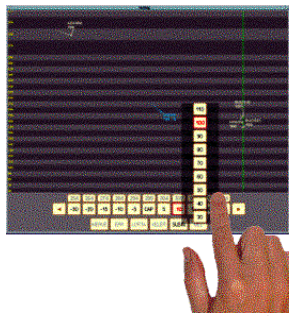


Figure 2 – Intuitive manual input

A Train of Ball Targets

The last item is about a representation change, rather than direct manipulation. To address the specific issue of sequencing, again using the vertical view, we chose to represent the delays suggested by the AMAN in a different manner. In fact, a delay means that a given aircraft is going to reach the IAF several minutes too early, either because it is too fast or too close to the IAF or a combination thereof. The idea is that the aircraft would meet the AMAN objective if it were slower or farther from the IAF. An image of where a ‘good aircraft’ should be would give an immediate and very natural perception of the situation, the way to correct it and the amount of action necessary to achieve that. For each aircraft on the screen, one target ball was therefore drawn on the vertical view, and located on the TFL horizontal line (Transfer Flight Level: the level at which the aircraft is supposed to be transferred to the Approach.) A line is drawn to link every arriving aircraft with its particular target ball. As for the horizontal position, the principle is the following: the target balls go at a similar speed¹ as that of the real aircraft, and their horizontal position is calculated so that they pass the IAF at the time required by the AMAN. See fig 3 for overview. The representation principle is similar to the ghost planes used to facilitate coordination between crossing or converging runways as quoted in (Hansman et al 2000). As a result, a train of balls running along the TFL line gives an immediate vision of how the sequence is building up.

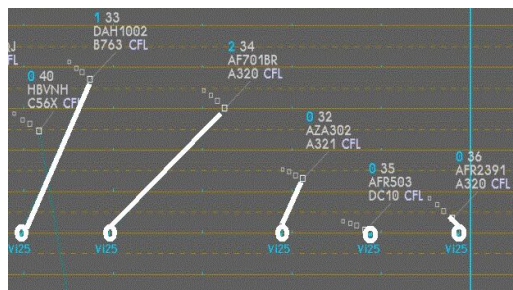


Figure 3 - Five arriving aircraft, and their corresponding target balls (in white)

¹ We chose the following principle: the ball ‘flies’ at the desired delivery indicated air speed (e.g. 250 knots for seamless delivery to the approach), but taken at the current altitude of its ‘master aircraft’.

It also gives a clear indication of what actions should be undertaken to fine tune the timing of arrival of aircraft on the IAF. Last, for mixed flows (turboprops vs. jet aircraft), the TFLs being distinct, one cannot mistake them and can easily tell the aircraft apart.

In the situation illustrated in figure 3, the last three aircraft are visibly ahead of time, and need speed reduction or diversion to pass the IAF on time (the IAF location is given by the vertical blue line to the right). In summary, the representation takes advantage of the combined vertical view-input device, and further enriches it with a sequencing information. Using perception instead of numerical value to describe the delay should, we believe, make awareness of the situation and decision-making more rapid and natural.

Working method. Depending on the construction of this train of ball targets, the working method can vary and sometimes be fairly straightforward. In our case, we chose a model whereby, as soon as an aircraft is vertically aligned with its target ball, a simple instruction can ensure it passes the IAF on time. By construction, in that case, it is sufficient to give a clearance such as ‘aircraft xyz, from position, set course direct to [IAF], descend Flight level [TFL], reduce speed [delivery speed]’.

Controllers’ Impression

Method

This interface has not been tested in real time simulation yet, as the concept is fairly new and development is ongoing. However, it was demonstrated to several visitors (approximately 40 demos). Of those visitors, roughly 15 air traffic controllers, half of them currently working in Terminal Sectors, saw the tool. The discussions were made informally. Most of the notes were made afterwards, and out of memory. The idea was to note as rapidly as possible, the verbalization that the audience made. As a result, some comments are in the form of quotations such as: “I’m sure this could serve for other than just terminal sectors”. Other comments have been reworded to give the essence of the remarks rather than the verbatim contents such as “suggests a what-if feed-back to be considered on the aircraft target balls”. Comments and remarks were archived on an intranet web page afterwards, with a web-form to be filled in. Some fields are automatically filled so that the person who made the demo has minimal effort to archive the content. The purpose was to make comments rapidly archived even by members of the design team not familiar with web pages edition. Also, making use of a form was initially intended to use as an electronic golden book for spectators to fill in themselves. It then appeared that people would not be so spontaneous and verbose if they had to express themselves in writing, and also we feared they might censor some negative comments. We therefore chose to keep the archiving work to ourselves, although trying to make it as close to the actual reactions we heard as possible. We focused on the controllers’ reactions in this study. Their first impressions are given hereunder.

Vertical View

The vertical view is not deemed as useful or natural as it would seem. Controllers have developed a habit of making up the vertical dimension mentally, and feel this view as redundant. Furthermore, they resent the fact that this view comes in place of the flight progress paper strips. This constitutes a radical change in their working habits, and a perturbation in their references and working methods. It seems that younger controllers seem more attracted to this representation, and some declared 'learning on such an interface could be fun'. Besides, some concerns come from the fact that this view, presented as a new interface, raises expectations for sophisticated tools incorporating a Medium Term Conflict Detection (MTCDD). Finding out that no sophisticated algorithm was in the VertiDigi interface resulted in minor disappointment. This contributed to some skepticism, due the common belief that without some degree of automation, no improvement in ATC can be reasonably achieved.

Input with Touch Screens

This aspect, in exchange, was extremely appreciated, and was seen as a good surprise. Most controllers declared they had lost hope for an input device that could match their speech rate. Most interfaces they saw or contributed to or were made to test were based on standard mouse inputs, scroll menus, and debate ran over which click was best suited and most rapid. In comparison, the advantages of touch screens are outstanding. No need for a great effort to learn or remember the menus: they are mainly in the direction of the intended action. The gesture becomes a new way of accompanying an aircraft towards where we want it to be. Many underlying techniques such as animations or transparency (Mertz et al 2000) make things even fail proof or explicit to co-workers, and providing accurate, information rich and yet non-intrusive feed-back.

Target Ball train to Represent the AMAN

Comments about this new representation were also positive on the whole, although not as firmly expressed as for the tactile input. Apparently, some controllers were intrigued at how exactly the target balls are calculated. Many controllers admitted to not making the best usage of the AMAN. They expressed the thought that these targets would make its usage more natural, and above all, less costly to achieve (mainly because delays would be visible, easy to perceive and no longer on a separate screen). The global impression is of curiosity as to how this works out in 'real life' and in actual working conditions.

Discussion

Perception vs. Symbolic

The most apparent difference between the current traditional environment and the one proposed here can be described as a trend to make all possible representation more

perceptive than symbolic. This line corresponds to a trend in Human Computer Interaction to try and reduce the distance between a user and the systems he deals with. As in (Rekimoto 1997), we believe this process reduces time and difficulty to perform tasks by hiding the system-side of a desired information, and delivering to the user a version in this case more on the perceptive level. The major difference is that of representation, which is either more processed, or expressed on a more analogical level. For example, the Arrival Manager we use is in no way different than the one in operation in the control centers, and the algorithms are unchanged. Our work was more directed at representing the same information graphically, instead of as a figure to be interpreted against a time line. This also capitalizes on the fact that controllers are experts at estimating a distance, the evolution of a situation on an image. So by transforming a time target (in the symbolic domain of cognition) into a visual or geographical target, we make things more accessible, and also easier to manipulate.

Similarly, by representing aircraft in the vertical plane, the interface gives immediate access to a representation that is otherwise achieved only at a high cognitive cost: transforming figures of Flight Levels for each aircraft into a global view of the situation. This perceptual layout can also provide opportunistic usage for Flight Level alarms: the interface is covered with horizontal lines representing consecutive Flight Levels. If an aircraft overshooting its clearance was represented as distorting the cleared FL line, the resulting image would be a non intrusive, yet very powerful *Alarm* to catch the users' attention, because it would break a seamless harmony in the image. Conversely, it would not cause too strong a nuisance, should the user elect to ignore it.

Manipulation and Materialization

This materialization of a symbolic notion or task is also used in VertiDigi. It is pertaining to the reification (Beaudoin-Lafon 2000) process. This says that when an abstract notion is turned into a physical object (even virtual), grasping it is made easier, and manipulating it or inventing new, innovative ways of using it is made more accessible. A good example of this is the elevator on the side of a word processor used to scroll in a document: it transforms scrolling (an abstract notion) into dragging the elevator, a physical action. We made extensive use of this technique on this interface, to contribute to the impression of ease and seamless understanding of how the interface works.

This issue is also, we believe, of paramount importance, and has far reaching implications beyond a mere ease of use. Several reports (Preux 1995, Leroux 1998) converge to state that there is more to paper strips than just writing clearances and remembering them. The physical manipulation yields better remembering, but also building of a better mental image or representation of the traffic situation. Further, it can serve as a means to maintain a physical activity to regulate stress or tension. Some anecdotal observations may better explain this: It has been repeatedly observed that controllers who were physically constrained by their working environment or setting, and

were deprived of their freedom to manipulate objects, spontaneously found ways around those constraints. They did so sometimes by inventing new means of manipulating objects in their environment, diverting some objects from their initial purpose to serve as physical artifacts and supports for their mental processes. An approach controller describing his usage of an arrival manager, thus testified that he used a function of the electronic environment, a “freeze” of an aircraft in the arrival sequence, as a means to make up his mind and materialize the sequence he was going to implement. He explained that, once frozen, the flight was easy to move about on the screen, and could be shifted around to “try” and “see” what best fitted to “make” or “build” the sequence. More extreme examples show that during some experiments, controllers instructed *not* to use the strips to arrange their traffic did it all the same and could not respect the instructions (Gronlund et al 2002). This urge to touch and move objects is inherent to the work and cannot be arbitrarily disconnected. The VertiDigi interface thus aims at respecting this user need, and tries to promote features that transfer this liberty of manipulation to an electronic environment.

Tactiles pins and tags. Future work is envisaged to develop and deposit ‘tactile objects’ on the interface. These should be simple, perhaps colored shapes like circles, triangles and squares that can be moved around on the screen with tactile drag and drop. These objects should be strictly functionless, neutral and passive. Their only interest consists in giving flexibility and freedom for an operator to invent means to use them, simply by dragging them and dropping them on the screen. A short list of possible usage is given: mark a given point in the sector at which aircraft should be reminded to initiate descent, underline the days’ TFL, round shapes could be used to mark the location of thunder storms (CB clouds) as reported by pilots, triangle to mark the wind intensity, etc. The idea here is to leave room for unexpected situations, which are so common in ATC. And count on the human being to improvise or innovate with the tools available.

Co-operation and Workload Management

This aspect was not explored in this study. However, the generalized use of proven interface techniques should grant the ability to incorporate more features into the interface dedicated to co-operation. Co-operation, flexible work share and explicit action are crucial to an efficient teamwork in control. The fact that interfaces are tactile, with designated feedback and animation should preclude many misunderstandings and clustering usually generated by switching to electronic environment.

More importantly, the fact that aircraft are spread on a distance-to-IAF scale yields interesting characteristics that need exploring. A distance scale, very similar in essence to a time scale in the case of arrival sectors, means one can anticipate on future positions of traffic. So the vertical view can be used as a workspace to project intentions, future planned actions, clearances that need to be triggered at a given moment etc. If a second similar VertiDigi view is provided to the planning controller, we believe this may be

used as a dedicated preparation workspace. Locating the desired action in time would be done by placing a symbol of the desired action at a corresponding distance of the IAF. Thus, the tactile pins mentioned earlier could be used to trigger a reminder on the executive controller side. If such and other methods are feasible, there is room for ample improvement in the work share on such terminal sectors. This better co-operation means being able to treat a higher level of traffic, and in a more comfortable and safe way, because the peak traffic would be better shared inside the controllers’ pairs instead of resting the entire burden on the radar controller as is mainly the case today in terminal sectors.

Conclusion

The interface that we propose, VertiDigi, to replace the paper strips has been shown in demonstrations to controllers, but not tested in simulated real time working conditions. The impression has been overall positive, and viewers have expressed curiosity and willingness to test it further. More testing is needed to better assess the validity of the concept, and improve it through participatory, iterative design.

The underlying design principles and philosophy are that some limitations often attributed to the users can be overcome by an appropriate design, and a detailed analysis of the work place and working methods. The design interface proposed here explores a new environment for Air Traffic Control in E-TMA, and provides many opportunities to support richer perceptual representations, easier to use and implement strategies for the user, and possibly more efficient co-operation and work share or workload management. All this, while the interface can be used in a fairly intuitive manner, given that it is designed to respect the users’ natural way of grasping the traffic and building his mental image of it. Adding to the materiality and physicality of notions that were, so far, symbolic or abstract, is an efficient way of achieving that.

Possibility to connect the interface to a real world environment could bring even further applications. For example, if the interface is proven to fit the controllers needs as an input device, connecting this appliance to aircraft via Data Link may enable testing in a non-intrusive manner. Having captured controllers’ intentions, their transmission to pilots could be seamlessly integrated, with no major cost of transitioning to a dedicated DL interface. ASAS applications are also envisaged as future work.

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