Tackling the problem of flight integration

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Abstract

The work described here is an attempt to improve an electronic stripping for terminal sectors, VertiDigi, in order to design a version dedicated to the Planning Controller (PC). A brief description of the existing tool is done, as well as its design principles. Past experiments are then evoked. They confirm the good acceptability of the tool for clearance input, but also show the emergence of a specific issue: the Flight Integration Process (FIP). This process includes all the mental, physical and manipulation processes that take place between the announcement of a flight and the actual call from the pilot on the radio frequency.

A field observation survey was conducted in summer 2006 in the three Paris Terminal Area centers (Orly, Roissy, and Athis-Mons). The method and tool used to conduct this survey are explained. The data gathered permits a better understanding of this FIP.

From there, an iterative design is started, to redesign the tool specifically to meet this FIP issue. The method involves operators as early as possible, and uses paper or low-fidelity mock-ups to capture their needs. The different steps are listed, and the convergence towards a final new design.

After a brief description of the new design functionalities, the advantages of this design method are discussed, and future experiments are envisaged to validate the HMI.

Introduction

The issue of electronic stripping

Setting up an efficient tool for electronic stripping has been a long standing demand in Air Traffic Control (ATC). Several options have been explored to address this issue. The most widespread one consists in using the radar image, namely the aircraft labels on the radar image, as an input area. This choice means that the Air Traffic Controllers (ATCOs) will use the mouse to click and scroll to select and input the clearances they tell the pilots on the radio-frequency. This choice has several implications:

- Most of the working time will be spent looking up at the radar image (to be compared with current practice: results observed with eye-tracking during Gate-to-Gate experiments [1] show that roughly 35% of simulation time is spent looking down at the paper-strips' board). The authors believe that this time spent looking down, although costly, is useful for the building of an accurate and critical mental image of the traffic: it forces the ATCOs to step back from a real-time moving radar image and take a different look at the traffic, anticipating and building a proactive plan instead of a more reactive work.
- Labels being used for input and feed-back result in radar image cluttering, and could jeopardize the analysis of the traffic, and conflict perception.
- Several implicit advantages of paper strips [2] are lost in the process, because the paper strips bears more than just the input functionality: support for manipulation and planning decisions [3], collaborative work [4], [5] and workload management for example.

To try and address these aspects, a project (ASTER : ASsistant for TERminal sectors) was started in 2001 to define, for the said terminal sectors, a tool for electronic stripping that would allow rapid input of clearances, while keeping several advantages of paper strips. To do that, some leading principles were adopted. First, a head-down display was selected, dedicated to input and work organization. The idea was to segregate functionalities [6]; here the analysis display (radar image) from the input and manipulation display, and thus keep interaction on the radar image to a minimum. Then, direct manipulation principles [7], [8] as well as situated cognition principles [9] were here adopted, to follow the example of a former DigiStrips HMI [10]. This includes touch sensitive input, graphical design, animations, but also possibility to move, manipulate and organize "flight-objects" in a way very similar to what is done with paper strips. Last, these objects have been presented as "labels" displayed on a vertical view of the traffic [11] to enrich the HMI and give it further representational capabilities in the vertical dimension [12]. The resulting HMI has been named VertiDigi [13] to reflect this combination of vertical view and digital input.

Initial experiments and emergence of the Flight Integration problem (FIP):

The first experiments were conducted in spring 2003, to verify the "workability" of the concept. Several results were derived. The most significant one concerns input: it was deemed satisfactory, and received complete support from ATCOs. The vertical view, although novel and unfamiliar, showed no impact on conflict detection and memorization, and even yielded a significant (40%) reduction in Flight Level clearances [14]. Two aspects were criticized, however.

- The first and minor one was that, for manipulation purposes, each label has a handle and can be moved around on the vertical view in a way similar to the paper strips. When the aircraft moves, however, it "drags" the label behind, which can then overlap another label. ATCOs asked for an automatic anti-overlap. The authors were reluctant to do so, fearing that this would mean losing the manual label manipulation process, and therefore the desired work organization from taking place.
- Second, and more importantly, the ATCOs criticized some design choices regarding the display of some route information. In current paper based environment, when a paper strip is printed, the ATCOs (mostly the Planning Controller (PC)) use it to analyze the flight to come, and make important decisions and anticipation on it.

This is called the *Flight Integration Process* (**FIP**). The information necessary for this FIP is more 'time-oriented': way-points and time estimates thereupon. But other information is used for this preliminary analysis of the flight: aircraft type, flight origin and destination, etc. This information could not fit into the input-oriented labels we had on the VertiDigi HMI. To avoid overloading the labels, the information was displayed on a dedicated area of the screen: a list on the side of the screen was created, where a series of "mini-strips" was displayed, one for each flight to come. This segregated area would, in the authors' mind, provide the necessary information to the ATCOs when needed.

Experiments showed that this did not work and that ATCOs didn't use those mini-strips. As they phrased it, it is difficult enough to keep a permanent mental link between a radar track and an input label (or paper strip). But to create yet another area just for the FIP is too demanding and generates a high mental workload. As a result, they could not perform an efficient FIP.

Further Testing – the Gate to Gate Real-Time Simulations (RTS3)

In the course of a European project, Gate to Gate [15], the VertiDigi HMI was selected as a tool for the arrival terminal sectors in a large scale simulation. Three (3) terminal sectors where simulated, feeding flights to a series of approach controllers. Each terminal sector was manned by two controllers: an Executive Controller (EC) and a PC; thus a total of 6 VertiDigi equipped position were tested. The results were consistent: even with a dedicated PC position, the FIP was deemed unsatisfactory. Also, input labels' anti-overlap was judged necessary and demanded. Input, which had been further refined and enriched with free text capabilities, was largely approved, and several sequences of traffic were controlled efficiently, sometimes with a traffic load high enough to lead to holding situations.

Field Observation

It was then decided to develop solutions to address this specific issue of FIP, and understand the underlying mechanisms. A field study was launched, in the course of a larger program on the Paris Region. Some observations were done to bring rationale into the design of the PC HMI, and to re-design the PC HMI to address this difficult issue of FIP. The pertaining results are given in next section 'Field Observation: the control room'.

Iterative Design and low fidelity mock-ups

Once the observations were made and compiled, a campaign was started to re-design the interface in order to account for the mentioned limitations and take into account the observations cited above.

The principle chosen is that of participatory, iterative design with users' in the loop. The expectation is that such method will yield a design that is not only quick but also rapidly converging towards the needs of the users, in the hope that this would save development costs and meet the users' expectations as much as possible. The method and the results are given in section 'Participatory user-centred design'.

Field Observation: the control room

This observation campaign was organised in Paris Approach and Terminal Sectors to address several research topics.

Research topics

Four research topics were selected: role and usage of the Arrival Manager, usage of the visualisation tools, role and purpose of the sector to sector coordination, role and usage of the paper strips. In our framework, we shall restrict ourselves to all that concerns the design and integration of strips into an electronic environment. We shall present here the objective, method and results of an investigation in these two directions and which enriched our understanding of the FIP.

Scope of the survey

This survey took place in the control rooms of Paris Approach, in the centres of Roissy-Charles de Gaule and Orly, as well as in the control room of Paris ACC (Athis-Mons). The survey was conducted by 5 observers, lasted 25 days during the period of May to July 2006.

Objective-Tools-Method

The *Objective* of this survey was to gather as much quantitative as well as qualitative information as possible concerning the real activity of ATCOs.

The way to do this was the definition, beforehand, of a set of observation criteria corresponding to the axes of the survey. These criteria, whenever possible, were broken down into observable (therefore measurable) indicators. The data were collected using a dedicated software *Tool* featuring ad-hoc observation. The tool was named OUI (Observation User Interface).

This OUI tool allowed a simple counting of certain events (number, duration) which were either pre-defined (observation grid) (e.g. **Figure 1**) or created dynamically by the observer (e.g. **Figure 2**). The tool also provided results on the fly, such as average rates of occurrence per observation session, or duration indicators for certain categories of events. This feature was developed to be able to collect unanticipated yet interesting events the observers could discover in the field.

Eventually, the recorded events were consolidated into a data base gathering the observations collected by the different observers.

Qualitative aspects were recorded via interviews, informal discussions with the ATCOs, some individual remarks made by the observers.

The results immediately presented with OUI permitted a debate, and constituted an objective support to the interviews. All these observations and interview notes enabled us to extract the common basis as well as the discrepancies in the role and the utilisation of the strips and the coordination for both approach centres and the centre in charge of terminal sectors.

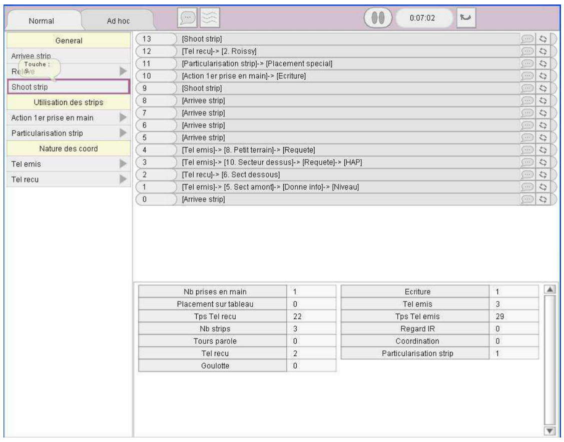

Figure 1. Predefined Events (Grid)

Figure 2. Dynamically created Events

As for the *Method*, the five observers spent the same number of sessions on all three control centres. Thanks to calendar organization, some sessions featured several observers being present at the same time on two adjacent positions in two different centres. During this three-month long observation period, several debriefings were conducted to better harmonise the observations, specifically regarding the way to timestamp the dynamically created events.

Some results have proven relevant, both from the quantitative (thus reliable) and from the informative point of view. A selection of these results will be presented hereunder. A more qualitative analysis of the data and the remarks gathered by the observers will help us propose some directions and thoughts, as well as principles or interaction modes that may be worth developing in the objective of an electronic stripping tool.

Results

We will first give the most reliable quantitative results (over 10 hours of observation). Next, a summary of qualitative results (ATCOs interviews, recurring observation, or important remarks that could not be measured) will be given. Each result is here presented in accordance with its relevance to the topic of FIP in an electronic environment.

Role and purpose of coordination

per hour	CDG	Orly	CRNA
Phone coordination (coming in or out)	13	15	19
Cumulated time (minutes)	5	9	7

Table 1. Coordination

This result shows that an average 15 coordination calls are made, per hour, and that this represents an average 7 minutes of activity per hour. Qualitatively, we have observed that the duration of phone coordination lasts noticeably longer in case of misunderstanding, or whenever an uncommon situation occurs (weather, transponder failure on a smaller terrain, problem with mode A). In addition to this, it should be mentioned that a large amount of coordination inside a centre (verbal coordination between two nearby control positions) occur. These can happen between adjacent positions, but also when controllers are more distant.

Role and utilisation of Strips

Number (per hour)	CDG	Orly	Paris ACC
Strip highlighting	15	2	8
Strip handover	22	26	All strips (PC to EC)
Moving strips on the board	43	27	20
Writing on strip	76	30	114

Table 2. Srip Management

Regarding the role and the utilisation of strips for all three centres in the survey, the strip is above all an item that provides information (e.g. information on the flight, indication of the workload), then a support for memory (e.g. recording clearances given to the pilot), much more than it is a tool for conflict detection.

The strip, in the FIP

We can identify two distinct periods in the life of a strip. One is what takes place before the first call from the pilot, the second stretches from the first contact to the transfer of the flight to the next sector. In the first period, what the PC does in terminal sectors is not really a conflict detection, but rather some anticipation about potential convergence between flights, and also the detection of anomalies on the strip or of some specific and uncommon characteristic of the flight [16]. This analysis of the strip is conducted in parallel with the sliding of the paper strip into a strip-holder of a given colour, this colour being chosen in accordance with the traffic-flow the flight fits in. This action may seem benign. It constitutes, however, the first mental and physical manipulation of the flight, and contributes to an ideomotor facilitation. The strip is then placed close to the EC strip board, so that the EC may, as a minimum, integrate the flight in his board, and at best, read entirely what information is on the strip. For the EC, this step seems to be what triggers his own representation, but also the beginning of a common representation, shared between the PC and the EC, because it is a visible clue of an informative intention [17].

In order to maintain this common representation, most efforts and demand are placed on the PC. He has to maintain knowledge of the context of the traffic under control, as well as the context of approaching future traffic. This, in order to perform his task as an assistant to the executive controller, such as is the practice in Paris ACC terminal sectors. And he has to do this without the help of manipulation nor direct access to the mnemonic aid, given that the strip does not belong to him any more.

During his initial integration, the PC also determines whether or not coordination is necessary. In view of the observations (see **Table 1**), coordination is one visible marker of the analysis the PC makes both on the strip and on the radar image. Roughly one in four flights is thus acted upon by the PC.

One other role of the FIP is to give the PC the opportunity to 'graphically' specify a flight, with the intention of sharing information with the EC, before physically handing over the representation of this flight (see **Table 2**).

In the light of these qualitative observations, further supported by the quantitative indicators, a complete re-design of the HMI was started. We also took advantage of a change in the display technology, which offered new interactions. The principles and understanding we had gathered about FIP and shared context will be used and carried over to the HMI. To do this, we decided to use a participatory design method.

Participatory user centered design

Three objectives were part of the work to be performed at that stage:

- First, even though the observers were familiar with Air Traffic Control, there remains a natural bias in the interpretation of raw data drawn from the observations. To reduce this risk, we confronted our results with ATCOs
- Furthermore, we wished to refine the first ideas emerging at the end of the observation stage, and complete them with more specific evaluations
- Last, our aim was to improve the VertiDigi application and benefit of the observation results

At first, we have tried to address the following issue: how to efficiently present our results to the ATCOs? The raw data were not explicit enough to be directly questioned by ATCOs. As for the conclusions, they were at risk:

- to be subject of interpretation themselves;
- to be rejected on the grounds of several ready-made prejudices regarding working methods.

We therefore decided to complete our observation stage with a participatory design phase [18] and a user centred design process [19]. This process enabled us to integrate, in a practical context, the conclusions we had reached through observations, and also permitted to evaluate them. Furthermore, by thus proceeding, we could also refine these conclusions by evaluating new and more accurate derived hypotheses.

Methodology of iterative design

We have organised our method in order to gradually refine the solutions proposed to the ATCOs. This refinement was also organised in order to converge towards our final objective [20]: the specification, in an electronic environment, of the problematic of FIP and of paper strip organisation. This refinement took the form of iterative mock-ups of growing accuracy, which served for small experiments. The results gathered during the evaluation of one mock-up were immediately recycled in the next mock-up and we privileged rapid and numerous iterations rather than deep formal experiments [21].

The number of mock-ups necessary was therefore initially not limited, the objective being to iterate as many times as necessary to reach complete satisfaction. In total, 4 iterations were needed. The first two were done with low-fidelity paper-mock-ups and permitted:

- to validate the observations relative to flight integration and the corresponding use of paper strips
- to determine the driving principles to be followed in order to carry over flight integration in an electronic environment.

The next two mock-ups, which were done in a software version this time, permitted:

- to complete and improve the FIP and the strip-organisation in an electronic environment;
- to evaluate complementary and additional solutions on how to share a context in such an electronic environment;
- to converge on technical and hardware solutions which would serve as the foundation of a new version of VertiDigi.

First round

The first iteration thus featured five low fidelity mock-ups (paper mock-ups), each of these reflecting the FIP as it was perceived by five different participants. These five persons either had participated in the on-site observations, or had built a mock-up to reflect their own understanding of the conclusions that came out of the field observation stage.

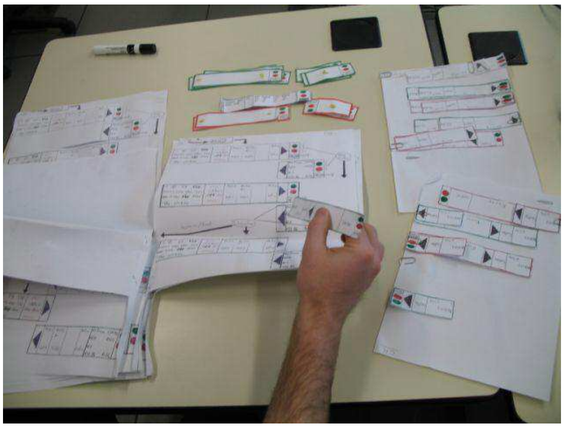

Figure 1. One of the 5 paper mock-ups

In this context, it was difficult to organize a rigorous and formal evaluation of the mock-ups. We therefore proceeded with a qualitative evaluation. Ten ATCOs compared the different mock-ups.

Working scenarios were run on each mock-up, with each ATCO. The interviews conducted after each run were then summarized and enabled the selection of two possible FIPs.

Second round

The second iteration was thus the continuity of the former one, and confronted two different strategies for FIP and for Executive/Planning controller cooperation.

The first strategy enforced a strongly scheduled organisation of the work. Each step of the work was performed in a separate and physically distinct locus on the workspace. The sequence of work was organised as follows:

- The paper strip was initially present to the PC.
- The latter could perform an initial integration of the strip, colour the strip according to the flow it belongs to, and, if necessary, coordinate the conditions of delivery of this flight with the former sector.
- After a given amount of time buffering (depending on the EC workload and availability), the PC transferred the flight object to the EC.
- From then on, a parallel work could take place on two distinct yet synchronized instances of the strip: the EC made input of clearances on his own, while the PC could still make exiting coordination (with the next sector).
- Last, the strip was transferred by the EC to the next sector.

The second strategy was somewhat more permissive. First, the organization of work was not constrained by any particular workspace on the HMI. Furthermore, the EC was given the possibility to by-pass the initial integration (normally allocated to the PC) and organize this integration himself.

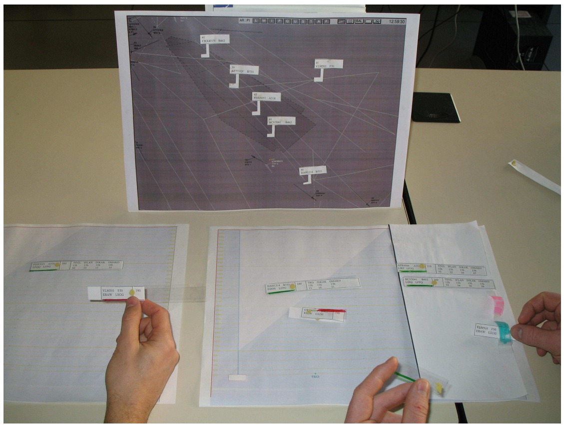

Figure 2. One of the mock-ups of iteration round 2

The two strategies were each reflected in a separate mock-up. These mock-ups, which were more detailed and elaborate than in the former round, were then submitted to a similar evaluation as in the first iteration.

The least constraining strategy eventually obtained a comprehensive support from the participants.

Third round

The fact is that each controller was allocated a copy of the flight instead of one paper strip for both controllers (as is the case nowadays). The main objective of this round was thus to evaluate whether this would cause problems in terms of context sharing for the pair of controllers.

This evaluation stage was performed on a lightweight and simplified software mock-up (Functionalities were kept to a minimum). Controllers could thus only input coordination (on the PC side) or pilot clearances (EC side), and each side could move and organize its strips:

- Either independently, each on his own screen representation of the strip board,
- Or in a "synchronous" way. In this case, any strip moved by the EC on his screen was simultaneously moved on the PC side (and the other way around)

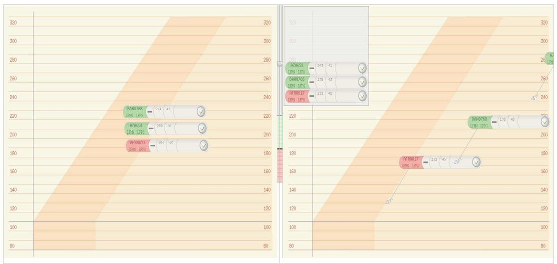

Figure 3. EC and PC HMIs

The second way was triggered on the PC side by an action which consisted in « metaphorically » capturing and dragging the EC HMI on his own side.

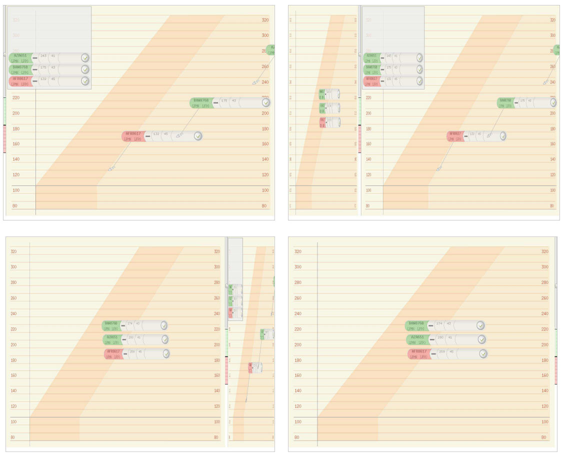

Figure 4. PC gradually captures the EC HMI

The controller pairs thus played working scenarios with two different manipulation modes. A third session offered them a free mode, in which they could alternate from one mode to the other.

Several aspects contributed to a clear preference for the 'non-synchronized' mode of strip movements:

- Except in some rare occasion when the EC permits the PC to shift some of 'his' strips on the board, the PC never moves the strips himself. The EC must be able to find the strip at the place where he had positioned it himself.
- Each controller being focused on a different aspect of the traffic, free individual positioning gave them the possibility to organize strips differently, according to their own priorities.
- The fact that both HMIs are located nearby still give the PC the possibility to check and verify the EC organization when needed.

Last design round

This iteration did not bring forward any new element or design feature, but it was the opportunity to materialize and bring together different elements resulting from earlier rounds. The result was implemented on a mock-up derived in two versions: an EC and PC side. This enabled the pair of ATCOs to manage all cases they meet in their nominal working practice.

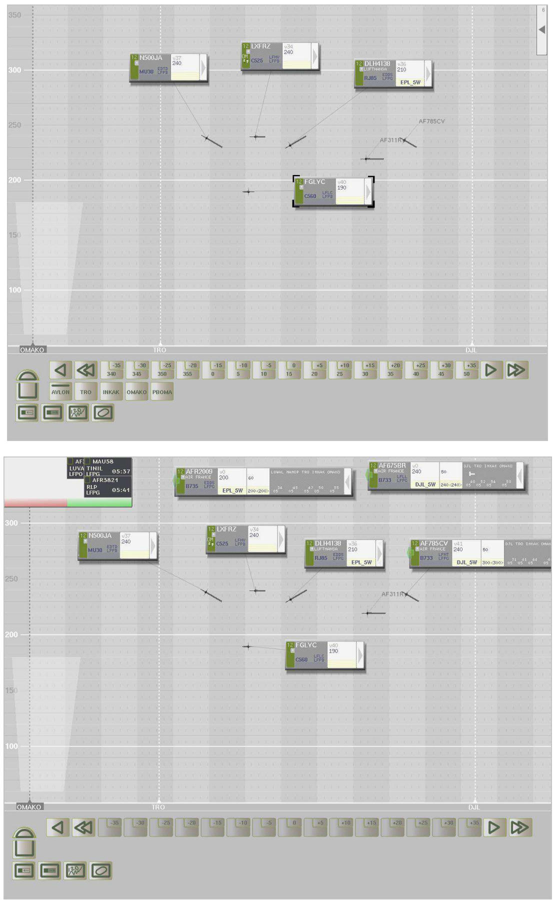

Figure 5. EC and PC Mock-Up

A pseudo-pilot and lightweight simulator connected to the HMIs made it possible to simulate the behaviour of aircraft and R/T communication with pilots to enhance the realism of the situations played.

This new evaluation enabled us to confirm the choices made earlier. It also brought forward a number of suggestions on how to improve the interaction modes used.

Result of the iterative design method

Being, as it is, a compromise between a formal evaluation and a simple design run, this user-centred iterative design [22] granted us two objectives we had in mind.

We have first been able to confront our field observations with the ATCOs, as well as the conclusions we had come up to at the end of the said observations.

The choice of paper mock-ups was an easy and very efficient way to evaluate various choices and rapidly converge on a solution. This method, besides, was very simple and saved us sizeable development costs.

Furthermore, this method was a way to gradually validate a migration of the FIP into an electronic environment. And, thanks to a relevant design process [23], which provided us with a technical method to support participatory design, we have laid the first stone of a new version of our HMI.

Last, the users appreciated this method involving them in the early design, and were happy to contribute.

Conclusion

The new design of the VertiDigi HMI was driven by the needs and drawbacks of the earlier version. Through the debriefings with ATCOs, we were forced to tackle this longstanding issue and aspect of the flight strips: the Flight Integration Process. We are not aware of any kind of electronic stripping (typically input conducted on the radar image and in the radar labels) that addresses this issue of FIP.

It appeared that the provision of elementary information needed to perform this FIP was not a sufficient solution: a better understanding of the physical location of this information, the way it was coded, and the way it is collected, shared and passed along can be significant. In other words, devil is in the details. Being aware of the importance of these aspects, it becomes fairly natural to try and respect them as guidelines, when it comes to designing an electronic stripping.

In practice, the new design includes several features:

- on the PC side, in the upper left corner, a special 'box' is placed. It serves as arrival dock for flights. A short label appears there whenever the Flight Data Processing System emits data concerning a new incoming flight,
- Optionally, this 'box' can be captured by the EC on his own screen, to account for the fact that the EC sometimes does the integration process himself,
- In nominal mode, the PC extracts a label passing through a coloured gate (red or green) which 'taints' the label. This reflects the flight belonging to a certain flow, but also to *implicitly* inform the EC that this initial analysis was done,
- The label expands to become a strip, complete with route information,
- The PC can further analyse potential problems with the flight, and perform any coordination needed,
- After a given time buffering (depending on EC workload), the PC physically passes the strip from his display to the EC display,
- The strip appears in condensed format on the PC side.
- The PC has clues about coordination performed, as some minute arrows indicate input fields concerned with coordination,
- He can either expand the strip to check them or proceed with his current practice and check them later, as appropriate,
- Last, the two displays are non-synchronous, and each controller can arrange strip to match his own needs.

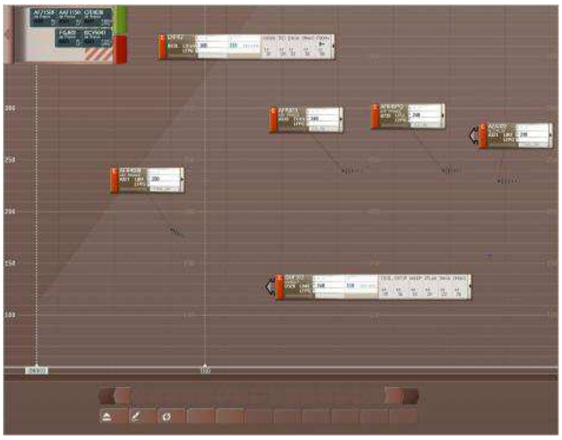

Figure 6. PC display (final design)

Several techniques and principles have been used, pertaining to the field of HMI, in order to give operators a feeling of comfort and familiarity when they get to work in a new environment. The most obvious advantage of this participatory and iterative method is its cost effectiveness and rapidity. In fact, it appears that low fidelity mock-ups constrain the designers into allocating more time to the end-users and operators. Their repeated involvement in the early design steps helps eliminate bad design options very early in the process. This saves a great amount of development and design efforts.

Plus, the users take active part in the design, and often come up with unexpected suggestions as to how an interaction should be done, and what priorities to allocate to different functionalities. In our case, it is interesting to remark that they have naturally chosen the more permissive and open philosophy for the interface. This means that their comfort is higher whenever there is room for flexibility, adaptability to cover unexpected situation etc. In short, a proper design is often one that is flexible enough to allow adaptive usage, not necessarily a comprehensive and very accurate one. Unexpected or non nominal situations being standard practice in air traffic control, this choice comes as no surprise.

Last, it is to be noted that the final design was obtained only by mimicking the current practice on paper strips. Naturally, the electronic environment allowed room for more creative and newer tools and working methods. However, this 'chameleon' option seems to be the one to grant better acceptance. Above all, it ensures a safe transition and preserves current practice and working methods. This means easy transition, quick training, lower stress and lower feeling of disorientation. These aspects alone are sufficient to drive the choice of end-users.

The result is an interface which is, to say the least, acceptable to users for what they perceive as their future work in an electronic environment.

This expectation now needs to be confirmed in further testing, using real time simulation which should be conducted early summer 2007.

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