Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Towards a Paperless Air Traffic Control Tower

Conference paper for HCII 2011

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Electronic Flight Strips
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Problem area
In Air Traffic Control (ATC) towers, EFS systems are currently being enrolled to replace paper flight strips. Flight strips are mainly used:

- to present flight information to the controllers;
- to allow the controller to administer his instructions;
- to build and maintain a mental picture of the aircraft under control;
- to support the handover of flights between controllers.
- In the process of the design of an EFS system, ATC the Netherlands required a prototyping process and human-in-the-loop evaluation to obtain system and implementation requirements.

Description of work
This article describes the design process of a digital strip system to replace the existing paper strips conducted by a multi-disciplinary team. The design process consisted of:

- a detailed investigation of working methods with paper strips;
- iterative prototyping of the defined system functions with intermediate part-task evaluations with controllers; and

This report is based on a presentation held at the HCI (Human Computer Interaction) International 2011, Orlando, Florida, USA, 9-14 July 2011.

- whole task evaluation in the NLR's tower research simulator with the final prototype.

Results and conclusions

The iterative participatory design process resulted in a prototype that proved to be fit for handling peak traffic after just 20 minutes of familiarization by experienced controllers.
The limited simulation set-up yielded several potential improvements and requirements for implementation. The controllers had the opinion that the hand-over of strips was better supported by the EFS system, because it reduced the noise in the working environment, and required less time and effort. Controllers can remain in their position which allows them to maintain their mental picture. Nevertheless, incoming strips were left longer unattended with EFS in comparison to paper strip. Furthermore, working with the EFS system resulted in an increase of head-down time. Moving the electronic strips requires more visual attention than paper strips. This simulation focused on the criticalities of implementing the EFS system. It provided enough confidence that the system with small improvements provides a sufficiently detailed basis for specification and development of an operational system. For future research it is of interest whether the head-down time decreases after more prolonged usage of the system and/or how this concept of interaction compares to a concept where the first most likely interaction is supported by a single tick, e.g., as to transfer the strip to a next location or to a next controller.

Applicability

The research presented is applicable to tasks in air traffic control towers in general and specifically to the replacement of paper strips with an electronic system.

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Summary

A prototype of an Electronic Flight Strip (EFS) system for air traffic controllers in the tower was developed in a multidisciplinary design process with rapid prototyping. The process which included five intermediate part task evaluations resulted in a prototype in which the existing working methods could be maintained. During a whole task evaluation of the EFS system in a tower simulator the usability of the EFS system was evaluated as well as the impact of the EFS system on strip hand-over, the controllers' mental picture and head-down time. It revealed that controllers were able to handle peak traffic with EFS after just 20 minutes of familiarization. Furthermore, the hand-over of traffic with EFSs was better supported according to the controllers. Nevertheless, incoming strips were left unnoticed longer with EFSs and head-down time increased by around 5%. For these reasons the support of the controllers' mental picture was rated slightly lower with EFSs. With small improvements and more familiarization the concept provides a sufficiently detailed basis for specification and development of an operational system.

Contents

Abbreviations

ATC	Air Traffic Control
EFS	Electronic Flight Strips
NLR	National Aerospace Laboratory
RC	Runway Controller

1 Introduction

The objective of this research was to prototype an Electronic Flight Strip (EFS) system user-interface for the air traffic control tower at Schiphol Airport Amsterdam and to evaluate it in a human-in-the-loop exercise in NLR's tower research simulator with a realistic traffic sample. This prototyping and human-in-the-loop evaluation was required by ATC the Netherlands to obtain system and implementation requirements for an EFS system.

In Air Traffic Control (ATC) towers, EFS systems are currently being enrolled to replace paper flight strips [1], [4], [5], [6]. Flight strips are mainly used:

- to present flight information to the controllers;
- to allow the controller to administer his instructions;
- to build and maintain a mental picture of the aircraft under control; and
- to support the handover of flights between controllers.

Each strip represents one aircraft or other traffic on the airport surface.
Paper strips are a representation of the flight or traffic information available in the central ATC system. After the strips have been printed, controllers administer the progressing traffic situation by making notes on the paper strips. These handwritten notes contain valuable operational information, not only for the controller himself/herself, but also for other controllers, in or outside the tower. Digitization of the strips allows the controllers to enter instructions in the central ATC system making the information available for more controllers and other parties such as airport personnel or airlines. In addition, the paper strips are put in holders requiring extra handling and creating a noisy environment in the tower.

This article describes the design process of a digital strip system to replace the existing paper strips conducted by a multi-disciplinary team. The design process (Fig. 1) consisted of: detailed investigation of working methods with paper strips, iterative prototyping of the defined system functions with intermediate part-task evaluations with controllers and finally whole task evaluation in the NLR's tower research simulator with the final prototype.

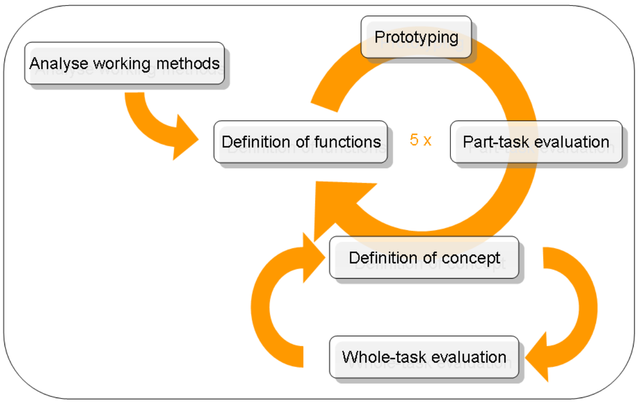

Fig. 1 Schematic representation of design process

2 Design process and part task prototyping

The first step in the design process was the analysis of existing working methods in the tower. For the fairly complex and busy airport of Schiphol Amsterdam it became apparent that the function of paper flight strips was much broader than administering the information of individual flights. Especially ground controllers – who have most aircraft under their responsibility simultaneously – use the organization of their strips to plan the traffic and to indicate future actions or conflicts very intensively. It appeared that the way in which paper strips were placed in the strip bay or holder were indications of the traffic situation. For example, paper flight strips are not always placed in the strip bay, not completely in the holder or are turned upside down. These are indications of certain events that needed to have their equivalent in the prototype of the EFS system. In addition, most standard controller actions (e.g. provide push-back and taxi instructions) were indicated by moving the strip to a next strip bay and were to be represented in the prototype.

In the design process, five design workshops were held with a multi-disciplinary team consisting of representatives of Human Factors, systems, safety and procedures and of each controller function: clearance delivery, startup controllers, ground controllers, runway controllers and assistants. In each workshop, part of the functionality was discussed that was to be prototyped, for evaluation in the next session. This resulted in an incremental prototyping process where existing functionality was improved and new functionality was added to the prototype and described in its specification after each session.
The resulting prototype consisted of an interaction concept allowing to drag strips and to move them by selection and choosing a new location on a touch display operated with an electronic pen.

The approach taken in the design of the EFS prototype was to adapt the system to the current way of working. This implied that all movements of strips were initiated by the controllers and the layout of information on the strip and of the placement of strip in bays were maintained. An important starting point for the hardware was that all positions should be generic allowing for interchangeability of positions independent of the role of the controller.

Because of the requirement to have six strip bays adjacent to each other to accommodate for all different statuses and taxiways of aircraft under control of ground control a decision was made to use two 21" WACOM displays per working position, to be operated using a single electronic pen (Fig. 2). The two displays were placed against each other and on top a transparent plastic sheet was placed to bridge the gap between the two displays. In this way strips could be dragged from one display to the other without lifting the pen.

Fig. 2 Ground controller using the EFS system in the simulation

To maintain the current working method, all movements and handovers were to be initiated by the controllers, as opposed to automatic transfers.
Strips could be moved in three different ways, by:

- dragging the strip, by placing the pen on a strip and dragging the pen over the screen to the place where the strip was to be placed to;
- ticking the strip and the intended position; or
- pushing strips vertically in a bay, in which case a number of strips could be pushed up or down.

Strips were handed over on initiation by the controller. The sending controller would place the strip in a pending bay, which is visible to the sending and the receiving controllers and in which

the strip was presented smaller and with merely the most important information. The receiving controller had to move the strip out of the pending bay in order to take the strip and corresponding flight under control.
For the transfer between two ground controllers it was desirable to place strips in the other ground controller's active field. To meet this requirement a picture of the other working positions could be accessed in which the strip could be placed. At the receiving controller's working position the strip would then appear in grey, and would be presented in regular colors after the acknowledgement (touching) of the strip.

The strip system allowed for making changes, for example change a runway or a gate through menus. Also annotations on the strip could be made as if writing with a pen on a paper strip. The latter was used for example by the runway controller to indicate a clearance for line-up and take-off.

3 Whole task evaluation

In a small scale simulation set-up in NLR's ATC tower simulator with a 360 degrees field of view, the use of EFS was compared to the use of paper flight strips for the most time-critical controller positions in the tower. The main objective was to provide insight on the following questions:

- Does the system adequately support hand-over between positions?
- What is the consequence for head-down time of the controllers with the introduction of EFS?
- Does the system adequately support the creation and retention of a mental representation of the traffic?

Due to limited size of the evaluation it was not expected that enough statistical information would be delivered and that controllers would be familiar with the system enough for a firm answer to these questions, but to get an indication.

3.1 Evaluation setup

The controller working positions of interest in this study were the ground controller (GC) and the runway controller (RC). These positions were considered most critical and moreover the GC has the highest number of strips (and flights) under control at a given time, with the most different statuses. This position was considered the most complex concerning strip usage.
In the simulation, two generic tower working positions were equipped with the EFS prototype allowing for the evaluation of two working positions simultaneously and the interactions

between these positions. Two set-ups were evaluated: two GC working positions adjacent to one another and one GC adjacent to one RC. Two crews, each consisting of two GCs and one RC participated in the simulation, each for one day. Each crew evaluated each set-up in two conditions: once with de prototype and once with paper strips. Runs lasted each 45 minutes. One crew consisted of controllers that had been involved in the development process of the prototype. The other crew was completely new to the system.

A training run at the beginning of the day was to familiarize the crew with the system, of 45 minutes. The GC and the RC position were available. The GCs took over from one another and it was practiced until all controllers felt confident to use the system.

Table 1 Experimental Design

Run	Day 1	Day 2
Familiarization EFS	GC, RC	GC, RC
Paper strips	GC1, GC2	GC, RC
EFS	GC1, GC2	GC, RC
Paper strips	GC, RC	GC1, GC2
EFS	GC, RC	GC1, GC2

3.2 Scenarios

Two traffic samples of 45 minutes were developed. They simulated an inbound traffic peak that gradually changed to an outbound traffic peak. During the inbound peak two parallel runways (18R and 18C) were used for landing and one (24) for departure. In the transitional phase runway 18C was closed and 18L was taken into use for landing. The traffic sample for the GC-GC exercise included around 64 flights, for the GC-RC exercise around 42. Events were included such as a need for de-icing, occupied gates for incoming traffic, an aircraft that had to return to the gate, and the need for aircraft to cross an active runway. Also two strips of inbound traffic appear in the wrong sequence and two aircraft of the same type and airline that were taxiing to the runway called the RC in the wrong sequence, to see whether the controller would notice this in both the exercises with paper strips and EFS.

3.3 Measurements

For the evaluation, questionnaires were to be completed by the controllers, debriefing sessions were held and analysis of simulator loggings and video recordings were made.
A questionnaire was to be completed by the controllers after each run with EFS. Several aspects were to be rated for the EFS system in comparison to the paper strips. The ratings were made on

a seven-point scale for which the tick box in the one end indicated “much better”, the other side “much worse” and middle indicated ‘the same’.
The aspects to be rated were about the primary functions of strips (e.g. support the mental picture of the traffic), the consequences of working with EFS (e.g. workload, efficiency) and the usability.

Hand over

The hand-over of strips from one controller to the other was assessed subjectively through controller comments during debriefing and in the post-experiment questionnaire. In addition, the time was assessed from the moment the strips were handed over until the receiving controller integrated the strip in the strip bays. For the EFS this was done by logging the time from the moment the strip appears on the working position until the time the controller first selects the strip.

Mental representation

In order to measure the creation and retention of the mental representation of traffic, the controllers’ reactions to certain events that were introduced in the scenario were observed. For example there were two aircraft of the same type and company taxiing behind one another, of which the second would call the RC for a line-up clearance before the first one. It was observed whether the controllers noticed this and reacted likewise. In addition, controller judgments in questionnaire and debriefing were analyzed.

Head down time

The percentage of time that the controllers were looking down was assessed. During the busiest moment in the scenario, a ten minute sample of the video recordings was taken and analyzed. This sample started after 25 minutes of simulation time for each run. A stopwatch function was used to time the head-down moments.

Table 2 Means of measurement per objective

Aspect	Observation	Logging	Questionnaire	Debriefing
Transfer between positions	Timing of video (paper)	Automatic logging (EFS)	X	X
Head-down time	Timing of video		X	X
Mental representation	Observation of events		X	X

4 Results

Even though the number of runs was limited and the familiarization time was short, the evaluation yielded some interesting results.

4.1 Use of the EFS

Controllers were observed to work with the EFS system quite easily. Nevertheless GCs and RCs mentioned that using the pen for all movements and changes of the strips is a change that requires more visual attention than moving the paper strips. During the movement of paper strips the controllers would often look to the outside view.
The use of EFS resulted in a much lower level of noise in the tower simulator and controllers remained seated in their position for each hand-over.
For the main research questions the results are reported in the following.

4.2 Hand-over

The support of the hand-over between positions was rated higher with EFS than with paper strips according to the controllers. The reasons mentioned were that it was quieter (paper strips placed in metal holders make noise), it was noticed that it costed less time and did not result in a temporary loss of the mental picture, because the controller could stay on the working position. Nevertheless, strips were left unattended longer in electronic than in paper form; EFS were left pending for 38 second on average, with paper strips only seconds. All GC had occurrences where strips were left pending for more than 100 seconds. One controller mentioned to use the pending strip bay also as the ‘passive bay’ and left the strips there longer for this reason, but other controllers did not notice incoming strips for quite a while. The silent appearance of strips was identified as a potential cause as well as that the location of the pending bays on the sides of the displays were outside the scanning field of the controllers.
For the transfer of strips from GC to GC, where the controller opens a picture of the other controllers strip display, also strips were left unnoticed longer with the EFS.
In the simulation this didn’t cause any potentially dangerous situations. However in hand-overs of active, moving traffic (e.g. from RC to GC and from GC to GC) it is undesirable that aircraft are left unattended for too long. The taskload at a position seems to increase the effect.
A sound for incoming strips could be a solution but it is also expected that more familiarization with the system could help as well.

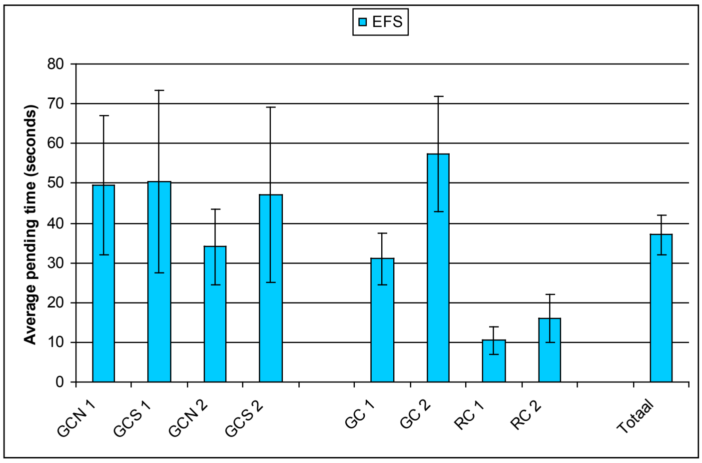

Fig. 3 Average time strips were pending for each position (GCNorth, GCSouth, GC and RC) on day 1 and 2 and 95% confidence interval

4.3 Mental picture of traffic

The events of changing runway configuration, de-icing, occupied gates, return to gate and crossing an active runway were handled well by both GCs and RCs. Also the events of aircraft calling in the wrong sequence or strips appearing in the wrong sequence were noticed and well responded to by the controllers.

Nevertheless, controllers rated building up and maintaining a mental picture of the traffic lower with the EFS prototype, on average 0.5 point below the paper strips (out of three points). A first reason identified, was the strips remaining unnoticed longer, and are therefore not integrated in the overall picture and controllers were 'surprised' by a call from a flight. Secondly, the introduction of an extra strip bay was a novelty that contributed to the unfamiliarity of working with the new EFS system, and the limited simulation time did not familiarize the controller enough to get used to this.

4.4 Head-down time

The time controllers were looking down to the displays and strips was assessed on the basis of the video recordings of the simulation. Time samples of ten minutes were analyzed. The time interval was taken between the 25th and the 35th minute in the simulation. The accuracy of the measurement was estimated around 1% since several repeated assessments revealed a maximum difference of five seconds.

The percentages of head-down time were very high, with paper strips as well as with EFS. On average a head-down time of 74% was measured with paper strips and 79% with EFS. In simulations, the head-down times measured are higher than in reality, in [3] head-down times of 80 % were measured. The lower resolution of the outside view in the simulator causes a certain simulator effect.

For the RC the task load was quite low, therefore the RC head-down times are not considered as representative. For the first GC-GC run on the first day the workload was too high, requiring the traffic sample to be altered before the comparable run with EFS. This did not allow to compare these two runs. Comparison of head-down time between paper strips and EFS including and excluding the GCN 1, GCS 1 and RC 2 data was significant using a paired T-test ($t=2.99$, $n=8$, $p=0.05$ and $t=2.27$, $n=5$, $p=0.05$). Thus the use of the EFS prototype increased the head-down time in comparison to the use of paper strips in the simulation. Controllers also mentioned that using EFS simply required more visual attention than paper strips. Controllers mentioned that unfamiliarity with the system was a factor and they had the feeling that more practice would decrease the head-down time. On the other hand it was mentioned that annotation on paper strips that also require inputs in the central system (which was not seen in the intervals measured) would require a lot more head-down time than with EFS.

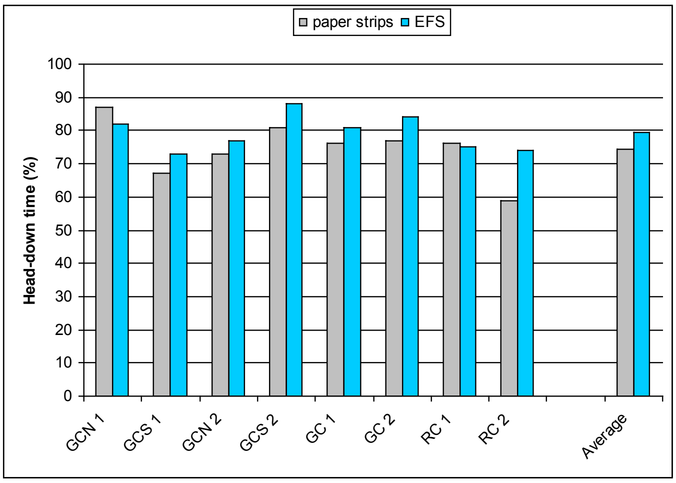

Fig. 4 Head-down times in percentages for the different positions (GCN, GCS, GC and RC) on day 1 and 2, for time samples of ten minutes starting from minute 25

5 Discussion of results

The iterative participatory design process resulted in a prototype that proved to be fit for handling peak traffic after just 20 minutes of familiarization by experienced controllers.
The controllers had the opinion that the hand-over of strips was better supported by the EFS system, because it reduced the noise in the working environment, and required less time and effort. Controllers can remain in their position which allows them to maintain their mental picture. Nevertheless, incoming paper strips were earlier noticed than EFS. After prolonged use, the controllers may adapt their scanning pattern on the new working position. The delay in noticing the pending strips is caused by their silent appearance in the peripheral field of view of the controllers. This can be mitigated by a sound to announce the appearance of a strip, especially for active traffic or as [3] argues that essential information should be presented within 15 degrees field of view.
Furthermore, working with the EFS system resulted in an increase of head-down time. Moving the strips requires more visual attention than moving paper strips. This may decrease when controllers are more familiar with the system, but it obstructs to a certain extent in building and maintaining a mental representation of the traffic.
This simulation focused on the criticalities of implementing the EFS system. The results provided enough confidence that the system, with small improvements provides a sufficiently detailed basis for specification and development of an operational system. For future research it is of interest whether the head-down time decreases after more prolonged usage of the system and/or how this concept of interaction compares to a concept where the first most likely interaction is supported by a single tick, e.g., as to transfer the strip to a next location or to a next controller.

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