4D ATM COCKPIT: SET-UP AND INITIAL EVALUATION

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Summary

Within the context of an European research project FANSTIC, NLR defined and implemented an example of an modified glass cockpit which allows aircraft operations within future 4D Air Traffic Management environments, using digital datalink as the primary means of communication.
The FANSTIC project is a collaborative research project, partially funded by the European Commission. The investigation presented in this paper involved partners from Germany, Ireland, France and the United Kingdom.

The cockpit with its environment was developed using the NLR moving base Research Flight Simulator (RFS) coupled to the NLR Air Traffic Control Research Simulator (NARSIM). In addition to simulated digital datalink (using Ethernet), analog radio communication was simulated through separate voice channels.

The purpose of the project was to investigate possible implementations of data link into future flight deck concepts, in which extended ATC/aircraft information exchange plays a dominant role. Three data-link applications were evaluated: ATIS, En-Route Clearances and 4D trajectory negotiation.
The cockpit user interface prototypes for these data link applications included graphical manipulations using touch input devices (including gesture recognition) and trackerball inputs in combination with an interactive Navigation Display, based on the HMI principle of 'direct object manipulation'.

Simulation tests with operational line crews, showed that the 4D negotiation application was well appreciated because of its strategic value and efficient use of data link, and particularly for its graphical user interface. Pilots experienced it as the natural next step in cockpit development using the current state of technology. The trackerball was generally preferred over the use of a touch pad. However, many issues still need to be investigated before a final cockpit concept will have evolved.

The En-Route Clearance application produced realistic benefits by reducing misunderstandings with ATC, common to RT use.
Current implementations of data links like Mode-S introduce significant transmission delays. Since time is a critical factor, the use of these data links for tactical applications will be limited.

Pilots preferred the ATIS information displayed as text on a display instead to the currently used voice method. Due to the low criticality level, ATIS can very well be combined with other data link applications or other functions on a single display (and control) device.

Abbreviations

4D	four dimensional
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
CDU	Control and Display Unit
CRM	Crew Resource Management
DDF	Display Definition Format
EATMS	European ATM system
EFIS	Electronic Flight Information System
EFMS	Experimental Flight Management System
FANSTIC	Future ATM, New Systems and Technologies Integration in Cockpit
FMS	Flight Management System
HDG	Heading
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
METAR	Meteorological Aviation Routine weather report
MFD	Multi Function Display
NADDES	NLR Avionics Display Design and Evaluation System
NARSIM	NLR ATC Research Simulator
ND	Navigation Display
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
PC	Personal Computer
PF	Pilot Flying
PFD	Primary Flight Display
PHARE	Programme for Harmonised ATM Research within Eurocontrol
PNF	Pilot Non-Flying
RFS	Research Flight Simulator
RT	Radio Telephony
TAF	Terminal Area Forecast

Introduction

Future ATC will impact on the required avionics of existing and future aircraft. NLR defined and implemented an example of an aircraft cockpit which allows operations within a 4D Air Traffic Management environment, using datalink as the primary means of communication. This 4D ATM environment uses time (as a fourth 'dimension') in a more strict sense to increase the airspace capacity through a reduction of aircraft separations. These reductions rely on the assumption that Air Traffic Controller (ATCo) workload will be reduced sufficiently through the shift from complete tactical control towards more strategic, planning based control.

FANSTIC

The results presented in this paper are based on the achievements of NLR in the context of the Future ATM, New System and Technologies Integration in Cockpit (FANSTIC) project. The FANSTIC Project is a collaborative research project, partially funded by the European Commission.

The project focused on new aircraft systems and interfaces needed to improve ATM capacity, through:

- studies and specifications of the required airborne functions, architecture, operational procedures and the Human Machine Interface (HMI) through identification of the future ATC Air Ground coordination data exchange requirements
- evaluation/validation of the defined architecture with a set of selected ATC applications, tested in a realistic environment, using a combination of a representative research flight simulator and ATC research simulator

FANSTIC goals were directed at:

- specification of a harmonised European standard simulation tool to validate future aircraft dedicated ATM systems and HMI devices
- studies on weather prediction and landing system capabilities based on a multi-function radar
- development of advanced multi-function HMI's (for control and information)

- demonstrations and crew evaluation of the HMI and dialogue capabilities of prototype display systems

The following companies, research centres and universities were involved in the project: Aerospatiale Aeronautique, Daimler Benz Aerospace Airbus, British Aerospace CA, Fokker, Sextant Avionique, NLR, CENA, Smiths Industries, VDO, ALENIA, CAPTEC, NTUA, Space Applications Services, University of Kassel, Aeroformation, Defence Research Agency, Britisch Aerospace Sowerby Research Centre, Thomson CSF, Dornier and FIAR.

Purpose of the investigation

The purpose of this study was to evaluate cockpit data link applications. Three data link applications were defined and implemented: ATIS, En-Route Clearances and 4D trajectory negotiation.
A different, potentially more efficient way of pilot interaction with displays and controls was investigated: emphasis was placed on graphical display interaction using touch input devices (including gesture recognition) and trackerball inputs. Both were tested in combination with interactive Navigation Display (ND) and Multi Function Display (MFD).

Research Flight Simulator (RFS)

The NLR Research Flight Simulator is a four degree of freedom moving base research simulator, equipped with reconfigurable graphical displays. A layout of the cockpit is presented in figure 1.

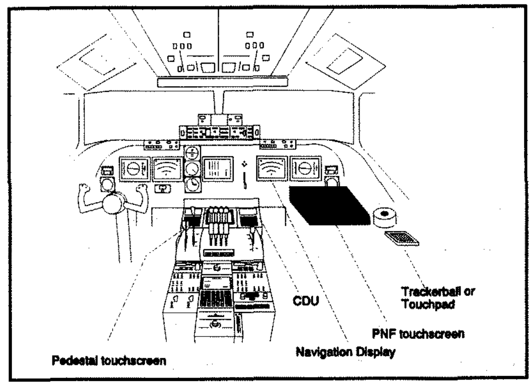

Figure 1: RFS cockpit layout

The Pilot Flying (PF), sitting on the left side of the cockpit, used a standard Primary Flight Display (PFD) and an enhanced ND. ATC messages and clearances were presented on the 'pedestal touch screen'.
The Pilot Non-Flying (PNF), sitting on the right side of the cockpit, used a touch pad or trackerball for the interaction with navigation screen. The PNF also operated the pedestal touch screen in order to create and retrieve both ATIS and En-Route Clearance information. During some of the trials a special PNF table touch screen was used to select ATIS information: this part of the experiment was set-up by Daimler Benz Aerospace. It used a centralised control concept, which is beyond the scope of this paper.

All graphical presentations and formats have been defined and implemented using the NLR Avionics Display Design and Evaluation System (NADDES[5]). This rapid prototyping tool uses an interactive editor in combination with a computer hardware independent description methodology (Display Definition Format or DDF) to define the graphics and its behaviour. The DDF descriptions can subsequently be converted into software program source code using hardware specific translators. Current translators include PC and IRIS systems.

Datalink common functions

During the definition of the datalink applications, it was noted that several functions could and should be shared. Those shared functions are e.g. the operation of the archive (message storage and retrieval), the provision of alerts and the data link status (e.g. using SATCOM or VHF, amount of errors encountered, pending messages). By implementing those functions only once, a consistent HMI can be created, which limits the amount of required training and possible input errors.

ATIS

Automated Terminal Information Service (ATIS) provides the crew with information regarding the runway in use, local weather conditions and specific airport conditions like reduced service capabilities of landing aids. Normally, the crew has to select a specific frequency in order to obtain that information via voice (listen out a continuously transmitted message). The message itself is been updated at irregular intervals by the airport.
The reception of ATIS messages is often cumbersome due to the low quality of the signal. In addition, the procedure to obtain the information is interfering with the operation of the aircraft. For those reasons, pilots and operators have requested another method to access the information. Current developments (e.g. ICAO SICASP) are directed at the introduction of automatic data uplinks.
In this project, an ATIS application has been defined which allowed the pilot to freely select the weather and status information from any relevant airport.

In the NLR set-up information was presented on the lower MFD at the front of the pedestal. Control inputs used the touch overlay of the screen allowing to initiate new selections or to retrieve previously up-linked ATIS messages from an (on-board) archive. An example of the ATIS airport selection screen layout is presented in figure 2.

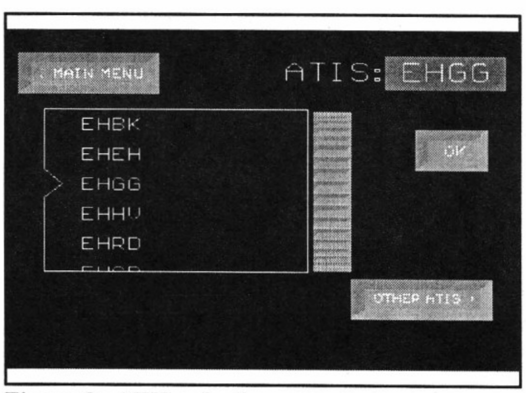

Figure 2: ATIS selection screen

For generating the data link command to apply for a so-called subscription to receive ATIS messages from selected airports, a drum-wheel like selector (scrollwheel) was used to select the airport. The scrollwheel could be operated by placing the finger tip on the screen, followed by a movement into the desired direction. The underlying HMI metaphor was that the words are attached to the drum. Based on the route information, a pre-selection is made of relevant airports to reduce the length of the list in order to speed up/ease the selection process.

En-Route Clearances

En-Route Clearances were used to test the flexibility of operations in an expected 4D ATM environment: ATC messages and clearances were created by a controller on NARSIM. In addition, so-called conditional clearances, to be executed late, (e.g. HDG 50 at BRAVO) could also be issued. This application shared the same MFD as the ATIS application. Pilots could confirm clearances by using the touch screen. Pilot requests to ATC could also be created using the same touch screen. Six basic ATC requests were selectable: Speed, Altitude, Climb (at), Descent (at), Heading and Direct to (see figure 3). Conditional requests are indicated with '(at)' 'time' or 'location'. For the selection of the

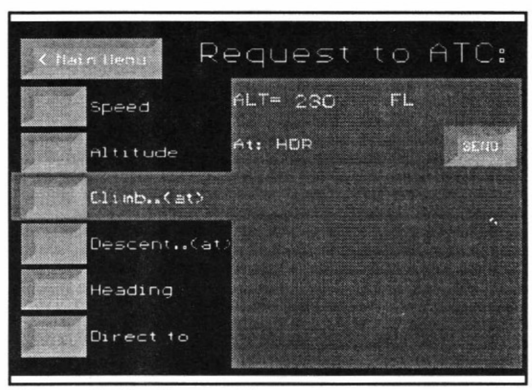

Figure 3: En-Route Clearances

location, a list of the most likely identifiers was presented using the scrollwheel indicator (see ATIS). An option was available to define other locations using an emulated keyboard. When all relevant information was entered, the request could be transmitted to ATC using the 'Send' button.

4D Trajectory negotiation

The 4D Trajectory Negotiation application is in line with the current way of thinking within PHARE (Programme for Harmonised ATM Research in Eurocontrol) and of EATCHIP phase IV (EATMS concept). In this application, an aircraft may initiate a negotiation with the ground counterpart. During the negotiating process an optimal as possible user preferred trajectory will be determined. This trajectory will then be used by the aircraft as a clearance for a given time period (e.g. 20 minutes ahead).

One of the essential elements is the use of an advanced Flight Management System (FMS). In the mentioned European programs known as the Experimental FMS (EFMS[4]).

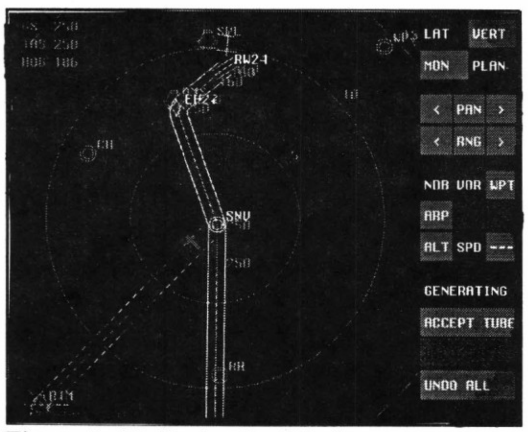

Figure 4: 4D Navigation Display

Pilots can use a conventional Control and Display Unit (CDU) or use an interactive navigation display to control the negotiating process. The status of the negotiation and the progress of the flight are displayed on both devices simultaneously. An example of the navigation display used is presented in figure 4.

A pointer selector was provided on the navigation display allowing control by multiple input facilities like trackerball or touchpad. The touchpad also operated in an experimental Gesture Recognition mode in which manually 'drawn symbols' were interpreted irrespective of the location of the pointer cursor.

Experiment set-up

Eight pilots in 4 crew configurations participated in the initial evaluation. Their experience ranges from 500 to 4000 flight hours per type on several commercial aircraft like inter alia the B737 & B747-400, MD11, F100 and A310.

Three flights were performed to evaluate all three data link applications:

Flight 1
* 4D negotiation on ND with touch pad
* ATIS on PNF touch screen (not presented in this paper)

Flight 2
* 4D negotiation on ND with trackerball
* ATIS on PNF touch screen

Flight 3
* ND with trackerball for FMS (without data link)
* En-Route Clearances on pedestal touch screen
* ATIS on pedestal touch screen

Two routes were specified in such a way that the crews would not become over-familiar with a particular route when carrying out a number of consecutive flights during any one measurement period.

During all flights NARSIM provided ATC through both data link and RT communications.

During a part of each flight 'moderate turbulence' was applied to the simulator to be able to verify the usability of the displays and controls in these conditions.

No malfunctioning of aircraft equipment was introduced since high workload situations would easily lead to neglect of data link communication tasks by the pilots. In this phase of the study, no error conditions were simulated for the data link system. The result was three typical flights on a standard route in a standard situation, allowing pilots to compare the experiment with their normal daily operations.

No specific crew procedures were imposed during the trials: natural work sharing between the PF and PNF was used at all times.

Results

All crews were exposed to the same flight scenarios to create comparable situations for all participating flight crews. However, each crew reacted in their own way to specific situations, which resulted in individual flights developing into non-identical ways. During the experiment, comments and ratings from pilots were collected. They were also asked complete questionnaires concerning usability of a specific combination of a MMI device and a data link application. The pilot had to indicate how 'successful' he was in performing the task (i.e. the data link application), the amount of 'effort' spent to fulfil this task and their perceived level of '(dis-)satisfaction' with the results.

ATIS

Pilots preferred the familiar abbreviations of ATIS messages (e.g. as in TAF/METAR) as compared to full textual descriptions.
Time stamps and message codes (standard letter code as used today) were regarded as essential to be able to verify the actuality of the information. Note: this remark is in-line with current operations: future experience with data link might change this opinion.
The list of airports listed near the scrollwheel should be limited: normally only the departure, arrival and alternate airports should be presented.
In case an update of an ATIS message is received, the difference with the old message should be indicated to improve situation awareness (displaying trends).
Transfer of relevant information into the FMS (uploading) is preferred.
The touch screen operated quite well (see figure 5), selecting softkeys to get ATIS information seems an acceptable way to operate. However a complete emulation of a 'A..Z' keyboard on a touchscreen should be omitted. Pilots indicated that touch screens can be used for simple applications as the ATIS

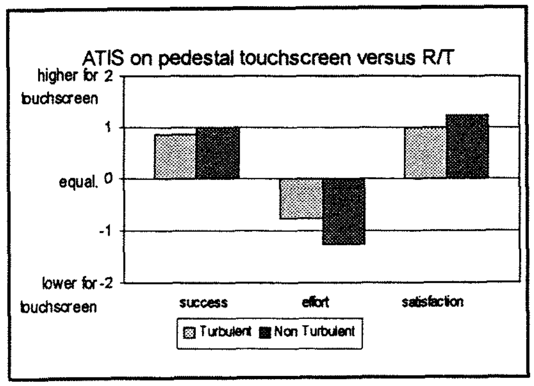

Figure 5: ATIS ratings

uplink, provided that the operation is kept as simple as possible. The used position of the display can have a negative effect on its acceptability: in the evaluation the pilot had to reach forward instead of being able to use it from his normal position. This situation is especially cumbersome for the creation of messages. On the other side a central position allowed both pilots to see all info at the same time, which is in line with results from other investigations[2].

En-Route Clearances

The general opinion of the pilots was that the touch screen implementation was usable for this application although the position of the display on the pedestal was not convenient for the creation of requests (see also ATIS).
The archive page contained too much information which was not directly relevant for the task at hand. A suggestion was to archive only the last clearance of each type. For instance for speed only last cleared speed is relevant instead of all speed clearances during the whole flight. So a 'selective' archive page should indicate the last clearances for all three control axis (lateral, vertical and longitudinal). Note: time and speed are inter-related and affect both the longitudinal axis.
The scrollwheel, used for selection of e.g. locations, was regarded as not very easy to use. Many mistakes were made since the appearance resembles a vertical speed selector, whilst the direction of movement is different. Up and Down keys were

suggested as an alternative. Note: it is well known from e.g. CDU operations that the Up/Down key implementation is also confusing: is the text going to move or moves the viewing window in the selected direction? Cockpit integration of particular 'stereotypes' in selectors is therefore required.

For the en-route clearance application in general, pilots indicated that they preferred direct RT communication since it is much faster and more flexible. Other pilots however were very positive about having clearances by data link since reading a message reduces the amount of misinterpretations when compared to voice, especially when received from a non-native English speaker.
Clearances via datalink require new Crew Resource Management (CRM) procedures since with RT both pilots are automatically kept in the information loop whilst with data link only the pilot operating the data link controls is in the information loop. Sharing information and dividing tasks can be conflicting design requirements that should be addressed during cockpit integration studies and experiments, including training and CRM procedures.

4D Negotiation

This application has been operated in two configurations: using control inputs from a touch pad and inputs from a trackerball. Pilots were asked to rate the use of both configurations in comparison to current generation CDU operation.
The overall opinion of the pilots was that the graphical user interface provided definite improvements. The ND provides more overview and does not require navigating through a page structure as with a CDU.
The display format used during the trials, however, could be improved in several area's. The edit functions should be optimised resulting in fewer required button selections. An option should be provided to clear the softbuttons from the display. This would reduce the amount of clutter when they are not needed (e.g. for the PF). After having touched the trackerball or touchpad, the softbuttons should appear again.
The range and pan functions to change the range of the display and to 'walk' through the planned route in a continuous manner (instead of the currently used discrete 'jumps') was very well appreciated.

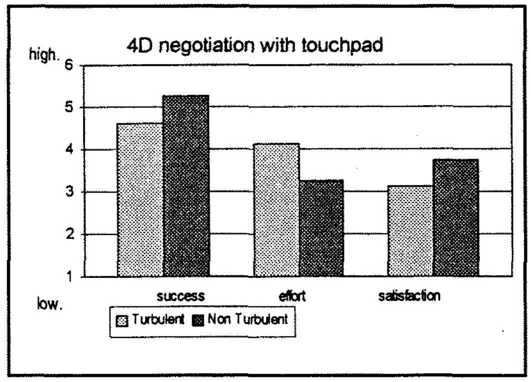

Figure 6: Touchpad ratings

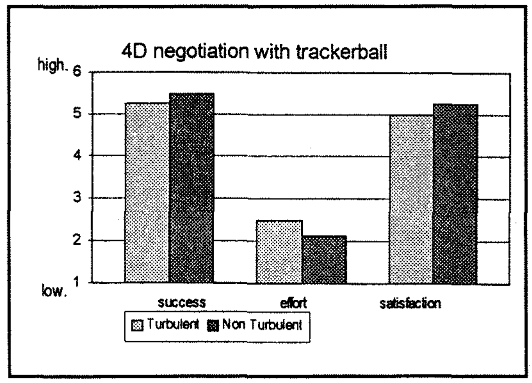

Figure 7: Trackerball ratings

Most pilots preferred the trackerball over the touchpad due to the fact that the trackerball allowed more accurate operation (figure 6 & 7). However, applying a more optimised gain schedule might improve the touchpad.
The implemented gesture recognition (using the touchpad) was too sensitive in this stage of research for small deviations: too much effort was spent on trying to draw the proper figures.
The response to the 4D negotiation process itself (not specific this HMI implementation) was very positive. It was considered as very natural and convenient to operate. This is especially true for the clearance mechanism in the form of a 'tube' for a large part of the route, including climb, level or descents. Since the clearance spans a relatively large time period, relatively long transmission delays are permitted in the negotiating process. In other words, the application allows more strategic control of the

aircraft. This factor was one of the main reasons for the positive reactions of line-pilots.

Conclusions

Using data link for air-ground communication is in line with current ATC requirements, technological developments as well as the use of improved man-machine interfaces. Pilots were in general positive regarding the implemented cockpit design.

It can be concluded that pilots liked to have ATIS presented textually on a display. Access to the application by the MMI should be kept as simple as possible. The ATIS display can easily be shared with other data link applications or other functions on a single display (and control) device like MFD. With 'easy access' applications a touchscreen is a suitable control device.

The en-route clearance data link application shows real benefits for flight crew understanding of uplink ATC clearances and their related onboard processing, provided a sufficient level of flexibility is available (capability for the crew to put a message on stand-by and to justify rejected clearances). Yet the advantages of the downlink counterpart (requests) appear more debated, as current radio telecommunication channels are faster and more flexible to request minor trajectory modifications. The results of the en-route clearance application confirmed that downlink requests for tactical ATC clearances are best passed by conventional RT (amongst others due to delays in the data link and required pilot actions).

The 4D negotiation application was well appreciated because of its strategic characteristics and therefore its natural use of data link, and because of the graphical user interface provided to the pilot. Pilots experienced it as the next step in cockpit development using the current state of technology. The use of a graphical user interface with a cursor control device was well accepted. The developed interface avoids pilots 'diving' into the CDU to find the right page to edit e.g. the route information. Working interactively on the ND allows pilots to keep an overall overview including other cockpit systems. Some pilots indicated that they were still able to monitor the PFD and to react to relevant interrupts other than from the ND. In contrary, working with a CDU absorbs almost all attention and therefore monitoring other systems is less possible. Distraction furthermore increases the chances for 'errors of omissions' as the interface does not support 'where was I' status information as compared to the graphical user interface.
The trackerball was generally preferred over the touch pad due to the higher accuracy in controlling the cursor.

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