Use of the ZFB A340 Full Flight Simulator for the Evaluation of the Cockpit Interface of a Digital Data Link

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Abstract:

A cockpit interface for digital data link communication with air traffic controllers and future multi-sector planners has been developed in the ZFB A340 full flight simulator using an iterative design approach with repeated usability studies. Examples of the step by step modification of the hardware components of the interface are included in the study. The results of simulator test flights and a questionnaire with approx. 20 professional pilots show that the prototype is accepted to a high degree and that this acceptance can be enhanced with the iterative design procedure.

1 Introduction

In future Air Traffic Control concepts, the information provided by the Flight Management System (FMS) aboard modern airliners will be used for traffic optimization. Sponsored by the "Deutsche Forschungsgemeinschaft" (DFG), an interdisciplinary research team has been established to investigate the possible changes in the man-machine interaction of work environments for pilots and air traffic control.

As a common guideline for the work of this research group, a future Air Traffic Management concept has been defined which is based on an EUROCONTROL proposal for the year 2005 and beyond in Europe [1]. In this ATM concept, a multi-sector-planner is included as a new ATC authority for long term traffic planning. A data link is used for communication and will supply air traffic control systems with information from the FMS (see Figure 1). This provides precise position data as well as 4-D Trajectory data. These technical improvements will increase the feasibility of scheduling and coordination between ground control and aircraft. Within this future co-operative air traffic management system, the layout of the experimental system is based on a human-centered approach.

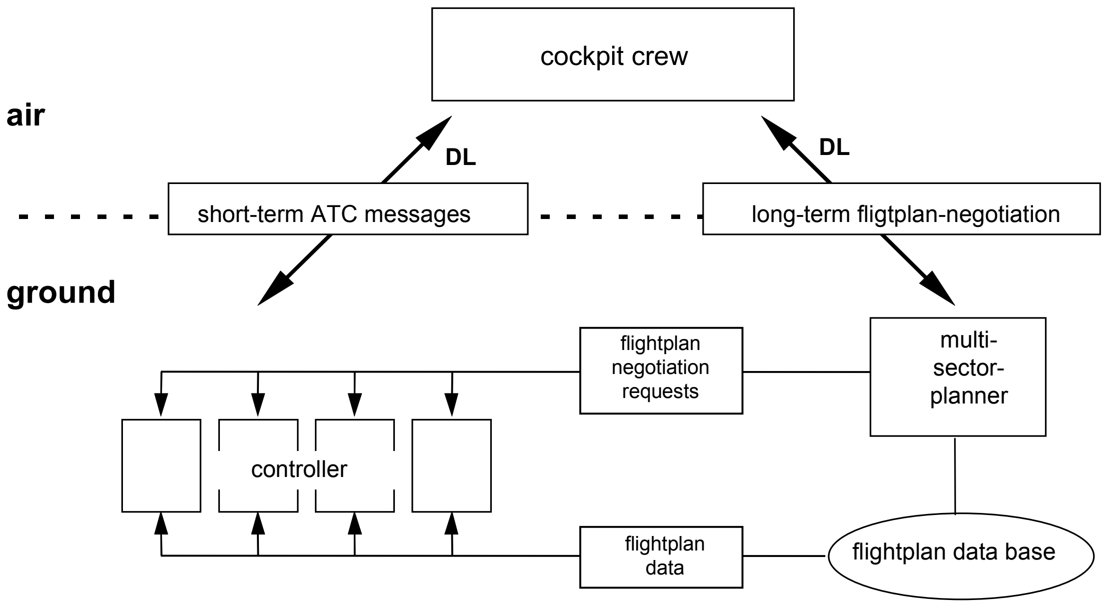

Figure 1. Cooperative Air Traffic Management

Experiments are now taking place to test the dependability of the changed system. Tools for the research and evaluation of aircraft and air traffic dependability will be developed and tested.

The term "dependability" is used in a qualitative sense. It characterizes the achievement of goals according to the man-machine-system as a whole, based on a systemic approach [5]. The term is used to differentiate from the well established terms "technical reliability" and "human reliability", which are strongly connected with the quantification of subcomponents that neglects qualitative dependencies. Dependability refers to the interaction of all subsystems and cannot be detected by examining single subsystems in isolation. To evaluate dependability, an investigation of the whole system is necessary. Therefore a high-fidelity simulation with experienced operators is of primary importance.

The operative premise was that the behavior of the pilots more closely mimics their behavior in the operational environment if they perceive that the simulation is realistic. A higher acceptance of experimental research is expected from professional pilots as well [4]. The realism of the simulation refers both to equipment and to environmental cues.

To investigate special aspects of man-machine-interaction (e.g. automation or assistance) in an experimental setting, a highly realistic simulation system was developed. The A340 full-flight training and research simulator at the Technical University of Berlin has been used to investigate data link communication in a highly automated aircraft environment. New data link functions were implemented into the simulator to study the implications of the changed environment on pilots in flight. Since the major research objective is to analyze the operational aspects of a data link in a future cooperative ATM system, the usability of new data link functions was the central focus. This not only combined a well integrated and consistent new functionality with adaptable crew procedures. It also required a thorough redesign of the man machine interface in compliance with existing Airbus design philosophy. This lead to an conservative design which is integrated into existing interfaces and has similar operating procedures. A further advantage of such an approach is that experienced airline pilots quickly comprehend the new functionality. Realistic evaluative experiments could therefore be conducted using the data link prototype for experimental data link communication. The following elaboration describes the development of this prototype including operational predefinitions.

2 Method

First of all, a dependable man-machine-system is characterized by the functionality of the system. The system has to serve its purpose in principle and has to be usable by the operators. During the design process of a man-machine-system, important restrictions are made for the dependability of a system. The realization of a design concept based on the knowledge of human sciences and of the operators is a suitable foundation for a dependable system. Therefore the system design was performed as a cooperative process by flight engineers, human factors engineers and professional pilots. Tasks and operational structures were designed simultaneously with technical systems in a rapid prototyping manner. During the design process, professional pilots had an opportunity to use the new system in the flight simulator. These usability studies were part of an iterative optimization process with which the experimental system was designed (see Figure 2).

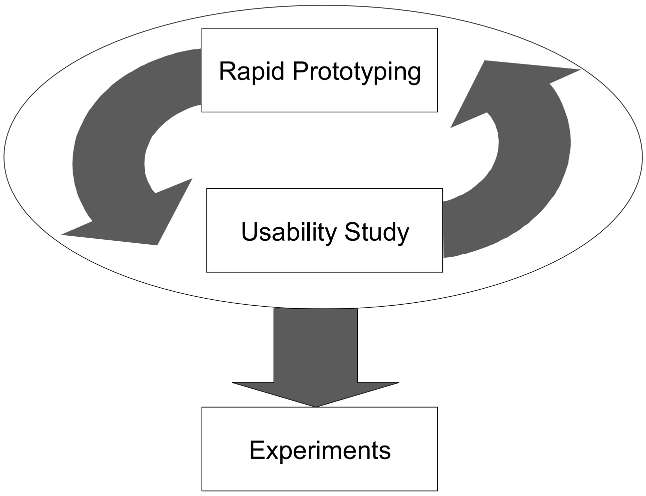

Figure 2. Design of a usable system

The A340 simulator in Berlin has considerably research capabilities. The simulator's Scientific Research Facility (SRF) allows the recording of different input/output parameters and flight data in real time and features a simulated programmable Flight Management System (FMS). This enables the rapid adaptation of new insights into system design. Two usability studies were conducted in which over 20 professional pilots participated.

In the first study, the new functions and procedures for flight-plan negotiation were considered by 13 pilots. The data link functions for short term communication between pilots and controller were investigated in the second study with 9 pilots. Each session started with an introduction into the system and a short flight briefing. Each crew had to perform a given flight using the new systems. Then the pilots were asked to answer a questionnaire. It included questions that referred to the design of the changed components (ND, MCDU), system changes as a whole, crew-procedures, and the pilot's attitude towards the use of a data link. The questionnaire was used to structure the following interviews, which promoted a lot of design comments.

3 Results

3.1 Data Link System

Since 1993, aspects of data links in a modern glass cockpit have been investigated at the Technical University of Berlin [2][3]. Step by step, a fully integrated ATC data link system was developed and implemented into the A340 full flight simulator. Figure 3 shows the main components of the data link cockpit interface.

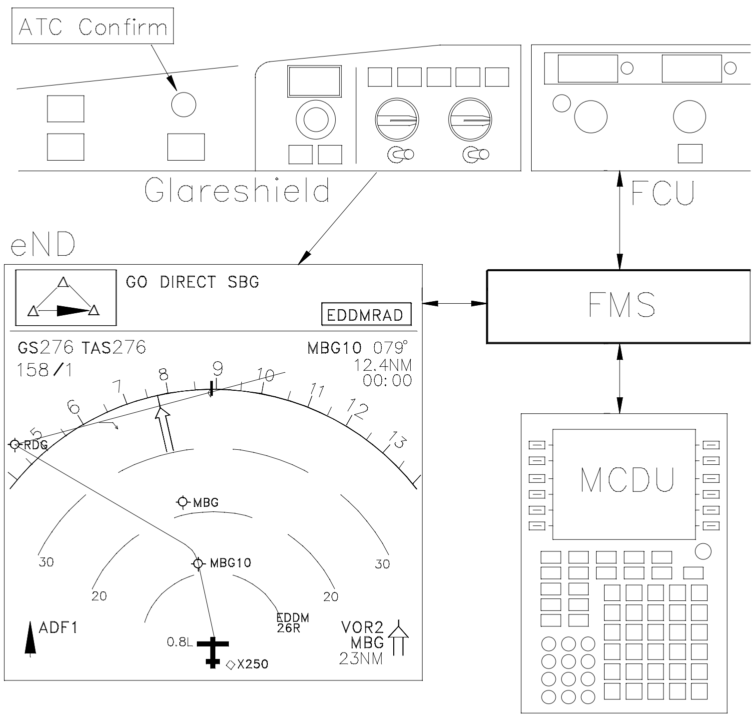

Figure 3. Data link system

The FMS and corresponding interfaces of the A340 were modified in order to implement the new data link functions. The FMS itself processes the exchanged ATC and flight plan data and supports pilot interaction. An experimental Navigation Display (eND) - which replaced the original ND in the simulator cockpit - incorporated a new area to display short term ATC messages. The Chrono-Button on the glareshield was utilized as a WILCO button to quickly comply to an ATC message presented on the eND. Nevertheless, the MCDU (Multi-purpose Control and Display Unit) was still used as the main input/output device for the data link operations. The FMS' control device was enhanced accordingly with additional functions and menu pages to display and operate short term ATC messages. In addition, pilot's requests, an ATIS display, a message history display, and long term planning functions to negotiate complete flight plans are applicable to the new system.

3.2 Iterative System Enhancement

During the iterative system design and development process, data link features were improved stepwise. Based on the results of the usability study with pilots minor changes concerning the color, size and syntax of the displayed information as well as major changes to display and functionality were incorporated into the data link prototype. The reasons for major changes were:

(a) Lack of functionality: A new function was needed to operate the prototype under data link conditions.

(b) Misinterpretation of information: The displayed information was ambiguous and allowed multiple interpretation.

(c) Clumsy operation: The operation of the system was not intuitively and led to input errors or into a dead end.

Two examples of the iterative design process that highlight the incremental improvements to MCDU pages are described here in detail.

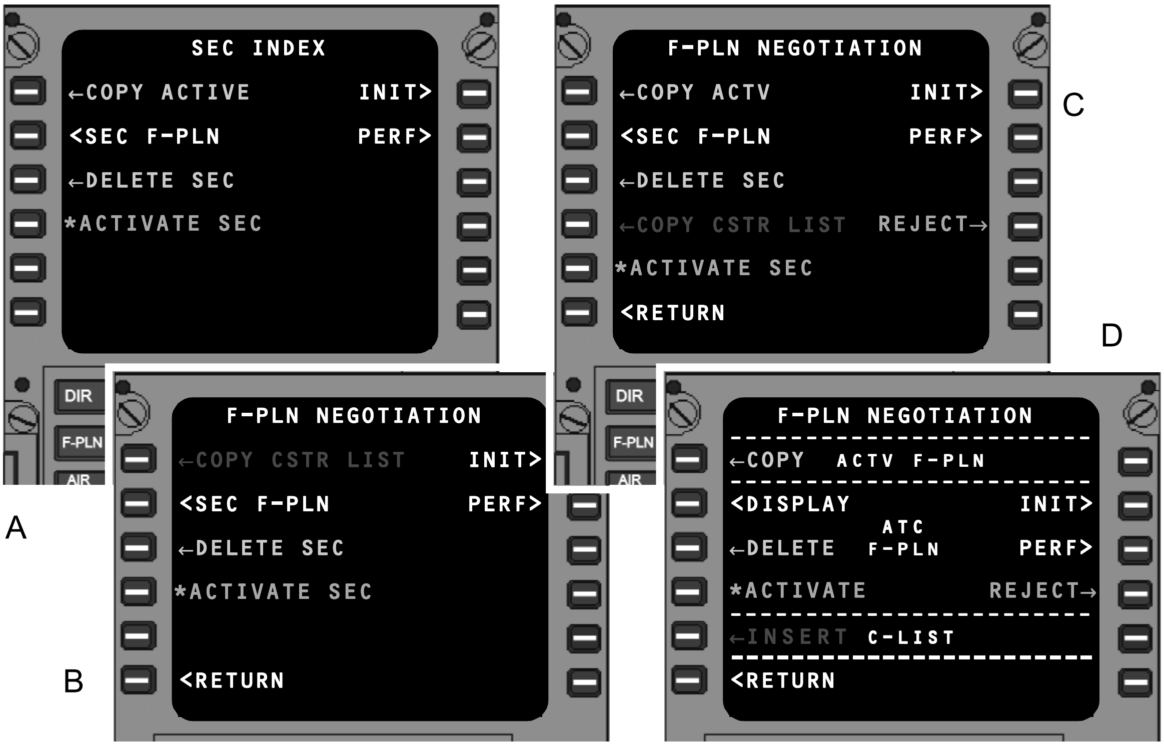

Figure 4. Incremental improvements of the flight plan negotiation page

The flight plan negotiation page is a completely new MCDU page that provides long-term flight plan functions for air to ground and ground to air trajectory negotiation via data link. Figure 4 shows the development of the page layout at different stages. Based on the existing Sec Index page (A), which is used for secondary flight plan operations, modifications were incorporated into the system to operate a so called ATC Flight Plan, which contains temporary trajectory information. The design process was based originally on the initial concept in which the needed functionality had to be identified and implemented (B, C). The final layout (D) was achieved after operational difficulties with the system were noted and pilot comments were taken into account.

The ATC Flight Plan page (see Figure 5) was derived from the existing Sec Flight Plan page and displays pending lateral and vertical trajectory data received from the ground. All complex functions that display and modify trajectory data remained the same as in the recent FMS and therefore pilots were familiar with it. Since the intention of this page is to support the pilots' decision whether a suggested flight plan change by ATC can be accepted or not, additional information was displayed.

Figure 5. Incremental improvements of the ATC flight plan page

During usability experiments, pilots had difficulties interpreting this information properly. The information about estimated time of arrival, distance to the destination and estimated fuel on board was changed from calculated values of savings to delta values. It was first assumed that a pre calculated savings value would be the most intuitive information. Experiments have shown the opposite. Pilots are accustomed to the MCDU information. They prefer absolute values where negative time, negative distance and positive fuel value stand for a saving. In addition, the modified section of the trajectory was highlighted to indicate differences between active and temporary ATC flight plans.

The participants of the two usability studies rated several characteristics of the prototype with regards to complexity, consistency, ease of use and learning requirements. On a scale from 1 to 5 (with 5 as the most positive rating), the average ratings were without any exception better than 3½.

The pilots were further asked to respond to eight statements dealing with data link in general. They had to give ratings on a scale ranging from 1 (‘I do not agree’) to 5 (‘I agree’). Figure 6 gives an overview of the results. Some of the scales are inverted for presentation, so higher values mean a more positive attitude toward data link. The ratings less than average on statement 2, 7, and 8 indicate that the pilots see some advantage in recent VHF voice communication. They also expect increases in flight safety (statement 1) and they disagree with the statement that work in the cockpit will be less interesting with a data link (statement 5). Differences between the ratings of participants of study 1 and 2 respectively are significant ($p < 0.10$) for statements 1, 3, 5, and 6. In three of the four cases, a data link is rated more positively by the participants of study 1 who used a data link for flight plan negotiations. This means that for these cases, a data link facilitates a new type of cooperation with ground authorities, whereas for the participants of study 2, data link just replaces voiced radio communication.

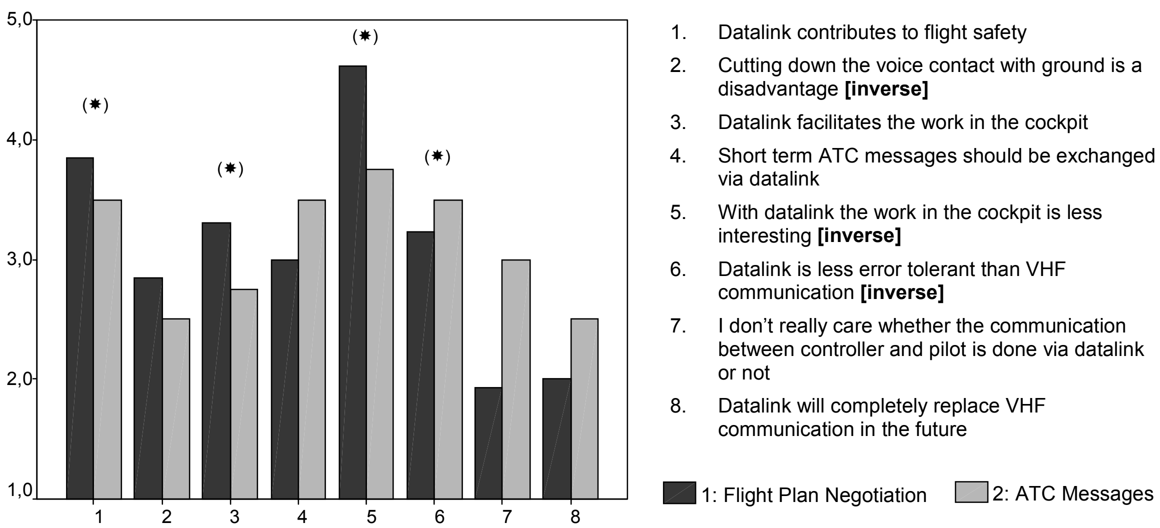

Figure 6. Attitude towards data link

To take a closer look at the effect of iterative design and evaluative steps during the first study, the results of all 25 questions were summarized in an factor analysis. A solution compromising 3 factors can be interpreted as 1: 'Usability of data link system', 2: 'Attitude towards data link' and 3: 'Procedures / Safety'. The results of the analysis show that factor 1 and 3 did not change significantly throughout the 3 iterative design phases. However, the attitude towards a data link changed noticeably.

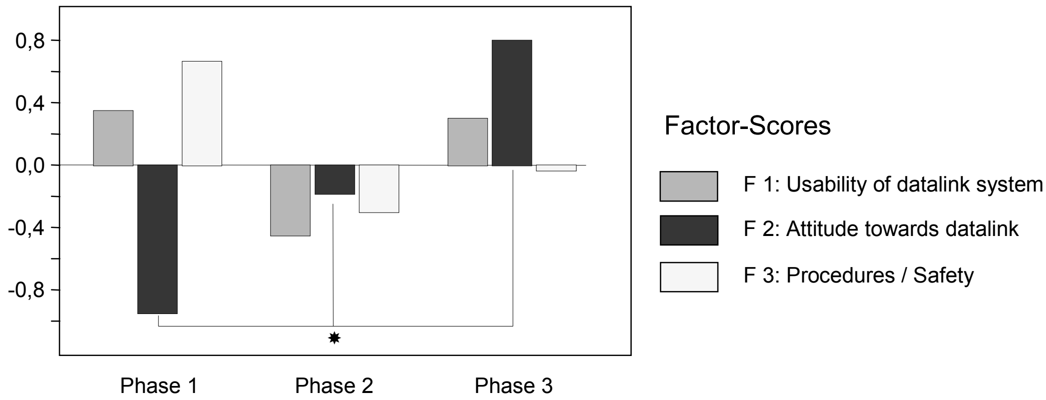

Figure 7. Factor scores of study 1

Assuming that the data link prototype was improved with each iteration, one may state: Experienced pilots are open-minded towards new systems. They can handle new functionality and they generally accept a prototype as long as it functions reliably - even at a pre-optimal design level. The improvements of the system have a positive effect on their attitude towards data link.

It can be concluded that the optimization of the system does not necessarily improve task efficiency, even though it does increase the acceptance of the system. This is true for the normal operations which were investigated in this study.

4 Conclusions for further research

The usability studies reported show that a basic data link communication system can be developed with hardware components already available in the cockpit. The integration into existing devices (ND, MCDU) may reduce training expense. Acceptance can be improved by using the technique of iterative design.

The simulator flight scenarios conducted in the usability studies were focused on communication under regular flight conditions. A recent study of the Berlin research group with an extended flight scenario including some critical events investigates pilot workload using data link communication under such conditions. Initial results indicate that data link communication further increases the workload in situations where it is already quite heavy.

Some problems have not yet been solved: data link communication is exclusive, i.e. it is restricted to information exchanged between a single aircraft and the responsible air traffic controller and/or multi sector planner. Recently, VHF radio has provided further information about surrounding air traffic ("party line"). How to replace this source of information under data link conditions is the scope of the next experimental series.

5 References

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