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National Aerospace Laboratory NLR, Amsterdam, The Netherlands

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AUTHORS P.G.A.M. Jorna	DATE 960322	pp 12	ref 7

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ABSTRACT
The present day generation 'Glass cockpits' provided many benefits with respect to aircraft performance and capabilities. Handling these capabilities has proven to be a task that is susceptible to errors and misunderstandings between the crew and the automation. Initiatives like the FAA Human Factors team and the automation issues presentation to the European parliament by the European Transport Safety Council, all point to the importance of solving the problems in order to maintain safety within an expanding aviation business scenario. Requirements for Air Traffic Management should also be included in cockpit modifications and new designs. In both cases human performance levels should be outstanding. After a review of requirements and trends, examples will be provided of attempts to define man machine interfaces that could realize such enhancements in the cockpit environment.

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COCKPIT AUTOMATION:

THE CHALLENGE FOR ENHANCED HUMAN PERFORMANCE

by

P.G.A.M. Jorna

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Cockpit Automation:
the challenge for enhanced Human performance

P.G.A.M Jorna
National Aerospace Laboratory
Amsterdam, The Netherlands

The present day generation 'Glass cockpits' provided many benefits with respect to aircraft performance and capabilities. Handling these capabilities has proven to be a task that is susceptible to errors and misunderstandings between the crew and the automation. Initiatives like the FAA Human Factors team and the automation issues presentation to the European parliament by the European Transport Safety Council, all point to the importance of solving the problems in order to maintain safety within an expanding aviation business scenario. Requirements for Air Traffic Management should also be included in cockpit modifications and new designs. In both cases human performance levels should be outstanding. After a review of requirements and trends, examples will be provided of attempts to define man machine interfaces that could realize such enhancements in the cockpit environment.

GLASS COCKPIT: (RE-)DESIGN REQUIREMENTS

Perhaps the most prominent and difficult to solve glass cockpit (or automated aircraft), concerns is the occurrence of accidents that apparently fall in the category of *'avoidable accidents'*. Although it is widely accepted that the 'Human Factor' is dominant in aircraft accidents, either related to the design, operation or maintenance of the aircraft, other perils have occurred. Next to human errors, so-called 'Unexpected events' confront the crew with problems not included in training. Examples are thrust reverser deployments in flight, insidious multiple failures and out of control states associated with loosing two engines as happened in Amsterdam (1992). Aircraft components are reliable and operations are normally not that exciting. Accidents of the so called 'Controlled Flight Into Terrain' (CFIT) type are intriguing as a fully serviceable, intact aircraft is flown into the ground. Clearly, no crew will voluntarily perform such maneuver, so some other quite dominant factor must influence this bad performance. The major issues are summarized in figure 1.

Pilot Aircraft Interaction: lessons learned

●**situation/system awareness**
 - mode confusions
 - understanding (intentions, interactions)
 - unexpected transitions
 - uncommanded transition
 - traffic and ground awareness

●**information transfer** ⟶ *suboptimal Pilot*
 - visual and tactile feedback   *performance*
 - cluttered displays
 - crew co-ordination

●**pilot workload**
 - uneven distribution
 - monitoring / vigilance
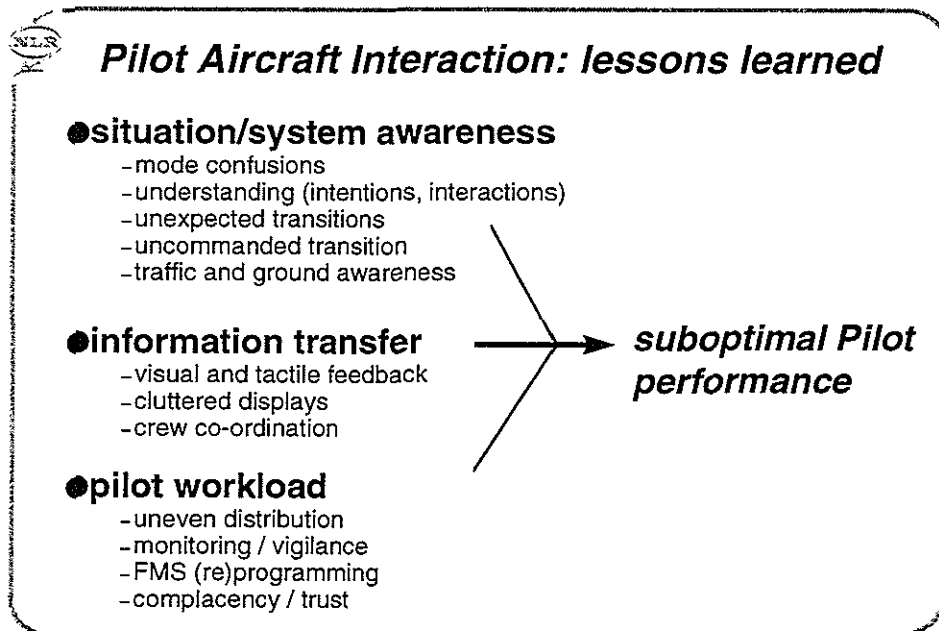 - FMS (re)programming
 - complacency / trust

Figure 1. Overview of main issues in pilot- aircraft interaction

Concepts like 'work load' and situation(al) awareness have been discussed and studied intensively, but their complexity with respect to human information processing, often initiated confusions and different interpretations between scientists, users etc. The emphasis of work load research in aviation has now shifted from issues of overloading individuals or crews to issues like possible under loading while working with highly automated systems. The term situation awareness is in itself ambiguous and needs clarification. Within the human factors community it is now well accepted to use the term together with a 'specifier' to provide more insight in what aspect of human performance, or what source of information to be ware of, is referred. It is therefore common to discuss issues like 'system' (or mode) awareness versus 'traffic' or 'ground' awareness.

Forthcoming ATM requirements

The demand for air travel is expanding and present day ATC procedures and technologies need revisions. A first issue is that two types of ATC already exist today, namely a 'High Tech-' and a 'Low Tech' ATC environment. Both are served by the same aircraft. The need for advanced updates will not only be challenging for the Western world within ICAO, but will place other sectors under economical pressure for increasing investments in facilities to accommodate air travel. A globally accepted ATM concept has not been established yet. Well known scenario's are the European PHARE (Program for Harmonized ATM Research in EUROCONTROL) concept of 4D-trajectory negotiations (x, y, z and time) between aircraft 4D-Flight Management System (FMS) and ATC. The United States CTAS (Center TRACON Automation System) system provides 4D advisories to non-4D FMS equipped aircraft and seems particularly suited for a transitory phase.
Recently, the so called *'Free Flight'* concept has gained considerable visibility in the media and bounded numerous advocates to its (quick) development. The role of ATC is intentionally changed and involves an *'arbitration'* role for the controller. The rapid rise of this concept can

be regarded as a response, or counter action, to the predominantly ATC oriented ATM concepts. These still put the aircraft in a dependent position and will only gain airline acceptance after validation of the costs benefits. Another problem is the enormous investment associated with either up-dating or installing sophisticated ground based systems.

Both aircraft 'Free flight ' and ground ATM thinking will influence flight deck Man-Machine Interfaces and procedural requirements. The key technology involved is the digital data link. Irrespective of its potential benefits, it allows a cockpit that can 'gate' up-linked trajectories directly into the FMS, creating a ground controlled aircraft with a crew monitor. Such development could further distance the crew from the aircraft and its systems. Better air-ground coordination could therefore have a penalty on the role and authority of the pilot depending on the specific ATM concept pursued.

A history of flight control (adapted from Billings) and the impact of data link is provided in figure 2.
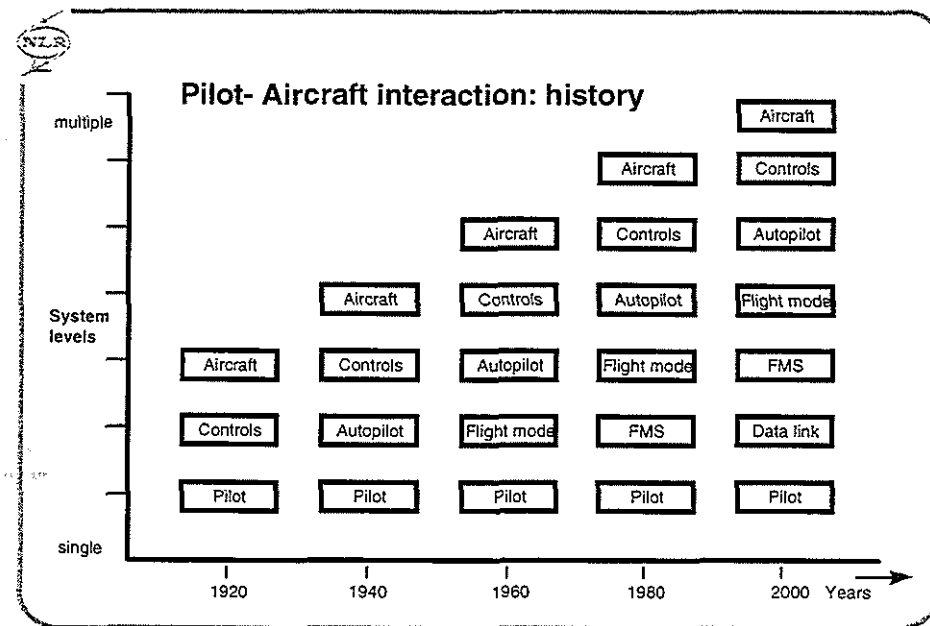

Figure 2. Trends in 'distancing' the pilot from the aircraft including data link 'gating'. The latter technique refers to forms of auto loading the clearances and/or trajectories in the Flight Management System. Note that the graph does not imply linearity.

The paradox of airline requirements

The principal users of airspace are the airlines. They generate the profit to provide resources for the ground systems. The 'user charges' or landing fees are not negligible. Investments in cockpit technology are weighted for economical revenues and will not easily be adopted. In the evolution of aircraft, an apparent paradox seems to have occurred. New technology requires re-training of crews and type ratings for advanced aircraft. The airlines nowadays do not seem to accept such a dependency. An example is the 'zero transition' requirement . Pilots with a type rating on one version of an aircraft should be able to fly the update with none (or very limited)

training. This factor could result in a design strategy of 'no change'. 'Trainability' of alternative cockpit concepts is therefore a decisive requirement for retrofit and new designs.

Practical implications for flight deck developers are therefore that:

- alternative concepts should be validated on both performance, revenues and costs
    - empirical data will be required to facilitate acceptance
    - training time requirements and reduction are a major quality item.
    - the proposed ATM concepts need an intercontinental context in order to be accepted.
    - flight deck design should resolve both present and forthcoming issues.

FLIGHT DECK DEVELOPMENT

MMI technology is often implemented by retrofitting existing aircraft. A particular example is the growing interest in Head Up Display (HUD)and Enhanced Vision System technology (EVS). The intention is to allow the airlines to operate independently of ground systems and weather as far as possible. Advocates of these systems point to the many advantages of using normal 'human sight' abilities of the pilot instead of relying on more abstract head down displays. Modern flight decks have provisions that allow the data link to interface directly with the FMS, leaving the pilot with another checking task. Such an integration of data link is potentially able to reduce human typing errors, but can also introduce new errors. Under time pressure, pilots could revert to a strategy of 'accept first, think later'. Opponents argue that it is not the human itself but the quality of the information and the MMI machine interface that determines proneness to errors. The automation level itself is not a threat to safety, but the transfer of information and so-called 'awareness' of system states and environment, in psychological terms 'Feedback' and 'Task involvement' issues, are key issues to be dealt with in new designs. Recent reviews by both the research community and pilots associations indicate that:

1) the major concern of cockpit design is ' the lack of a scientifically-based philosophy of automation.
2) 'the human limitations and capabilities *must* be the controlling parameters of flight deck design'

Design principles and guidelines

A practical philosophy should provide principles and concrete guidelines to direct essential decisions concerning the interaction of the crew with the aircraft systems. It typically deals with issues like function and task allocation, levels of automation, authority, responsibility, information access and feedback in the context of human interactions with complex systems. So called 'Human Centered Automation' is the contemporary context for initiating such design process. It is however difficult to translate theory into crisp and clear requirements that serve the formal certification process. Recent developments in cognitive engineering theory and the activities of the FAA Glass cockpit review team, will facilitate acceptance and legal endorsement of design recommendations.

There is a clear need for translation and definition of 'Human Centered Automation' design principles and guidelines to assure clear and measurable criteria that can be assessed by an accepted 'design evaluation methodology' and force certification to affordable levels.

ENHANCING CREW PERFORMANCE

The modern airliner contains so many systems that it is practically not feasible to design, test and evaluate all possible design options. The present day generation of aircraft will continue to be operated for many years. Retrofit will remain a reality and a challenge to both human factors sciences and certification authorities. Modifying components involves the risk of poor cockpit integration. A possible strategy for assessing design effectiveness with respect to integration and ATM issues is to compare competing cockpit concepts [1]. Two cockpit concepts were proposed that could serve to study crew performance under different ATM regimes. The concepts were denoted as :

1) the DRONE concept (Data Link Ruled Obedient Navigation Environment) and
2) the PRIDE concept (Pilot Ruled Informed Decision Environment).

The DRONE aircraft is typically equipped to improve the Air- Ground coordination by allowing ATC some form of access to the FMS, thereby reducing pilot delays associated with programming the FMS. In principle, full automatic, ground controlled flight is possible. The pilots task is to evaluate/accept trajectories and to provide a consent. The alternative is to start negotiations. The risks of this concept are low vigilance of the crew and potential errors by an 'accept first, think later' strategy under time pressure situations. The DRONE concept is close to an existing aircraft kept up to date by retro fit. It is modified to perform in an ATM environment.

The PRIDE aircraft exploits crew abilities by creating working conditions that involve the crew in the total definition and accomplishment of the mission and goals of the airline. The pilots task is not only to monitor the aircraft, but also to guide, or fly it, during most, if not all of the mission segments. The MMI's typical for this aircraft exploit general human capabilities like vision and flexible decision making by integrating 'data' into mission relevant 'information'. A major goal for the research is to provide empirical data on particular successful MMI combinations with respect to human performance and cost reductions by identifying 'redundant' systems. Based on the experience gained, a hybrid cockpit could evolve combining strong - and alleviating weak points.

NLR FLIGHT DECK RESEARCH

Moving versus non-moving throttles: this study [2]revealed that the 'throttle lever information' could only be partly substituted by other sources i.e. by commanded thrust data on the engine display. The human performance cost was a variable time delay in detecting problems. The scanning of visual displays is slower as compared to the direct hands-on throttle motion. Individual scanning was biased to particular displays. Surprisingly, lack of motion of the throttle levers was a strong stimulus for pilots when they expected such motion to occur. Throttles provided prompt feedback on intended aircraft actions and served less as a (visual)

device alerting the pilot to unexpected events. Detection times of system problems varied between 15-30 seconds. Back driven throttles are preferred.

Input and display devices: touch screens, pads and track balls were compared in several studies [3] to keyboard, line select keys etc. Touch screen effectiveness depends on its location, preferably as a 'table' in front of the pilot. Turbulence is a problem, especially in sub optimal locations. Track balls were well received. Scrolling and selection are only effective with short intelligent lists. The software integration in the cockpit allows a redistribution of information over displays and sharing of input devices. The Multi Function Displays (MFD lower center of pedestal) has useful display options and can share input from several devices including CDU keyboard. Non back driven side sticks lack a feedback capability on automation or pilot flying intent. Alternatives information sources are under investigation.

Data link MMI: retrofit solutions (CDU, IDU ACARS) were compared with a forward MFD against a voice baseline in a realistic operational flight simulation [4]. Up links resulted in a head down position for both crew members despite crew resource management procedures. The pilot flying is curious and needs an easy access to the data link information. The CDU proved a likely candidate for data link, provided that the page lay out was simplified. The implementation of the lessons learned in follow up research increased data link acceptance as an overall communication device to 94%.

Primary Flight Displays (PFD): traffic loads in terminal areas are increasing, leading to complex Arrival and Departure routes. Traditional displays were modified to include 4D guidance and serve as a baseline for 'Tunnel in the sky ' concepts [5]. These displays consistently increase the spare capacity of the pilot and provide options for improved automation monitoring by speed/time, lateral and vertical feedback.

4D interactive NAV display: effective and expeditious trajectory negotiation requires easy manipulation and management of existing, planned and proposed lateral and vertical trajectories. A direct manipulation display allowed on screen trajectory modifications by a track ball even with turbulence[6]. Zooming (ranges) and panning (moving map) were also track ball controlled. The results were promising and show that evaluation of generated routes by the 4D FMS and ATC is complex as does management of multiple routes on a single display. The display improved crew performance and acceptance of ATM concepts.

Flight modes: many different flight mode categories exist and the evolution of automated functions over time created an ad hoc environment. It is hard to anticipate all possible mode transitions and characteristics. A study investigated the possible application of icons to explain mode intent. Results showed better performance on memorization and recall especially for multiple mode combinations [7]. An integration of mode intent in the display of the respective axes of control (PFD tapes, NAV or MFD), could enhance performance in high task load conditions. A study is prepared to reduce the complexity of the mode matrices and compare alternatives to traditional mode annunciation.
An example of varying mode characteristics that can conflict with crew expectations is presented in figure 3.
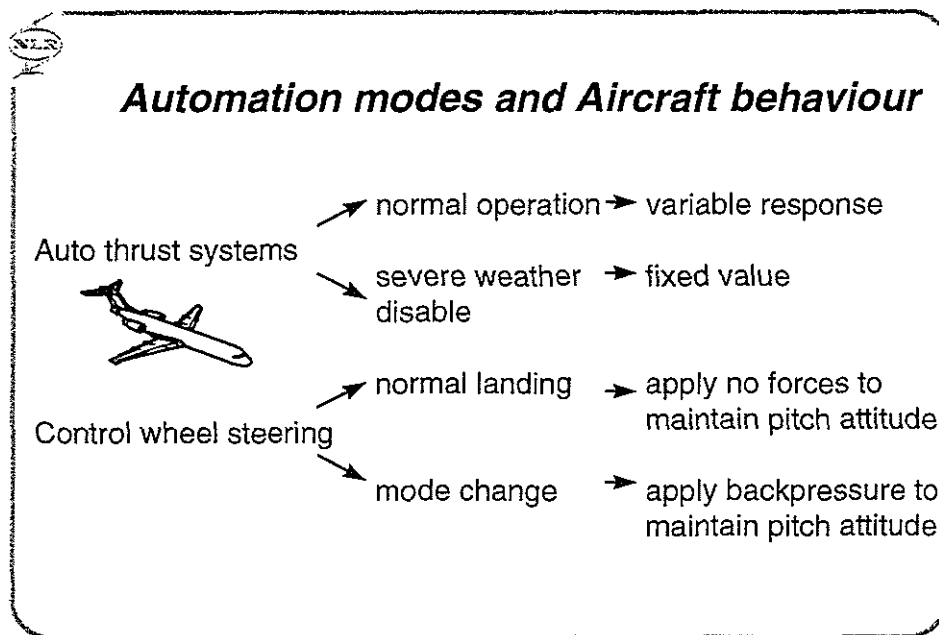
Figure 3: Mode characteristics that can surprise pilots

Cockpit training: research initiated by the European commission studies training issues, emphasizing the transitions between steam gauge and glass cockpits, as well as transitions between aircraft types. The results will be incorporated in research on cockpit integration issues emphasizing the collaboration between cockpit devices and consistency in operations.

Free flight deck: modifications to support 'Free flight ' operations are the provision of positions of other aircraft, the intentions of other aircraft and means for conflict detection and conflict resolution. The simulations will be performed in collaboration with NASA, FAA and RLD (Netherlands aviation authorities).

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