A Design and Training Agenda for the Next Generation of Commercial Aircraft Flight Deck

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Abstract. To maximize cost efficiencies the design of the modern commercial airliner flight deck must change quite radically. However, these efficiencies cannot be realized unless there are concomitant changes in the rest of the system, and in particular, the training aspect. This paper proposes a radical design agenda for the flight deck and outlines how efficiencies can be gained through a careful re-alignment and re-appraisal of the training requirements to operate this aircraft.

Keywords: Flight Deck Design; Human Factors Integration; Training.

1 Introduction

Human Factors Integration (HFI) or Human-System Integration (HSI) is essentially a human-centric acquisition management process. HFI/HSI considers not just the specification, design and development of the user-centric aspects of the system but it also takes into account other functions, such as training, personnel skills and availability, and organizational issues. It can broadly be characterized as socio-technical systems based approach for the requirements specification, design, development and in-service operation of large pieces of equipment.

This short paper argues that as commercial aircraft are not specified by the end users (they are commercial products – the aircraft most closely matching the requirements of the purchaser is the one that is bought) many of the benefits from a well-managed HFI/HSI procurement process are not available to the airlines. Pilot training, especially its earlier stages, has also become divorced from the initial requirements of the airlines and it is also likely to fall further behind developments in flight deck design and operating concepts. As a result, the training burden on the airlines is increased in converting novice pilots into safe and efficient First Officers: much initial training is wasted as it is not required and a great deal of desirable instruction is not provided until they join the airline.

However, this is intended to be a forward-looking discussion suggesting a direction for future flight deck design and pilot training. Evolutions in flight deck function and layout are hampered to some degree by regulatory requirements which specify tightly many aspects of design where true efficiencies could be achieved. However, perhaps more importantly, future concepts in Air Traffic Control/Air Traffic Management

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2009, LNAI 5639, pp. 529–536, 2009.
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(ATC/ATM) will require new functionality to be developed for the flight deck and hence further new skills and abilities in the crew operating them will be required. The demands on the skill set of pilots could increase considerably.

One of the greatest problems with Human Factors in the civilian domain is that it can be regarded almost be as a 'hygiene factor' (Harris, 2008). It almost goes without saying that a poor user interface will result in a flight deck which is difficult to use and which promotes error. However, providing a 'good' human-system interface does not 'add value' although a failure to provide a user-friendly flight deck does detract from the aircraft's usability. As a result, it is often difficult to make a convincing argument for investing heavily in Human Factors. As a result flight deck interface inadequacies become a training or selection issue to be dealt with within the airline.

In the Defense community, though, human performance is put at a premium. Military personnel *must* be able to use the equipment they are provided with in a range of stressful, high-pressure situations. The military customer has a further advantage in that any new equipment may be tailored precisely around the capabilities of their end users. Dedicated, comprehensive training can also be provided. While the military is unique in these aspects, by drawing upon the experiences of the Defense sector from studying best practice in the acquisition of equipment, a great deal of knowledge can be 'spun out' into the civilian aviation domain.

2 How Did We Get to the Current *Status Quo*?

There is little impetus to change many aspects of the flight deck. This is largely as a result of external constraints and commercial issues unrelated to their design and functionality. As a result the evolution of commercial flight deck interfaces does not progress as quickly as ground-based applications or military aircraft cockpits. Even the interface in modern cars is evolving faster.

Consider the civil aircraft certification requirements. No aspect of the flight deck associated with the control of an aircraft can be installed and operated without the approval of the airworthiness authorities. The airworthiness regulations – *e.g.* CS/FAR 25.1309 (ACJ 25.1309) require that systems such as the FMS/FMC (Flight Management System/Flight Management Computer) are required to show a level of reliability (in terms of system failure) in excess of 1×10^{-7} per flight hour. Attaining and demonstrating this level of reliability in a joint software/hardware system such as the FMS/FMC is no small matter and it certainly isn't cheap. However, like the vast majority of the certification regulations only 'machine' issues are addressed. As many incidents, accidents and much research has demonstrated, the major source of unreliability in a joint cognitive system composed of a pilot and an aircraft lies on the human side of the equation. This is not to say that the pilot is to blame; far from it. The difficulties the pilots experience are as a result of the poor design of the human-machine interface, such as it being incompatible with the pilots' working environment; having unclear system logic and/or having to workaround shortcomings in the design of the system. As a result, the training provided to use some systems includes almost as much about avoiding error as it does about its actual use.

A further factor in maintaining the *status quo* is the longevity of commercial aircraft. It is not uncommon for a basic design to be in production for 30 years and its service life can itself be over 30 years. When it is also taken into account that the design freeze for the flight deck can occur five years before entry into service, it is possible that the basic design of the computers and their interface will have to survive for well over half a century.

Revolution in flight deck interfaces (or even step changes in their evolutionary process) also cause logistical problems for the operators and hence are not undertaken with great frequency. Take a hypothetical example of the requirements imposed on an airline operator when performing a mid-life update on a commercial aircraft's FMS from the current text-based interface to a more 'modern' graphical user interface (GUI). The airlines will need to make investments in equipment to train the pilots, for example developing computer-based training programs for introducing the new GUI and investing in updating part-task flight deck simulators and full-flight simulators. The re-equipment of the simulation facilities will also require approval by the airworthiness authorities. With regard to the training requirements the airworthiness authorities must approve all training courses. The trainers will also need training. Furthermore, there is also the expense of removing pilots from line flying onto training courses to instruct them on the operation of the new GUI to the FMS/FMC. The new FMS/FMC will also impose other new requirements, for example on the training of maintenance personnel and spares holdings. To re-iterate HFI/HSI all aspects of the system not just the user-centric design aspects. You cannot separate design issues from training issues (and other aspects of operation not directly involving the primary users).

The list of reasons why not to adopt a particular new flight deck interface just goes on and on. Only occasionally do you get a relatively large change on the flight deck (for example, the new Airbus A380 is quite different). But these opportunities only happen rarely when a completely new type is introduced and even then, the airlines request commonality with other types to speed the process of pilots achieving a new type rating. As a result, interface design progresses slowly and deficiencies become training issues as this is perceived to be a cheaper solution. But while this may be true in the short term can his argument be supported in the longer term, taking a through-life costing approach? This is where through careful design and analysis HFI/HSI can provide benefits even to an airline. Paying more in the short term may cost less in the longer term.

3 The Future Flight Deck

The modern civil transport aircraft flight deck is still a highly evolved version of the cockpit of the first airliners flown in the 1930s. It is a place from where the pilots exert control over their aircraft. As such, it is still primarily optimized around manual control requirements. You simply have to look at the design of the major controls and the primary flight displays. As will be argued shortly, what pilots' will require in the future is the ability to execute their desired 3D path through space (4D if time is also considered) hence they will need graphical flight planning and surveillance tools and the ability to visualize their flight plan relative to the terrain, airways (if they still exist), restricted airspace and other traffic. The manner by which the flight plan is controlled and executed is irrelevant. To illustrate, the Airbus A320 has 10 vertical navigation (VNAV) modes and seven lateral navigation (LNAV) modes (all modes associated with aircraft control). However, most of these control modes are aircraft referenced, thus do not relate to its actual flight path. They do not correspond directly to ground based features (such as terrain) or ground referenced features (such as airways). Navigation is a ground-referenced problem but aircraft control is an air-referenced problem (e.g. stalling is an issue in a lack of airspeed not groundspeed; pitch attitude/angle of attack is not related to obstacle clearance or flight path). As a result, the navigation requirement and the control requirement have become separated to some degree. The modern flight deck needs to make these issues congruent again. A pilot's job is to control an aircraft's flight path.

With the exception of take-off, there is no mandatory requirement to fly the aircraft manually. The conventional mode of operation of any commercial airplane is now one of supervisory control. The normal method of exercising control over the aircraft on a minute-to-minute basis is via the autopilot system (typically using the mode control panel); on a strategic level, control is exerted via the FMS/FMC. With changes in the management and configuration of airspace increasingly towards a free-flight environment where ATM provides a largely supervisory oversight role (rather than positive control) there is a change in the required function of the flight deck increasingly towards that of flight planning, communication, navigation and surveillance (CNS). Longer range flight planning tools optimized for 4D-navigation are now needed. With highly aerodynamically efficient aircraft, pilots are now required to plan ahead and manage the aircraft's energy with respect to the desired flight profile: control of airspeed, altitude and rate of descent are no longer enough to achieve optimum control of the aircraft on complex, fuel efficient flight profiles. Furthermore, with increasingly sophisticated aircraft systems for power, environmental conditioning and even passenger entertainment, their management is also of increasing importance. Basically, the flight deck is now a management and information centre for the supervisory control of the whole flight. The question becomes simply this: does the flight deck properly support these functions? Furthermore: does the pilot's initial training?

The pilot of future generations of a highly automated aircraft will still be a pilot but one with a very different skill set. As Dekker [2] has noted, automation has made most of the dedicated flight crew functions redundant (e.g. the radio operators, navigators and flight engineers) and the pilots have been left to fill any gaps remaining that can't be adequately covered by the automation. As a result they have been required to attain competencies beyond their original job mandates. Evolution (even revolution) in ATM concepts will change the role of the pilot and the design of the flight deck interfaces even further.

3.1 An Example

Future ATM practices will require aircraft to navigate in a different manner. Direct Routing (or 'Free Flight') will significantly affect the pilots' roles and responsibilities. Responsibility for ATM will be delegated to the flight deck (self-assured separation). Aircraft will fly direct routes and maneuver freely at their optimum speed and altitude, without consultation with ATC. The impetus to move to such a system is driven by the current inefficient use of airspace and a desire to spend less time in the air and save fuel. However, such changes demand wide-ranging transformations throughout all other components of the system: both ATC/ATM and aircraft need to be re-equipped with new navigation and surveillance equipment and crews need to be trained.

Such changes in ATM concepts cannot be fully exploited if aircraft are not equipped with suitable display technologies allowing pilots to maneuver to maintain separation from other traffic, avoid weather and undertake other aspects of real-time flight re-planning (CNS functions). Much work is being undertaken developing Cockpit Display of Traffic Information systems. This has principally centered on the real-time representation of 4D traffic information to aid situation awareness and decision-making (*e.g.* Johnson et al; [3]) and the development of rules for resolving airborne conflicts (*e.g.* Johnson et al., [4]). However, without automated assistance pilots were found to be inefficient at resolving conflicts clearly demonstrating that training is also required.

More wide ranging options are also being considered by Air Traffic providers. For example, one concept would be for the various national/international ATM facilities to provide directly to the airlines quality assured, de-conflicted routes – the more you pay for your route, the more direct it is! These would be up-linked directly to the aircraft, obviating the need for an airline's flight planning department. The function of the crew on the flight deck would be to supervise the execution of this route. However, consideration of this concept reveals that the functions of the airline/flight deck and the function of the Air Traffic provider have now reversed in several aspects. Flight planning is done by ATM; CNS, originally the core function of ATC, is now undertaken by the crew.

3.2 A Flight Deck Design Option

If the flight crew are required to undertake the CNS function this implies that there will be design changes required on the flight deck. This gives the opportunity of producing a radical flight deck design solution. For example, why does a flight deck require two highly qualified pilots? Should the future flight deck have a pilot and a CNS specialist (who also has some flight skills)? Why should both sides of the flight deck have the same functions and displays (as they do today)? Why not optimize one side of the flight deck for flight path control and system management, and the other side for the CNS function? All of these options would provide better targeted functionality, optimized controls, displays and computer software, and flight crew with superior knowledge as a result of better targeted training (*i.e.* specialists, not generalists). It could be argued that this is a step back to a flight deck with a pilot and a navigator. However it begins to treat the workstations on the flight deck as two components in a distributed air/ground system and not simply isolated places from where to control the aircraft. Design architectures are already being developed for single crew commercial aircraft [5] which regard the flight deck as part of a distributed air/ground system. This design solution simply develops this notion in a slightly different direction. The important thing to note, though, is that it does not consider radical hardware/software design options separately from training.

4 Training

The early stages of initial pilot training are concerned almost solely with the control of the aircraft, followed by the development of communication and navigation skills. The new pilot then develops these skills further for use at night and in instrument conditions, followed by an introduction to airways flying. This initial training takes place in a low-powered, piston-engined aircraft with limited performance, simple systems and dated instrumentation. The basic syllabus has not really changed since the 1930s. Until the 1950s the technology in small aircraft cockpits was similar to that in large aircraft. Large aircraft flew differently simply because they were bigger and they were often slower. With the advent of the jet engine things changed. Flight deck technology had to develop to accommodate the new levels of performance and the aircraft flown by 'professional' pilots began to diverge from that of the initial training aircraft.

The transition to a modern highly automated 'glass cockpit' occurs relatively late in the training of a new pilot, usually after they join an airline. It is also usually concurrent with being introduced to multi-crew and jet-transport flying. Several authors have recommended that to alleviate problems with this transition the introduction to 'glass cockpit' technology should be made earlier (e.g. Rignér & Dekker [6]). Higher technology aircraft have been introduced into the early stages of flight training predicted on the basis that they resemble the future flight deck environment in terms of the type of instrumentation they contain and they also provide some of the automated functions found in advanced commercial airliners. But this reasoning is over simplistic. The question needs to be asked 'are we teaching the right thing'? The syllabus and training concept needs revision, not its means of delivery. A full training needs analysis (TNA) needs to be undertaken for the airline pilot operating a modern commercial transport to establish the best lead in training. Simple evolution of technology and teaching is ineffective and inefficient.

Even a cursory analysis of current training shows many areas of limited utility, for example low-level visual navigation (most large transports don't even have VFR charts in them – and for what area should they carry them)? There is no need to learn the management of an Avgas fueled piston engine attached to a fixed (or variable) pitch propeller. When transferring to jet transport aircraft with fly-by-wire systems, as a result of the advanced flight control laws employed, the aircraft do not even respond in the same manner to stick inputs as a simple, light aircraft. Even the teaching of navigation using VOR/DME equipment may be questioned. The objective here is not to provide answers but simply to provoke debate and begin to encourage exploration of the question 'could this training time be used to better effect'?

There have been some superficial evaluations to evaluate the training effectiveness of introducing higher levels of automation training earlier in the flight training syllabus but these have also addressed slightly the wrong question [7]. For example Wood & Huddlestone [8] observed that the problem was not an issue in managing the automation interface but was rather an issue in understanding *what* the automation was doing and *how* it was trying to control the aircraft. This knowledge is required first before it is possible to 'manage' the automation. Teaching automation is not about teaching how to use its interface. It is what lies unseen behind the interfaces that is important. Even later in the training process there is still an inappropriate focus in training. Training (as a result of flight crew licensing requirements) focuses heavily on technical malfunctions and aircraft control (particularly manual control). However, Thomas [9] observed that the vast majority of day-to-day threats encountered by flight crew during line operations stemmed not from system malfunctions but from other issues such as weather, traffic, terrain, ATC and airport conditions.

5 The HFI/HSI Approach

The design of a radically new flight deck offers the ideal opportunity to re-design the training syllabus so the two are congruent. Flight deck design commences with a requirements analysis (what functions must the flight deck perform?) which also forms the basis for the TNA. If the functions of the flight deck are now split between piloting (flight path control and system management) tasks and CNS this will allow simplified, less compromised interfaces to be developed and better targeted training to be undertaken, specific to the crew role in question. Simplified, less compromised flight deck equipment is quicker to develop and certificate; cheaper to design and produce *and* requires less training time and has significantly reduced error potential. In this way safety and cost benefits may be available to the airlines.

However HFI/HIS also encompasses organizational issues. Re-design of the flight deck in the manner specified will also create two distinct roles on the flight deck. Other matters will emerge such as issues concerning career progression and establishing exactly who is in charge of the aircraft. Will CNS flight crew attract lower pay (or vice versa)? The flight deck design revolution isn't simply about the flight deck.

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