Optimization of automation in the civil flight deck

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Abstract

The development of automation, since its appearance during the 1930s with the first autopilots on the flight deck, has caused very important debates, studies and, especially, changes in flying practices. Designers, certifying bodies, operators, researchers and pilots have worked over many years for the progress and improvement of optimal relationships between humans and automatic controllers. Progressively, computer software has taken the lead on traditional automation devices. Today, pilots have to deal with software agents that handle tasks and roles traditionally devoted to humans. Pilots have become managers of these new species of artificial agents. They do not need to know how software agents perform their tasks, however they need to know what they do. A great deal of work has shifted from doing to thinking. Traditional energy-based control has shifted towards information-based management. Human-centered automation has become a requirement. Designing automation is no longer a matter of repairing previous flaws to avoid so-called «human errors» by substituting human activities by machine activities. Automation has now become part of the overall design of modern systems. Most human-machine interfaces are computer-based and much deeper than before. They are software agents that mediate interactions between human operators and machines. Usability of such software agent-based machines needs to be tested very early in the design process by real users. We must acknowledge that there are no widely accepted standards for certifying software agent-based machines so far. This paper discusses related issues.
Emerging concepts and issues

Automation is fascinating. Without automation, we could not do what we can do today such as flying for instance. Automated tools have existed for a long time and assist us in a wide variety of activities. Clocks structure our time. Calendars have become electronic agents that assist us in managing our schedules. Automation enables humans to perform tasks much faster and better, but it also has its drawbacks. In order to better understand the evolution of automation in the aviation domain, we introduce basic concepts that have emerged over the last decades: supervisory control, cognitive function transfer and human-centered automation.

Supervisory control and software agents

Automation is designed to extend the capacity of machines to perform certain tasks formerly done by humans, and to control sequences of operations without human intervention. Automation provides autonomy to machines in limited contexts that need to be defined. The more automation becomes complex the more difficult it is to define the context of use of highly-automated systems. The concept of automation and supervisory control are nowadays well established in the domain of engineering and design practices (Sheridan, 1992).

Advanced automation is now related to the definition and implementation of software agents. The concept of software agent is less well defined however. A software agent is represented as an object that can be simulated on a computer, and an attitude that is the result of the performance of the object (perceived behavior). It is extremely important to master both the analytical part of a software agent (or artifact) and the situational part that is called an attitude. Glass cockpits have introduced the concept of pilot as a «flight manager» supervising several computers (i.e., software agents), which perform direct control, executing tasks and reporting back to the pilot as to whether the goals have been achieved or there are troubles in the flight management (Figure 1). Usually, the pilot communicates with these computers through another type of software agent that constitutes a deeper interface\(^1\), which has the following roles:

- interpret and provide a synthesized package of information coming from the many sensors scattered around the aircraft (integrated display functions);
- provide advice and planning options by means of «expert systems» or off-line models;
- enable the pilot to query the system, change set points, or specify sub-goals through a user-friendly high-level command language.

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\(^1\) We make a clear distinction between a shallow interface that includes displays and commands that enable the pilot to control the aircraft, and a deeper interface that is constituted of computers (here called software agents) mediating the interaction between the pilots and the aircraft.
Cognitive functions

There are functions that are allocated to people and others that are allocated to machines. Some of the functions that were allocated to people have been incrementally transferred to machines. For instance, autopilots perform functions such as following a track, maintaining an air speed, etc. By using such automated devices, people have transformed their initial functions (i.e., a mix of physical and cognitive functions) to more cognitive functions such as supervisory control, diagnosis, or flight plan execution (Boy, 1997b,c). In human-machine systems where people need to communicate through machines, the number and the content of cognitive functions are even greater. In an aircraft cockpit, cognitive functions are used at various levels such as communication, supervisory control, cockpit resource management, situation awareness, etc. They can involve general knowledge that has been incrementally refined, contextualized and generalized through training and reflection. In any case, the perspective of human-centered design is to identify which cognitive functions can be transferred (delegated) to the machine without perturbing the usual harmony of the human-machine system. The main goal is to identify the right compatibility between interface objects (IOs) and the situated requirements for human operators. For this reason, the elicitation of cognitive functions is an essential exercise that greatly contributes to the control of ergonomic design.

Automation tends to reduce energy-based skills and enhance information-based skills. Modern machines are more managed than controlled, in the traditional sense of control. The perception of energy has changed. Proprioceptive feedback and sensory-motor interaction have been progressively removed to the benefit of software-based alarms. Human operators need to think more than they do, and as a result energy-based skill erosion has become a reality, e.g., reversion to the manual tracking task. In contrast, information-based skills need
to be learned and taught. Since many tasks traditionally performed by humans have been
delegated to highly efficient machines, human operators have become managers of
automated systems. Management skills are not immediately appropriated. There are several
issues that need to be investigated such as trust, supervisory control, delegation, planning,
etc. There are two philosophies that may lead to the design of highly automated systems:
• keeping traditional ergonomics principles and designing by using augmented reality; or
• recognizing a socio-technical evolution and the emergence of information-based tools.

The role of the pilot as a flight manager covers five main functions:
1. planning the flight and the computer tasks;
2. programming and supervising the computer using several appropriate displays and
   control devices, such as Flight Management Computer, Flight Director, Navigation
   Display and Attitude Director Indicator;
3. monitoring system performance, detecting and diagnosing failures and malfunctions that
   are not automatically detected and diagnosed by the system; this function requires that
   the pilot must maintain sufficient expertise to handle not-automatically-processed
   failures;
4. intervening to take over control when necessary; and
5. learning from experience.

*Cognitive functions transfer restructures work*

Technical components are usually certified with a very high reliability. Methodologies were
developed to insure technological reliability. *Human reliability* however, is extremely
difficult to predict. The reliability of artificial cognitive functions that are transferred to the
machine is tested and measured. What is difficult to predict is the interpretation of the
possibilities of artificial cognitive functions by their human users. They are usually defined
and certified within a specific context, i.e., the range of situations in which tasks can be
delegated to artificial cognitive functions is limited. Human operators need to know this
range of use. Initial training is not enough to master the corresponding system. The use of
artificial cognitive functions (software agents) is again a matter of *context*. By accumulating
experience in many contexts of use, we will increase our knowledge on the predictive power
of software agents via human reliability testing. This is a good reason to further investigate
integrated experience feedback mechanisms.

The problem of *task and role allocation* has become more crucial than before. Automation
was designed and developed to increase efficiency, comfort and safety. In practice, it has
changed the nature of work introducing new problems of efficiency, comfort and safety. The
main issue is the nature of criteria used to define and allocate tasks and roles to either
humans or machines. For several decades, automation was implemented from an engineering
perspective rather than from a human operator perspective. Cognitive functions that were
transferred from humans to machines correspond to currently well-understood concepts and
available technology. These cognitive functions usually enable the execution of simple and
repetitive tasks. Complex tasks have not been automated because they are very infrequent or
very expensive to automate. These low-frequency tasks are also often poorly supported. To summarize, work has become easier for simple and routine (usual) tasks, but might be very stressful and complicated for unexpected or exceptional tasks such as fault diagnosis and emergency situation management.

The use of human cognitive functions requires operational knowledge that is documented in the form of interaction descriptions (IDs) usually available in the form of procedures and checklists. Delegating some of these functions to the machine requires the reformulation of corresponding IDs. It is inaccurate and unfortunate to consider that work can be done in the same way as before (i.e., before automation was introduced). Automation influences human performance because the allocation of cognitive functions is different. The organization and nature of human cognitive functions allocated to a newly automated system changes work. In addition, people may not welcome work changes usually because they were not involved in design decisions. This is a good reason to involve end-user representatives in design teams.

*Cognitive function transfer needs to be experimented by end-users.* For instance, humans have thought of flying for a long time. They tried to put their ideas into concrete form by building flying machines at the end of the XIXth century. They never attempted to improve their experiments on these flying machines by improving interaction between pilots and aircraft. They have developed systems that enable them to amplify their possibilities in order to perform more efficiently. Commercial aviation has tried to incrementally improve safety and comfort by either substituting functions that cannot be implemented by humans, or by amplifying functions that humans can implement but where the corresponding tasks are too difficult to perform. In particular, some control tasks need to be amplified to enable specific classes of users to perform them. For example, power steering and noise insulation were introduced on cars to enable all drivers to comfortably drive without effort. At the same time, automation introduced infrequent but dangerous situations: when some users are not familiar with information-based human-machine interaction, they may wrongly interpret the occurring situation. For example, inappropriate force-feedback on the steering-wheel may enable the driver to perform inappropriate steering actions and induce serious damages. Indeed, situation awareness has emerged as a crucial concept since several intellectual processes that were handled by humans before and enabled them to maintain an appropriate level of situation awareness, are now handled by computers that provide a restricted amount of information that may not be either perceived nor sufficient for the human operators to maintain a reasonable level of situation awareness.

The fact that many tasks are delegated to artificial agents does not mean that humans are no longer in command. Humans are involved in a *management activity* that needs to be assessed using human factors principles and heuristics that have to be defined and certified. The more tasks and roles are delegated, the more humans need to be aware of what is going on. They do not need to know how work is being done, they need to know what is being done, to what end, when the current task will be finished, what will happen next, etc. This is what *situation*
awareness is all about. It is the same thing as becoming a team manager. New information-based skills need to be learned and practiced.

On the machine side, automated systems should be predictable by the human operator at the right time. They should be designed in such a way as to provide the right feedback at the right time and in the right format. We also can think that software agents might monitor human activities and anticipate human goals to insure predefined levels of safety. Cognitive function transfer needs to be controlled and well understood. To this end, a methodology for human-centered design, called cognitive function analysis (CFA), was proposed and evaluated (Boy, 1997b,c). Advanced automation design needs to be thought of as designing multi-agent cooperative systems. Finally, appropriate usability criteria should be further defined to insure that automated systems are easy to learn and retain, efficient, tolerant and resistant to human deviations, provide pleasure, etc.

CFA uses the concept of (human and software) agent. CFA enables knowledge elicitation from potential users through an incremental trial and error process where both designers and potential users are involved at the same time. We have developed the group elicitation method (GEM) that enables the elicitation of knowledge from various groups of people and enhances decision making (Boy, 1996). This method could be used to elicit cognitive functions that are involved in cockpit automation. Groups of pilots, designers and airworthiness authorities could generate and debate various viewpoints on cockpit design and certification issues. Several experiments have been already performed successfully in the aeronautics domain.

The use of CFA is enhanced by the use of various evaluation criteria that need to be refined and customized in the aeronautics domain. It should be noted that such a customization is performed by doing the design and the evaluations incrementally during the design cycle. One of the first distinctions that needs to be acknowledged by designers is related to the purpose of technology, i.e., technology can enable the performance of new jobs that were not possible before; substitute jobs that were painfully done by people; amplify performance. Whenever a new system is built that makes it possible to do things that were not possible before, people must learn new abstractions that need to be referred to existing cues and skills. Flying an airplane is a good example. This kind of automation is equivalent to adding prosthesis to human beings. Job substitution includes the notion of delegation, supervisory control and management. In any case, the job nature changes. Amplification was certainly the most commonly used principle for a very long time. It is better mastered than other types of automation.

Human-centered automation

People are recognized to be good at monitoring when they are fully controlling a machine. However, they make errors. To avoid the recurrence of such errors, automation is added to the system. Unfortunately, such automation tends to increase monitoring and decrease the number of control actions. It has been observed that people are not good at monitoring when
they are not involved in the control loop, their vigilance and situation awareness decreases. This is a major handicap when they need to re-enter the control loop after an unexpected event. Thus, what is a good compromise? It seems that we need to better understand human performance in the use of increasingly information-based systems. *Automation should be driven by actual needs rather than by technological options.* This is the reason why cognitive function analyses ought to be performed very early on in cockpit design. The difficulty is to appropriately use the right technological option in response to CFA-generated recommendations.

A crucial question in HCA is the *allocation of control.* Automation is usually motivated by safety, economical or comfort reasons. Safety is defined by default criteria that are valid until a new type of accident or better understood safety issues evolve with technology and people. One of the major issues is the definition of the *context* of an accident or an incident. It is almost impossible with current incident databases to predict accidents. This is due to the fact that these databases are dry knowledge and are not integrated into a modeling framework that would lead to a predictive tool. We think that HCA will be enhanced when *experience feedback* will be embedded in a user modeling practice where operations delegates, modeling specialists, training people and designers will work together towards this goal. Taking into account human factors during the whole life cycle of a product is necessary. This is an incremental process. However, the earlier operations knowledge can be taken into account during this life cycle, the better it will be for the sake of rational design and development of the product.

HCA should address the difficult problem of *responsibility* allocation. The human operator should always be in control, i.e., he/she should be aware of the current evolution of the state of the system and the environment (situation awareness), and be able to act appropriately according to the situation and his/her mental state. Responsibility is not limited to end-user performance. It needs to be addressed at the design stage as well as the certification stage. Design team constitution is an important issue that can be enhanced by modern technology such as computer-supported cooperative work. The same kind of concern applies to automation certification. This responsibility allocation problem can be seen as a cooperative activity. New concepts and methods need to be developed and customized in cockpit design and certification by applying principles for human-centered automation (HCA). Billings (1991) has already provided several useful HCA principles that should be extended.

**Integrating human factors principles into design**

The need to apply human-centered design principles is nowadays fully recognized and adopted by manufacturers and operators when developing flight deck designs and operations criteria. These principles aim at maintaining the central role of the pilot in the supervisory role of flight management and control. This requires that the pilot constantly anticipates the
aircraft behavior and master perfectly the control principles and procedures applied by the automatic systems.

The 4P’s Approach

In order to reach this goal it is necessary that a well thought management strategy be put into practice. An approach based on four criteria, called the 4P’s, philosophy, policies, procedures and practices (Figure 2), has been proposed by Degani and Wiener (1994). The practices are the actual forms of crew interaction with the automation.

These practices need to be fully accounted for in the process of the development of procedures by designers and operators of new generation aircraft. This implies that the policies, by which manufacturers define how automation is implemented in the design and by which operators specify the way to perform in the cockpit, are clearly adapted to the needs of pilots. Policies, however, derive from an overall philosophy, by which the management defines the overall way to include automation in the design process and the way to conduct the airline, in particular by defining flight operation criteria.

![Diagram of the 4P's approach](image)

Figure 2. The Four P’s (adapted from Degani and Wiener, 1994).

The Manufacturer’s Viewpoint

The major industries and manufacturers seem to comply with these research findings. Automation design and implementation is nowadays discussed with all involved parties including designers, pilots, maintenance engineers, as well as dispatch and ramp personnel. A clear example of this new attitude is the process of development of the design of the Boeing 777 cockpit and control systems to which many different perspectives have been accounted for since the beginning of the design development. Similarly, Airbus is
continuously monitoring and confronting, in recurrent meetings throughout the world, the design principles and methods of its engineers and specialists with the views of users and human factors experts (Airbus, 1995, 1996a, b, c). The 4P’s approach of Airbus has been presented in many circumstances. As an example the philosophy of the company towards automation is that «.....if technology is available to automate a function that would prevent a pilot from inadvertently exceeding safety limits this should be done... » (Speyer and Fatemi, 1995).

The need to consider pilots’ opinions and to include pilots’ viewpoints in the process of design of interfaces, control systems and procedures for flight management has been largely proven by a great deal of research work carried out on glass cockpits and highly automated aircraft (Moricot, 1996; Tennery, Rogers & Pew, 1995; Gras et al., 1994; Sarter & Woods, 1994; Boy, 1997a).

Actions of Regulators

A very recent effort promoted by the Federal Aviation Administration (FAA) of USA, in collaboration with some European experts of the Joint Aviation Authorities (JAA), has resulted in a very exhaustive and thorough report on the current needs for considering human factors in modern flight deck systems (FAA, 1996). This report contains a very high number of recommendations which are aimed at improving all aspects involved in the development and management of modern aircraft. In particular, the objective of the report is the identification of regulatory standards, of criteria for design, training operations and certification, and of tools and methods for design and management. All actors involved in these processes are considered, namely designers, users, evaluators and researchers.

Focusing on automation and certification issues, one major guideline is again identified as the need to establish a clear philosophy by manufacturers and companies, and thus to define the consequent links with policies, procedures and practices for designing and managing human-centered flight deck automation.

Moreover, specific aspects for inclusion in the design and certification process are identified, as for example the definition of flightcrew functions and task allocations, the consideration for cognitive processes in the analysis of pilot behavior, including human errors and design-induced abnormal behavior. Cultural and national factors should also be considered in the design and training process. At the European level, the co-ordination of JAA has given rise to a number of regulations and requirements that are presently under review and discussion by the Human Factors Steering Group committee.

The Data Issue

Another fundamental issue in the process of the development of sound design of systems is the availability and use of «good» data, parameters and indices for prospective and retrospective studies of human-machine interaction.
The way in which data are recorded and collected is largely responsible for the quality of the analyses that are performed in support of design and safety cases. Data can be gathered in a number of ways (Figure 3): from actual training sessions; in the working environment and within the organization by observation of normal operations; by interviews with experts and by questionnaires at all levels of the organization; from mandatory and voluntary reports on accidents, incidents and near misses (Cacciabue, 1996).

Data and parameters are usually collected and assigned in accordance with a precise reference paradigm of behavior. Data collected from the direct observation of real working contexts are unbounded by definition. However, they are eventually constrained to fit the reference model.

This is a normal practice for hardware and plant-related data. However, the problem becomes particularly difficult when data concern human behavior, as this implies that a model of reference for pilot behavior is needed.

*The Human Model Issue*

The use of models of the pilot-vehicle system is a well-established practice for the prospective evaluation of a large number of human-machine interactions, procedures, operational envelopes and mission requirements. There are many advantages in using models and simulations of pilot-aircraft interactions, such as the variety of test cases that can be performed and reproduced in case of need. The cost of simulation is very low and it is a time saving exercise, that can be carried out during early stages of design. This means that
improvements and modifications can easily and economically be introduced during the development process.

The remarkable advantage of using cognitive simulations, over the classical approach of technical inspection and certification by experts and experienced pilots, is that a much greater variety of cases can be evaluated and tested at a very low price and in a relatively short time. There is another advantage in using cognitive simulation over direct technical evaluation, i.e., the evaluation of a design and associated procedures can be performed during the early phases of the project development and is very cheap to perform. In the case of the human expert, it is necessary to perform the analysis on an already developed prototype which is much more costly.

The drawback of simulation is that models are not simple and exhaustive and that data in support of human behavior models are difficult to collect. Moreover, specific data need to be obtained for each type of cockpit and population of pilots under study. Human factors data cannot be easily generalized.

Moreover, as automation and supervisory control demand a high level of mental and cognitive work, pilot models must account for these high level cognitive functions, and relative data parameters and indicators must be identified and collected. These data are obviously even more difficult to collect than simpler behavioral data.

Several pilots models have been developed and are presently still under development or improvement with the objective of capturing the major pilot aircraft interaction processes (Boy & Tessier, 1985; Baron, 1988; Smith, Govidaraj & Mitchell, 1990; Amalberti & Deblon, 1992, Cacciabue & Cojazzi, 1995).

As an example, a specific application of modeling of human-machine interaction is the analysis of tasks assigned to pilots and automation in glass cockpits. Degani, Mitchell and Chappell (1995), have shown that such a model can be successfully utilized in this case and is able to highlight « the relationship among the environmental demands and states,.....the functions and tasks to be accomplished, .... and the physical and cognitive actions the crew has to undertake. »

The single-agent view (Wickens & Flach, 1988) is not sufficient to explain and model multi-agent interaction. Distributed cognition among agents (Suchman, 1987, 1993; Vera & Simon, 1993) has become crucial as software agents have emerged from the massive introduction of computers in work environments. The distributed cognition paradigm states that knowledge processing is distributed among several agents that can be humans or machines (Hutchins, 1995). In particular, Hutchins showed various ways in which the same
information is represented and how representations are modified and exchanged between agents².

Combining methods for certification and regulatory process

The results of this large amount of research can be very useful to certifying bodies for identifying methods, criteria and tools to evaluate and test flight deck design. Unfortunately, while it is relatively easy to get agreement that automation should be human-centered, it is much more difficult to get agreement on how to achieve these objectives and on how to evaluate when they have been reached. The cognitive function analysis approach provides a framework for both incremental design and evaluation. Evaluation criteria are defined by appropriate experts and refined according to the novelty of design. Accordingly design is incrementally improved by applying evaluation criteria from the beginning to the end of the design cycle.

An important stand for certification bodies is to be able to perform independent evaluations of the design and systems proposed by manufacturers and operators. In this sense, certification is different from incremental evaluation performed during the design cycle.

There are two possible way to evaluate the salient features of a design: by perspective analysis and/or by retrospective evaluation. Two generic and complementary approaches to evaluation can be combined for a complete process of certification of modern cockpit design and control procedures:

1. **Analytical model-based evaluation** includes task analyses, cognitive simulations and user modeling. A prospective method assesses the consequences in time of human-machine interaction given some initial and boundary conditions. The data and parameters utilized by the manufacturer can be re-utilized to perform an independent evaluation of performances of the pilots, for a wide variety of situations and circumstances; usually prospective studies are quantitative assessments, but sometimes also simpler logical models and qualitative estimations can be utilized to predict behavior.

2. **Usability and quality assurance** provide an experimental approach to evaluation; a retrospective analysis consists in the development of a method, qualitative in nature, for the review and evaluation of the safety cases presented by the manufacturer to sustain the appropriateness and soundness of the design. These studies are usually based on the analysis of a number of maximum credible accidents or on a systematic safety assessment of the flight deck. The goal of the certification process is to retrace backward in time, i.e. retrospectively, the processes, assumptions and data applied for the safety studies.

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² EURISCO has started a novel approach to cognitive modeling that emphasizes the social aspects of interaction.
Analytical model-based evaluation

The key aspect for the development of independent methods for certification is the availability of a modeling paradigm of human behavior and a computerized simulation able to cover a substantial part of human cognitive and behavioral performance. In this way it is possible to describe the integrated performance of the pilot-aircraft system for the evaluation of consequences of postulated behavioral and erroneous performances. With such a computerized tool, many procedures, human errors, human-machine interactions could be fully evaluated and tested for a very high number of different hypothetical situations. In this way validation could also be carried out in parallel to the certification process.

As already mentioned above the most difficult aspect of the simulation resides in the definition of a reference model of behavior and in the identification of appropriate data and parameters. In particular, models of pilot behavior and cognitive functions have to be defined and consistently applied for prospective and retrospective methods. The modeling paradigm that has been proposed and widely accepted as an appropriate description of human behavior in dealing with modern machine systems, is the so called Information Processing System (IPS) metaphor (Neisser, 1967). This paradigm enhances the cognitive aspects of human behavior and demands the modeling of those mental processes (perception, diagnosis/interpretation, planning and decision making) which link the stimuli and the explicit responses of operators. Many simulation approaches have been developed in recent years, based on the IPS paradigm and on cognitive psychology and advanced programming environments. In addition to the human model, new elements are being included in a simulation context. These account for the behavior and effects of the machine and, especially for the environment surrounding the operator. The inclusion of these contextual effects allows for the formulation of external factors affecting behavior and eventually human error. Finally, a sound set of data and parameters to sustain the human model need to be collected and derived from field studies or existing data, as has been described above. The necessity of performing independent review of design proposals requires also that this step of data collection be performed independently and autonomously by the manufacturer. The key issue here is that data collections and classification schemes have to be congruent with the model of human behavior and overall simulation architecture utilized for prospective and retrospective analysis.

In summary, the development of independent quantitative and qualitative simulation approaches is a very relevant issue for certification. To reach this goal a number of requirements have been identified as:
1. the development of a simulation architecture and a methodology for prospective and retrospective analyses;
2. the availability of a human behavior model, based on the Information Processing paradigm, i.e. able to account for human cognitive functions;
3. the application of a model of aircraft behavior, in consideration also for the environment and context affecting pilot behavior;
4. the generation of a data classification scheme (taxonomy) congruent with the model of human behavior;
5. the collection of data and parameters by field observation and strictly correlated to the taxonomy and to the working context.

Quality Assurance
A number of innovative elements for the definition of these special quality assurance principles seem to emerge as a common ground of agreement within the communities of designers, practitioners, researchers and users. These elements make up a set of criteria able to sustain a certification procedure, at least from the qualitative viewpoint and can be summarized as follows:
1. the formulation of a set of explicit and transparent criteria for the design and training philosophy, policies, procedures and practices;
2. the inclusion of specific consideration for cognitive behavior and for differences in culture, nationality and language;
3. the review of the scope of modeling paradigms utilized to describe human behavior;
4. the evaluation of the consequences and automation response to human errors;
5. the consideration for design induced inappropriate behaviors;
6. the specific analysis of most critical automatic systems, such as autopilot, autothrottle and flight management systems, with particular reference to pilot situation awareness;
7. the evaluation and assessment procedure for human factors data and data collection methods, including a study of precursors and indicators;
8. the analysis of principles for pilot selection, initial and recurrent training.

Extending basic usability principles to optimize automation
Usability principles are defined according to the cognitive engineering model that was adopted by the design team. Basic usability principles were elicited by Nielsen (1992) as high-level evaluation heuristics that include the following:
• use simple and natural dialogue;
• speak users’ language;
• minimize user memory load;
• be consistent;
• provide feedback;
• provide clearly marked exits;
• provide shortcuts;
• provide good error messages;
• prevent errors.

Basic usability criteria, such as ease and speed of learning, efficiency of use, ease of memorization, number of human errors and ease of recovery, and subjective satisfaction (Nielsen, 1993), can be extended according to the agent-to-agent communication. On modern aircraft, flight modes were introduced to handle various tracking and navigation tasks. For instance, suppose that an aircraft crew decides to climb towards a flight altitude of
thirty thousand feet. They insert a flight level of thirty thousand feet in the corresponding computer on the aircraft. After they have sent the order to the computer to expedite the climb, a software agent performs the corresponding task until the desired altitude is reached. During this time the software agent is in a «climb» mode. After it has reached the desired altitude, it enters into an «altitude hold» mode. It is very important that the crew be aware of this mode change because the cognitive functions involved in the supervision of the first mode are quite different from the cognitive functions involved in the supervision of the second mode. This is a case where situation awareness is crucial.

A human agent interacting with a machine agent must be aware of (Boy, 1997b):
• what the other agent has already done before (history awareness);
• what the other agent is doing now and for how long (action awareness);
• why the other agent is doing what it does (action rationale awareness);
• what the other agent is going to do next and when (intention awareness).

These three issues correspond to the most frequently asked questions in advanced cockpits (Wiener, 1995).

Agent-to-agent communication has been described by many authors working in the domain of highly automated systems (Billings, 1991; Malin et al., 1991; Sarter & Woods, 1994). Several attributes were used to describe automation. Among them and in addition to basic usability principles, the following should be considered:
• predictability, that is the ability to anticipate consequences of actions on highly automated systems;
• feedback on activities and intentions;
• autonomy, that is the amount of autonomous performance;
• elegance, that is the ability not to additionally burden human operators in critical contexts;
• trustability, that is the ability to maintain trust in its activities;
• expertise-intensive necessity versus common sense interaction;
• programmability, that is the ability to program and re-program highly automated systems.

Conclusion

We consider that automation is about interaction between people and technology. If we accept the model of agent for both humans and machines, these agents should be able to cooperate with each other. Creating new machine agents requires that users acquire new skills and knowledge. A new society of agents is usually created and should be analyzed. Evaluation criteria should be derived, implemented and refined by use. It is usually false to think that automation (as a creation of new machine agents) reduces human activity. It creates new activities, usually management activities. New types of errors are also generated, however, it is better to think in terms of risks and error recovery than in terms of error
reduction. Training is a requirement. There is always a tradeoff between flexibility (more options) and guidance (less options). A remaining question is the possible prediction of the effects of automation at design time. New ways of processing incident and accident data bases need to be investigated both for design and training. EURISCO has developed a human-centered design approach that is based on the creation and management of active documents that enable collaborative design of highly automated systems in aeronautics and traceability of design rationale. In particular, active documents that support the CFA methodology enable design teams to evaluate and document design options during the design cycle that is very useful for certification purposes (Boy, 1997b,c).

The certification issue is not only a matter of national and international agencies. We think that the rapid evolution of technology in the aviation domain as well as in our daily lives stresses the need for more investigations on the emergence of software agents that are more integrated in traditional tools and systems. New certification standards need to be elicited and experimented. There is also a need for a revised education and training system on the way aircraft and especially cockpit design is being done. In particular, engineers should be trained in human factors. Collaborative work should be enhanced to incorporate users’ needs and requirements during the whole design life cycle. In particular, human-machine interaction should be defined and experimented very early on in the design process. Traceability links should be established in order to access design rationale at all stages of the design life cycle, and especially at the certification stage. Design teams should include airline pilots as well as test pilots, designers, certification people and human factors specialists.

A number of issues on the optimization of automation in civil flight decks have been reviewed. These have been derived from the most recent studies and actions carried out by practitioners, manufacturers, operators and regulatory bodies. Two lines of development have been proposed. The first approach considers the use of simulation of human behavior, coupled with models of machine and context and with specific classification schemes. It is proposed as the way forward to develop methods for prospective and retrospective analysis tools. The second one is the usability and quality assurance approach for the evaluation of the overall design and training practices. A number of innovative aspects have been identified, as for example the inclusion of cultural and national characteristics, human cognition as crucial element for assessing human behavior and human errors, the consideration for practitioners and human factors experts in the design process, from its early stages of development. Basic usability criteria should be extended to carry out evaluation and certification of advanced flight decks.

In summary, many studies and analyses of human factors and human-machine interactions seem to converge gradually towards a general acceptance of the need to include this issue in all stages of the design, evaluation and training processes. The means and methods for development, inclusion and certification of Human Factors are also converging towards a body of accepted rules and standards. This is, in substance, the most important result of
many years of work of human factors specialists and will inevitably lead to better design and
certification processes for modern aircraft and for all modern automated machines.

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References

AIRBUS (1996a). Proceedings of 2nd Regional Conference on Human Factors. February 26-
29, 1996. Miami, Florida, US.
18-21, 1996. Hong Kong.
step towards an intelligent onboard assistance system. *International Journal of Man-
Machine Studies, 36*, 639-671.
Baron, S. (1988). Pilot Control. In E. L. Wiener and D. A. Nagel (Eds.), *Human Factors in
Memorandum 103885, NASA Ames Research Center, Moffett Field, CA, USA.
EKAW’96*, Published by Springer Verlag, Berlin.
Boy, G.A. (1997c). Cognitive function analysis: an example of human-centered re-design of
a flight management system. *Proceedings of IEA’97*, Tampere, Finland.
pilot-airplane interaction. *Control Engineering Practice, 3* (2), 257-266.
Safety. 3rd ICAO Global Flight Safety and Human Factors Symposium. April 9-12, 1996,
Contractor Report 177642, NASA-Ames Research Center, Moffett Field, CA, USA


