Human-centered design methodology: an example of application with UAVs mission

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Abstract. Reviewing the accidents and incidents with UAVs, many of these are a consequence of events that were not imagined before starting to use them in a specific setting. Among the known origins, a strong contribution of human factors deficiencies is mentioned. In our industrial context, we propose an engineering methodology focused on human factors, and an application to the design of a ground control station of UAVs. Its processes are described with concrete examples of application in our UAV laboratory. This paper focuses on the need to integrate the aspects related to the human activity. The use of human factors approach in the design of process control systems throughout the industry presents many opportunities for improvements with regards to systems efficiency, effectiveness, reliability and safety.

Keywords: human-centered design, UAV mission, human factors, human activity.

1 Introduction

Well-known advantages of Unmanned Aircraft Vehicles (UAVs) have led to their increased request in operation. Long-term use, flexible adjustments and easy replacements make the pilot-less aircraft a preferred mean in civil and military applications. At the same time, national and international regulatory initiatives are undertaken to prepare their integration in civil non-segregated airspace\cite{11} intended to further increase their efficiency. However, since the beginning of using UAV, numerous problems were encountered during the use of this technology. Compared to civil aviation, the implementation of UAV is related to a high number of incidents and accident. A remarkable issue therein is the strong contribution of human factors issues, which statistics are assuming to generally...
represent about one third of all factors [18]. Looking more in detail, these issues can be attributed to the design of the technical system itself (e.g., inappropriate alerts, feedbacks; [34]), related procedures, individual use of strategies, and organizational distribution of roles and responsibilities [35].

Many of these accidents are a consequence of a concatenation of events that were not imagined before starting to use them in a specific setting. Variation in the way human operators execute assigned tasks lead to differences in observable outcomes. The notion of cognitive functions [5] etc. helps to explain why such a variety occurs. Operators dispose of different strategies to transfer a prescribed task in an effected activity [16]. Indeed, analysis of several situations shows deviation between that which is foreseen (at the design stage) and that which is integrated into and installed on the production site, and that which takes place during operation. The deviations reflect the differences between the task and the activity which is well-known in ergonomics but also between nominal technical and the real operation including different situation recovery events, faults and failures (technical, organizational, human, etc.) [12]. And finally, work is achieved by regulations and adaptations, the optimal operating conditions very rarely being met.

Thus, when designing an achievable interaction between the human and the artifact, numerous possibilities need to be taken into account. When a human operator is interacting with technologies in a certain way, potential activities need to be anticipated to reduce non-desirable impact on the UAV environment. One way to obtain this anticipated variety in behavior is through integrating operator experience from the beginning of the design process to determine potential emerging functions. Moreover, the need to understand and facilitate crew communications is critical with a focus on inter-crew coordination during UAV mission from one team of operators to another [35]; [29].

In this field of research, a human-centered approach helps to make sure that user needs are elicited and transferred in requirements, integrated, and evaluated throughout the product life cycle. To tackle these issues, we propose a methodology to integrate operators throughout the process and supported by an interdisciplinary design and development team.

This paper aims three points; i) to present a state-of-the-art about the various systems engineering methodologies, ii) to propose a human-centered methodology showing the importance of understanding and designing human factors into steps of conception, and iii) to propose a case of application of this methodology for a ground control station of UAVs.

2 State-of-the-art about the various systems engineering methodologies

In the field of systems engineering and cognitive ergonomics, reflexion has focused on innovation processes since a few years. Various changes have occurred progressively in engineering methods from linear engineering methodologies used classically (e.g. design cycle V-shaped, spiral, U) to concurrent or participative methods.
engineering methodologies. So, whereas the former engineering methods focused on the proposal of technical products and information networks, the latter focus particularly on system activities.

In order to guide the design of interactive systems, various methods were proposed. They provide a methodological framework of design that makes it possible to validate the various stages leading to an interactive system for the human operators. These various models are known under the name of V-Model, cascade or spiral Model, and described briefly below.

The cascade model [28] describes the life cycle of an application according to eight stages ranging from the specifications to the maintenance of the software. This model is characterized by an obligatory validation of each stage before being able to engage the following one. If a stage cannot be validated, the designer has the possibility of re-looping on the preceding stage in order to correct the possible errors. However, the designer cannot integrate several stages in only one. The principal default of this model, within the framework of design that interests us, is that it applies with difficulty to the design of Human-Machine systems using the concept of task sharing.

The V-model [15] is an evolution of the cascade model, which is composed of a downward part of design followed by an ascending part of evaluation. This model has the characteristic to put each stage of design of the downward part opposite the corresponding stage of evaluation in the ascending part. However, this model requires, like the cascade model, that the application’s needs had been defined at the beginning of design without being able to be updated when the design process is started. The V-Model is not appropriate for the systems containing risks, i.e. these whose objectives are badly defined such as for example empirical research, those whose safety is crucial as in the process control... Indeed, these fields request a design framework that is more empirical and more tolerant with respect to the errors of specification that can be made at the beginning of the cycle of design [1]. The Spiral-Model can answer these situations and is presented as being a meta-model of design [3].

The spiral model [2] is characterized by a methodology of design based on the analysis of the risks performed for each cycle of the spiral. The final software is obtained after a succession of study-developments being based progressively on the preceding cycle of the spiral of which all the detected risks were solved. The software risks can be due to failure of the users, to development of inappropriate functions, incomprehension of the needs, missing external components and problems of performance. Each cycle of the spiral is composed of four stages: i) Definition of objectives, alternatives, constraints starting from the results of the preceding cycle; ii) Risk analyses, evaluation of alternatives and, eventually, prototyping; iii) Development and checking of the selected solution; iv) Review of the results and planning of the following cycle.

These various models are adapted to the design of interactive systems. However, they do not explicitly use the characteristics of the human operator, for example in terms of human factors or inter-individual differences.
3 A human-centered methodology and designing human factors into steps of conception

In the Thales industrial group framework, the scope of this section is to describe the different parts of the methodology related to the initial objective to better take into account user needs and human abilities (in particular cognitive abilities) in order to reduce the occurrence of incidents and accidents, based on existing knowledge.

Actually, advanced interfaces should use a human-centered approach in order to improve the appropriateness of the technical solutions. The H/M interfaces and procedure design impose new coordination demands on operational teams (e.g. the need for communication to construct situation awareness) (see [23]; [21]; [10]). Nevertheless, the deficiency of specifications as regards work activity underlined in the literature shows the difficulties in having the industrialist (manufacturers) clarify these data.

In our actual industrial setting, the methodology SYS EM (for SYStem Engineering Method) developed in Thales group is usually used and appropriate to propose a technical solution. Human factors are not playing the role they deserve in the design making them less controllable that they could be if they were adequately incorporated. To attain this, designers and evaluators must be able to quantify human performance and various metrics have been defined and standardized to be shared across systems.

This paper underlines the need to integrate the aspects related to the human activity. The human-centered methodology design is proposed figure 1. Even though work activity cannot be a priori defined, it can be reconstituted by the operators by a process whose installation concerns the responsibility of each member to well knowing its system work [13]. We focus particularly on the use and the user needs point of view since the beginning of the cycle life design.

In the following, we describe such specific processes which are crucial to contribute to the major objectives of systems efficiency, effectiveness, reliability and safety [6]:

- User need analysis contributes to providing needed systems within a specific domain. The context of this domain can be characterized through describing its main actors and regulations. User needs can be obtained by knowledge coming from previous data uses case in the same field or in similar applied research field, and the most important by direct contact with operators and future users through observing their activities or interviewing them. This first step is critical to determine system tasks and functions allocated between human operators and artifact and the degree of interaction between them through analyzing prescribed tasks. These prescribed tasks state the who is doing what when and how and how long and why and makes emerge constraints. Amongst the essential issues to address are the degrees of freedom in decision making, time and task variation, information accessibility, or transparency. Eliciting user experience can be supported through the user-based definition of scenarios. Scenarios are an extension of use-cases, as they
Fig. 1. Human-centered design methodology.

allow us to focus on both declarative as well as procedural aspects to well understand the underlying conditions and constraints of activity in its context. In addition, user experience helps to fine-tune performance criteria. Indeed, lots of models for task execution are described in form of a procedural approach. The declarative approach is only considered as a concep-
Virtual process. During our human-centered process, scenarios are developed with operational experts and contain declarative and procedural components. Declarative elements comprise human and machine agents, their roles and resources (the who and what). External resources are for example mission plans, available documentation, and checklists. In the same case, internal resources may be mental representations (mental database) as for example of the geographic environment. Procedural aspect combines these elements in interaction by adding the time element and the context (the how and when). Thus, in addition to the standard functional analysis, we take into account the prescribed task as described by the user at the beginning of the process. With this approach, we provide a set of use-cases linked with the context of the user task. By integrating it with the declarative approach, we provide a H/M model as close as possible to the effected activity. This allows us to assess the interaction between the user and the system.

– Operator modeling. This process is crucial during the cycle life of design and useful for engineers. It provides a profile of potential human operators via their cognitive abilities which would be solicited during activity and personal characteristics (i.e. age, gender, degree of expertise). In more details the cognitive abilities underlying the human capacities need to transform a prescribed task in an effective activity. It includes perception of contextual information, using knowledge, understanding and interpretation of data to realize an adapted and relevant action.

In this way, researchers have developed theoretical models that we take into account: mental models, individually and shared across the team operators. It is essential in a collaborative work that members have a common reference, the identical representation of the situation. The anticipation model serves to predict reactions and prevent risks in nominal or abnormal situations. It is completed by the human error model and a cooperative work model or cognition team model based on the knowledge management between team members. These models serve to measure the executed human activity and lead to the choice of tools for human factors evaluation during prototyping and evaluation. At the end of design, a comparison between the executed activity and this model helps to adjust it and to construct a human activity model.

– Function allocation. Once task analysis provides the theoretical tasks to do by the system, functions are allocated within the H/M system. At this step, we define the level of automation of the system, the need of assistance for the operators to effect tasks efficiently and safely. In this way, it provides also the degree of cooperation to effect the task and the mean to do them, between human team and between the human/machine interactions. In the subsequent design step, it will be used to evaluate the system efficiency during the real activity. Amongst the solutions to design cooperation are
the delegation of goals to other human or machine agents [7]; [27] or the application of negotiation to distribute tasks.

- Performance criteria are relevant for function allocation and defining cooperation modes as well as evaluation. To match system activity outputs and task goals, a set of indicators of major outputs and their consumption of resources is identified that enable the judgment of a design solution. For these performance criteria a system-oriented framework is used that takes into account high- and low-level criteria for the cooperation between human and machine agents. For example, it verifies that high performance of the human and high performance of the system also produce a high joint human-machine performance.

- Evaluation makes emerge functions that lead to an unintended use of a system, and anticipated nominal and degraded modes of system. Iterative prototyping aims to test a certain number of solutions several times in order to attain a satisfying and adapted solution (based on user needs and performance criteria). We are talking about iterative because if a solution is not appropriate we will take it back to design and bring to operators through another prototype for evaluation. Such a prototype can range from static graphical human-machine system representations to dynamic power-point representations up to low-scale or full-scale simulators enabling direct interaction. In addition, the experimental evaluation helps to make emerge the contribution of other cognitive functions in the use of the system and define human factors issues critical during work activity (i.e. workload, situation awareness, shared knowledge, physiological measures). These cognitive functions need to be addressed when specifying the human-machine interface, cooperation means and support systems.

- Training task. Once the best solution is obtained, the next step is to prepare operators to the use of product via practical sessions.

4 A case of application of this methodology for a ground control station of UAVs

We propose to apply this human-centered system engineering methodology as part of the SOUL project (System Oriented UAV Laboratory). Thales has developed a simulation environment on laboratory scale called SOUL to reproduce a ground control station (GCS) for conducting UAVs missions. It is composed of several operator displays dedicated to the different phases of a mission (i.e. take-off, landing, navigation, management of payloads, picture interpretation). Developed initially by engineers, our goal is to apply our human-centered methodology in order to provide improvements for the GCS. It is intended to optimize its use and promote its future utility.
Various methods are available and can be used in our study in the various stages of the human-centered design exposed above. To do so, for illustration we take the mission phase concerning the service functions: “provide information on an area of interest”.

- Users need: it consists if the capture and expression of operational needs and feedback experience: The collection of user needs will be made from, on the one hand, collective and individual interviews, operation observation on the other hand, and document analysis to collect database to make the functional analysis. We use the Group Elicitation method, GEM [4], which allows the capture of knowledge of each member of a multidisciplinary team (optimal number of participants = 7) and assists in obtaining a consensus. In this method, a moderator plays the role to coordinate the session.

At the beginning, he presents precisely the topic of the session GEM: it is to respond to a global issue but precise and sufficiently open; defining the list of participants and the conditions the course of the session (where, when, how). For our SOUL project, the question is: “Under the leadership of a mission of collecting information on an area of interest, what do you need (in terms of system functionality, cooperation, organization, information, knowledge) to help make that steering the payload”. Each participant is facing his computer monitor individually which allows him to express his own views with regard to the question (3 to 6 points of view by participant).

Then, everyone comment viewpoints previously generated by other participants. This step of brainwriting facilitates the anonymous and free expression of different points of view. Then, the main concepts are identified and synthesized from the various points of view and presented visually to all participants. This step allows to participants to classify and prioritize the concepts and, eventually identify other important concepts.

Finally, the debriefing step helps to formulate the main selected concepts. Decisions are then taken with plans of actions associated, and distribution of responsibilities. After registration of all views and comments of participants, the moderator of the session GEM immediately provides an account of meeting structured to the appropriate people.

This method offers the advantage of managing written or oral interactions of various participants and provides an account and an organization of different viewpoints, concepts, decisions and actions to address the situation. Its main advantage is to reduce the time spent in meetings and improve work productivity by providing a collaborative work environment and managing participatory traceability for reuse of knowledge. Moreover, we decided to conduct individual interviews, in order to address details of certain issues regarding tasks analysis of the payload operator, the head of mission, or the navigation operator entering in interaction with tasks of payload operator. Among these issues, we can cite: What are information necessary for what task, what pretreatment necessary, which tool used or desired? How operators have been trained in these procedures (guide, explanation, training
simulator)? What are the sessions and training facilities available? Explain your level of decision-making and autonomy?

In addition, to formalize various service functions and adaptation to different environmental constraints and associated functions initially set out: “Leading the payload” and “provide information” we also used the methodology SpecRight [8]. This method leads the identification of needs, environments and constraints, the expression of the requirements for obtaining a Tender Functional, and a Technical Specification of Need. This method, used tool and consists of interview of a working group or individually, or on an document analysis. It is based on principles of functional analysis (analysis environments and relations between the system and observed the different elements of this environment).

The focus is to first establish the initial user needs and produce the tender functional 0. This latter aims to explain the most neutral possible the solution to solve the problem, the need to be met, must be eliminated as much as possible any reference to a solution.

This method takes the advantage of allowing the formulation of functions and requirements, the structuring of documents involved in this process. Finally, a systematic approach integrating GEM and Specright was developed. It can be adapted according to the constraints of the setting and is based on the mission scenarios provided around the “leading payload” and “provide information” functionalities. The scope of this method is to provide detailed information to be able to complete functional analysis from the user perspective.

– Functional Analysis: In the SOUL study, we make the functional analysis for the use-case “provide information on an area of interest”. A use-case is composed of a set of scenarios to achieve an objective. The use-cases come from previous missions and available reports and for each one, we have: a description with the actors involved, the pre-conditions, the nominal scenario, the post-conditions and non-functional constraints. The H/M system functional analysis is realize by using the UML method It consists of represent by graphs, tables and icons the dynamics of a scenario (many actors, many messages exchanged,...) constituting sequence diagrams and possibly a state diagram giving all alternatives for each actors included in the use-case “provide information on an area of interest”.

– Analysis of tasks and modeling H / M system: This phase aims to analyze the work to be done in terms of analysis of cognitive functions, taking into account different models of the operator associated with different types of tasks (for example, the model of Rasmussen for the tasks of decision-making; [24]). Among various methods, cognitive functions analysis (CFA) will be carried out by identifying influential factors associated with the task, the operator, with the artifact, organization, and the situation [5]. A modeling H / M system integrating this model to both tasks shared between artificial and human agents. A set of detailed scenarios is developed based on the use
cases through integrating user needs, task and functional analysis outcomes. According to the approach suggested in [32], declarative elements and procedural events are developed in context. A soft modeling approach supports especially the representation of interacting agents based on the concept of interaction blocks to understand the relation between functions, resources, and context [33], to be published. The interaction block representation was considered appropriate to describe the local and cognitive level from an agent perspective, and to characterize scenarios in a multi-agent context.

- **Functions allocation:** This phase aims to determine criteria taking into account human factors in order to achieve the allocation of functions between H/M system. This involves to specify the type and degree of cooperation, needs of assistance that best suits our needs, and also determine the level of autonomy of individual agents who cooperate. To enable cooperation, the concept of common workspace is used. Based on the study of [27] and [19], we applied their method and tool to allocate functions and determine the common frame of reference for cooperation between operators and machine systems. Agents need to be able to create a model of the other agents’ activities by disposing of a common reference. Thus, within the common workspace, a task can be characterized according to required information elaboration, identification or diagnosing, schematic and precise decision-making, and solution implementation. This description can be effected based on the analysis of prescribed tasks and cognitive functions. To define appropriate assistance tools, automated functions need to be analyzed regarding the emerging human-machine interaction and may be supported by additional information.

- **Prototyping and Evaluation:** Since technical adaptations of SOUL as a simulation environment are costly and time-consuming, alternative forms of prototypes and thus adapted methods of evaluation need to be imagined. The use of SOUL as a complex simulation platform occurs at a final design stage. At an earlier stage, different design solutions for function allocation or cooperation modes can be tested thanks to simplified platforms or mock-ups. Even before that, conceptual demonstrators in paper or power-point format help to elicit first user reactions that can be fed back in the next design step. Thus, experimental approaches are completed by heuristic evaluations to determine if the desired performance criteria can be achieved.

- **Training:** The remarkable issue within SOUL in relation to training concerns the aspect that training needs analysis was already integrated at an early stage of the design process and can thus be integrated as criteria during the design of the cooperative H/M system. The final training concept to be adapted is however to be reviewed after a decision for a final solution. The learning and training will be by the use of driving simulator of UAVs mission. One or more operators is placed in front of a computer screen where he is
to lead a mission to overfly zone and capture images, with or without tools. During the simulation, performance data are recorded and will be reused later. It involves gathering the performance of the operator by recording reaction time, number of mistakes, learning capacity, workload, etc. Training need analysis is used in our study because it takes the advantage to take into account activity and analysis of human factors. It will lead to a modeling of operators and the proposal of training systems adapted to the end-user.

– Finally, according to an envisioned life cycle approach, also maintenance is an issue to be taken into account during the design and development process.

Moreover, it should be noted that the current study is still underway and some aspects are still to be deepened and developed in the coming months.

5 Discussion and Conclusion

In this paper, we propose a methodology to integrate operators throughout the process and supported by an interdisciplinary design and development team. We describe the different parts of the methodology and illustrate them with an example of application for a UAV ground control station.

In the present industrial setting, the engineering methodology classically used by industrials and designers define the requirements in terms of process, activities, tasks and solutions. Even though it can be applied to any type of tools and software, this methodology is focused on the obtaining of engineering solution and is not really adapted to integrate end-user during the product design. In order to design an adapted solution taking into account the user needs, it is also necessary to consider the collaboration of an interdisciplinary team. It is what we proposed by the methodology exposed in this paper. It consists on viewing the design processes by the point of view of users and their real work activity and so integrating human factors since the beginning of the cycle life. Seeing the specific requirements of each process, the collaboration of an interdisciplinary team of HF experts, designers/engineers, assigned operators, and management is significant. This is supported through submitting the team to a continuous learning process on each other’s task. Additional difficulties concerning the use of domain- and culture-specific notions will require finding compromises.

Each part of the human-centered design aims to contribute to the major objectives of performance and safety at each level of organizational structure. As we describe each process, prototyping and evaluation will make emerge functions that lead to an unintended use of a system and help to explain why operators do what they do in their work activity. A holistic approach covers the human-machine system in its organizational and regulatory context. This concerns as well the approach to tackle specific problems in relation to known incidents and accidents. For example, alerts and feedbacks do not only need to be addressed during the design of the interface, but also in the design of the appropriate training.
Moreover, the application to UAV systems presents human factor challenges. One of the goals of this work is to identify human factors issues in UAV operations, with establishment of a human operator modeling to increase the efficiency and reliability of the system. As military data indicate that a disproportionate number of accidents for which human error is a contributing factor occur during these phases of flight [35]. Research will also be necessary to examine the interaction of human operators and automated systems in UAV flight. In addition, studies will be necessary to examine and determine the crew size and structure necessary for various categories of UAV missions and to explore display designs and automated aids. Efforts are also necessary to determine the core content of ground school training for UAV operators, and to explore flight simulation techniques for training UAV pilots in the context of interdisciplinary collaboration.

However, we cannot anticipate all problems that may emerge, thus, the main interest should focus on developing resilient systems that enable adaptive behavior when pending between flexible and robust environments.

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References


