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EARLY HUMAN FACTOR INVOLVEMENT IN PRODUCT DESIGN PROCESSES

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ABSTRACT

During the design of man-machine interfaces, Human Factor issues are a key element of the design process performance. However, Human Factor analysis is mostly performed a posteriori, when a prototype of the product can be manufactured. The Engineering and Human Factors communities still have communication difficulties and thus Human Factor approaches are not well integrated into Systems Engineering processes.
The emerging concept of Human Views seems to be promising as it allows for a human-centered design process.
Human Views were developed for large systems. However, in this paper the opportunity to use these Views in the traditional product design process is studied.
We investigate the different artifacts generated during the product design process, and also the managed data. They are compared to the Human Views and their contents in order to see if a correlation is possible, particularly during the preliminary design phase.

Keywords: Human Factors, Human Views, product design process, design artifact, man-machine interface

1 INTRODUCTION

1-1 Difficulties

Difficulties emerge when designing socio-technical systems or man-machine interfaces.
Human Factor practitioners and Systems Engineering practitioners often find that they have communication difficulties due to differing philosophies and languages, and so a common language between designers and human factor experts is needed [1]. A design tool is also lacking, in order to ensure a common modeling approach [2].
Human Factors Integration (HFI) is a systematic process for identifying, tracking, and solving human-related issues, ensuring a balanced development of technologies and the human aspects of capability, and it is now recognized that HFI needs to be understood and practiced as an integral part of Systems Engineering [2].

Design knowledge can be implicit [3], intuitive or tacit [4]. It is obtained through experience and expertise. Explicit knowledge is expressed through methods, design models, strategies or former projects.
Design knowledge management is not very widespread in Human Engineering. Thus, in the case of man-machine interface design, the point of view of the engineer-designer, with his tacit knowledge, can be different from that of the end user, with his own understanding of the designed system.
For the moment, Human Factor analysis is mostly performed a posteriori on a prototype, on a finished product or when problems occur during system usability or maintenance. In the case of a man-machine interface manufacturer (figure 1), Human Factor experts can intervene during the capture of requirements and specifications, but they mainly guide choices on the basis of experiments, and so they need prototypes.

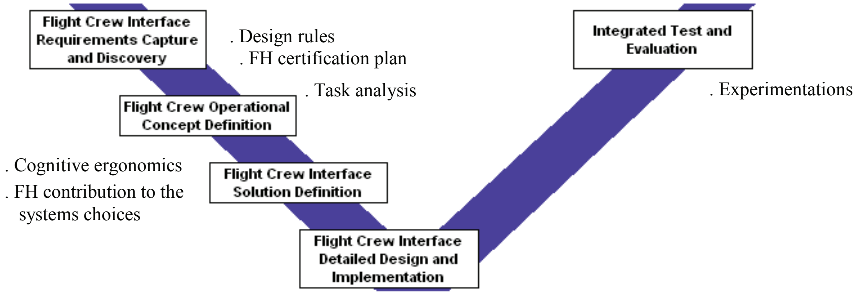


Figure 1. V design cycle of an aeronautic supplier and Human Factors experts interventions

Human Factor practitioners and Systems Engineering practitioners can find it difficult to communicate and work together because there are few methodologies and tools linking, on the one hand operational analysis, where the systems are seen as socio-technical and, on the other hand, functional analysis where systems are regarded as technical systems. Thus, people-related design decision areas need to be specified [2].

1-2 An example of actual human factor integration into design process

Nowadays in the aeronautical industry human factors are taken into account in an implicit way. To illustrate our purpose, we use the example of the head mounted display design process.

Several pilots commented on the comfort of their night vision goggles, a lack of head mobility and a restricted field of view. These points led designers to devise a system offering a compromise between mass and center of gravity on the pilot's head.

To do this, engineers modified the disposition of the intensifier tubes in order to distribute mass on each side of the head. This system has many advantages:

- From a biometrical point of view, it gave an optimizing mass and center of gravity, factors which reduce aircrew fatigue and minimize risks of long-term pathological consequences
- From an operational point of view, it gave better eye relief and an optimization of outside scene transmission through the various transparencies (windshield, HUD, standard, ballistic or laser visor, etc.). The visor projection concept allows the pilots to use any bit of information available from both aided image and direct vision of outside scene.

However, this compromise raises another problem. From a cognitive point of view, the increased separation of side-mounted intensifier tubes introduces changes in the way pilots look at things. This is different from traditional night vision goggles and some specific training is required.

To summarize, human factor studies made it possible to understand the characteristics of night vision using a head mounted display and to optimize the human habituation process and adjust the performance model (reinterpretation of visual cues, head mobility and visual strategies, reorganization of references and landmarks, etc.)

A discussion between engineers, designers and human factor specialists was necessary to design a system which corresponds to the pilots' needs in terms of performance and comfort, and which also respects all protection characteristics (in terms of physiology, biomechanics, crash resistance, etc.) as described in the standards.

In this example, this partnership made it possible to produce this system respecting the design cycle from the "Flight crew interface requirements capture and discovery" phase to the "Flight crew interface detailed design and implementation" phase (see figure 1). Currently, several human factor assessments can be carried out to improve visual and biometrical performances. However, it is often at a redesign stage and the exchanges do not take place within a formalized process.

1-3 Proposal

The challenge of Human Factors (HF) integration during the design process is to improve the usability and the reliability of the product, without affecting the functional specifications. This integration enables designers to understand what end users can and cannot do compared to the tasks they will be required to undertake once the 'system' is operational.

For a better integration of Human Factors during the early phases of the design process, we have studied the opportunity to use the emerging Human Views, which are currently being used for designing organizations and systems of systems. The Human Views concept is completely new in the aeronautical industry, but seems relevant because it allows for the analysis of human issues, in a human-centered design process. Such an approach helps to ensure that user needs are translated into requirements, and integrated throughout the product life cycle [5].
For designers to be able to appropriate these views successfully, they must be usable with information available in the first phases of the design process and applicable to whatever system is being designed.
In this paper, we study the different artifacts generated during the product design process, and identify the data managed during each design phase. They are compared to Human Views and their associated representations, in order to see if correspondence and integration are possible, in particular during the preliminary design phase. The opportunity of using Human Views in a product design process is discussed.

2 DESIGN PROCESS AND PRODUCT ARTIFACTS

A design process can be seen as a succession of states [6] or artifacts. These intermediate objects are produced and used during the design process and they are supports for the design action. They have a triple role of translation, mediation and action representation [7]. They are the result of the following 4 phases of the design process:

1. Clarification of the task: phase of information specification, in a list of requirements. The functional formalization of need; does not predict feasible solutions.
   In the approaches generally used during Functional Analysis, the human operator is considered only as an external medium of the system to be designed.
   Moreover, the "use" of the product is under-considered in the design process [5].

2. Conceptual design: phase concerning functional structure research and principle solutions, which are then combined into concepts (including definition of the concept, exploration, evaluation and selection). The "working structure" stage [8] defines functioning principles and describes global solutions in a diagrammatic form.

3. Embodiment design (phase also called "layout design", "hardware design", "shape design"): concepts are translated into architectures. This phase includes structural choices, as well as the choice of components and their relevant parameters, and the principal dimensions of the system. Some forms and materials are determined, taking into account economic criteria. This phase can be divided into three stages: divide the task into feasible modules, develop architectures of key modules (preliminary layout), and supplement higher architecture (definitive layout) [8].

   Dieter also proposes three stages for the embodiment design phase [9]:

- Product architecture: corresponds to the arrangement of physical elements which define a solution, designed to satisfy a need expressed by a functional architecture.
- Configuration design: definition of component forms and general dimensions; fitting of standard elements; assembly of the concepts, checking if the product is feasible; preliminary material selection and manufacturing processes.
- Parametric design: final tolerances, dimensions, robustness.
  This phase requires a lot of time and effort. Activities like calculating components, searching for elements in catalogues, satisfying geometrical constraints, etc., constitute an iterative and often recursive process. Moreover, key decisions are made [10]. Computer-aided systems are not used to assist the embodiment design phase, but rather the detailed design phase [11].

4. Detail design: phase of plan production and detailed specifications, installation of the manufacturing and control processes.

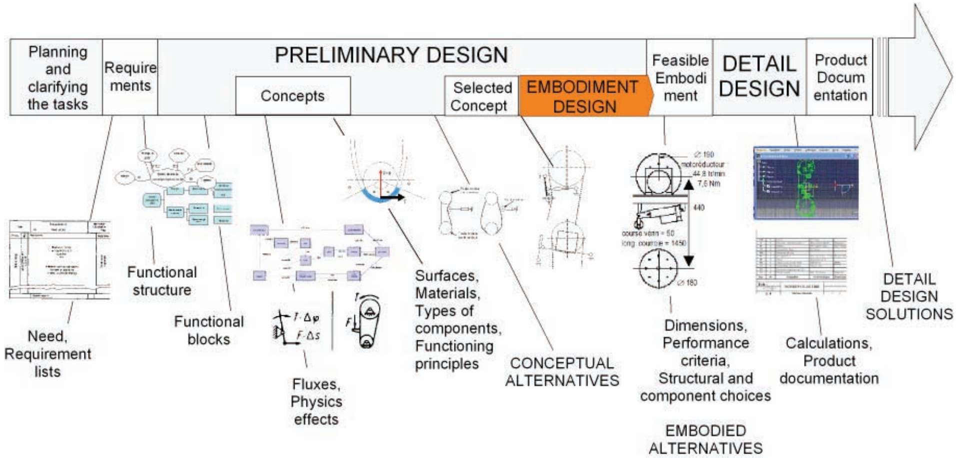
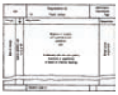
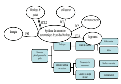
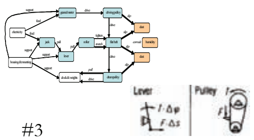
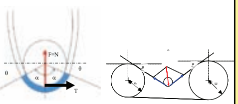
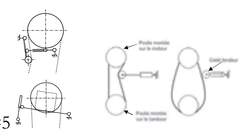
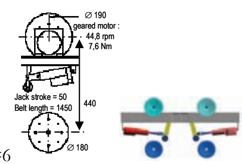
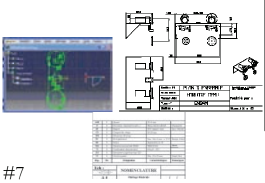


Figure 2. Positioning and evolution of artifacts and product data during each design process phase

The objective of the preliminary design phases (from need identification to detailed design) is to create a design that will correctly and completely fulfill all the requirements. The main goal is to map out how they will perform the functions specified in the requirements, within the constraints of the device, the defined interfaces, and the environment within which the device will operate. During this phase, the designer needs to maintain a products perspective and look at the future adaptation of the designed product by the end-user. Subsequently he also identifies inconsistencies, misunderstandings, and ambiguities during the preliminary design phrase.

Several product design processes were compared [12]. The different phases and milestones displayed in figure 2 are often found. This figure also shows the product artifacts generated throughout the design process. Once the evolutions of the product artifacts are identified, we specify which kind of design knowledge is generated at each step.
As the design process progresses, model abstraction decreases and representations are increasingly explicit on the physical definition of the product. Figure 3 describes the evolution of intermediate objects and the managed data. We wished to determine what information was handled at each stage of the design process, in order to then propose a relevant insertion of Human Views, so that Human Factors constraints could be taken into account at various levels.
The last column of figure 3 illustrates the choices carried out at the end of each design phase: the corresponding example of design is a disengageable power transmission system (automatic winding up system for monumental clock weights [12]).

Models	Intermediate objects	Data	Achieved choices (example: clock mechanism)
 #1	Need, requirement list, Specifications.	Requirements of geometry, cinematic, material, signals, safety, ergonomics, control, manufacturing …	Automatic system Rotation speed; load on axes
 #2	Functional interrelations, Functional structure. Organic structure.	Kind of function (criteria, level) Function assignment Kind of linking	Electric energy. Use of a transmission, of a clutch.
 #3	Actions between elements, fluxes, physical effects	Fluxes (energy, material, signal) Physical phenomena	Driving by an electric geared motor. Transmission by pulleys-belt
 #4	Surfaces, materials behaviour, types of components > Functioning principles > Concept	Geometry , surfaces, movements, materials Technologies used.	Coupling by tension of the belt. Use of a flat belt.
 #5	Conceptual alternatives > Working Structures (WS).	Input / Ouput Principle architecture.	Use of an electric actuator. 2 alternative WS.
 #6	Topology, structural and components choices. > Architecture , embodied alternatives.	Main dimensions, performances criteria, interfaces. Components arrangement Predimensioning, cost elements.	Choice of : WS, standard components. Positioning of the elements.
 #7	Product documentation	Calculations, final material choices Bill of materials. User specifications. Connections. >Detailed design	Shapes and precise dimensions of all the parts.

Models abstraction degree

Data completeness degree

Figure 3. Models and data within the product design process (from the definition of need requirements to detailed design)

The human factor is mainly taken into account during functional analysis (phases #2 and #3) where the human being is an external medium to the studied system, enabling functions to be fulfilled or through which fluxes can pass.
Human factor constraints can also be involved when ergonomic simulations can be made on a digital mock-up (detail design phase, #7).

3 HUMAN VIEWS

3-1 Emergence, development and significance of Human Views

To develop a correct design process, it is necessary to take into consideration and to describe the roles assigned to the human and his performances [1].

- The human roles to be described are: organizational structure and number of personnel required; roles and functions assigned to teams and individuals; identification of responsibility.
- The human performances to be described are: tasks and activities to be achieved, based on the functions allocated; task performance required or expected; workload; knowledge; skills; abilities required; training requirements.

According to Langevin et al., Systems Engineering methodologies do not explicitly involve the characteristics of the human operator and his abilities [5].
Using the emerging Human View concepts [2][13][14] all these issues can be taken into account.

Human Views are proposed as being complementary to the existing Architecture Frameworks Views. They fall within the views of existing Architecture Frameworks (MODAF, DODAF, NAF, etc.), between the operational level and the system level [14] (figure 4). We aim to see if it is relevant to use Human Views during the design process of fairly simple systems or mechanisms, for example a man-machine interface.

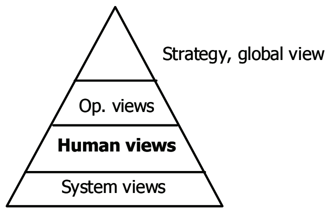


Figure 4. Fitting Human Views into the Architecture Frameworks views

The concerns of Systems Engineering architects are related to operational activities, information networks, timescales, technology trends and organizational structure, whereas the concerns of HFI practitioners are related to people capability, training and tasks.
Human Views concerns are related to operational requirements, skills and capability requirements, technological and organizational structures, human resources fulfilling functions, task/process dependencies. Human Views provide a link between architectural models and HFI concerns [2].
Handley et al. propose an overview of different Human View concepts. For these authors, the purpose of the Human View is to define the role of the human in the system and to capture the human operator activities, tasks, communications and collaborations required to accomplish mission operations and support operational requirements [15].
A synthesis of different considerations on Human View has also been made by Bruseberg et al. [14]. Here, a set of Human Views was developed by a consortium (industry, academia, UK Ministry of Defense). The challenge was to propose a cross-national consensus on human views. The Views described below result from the published handbook [13].

The seven retained Views are called HV-A to HV-G. They include resource availability (captured through HV-A), relationships & boundaries (HV-C, HV-D, HV-F), functions & activities (HV-E), behavior & dynamics (HV-G), and values & metrics (HV-B).
We describe these views and detail more particularly those which to us seem interesting for product design by giving possible examples of graphic representations for these views.

3-2 Contents

- **HV-A "Personnel availability":**

Personnel availability defines the number and characteristics of required personnel, forecasts, training processes and career issues.

- **HV-B "Human performance criteria and metrics":**

This View provides a repository for human-related priorities, values and performance criteria, from high-level quality criteria to metrics that are specified with measurable targets.
Sub Views may include Health Hazards (the design features and operating characteristics of a system that can create significant risks of illness, injury, or death), Human Characteristics (considers the

physical characteristics of an operator and movement capabilities and limitations of that operator under various operating conditions).

Figure 5 breaks down high-level safety objectives into measurable metrics for evaluating cockpit interfaces. This involves specifying states and behaviors to be avoided. It shows the measurements that need to be combined to provide a complete set of evidence for compliance with safety requirements [13].

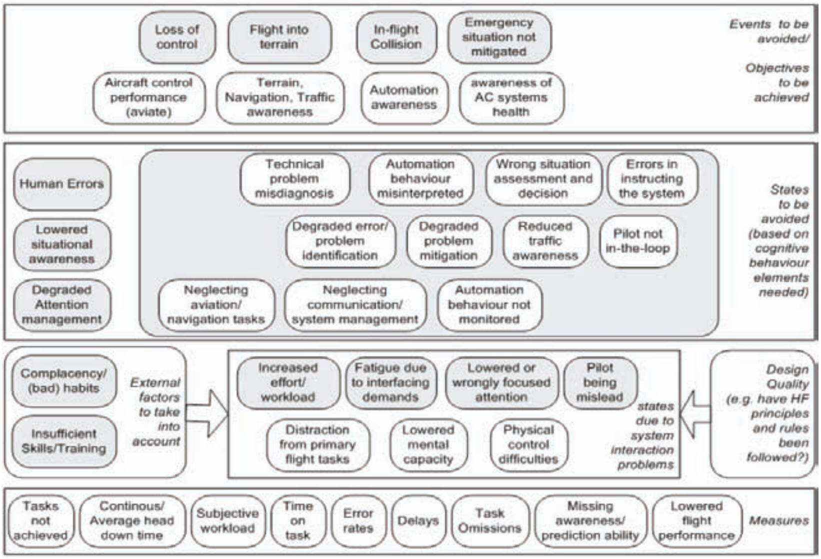


Figure 5. Values, behavioral objectives, and metrics for assessing cockpit interfaces

- **HV-C "Human interaction structure":**

The Human interaction structure captures the structure of human role networks supported by technology and the need for frequent (or critical) information exchanges. The locations of human operators are also defined.

Figure 6 shows the exchanges and operational activities carried out with Controller Pilot Data Link Communications (CPDLC). CPDLC is a communication system between Air Traffic Control (ATC) and aircraft, where information exchange is in text form.
This view describes a specific operational concept: data are entered manually into the Flight Management System (FMS). Three sequences of actions follow one another:
- The "pilot non flying" (PNF) receives the message by CPDLC and confirms reception;
- The PNF informs the "pilot flying" (PF) who makes a decision and informs the PNF;
- The PF then returns the order into the FMS.

The interest of this View is that it represents man-machine exchanges at the design level, without a priori on the future material system. It is a reflection base for questioning the operational concept.

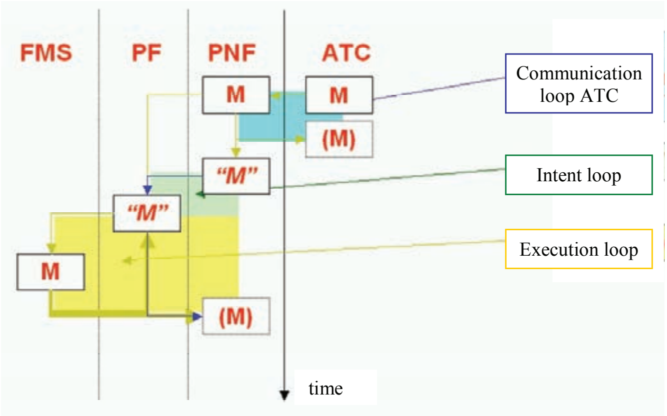


Figure 6. CPDLC with manual FMS entry

- **HV-D "Organization and procedures":**

The Organization and procedures View defines organizational units and relationships.

- **HV-E "Human functions and tasks":**

The Human functions and tasks View specifies human functions and activities in relation to system definitions. HV-E describes the functions that have been assigned to humans in a system over its entire life cycle. Thus the allocation of functions between humans and machines is determined. It also considers how the functions are broken down into tasks.

In the example below, a high level task is decomposed into sub-tasks. The succession of sub-tasks is depicted on a graph with a time axis (horizontal) and a decomposition axis (vertical). Figure 7 shows the sequence of tasks required for a return to a normal situation in the case of a fuel imbalance for a civil aircraft, with the formalism of CTTE [16].

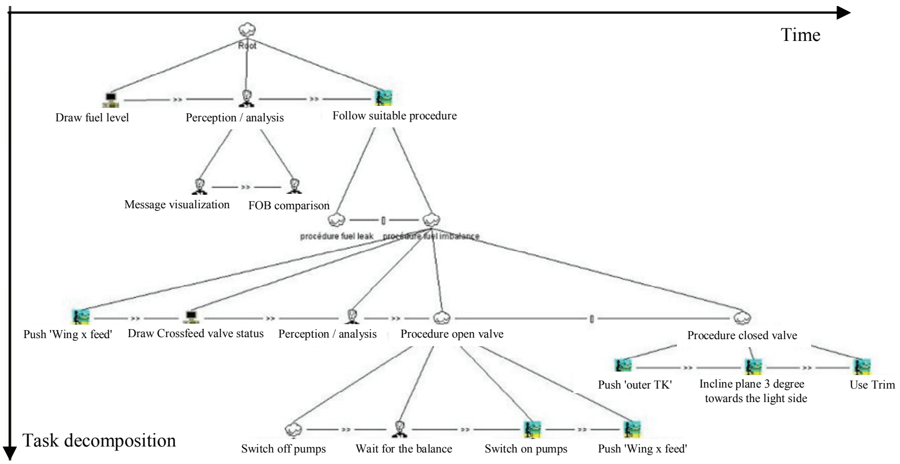


Figure 7. View of the fuel system, situation "fuel imbalance"

It is possible to allocate some characteristics such as time or resources used for each task, and thus to check the coherence of the operational scenario. Indeed, this chart shows:

- Abstract tasks, with a high level of abstraction and which will be broken down into sub-tasks of various types;
- Task systems, which will be carried out by the system;

- Interaction tasks, which specify interactions between the user and the system through input devices (buttons, trackball, etc.);
- User tasks, which will be carried out by the operator.

One interesting feature of this View is that it defines the sequence of tasks necessary to carry out an operational activity. It defines the way the activity has to be carried out.
It then makes it possible to question the allocation of the tasks to the various human operators or to the system. With this kind of analysis, designers can assimilate information about the interfaces (useful for the realization of the studied activity), and also provide justification for the allowance of functions between man and machine.
Finally, the temporal aspect is also interesting because successions of tasks and recursions cannot be described using Functional Analysis tools. Indeed, using FAST (Functional Analysis Systems Technique) for example, functional decomposition is possible but temporal aspects or task assignment cannot be described.

- **HV-F "Roles and competencies":**

The Roles and competencies View specifies personnel ability requirements (skills, knowledge, attributes, etc.) and task-role-competency dependencies.

- **HV-G "Dynamic drivers of human behavior":**

The Dynamic drivers of human behavior View creates predictions for dynamic aspects of human behavior for individuals and teams, such as the workload.

We have thus highlighted the significance of Human Views in a product design context with some examples of graphic concretization of some Human Views. The Human View Handbook for MODAF [13] also gives a set of possible visualizations and charts. These graphic tools are a way to bring Human Factors experts and Systems Engineering practitioners or design engineers together: they facilitate and simplify exchanges between them by concretizing HF issues.

3-3 Integration into the Architecture Framework and the preliminary product design process

Decisions taken at the preliminary design stage influence up to 70% of the life-cycle cost [17]. Methodologies and tools for decision support in preliminary design have been proposed [18][19], but human factors are not currently incorporated into this phase.
Using the works of Bruseberg et al. [2][13][14] and considering the information contained in each Human View, these views can be positioned in relation to the design elements of the Architecture Framework (white squares on figure 8), along an axis defining the degree of data abstraction (previously defined in figure 3). Elements which are in close proximity have a closer relationship (figure 8).

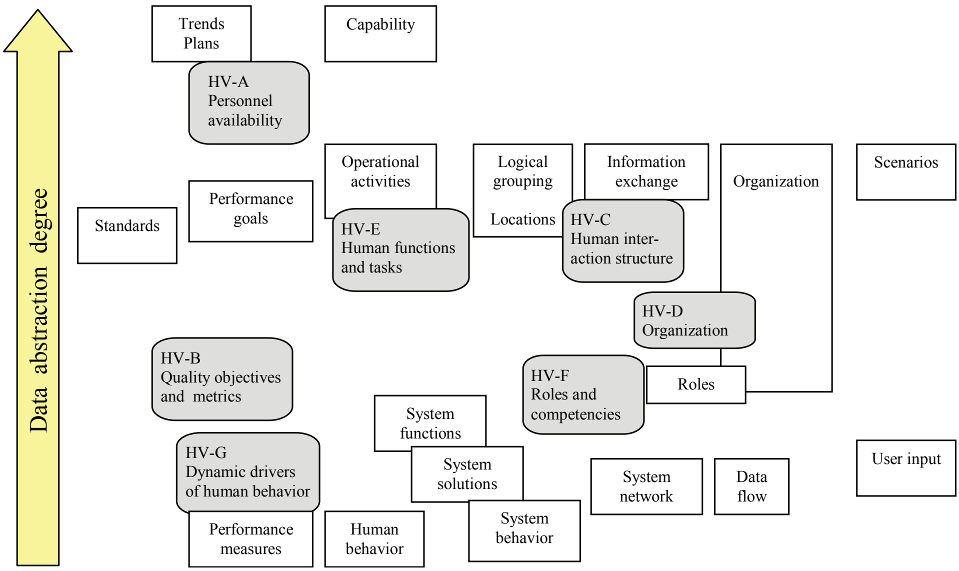


Figure 8. Human Views location, from abstract to concrete concepts

Finally, a relationship can be made between, on the one hand, evolving knowledge during the early phases of the design process and the produced artifacts discussed in part 2, and on the other hand, the contents of the Human Views and their degree of abstraction. Figure 9 specifies the suitable level of integration of Human Views into the steps of the design process described in figure 2. By considering handled information, the majority of the Views can be used and processed during the preliminary design phase (from the requirements to the embodied alternatives). HV-G is, on the contrary, at the boundary between the preliminary and detail design phases, because it may require simulation tools or experiments. An advanced definition of the product is therefore required.

For the example of a flight crew interface (figure 1), the characteristics of the personnel and training required are known in the first phase of design process, with the requirements and specifications. This corresponds to HV-A.

The operational scenario defines the roles, the successive functions, the relations between crew members and also with external operators (like ATC, see figure 6). These issues are described in HV-C. At this stage of the design process, functional analysis is carried out in order to translate customer requirements into functional requirements. This process can be completed with HV-E, defining the allocation of functions and their succession (in accordance with operational scenario).

HV-D can help to define the whole organization when the operational concept is defined.

Finally, the physical and mental limitations of crew members must be included when defining the architecture and components of the system. In this case, HV-B and HV-F are relevant.

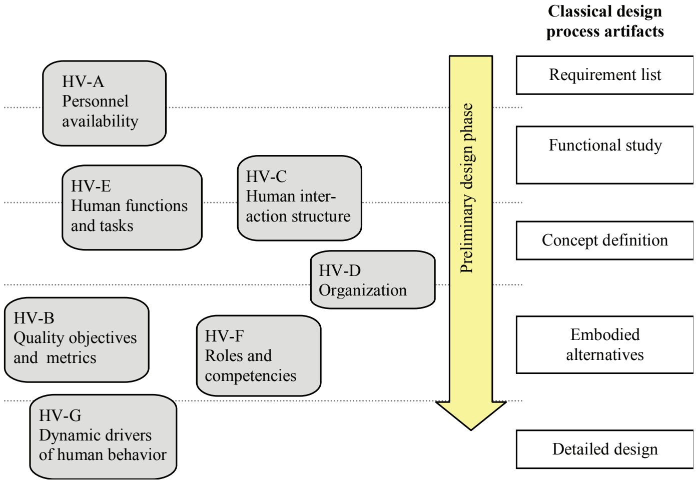


Figure 9. Positioning Human Views compared to traditional design process artifacts

CONCLUSION

Although they can be applied to large systems, Human Views enable designers to understand the human role within systems. Moreover, these views are key elements for linking the engineering and human factor communities [15].

Using Human Views, it is possible to list every constraint and specification related to the Human Factors, and also to formalize operational concepts, and describe successions of tasks and task allocation.

A link between Human Views and traditional design artifacts has been proposed here. This is a first step towards integrating these Views into the preliminary design phase of small devices. We are currently using these views in the context of the flight deck element design.

The use of graphic representations gives system engineers a better understanding of Human Factor issues, and leads to a better incorporation of Human Views into the product design process. We aim to study the links between the diagrams and graphs used in Functional Analysis and those proposed in the context of Human Views in order to suggest complementary elements for the tools normally used by designers.

REFERENCES

[1] Baker K., Pogue C., Pagotto J., and Greenley M. Human Views: Addressing the human element of capability-based decisions. In TTCP HIS Symposium, DSTO, Australia, 2006.

[2] Bruseberg A. Human Views for MODAF. In Integrated EA Conference 2008, London, Feb 2008.

[3] Reymen I. Improving design processes though structured reflexion – A domain-independent approach, Ph.D Thesis, 2001 (Eindhoven, The Netherlands).

[4] Hubka V., Eder E. Design Science, 2001 (Edited for the web by Filippo A. Salustri).

[5] Langevin, S., Joseph, B., Brenklé, J., Straussberger, S., Guiost, B., Lantes, J.-Y., Boy, G. and N'Kaoua, B. Human-centered design methodology: an example of application with UAVs mission. In Proceedings of the first conference on Humans Operating Unmanned Systems, HUMOUS'08, Brest, France, 2008.

[6] Ullman D.G. The mechanical design process, 3rd edition, 2003 (McGraw-Hill Higher Education, New York).

[7] Jeantet A. Les objets intermédiaires dans la conception. Eléments pour une sociologie des processus de conception. Sociologie du travail, 1998, n°3.

[8] Pahl G. and Beitz W. Engineering design; A systematic approach – 2nd edition, 1996 (Springer-Verlag, London).

[9] Dieter G.E. Engineering design - A materials and processing approach, 3rd ed., 2000 (Mc Graw-

Hill International Editions).
[10] Hicks B.J., Culley S.J. An integrated modeling environment for the embodiment of mechanical systems. Computer-Aided Design, 2002, n°34.
[11] Popma M.G.R. Development of a Generic Object Builder, with focus on support of What-If Synthesis, MSc Thesis, 1999 (University of Twente, Enschede).
[12] Scaravetti D. Formulation préalable d'un problème de conception, pour l'aide à la décision en conception préliminaire, Ph.D thesis, 2004 (ENSAM Bordeaux, France).
[13] Bruseberg A., Fletcher G. The Human View Handbook for MODAF, 2008 (Systems Engineering & Assessment Ltd. on behalf of the MoD HFI DTC).
[14] Bruseberg A., Lintern G. Human Factors Integration for MODAF: Needs and Solution Approaches. In INCOSE 2007 Symposium, San Diego, June 2007.
[15] Handley H.A.H., Smillie R.J. Architecture framework human view: The NATO approach. Systems Engineering, 2008, Volume 11 Issue 2.
[16] Mori G., Paterno F. and Santoro C. CTTE: Support for Developing and Analyzing Task Models for Interactive System Design, IEEE Transactions On Software Engineering, 2002, Vol. 28 n° 8
[17] Berliner C.and Brimson J.A. Cost Management for Today's Advanced Manufacturing: The CAM-I Conceptual Design, 1988 (Harvard Business School Press).
[18] Scaravetti D. and Sebastian P. Generation of design spaces and trade off between feasible embodiments : the bootstrap design problem. In International Conference on Engineering Design, ICED 07, Paris, September 2007, Proceedings CD ROM, ISBN: 1-904670-02-4.
[19] Scaravetti D. and Sebastian P. Design space exploration in embodiment design: an application to the design of aircraft air conditioners. International Journal of Product Development – Accepted March 2008.