DESIGN OF A DISTRIBUTED HUMAN FACTORS LABORATORY FOR FUTURE AIR SYSTEMS

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Abstract

This paper presents a rationale for structuring a distributed human factors laboratory for future air systems. The distributed herein refers to two aspects: content and geographic. As for content, the laboratory is structured in two levels, namely, individual, and team. As for geographic, the laboratory infrastructure is distributed in three physically separate facilities, namely, Department of Computer and Information Science (IDA) and Department of Management and Engineering (IEI) from Linköping University – Sweden and the Competence Center in Manufacturing from the Aeronautics Institute of Technology (ITA) – Brazil.

1 Background

The current aviation system is considered to be a safe industry as safety records have been constantly improving over the last decades. The accident rate per million departures appears to be reaching an asymptote but with the increase of the worldwide fleet and consequential increase in annual departures [1], it is necessary to further increase the levels of safety, otherwise the absolute number of accidents (and consequently the number of fatalities) might increase.

Based upon this scenario, it is necessary to find new ways for improving aviation safety standards. According to a research carried out by the Flight Safety Foundation [2], approximately 80% of the aeronautical accidents can be attributed to factors that emerge from the human factors domain such as poor human-machine interface, human-automation issues and so forth. This figure turns the studies about human factors aspects in the design, operation and maintenance of aircrafts into a strategic matter for reducing the aviation accident rates.

Human factors have been studied for a long time by the aviation sector [3], [4]. Nevertheless, they remain as the major responsible for airborne accidents. This is not surprising as the aircraft system is designed operated and maintained by humans and “it is impossible to eliminate human error, all you can do is to change its place or nature." [5]. To consider human factors aspects only in the final phases of the development of aviation systems will always result in products that do not meet the performance, safety and contentment requirements. Significant savings in human and finance resources might be obtained with the incorporation of human factors aspects into the preliminary stages of the products and complex systems development processes.

Hence, the design and commission of a human factors laboratory for future air systems may provide the industrial and academic community with critical infrastructure to fulfil the demand for human factors studies identified above and providing and ideal environment to identify and model the human behaviour in simulated operations. The results acquired will be translated into well-elaborated requirements for the design of aeronautical products and processes which might raise the safety standards, following the global tendency, as described in [6].

1.1 Purpose

This paper reports ongoing work concerning the development of a joint research environment for Human Factors studies of future aviation systems (HF-FAS). The research environment will consist of a number of laboratory settings in Sweden and Brazil, involving both academic settings such as universities and research institutes as well as industry. The intention is to create a research and development environment where a wide range of studies can be conducted, from basic research on human performance in complex settings to applied studies concerning specific aspects of the implementation of new human-machine interface components. Further, several different simulation environments will be used with varying degrees of fidelity depending on the needs and aims of the concerned studies.

2 Project outline and aims

This project has been supported by funding from VINNOVA, the Swedish Innovation Agency. As stated above, the project revolves around a set of partners that jointly aims to create a distributed, but interconnected, set of competences and physical resources (facilities, equipment) that can be used to perform a wide range of studies. The HF-FAS thus takes on a holistic stance towards Human Factors research by pooling a number of different resources under one umbrella. The aim is to be able to offer a variety of research tools and competences that can be utilized to approach the complexity of concurrent aviation systems. This approach assumes that is necessary to move beyond the individual pilot-aircraft unit of analysis in order to be able to perform research on constellations of humans, such as teams and the technologies they use, or even human-autonomous teams consisting of both humans and artificial agents [7]. This demands a repertoire of theories, methods and tools that can be used in a complementary way. For example, performing a study of how a pilot in a modern fighter collaborates with a semi-autonomous Unmanned Arial Vehicle (UAV) while interacting with ground control demands methods and tools that can collect data about both how pilot cognition is affected and how well the team (pilot, UAV, and ground control personnel) are performing. The holistic approach depicted in **Fig. 1** presents a snapshot of the competences and tools that the proposed research environment can offer to support future studies.

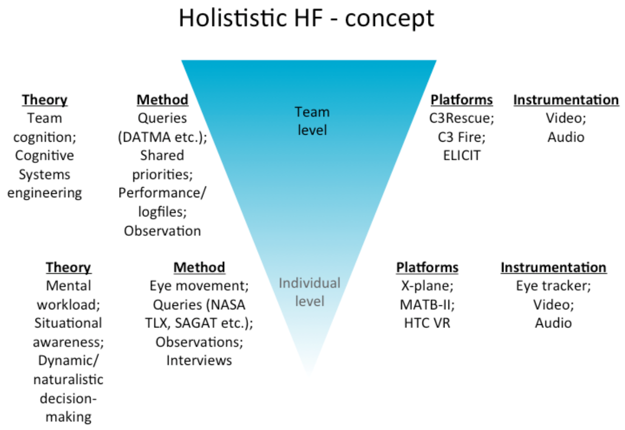

Fig. 1. The holistic HF-FAS approach.

The left part of Fig. 1 provides examples of theories and assessment methods that are relevant for studies of future air systems on both team and individual level, such as Team Cognition [8], Cognitive Systems Engineering [9], Mental Workload [10], Situational awareness [11], and decision making. The right part exemplifies various simulation platforms suitable for performing studies on the respective levels, or when combining levels. Lastly, to the far right, examples of instrumentation that can be used for collecting data are presented. Some of these platforms and instruments, as well as their physical location, are described below.

2.1 Consortia partners

The project is conducted as a joint effort of the Department of Computer and Information Science (IDA), Department of Management and Engineering (IEI) of Linköping University, RISE SICS East research institute, Saab Aeronautics AB, Sweden, and Instituto Tecnológico de Aeronáutica (ITA) in Brazil. Project management is situated at Saab Aeronautics, while facilities are located at Linköping University and ITA. RISE SICS East provide methodological support as well as software to some of the included simulations.

2.2 Facilities and equipment

The *Human Factors laboratory* facilities are distributed between Sweden and Brazil but share some common features, e.g. XPlane™ flight simulator platform, which allows for parallel studies and sharing of experimental configurations experiences.

The facilities *at* Linköping University, including different personal computer-based aviation training devices (PCATD) (Fig. 8), plus several in-house developed software's e.g. for decision support or situation awareness. The department for Computer and Information Science host researchers specialized in interface design and assessment of team cognition aspects as well as mental workload measures while the department of Management and Engineering specializes in modelling of aircraft system components and physical environments.

The Instituto Tecnológico de Aeronáutica in Brazil contributes to the lab with its *Robot Based Flight Simulator* (Fig. 10) and its well-established connections to aeronautical industry and a strong position in the field of robotics.

The resources in terms of equipment and available software's are listed in Table 1. Some of the resources are subsequent described in detail.

Table 1: Resources of the HF-FAS joint research facilities.

RESOURCE		**IDA -LiU**	**IEI-LiU**	**HumAer-ITA**
1.1	XPlane™ flight simulator	X	X	X
1.2	MATB-II	X	X	X
1.3	C3 Fire	X		
1.4	C3 Rescue	X		
1.5	Distributed user interfaces (DUIs).	X		
1.6	Cockpit and human thermoregulatory models		X	
1.7	Desktop flight & engine simulator		X	
1.8	2x Flight simulator	X		
1.9	Robot based flight simulator			X

Item 1.1 in Table 1. is XPlane™ (Fig. 2), which is a flight simulator mainly developed for gaming but with physical as well as visual simulation qualities sufficient for academic research. In addition, XPlane™ offers with via the user-datagram protocol (UDP), the possibility to access flight-simulation data in real time which can be used both as input for external software/models or to investigate reactions and behaviors of the pilot. A new feature in XPlane™ 11 is a native Virtual Reality (VR) feature, which allows a high level of pilot immersion if required. X-Plane™ also offers more than a dozen different types of aircraft and sceneries spanning the aircraft handling and flight task complexity.

Fig. 2. A typical XPlane™ interface as seen by the pilot

Item 1.2 MATB-II is a computer program that simulates tasks in cockpits in order to evaluate operator performance and workload [12]. The original MATB has been modified to MATB-II and the major changes include adaption to later versions of Windows™ operating systems and new graphical interfaces

[13]. There are four different tasks presented to the user: System Monitoring, Tracking, Communications, and Resource Management. The tasks are displayed simultaneously in a computer screen as shown in Fig. 3.

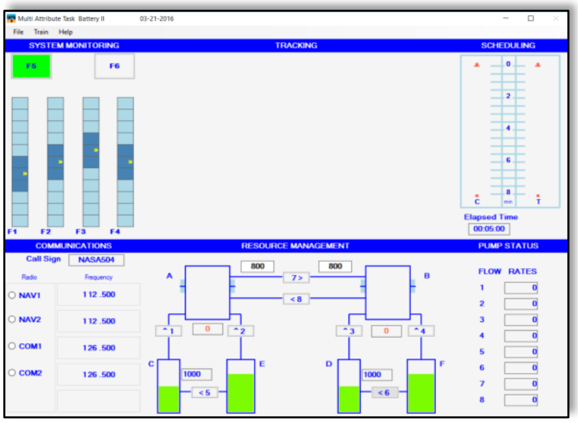

Fig. 3. A typical screenshot from MATB-II.

The MATB-II program is mainly developed to simulate tasks that correspond to a pilot's mental workload during flight, but can be used for other purposes such as measuring general multitasking capacity [14], [15]. Further, it does not demand piloting skills, allowing for studies using non-expert participants, which can be useful in basic research.

Item 1.3 C3Fire is a micro-world [16] (scaled-world) [17] that provides an environment that allows controlled studies of collaborative decision-making in a dynamic environment [18], [19]. The domain, which is forest fire fighting (see Fig. 4), is of subsidiary interest and has been chosen because it creates a good dynamic environment for participants in a research study.

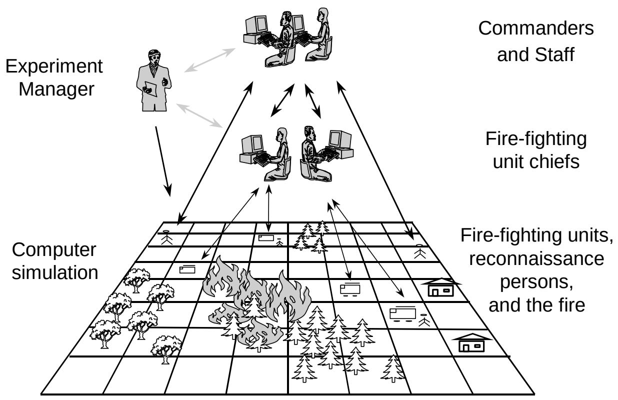

Fig. 4. Typical organisation of a C3Fire experiment.

It is possible to view the generated session as a simplified version of the work tasks and the division of labour conducted within a team, or a set of teams, during an emergency task, a company business task, or a military task.

The C3Fire system is highly configurable which makes it possible for the researcher to configure the system to meet their research goals [19]. The players' organization and communication structures can be set up as wanted depending on the research goal. The user interfaces and communication tools can also be individual set-up for all players. When the collaboration is mediated via C3Fire's communication systems, the session design will affect the collaborative process. This means that the researcher may have explicit control over some aspects of collaboration. The size of the organization can be freely configured from one up to around twenty players depending on the cognitive tasks and the speed of the used computer systems.

Item 1.4: C3 Rescue is a parallel product in the C3 family that incorporates a higher degree of configurability and realism than the C3Fire microworld. In C3Rescue, simulation participants can perform emergency response tasks at command level and perform team tasks as co-operation and coordination of actions and plans. The training manager or researchers can select resources and some important characteristics from the real world and created a well-controlled simulation that creates the wanted decision and teamwork situation for the players in the simulation. The system generates a task environment that has the desired resources and geography, and generates a complex, dynamic and opaque characteristic, similar to the cognitive tasks that people normally encounter in real-life systems. The selected geography area is imported as Open Street Map data and can freely be downloaded from the open street map site (www.openstreetmap.org).
The open street map contains information about roads, houses and the vegetation in the selected area. C3Rescue can be used in teamwork research and generates a task environment in which a group of people co-operate to perform an emergency response task at command and

control level. It is typically used to study resource management, planning and usage off different decision support tools. The goal of the system is to make the environment generate a good environment for study of a team collaboration tasks (see Fig. 5).

Fig. 5. The C3 Rescue interface as seen by a simulation participant.

Item 1.5: Distributed User Interface (DUIs) is an enabling technology that might be used to implement a safe and speedy integration among the HF-FAS simulation resources. The solution allows for distributed user interfaces (DUIs). These are user interfaces where parts or the whole interface can be spread across multiple devices, screens and/or users. The DUIs provide new degrees of freedom to the distribution of systems, in particular runtime reorganization and adaption to new environments with varying amounts of devices. DUIs introduce net-aware user interface components that can be moved across the network according to specification set up by programmers or by choices made by users in multi-device settings. In essence, DUIs propose a natural continuation from single-device GUI systems to multi-device DUI systems. Fig. 6 shows a simple example of a DUI application where a user interface for a calculator is distributed over two devices. During runtime as the second device is connected to the application, the keypads are moved from device 1 to device 2.

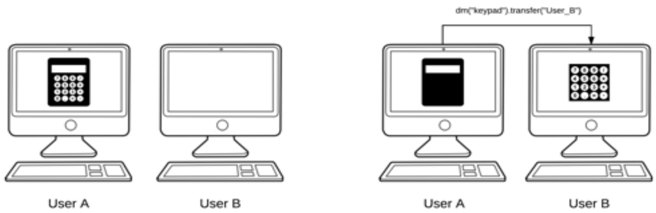

Fig. 6. A simple example where a calculator is partially distributed between two users.

Item 1.6: The cockpit and human thermoregulatory model are Matlab/Simulink™ based models developed to assess the thermal conditions inside an aircraft and its physical, mental as well as thermal comfort effects on pilots and aircrews. The model consists of two major parts: the human thermoregulatory model, Fig. 7 a), and the cockpit climate model, Fig. 7 b). The human model, which is based on models presented by Fiala [21] and Westin [22], is built up of one spherical and 15 cylindrical (one-dimensional) segments representing different parts of the body. The model simulates the heat transfer through each body part applying a finite difference approximation. In addition, the model can actively control a body temperature by vasoconstriction, vasodilation, sweating, shivering, and respiration. The passive system in the model simulates the heat exchange between the pilot and the cockpit and links thereby the human and cockpit model. The cockpit model combines lumped systems with finite difference which model the basic heat exchange mechanisms (convection, conduction, and radiation) within the cockpit and the cockpits external surrounding. Both, the cockpit model and the human thermoregulatory model, can be linked, by utilizing the Functional Mock-up Interface (FMI), separately or together additionally to other models e.g. an Environmental Control System, Fig. 7 c), providing valuable inputs to the simulation. In this way it is possible to combine models as required, connect models implemented in different program languages and/or providing the user with a more heliocentric picture of the simulated thermal situation.

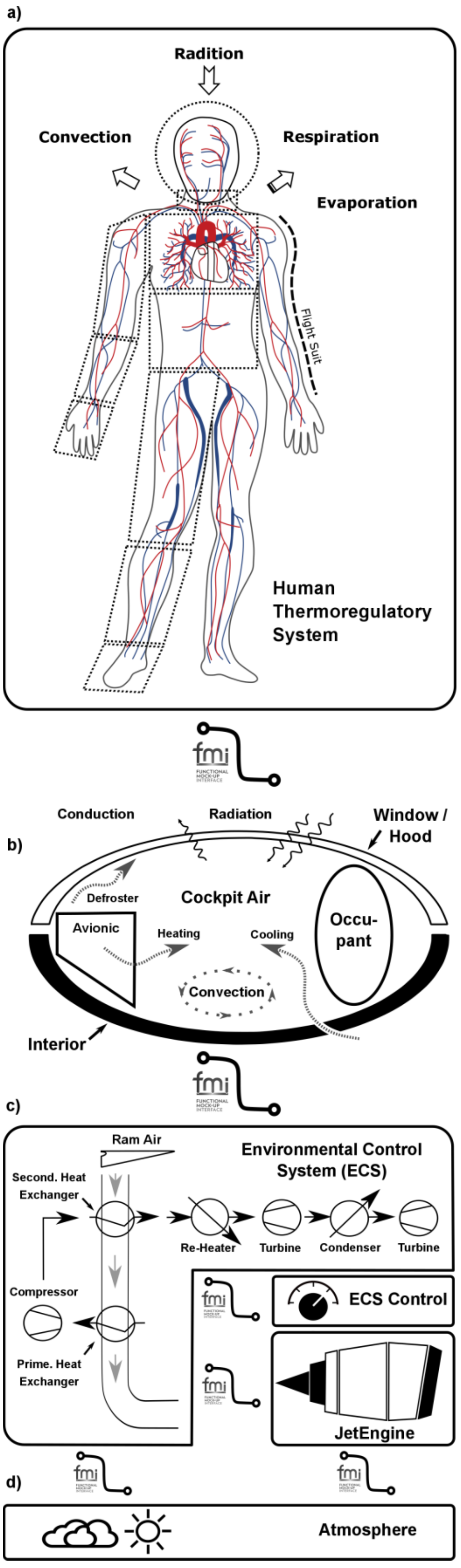

Fig. 7. An overview of the thermoregulatory model

Item 1.8: Dual Flight Simulator set-up is currently hosted by the Human Factors Laboratory at the Department of Computer and Information Science, Linköping University. It consists of two flight stations based on the highly configurable Volair Sim Flight™ cockpits equipped with the Thrustmaster Hotas Warthog™ flightstick and throttle. Up to three curved Samsung 32 inch screens can be attached to the cockpit rig (see Fig. 8). The system is connected to standard computers running the XPlane™ flight simulator software. All computers are connected to the local network as well as the world wide web, meaning that it is possible to evaluate team aspects with for example two pilots jointly undertaking a flight mission.

Fig. 8. One of the HF-lab flight simulators

Item 1.9: Robot Based Flight Simulator In Brazil, the flight simulator SIVOR (*SImulador de VOo de base Robótica*, robotic flight simulator) at ITA is the first using a anthropomorphic robot as a mobile platform for a flight simulator. The project started in 2015 and is organized into two modules, in order to support the parallel development of control algorithms and hardware equipment. The first module includes building a simple prototype of a robotic simulator. It should support the development of the motion control system and the analysis of robot dynamics and workspace when combined with washout filter. In this version of the simulator, the motion platform is a KUKA robot KR500-2, with a payload of 500 kg and a maximum reach of 2826 mm. The inceptors are the Saitek X52 Pro Flight System, composed of throttle, sidestick and rudder pedals. The vision system is a full HD LCD TV of 50". The image is provided by XPlane™ 10. Additionally, a black out coverture isolates the pilot from the external environment. The simulator is configured as the Phenom 300 executive jet, produced by EMBRAER. The classical washout filter has been implemented in LabView™ and tuned based on the opinion of 3 professional pilots. Communication between the washout filter and the robot controller is performed using RSI interface, provided by the robot manufacturer. Fig. 9 illustrates the first SIVOR prototype.

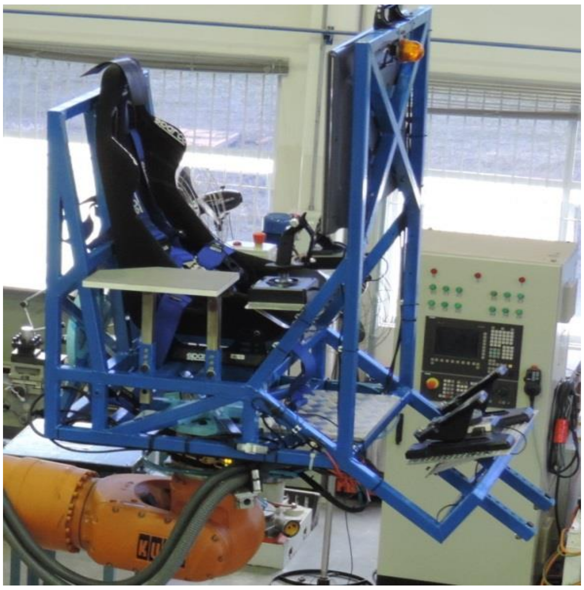

Fig. 9. The first SIVOR prototype.

The second module of the robot based flight simulator targets at a high fidelity simulator, with flexibility to be configured to different aircrafts. The motion platform is the KUKA KR 1000 Titan, installed in a 10 m rail. This simulator is currently under construction and is illustrated in Fig. 10.

The facilities and resources presented in this section has shown a variety of possibilities for conducting studies ranging from basic research to evaluations of systems near productions, or even modifications of existing aviation systems.

While simple desk-top simulations like MATB-II can be used to study individual aspects of workload and multi-tasking with non-professional participants, high-fidelity robotic simulators like the ITA SIVOR can be used to evaluate for example alterations to actual aircraft interfaces with real pilots in a highly realistic setting. Further, the contributing partners also provide a high degree of expertise in the area of human factors in aviation.

Fig. 10. The high fidelity SIVOR flight simulator.

4 Discussion and Conclusions

The research integration effort described in this paper points to the possibilities that arise when combining the expertise and capabilities available in the partner organizations (LiU/ITA/SAAB/RISE). Each organization contributes with a number of senior researchers and engineers, all working with different aspects of HF. Each organization also contributes with unique research platforms and tools, as presented above. By combining these resources, research efforts can be applied in a holistic way, allowing multiple theories and methods to evaluate from several perspectives simultaneously.

Furthermore, this approach allows for research to be applied on a range of levels of technological readiness (TRL). The LiU and RISE competence and platforms can be utilized for conceptual and early development efforts as well as evaluations of various designs, the ITA facilities can be applied for studying and developing at more mature concepts, and SAAB have the competence and ability to turn concepts into products.

Besides the software-hardware integration issues, perhaps most important outcome is the prospect of future joint resource projects. The consortium holds the potential to contribute to the area of future air systems by identifying possible areas of research where the participating organizations can jointly apply for funding and work together.

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