Development of the Human Performance Envelope Concept for Cockpit HMI Design

Ilenia Graziani, Bruno Berberian, Barry Kirwan, Patrick Le Blaye, Linda Napoletano, Laurence Rognin, Sara Silvagni

Development of the Human Performance Envelope Concept for Cockpit HMI Design

Ilenia Graziani

Deep Blue Srl, Piazza Buenos Aires 20, Rome, 00198, Italy

ilenia.graziani@gmail.com

Bruno Berberian

ONERA Systems Control and Flight Dynamics department, BA 701, Salon de Provence, 13661, France

bruno.berberian@onera.fr

Barry Kirwan

EUROCONTROL Experimental Centre, Centre de Bois des Bordes, BP 15, 91222, Brétigny/Orge, Cedex, France

barry.kirwan@eurocontrol.int

Patrick Le Blaye

ONERA Systems Control and Flight Dynamics department, BA 701, Salon de Provence, 13661, France

patrick.le_blaye@onera.fr

Linda Napoletano

Deep Blue Srl, Piazza Buenos Aires 20, Rome, 00198, Italy

linda.napoletano@dblue.it

Laurence Rognin

EUROCONTROL Experimental Centre, Centre de Bois des Bordes, BP 15, 91222, Brétigny/Orge, Cedex, France

laurence.rognin@eurocontrol.int

Sara Silvagni

Deep Blue Srl, Piazza Buenos Aires 20, Rome, 00198, Italy

sara.silvagni@dblue.it

KEYWORDS

Human Performance Envelope (HPE), HMI design, automation, Human Factors, pilots, cockpit

ABSTRACT

In this paper, we introduce a new approach based on the definition and delimitation of the Human Performance Envelope (HPE) concept for cockpit operations and design. Instead of considering one or two single human factors, the HPE investigates a set of interdependent factors, working alone or in combination, leading to a performance decrement that could affect safety. The HPE approach is needed to improve the HMI design to develop innovative solutions and adaptive automations, which can provide effective recovery measures, if the human performance is compromised.

Development of the Human Performance Envelope Concept for Cockpit HMI Design

Ilenia Graziani[1], Bruno Berberian[2], Barry Kirwan[3], Patrick Le Blaye[2], Linda Napoletano[1], Laurence Rognin[3], Sara Silvagni[1]
[1]Deep Blue Srl, Piazza Buenos Aires 20, Rome, 00198, Italy
[2]ONERA Systems Control and Flight Dynamics department, BA 701, Salon de Provence, 13661, France
[3]EUROCONTROL, Experimental Centre, Centre de Bois des Bordes, BP 15, 91222, Brétigny/Orge Cedex, France

ABSTRACT
In this paper, we introduce a new approach based on the definition and delimitation of the Human Performance Envelope (HPE) concept for cockpit operations and design. Instead of considering one or two single human factors, the HPE investigates a set of interdependent factors, working alone or in combination, leading to a performance decrement that could affect safety. The HPE approach is needed to improve the HMI design to develop innovative solutions and adaptive automations, which can provide effective recovery measures, if the human performance is compromised.

Keywords
Human Performance Envelope (HPE), HMI design, automation, Human Factors, pilots, cockpit

INTRODUCTION
With the development of more and more complex systems in aviation, and in particular in the cockpit, the flight crew has to cope with an unavoidable increase of cognitive demand. Aviation accidents in fact, inevitably involve the pilot and are usually associated to human errors. Regarding the potential dramatic consequences of poor pilot performance, identifying the different causes of "pilot error" has become a first concern.

During the last decades, the human factors research focused on this issue trying to prevent or recover the degradation of performance that could bring the pilot out of the flight safety limits. However, previous human performance and error research have focused on the effects of a single factor on performance (e.g., Svensson et al.; Loft et al.; [38], [27]). In contrast, few is known about both the potential interaction between different factors and the availability of technical resources, e.g., HMI and automation support, enabling pilots to be in a situation where they have sufficient cognitive resources to perform efficiently their tasks.

HCI-Aero 2010, November 3-5, 2010, Cape Canaveral, Florida, USA.

With this respect, in this paper we present a new approach to progress both on the definition and delimitation of the concept of Human Performance Envelope (HPE) for cockpit operations and the design of solutions to extend this Envelope. To achieve these goals, a three steps approach is introduced. Step 1 consists in the identification of the HPE components affecting the performance and their measures (behavioural and physiological) through literature review. Step 2 identifies the potential interaction between the HPE components through experimentations. Finally, Step 3 concerns the design and the evaluation of innovative solutions to increase HPE. Particularly, some examples of mitigation and recovery measures are introduced to take back the crew's performance to the centre of the envelope, into the "tolerance zone". In the rest of this paper, we will consider each of these steps in turn.

FROM HPE CONCEPT TO HPE FACTORS

HPE definition
The metaphor underpinning the HPE concept suggests that when studying human performance and recovery, we need to consider a full range of factors that can affect performance, and be able to detect when one or more is moving out of 'tolerance'. The performance envelope is defined by the relevant factors and associated scales, which contains a region where performance will be tolerable, and where it starts to become hazardous. This set of related factors affects pilots' performance and play a role in the achievement of the intended goals. If these factors are studied borrowing the envelope metaphor, it can be possible to determine the starting point in which significant performance degradation could affect safety.

A wide review of aviation human factors studies and cognitive science literature resulted in the identification of the HPE components affecting the performance and their interdependencies. Starting from precedent studies on air traffic controllers and incident reports analysis [11]-[13], a series of nine factors (and their relationships) were identified: Workload, Stress, Situations Awareness, Fatigue, Attention, Vigilance, Teamwork, Communication, and Trust.

Depending on the value of each factor, in a specific situation, the resulting HPE could evolve from fully acceptable (e.g., guaranteeing a nominal set of cognitive resources available to operations) to not acceptable (e.g., inducing an error-prone cognitive and physical environment). However, even if a single factor could have a non-acceptable value (e.g., low vigilance), it is possible that the interaction with the others could enable compensations, and consequently overall acceptability of HPE. For each factor, there is a "No Go" limit beyond which there should be a degradation leading to a negative impact on the human performance (Figure 1). For each factor, this "No Go" limit varies according to the situation (e.g., task, environment, context). There is a mutual influence of each factor level on their respective "No Go" limit, i.e. the limit for a given factor could be larger if another factor is far from its own limit (e.g., a high level of workload could be acceptable in a situation where stress is quite low and teamwork quite good – i.e. efficient).

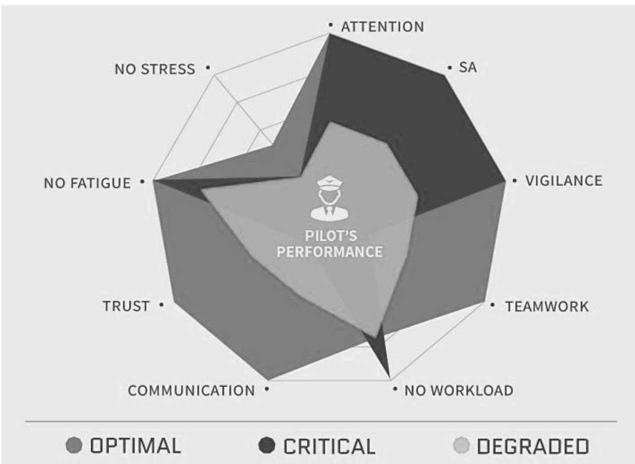

Figure 1. Representation of HPE concept

HPE factors and their measures

The literature review conducted, provided a description of the state-of-the-art of the research on the HP factors (and their relationships) that affect the human performance in the cockpit, by managing the cognitive demand. It also provided shared and consolidated information about the HPE components.

The HPE boundaries can be used as the starting point for determining methods to recover the pilot's performance to the centre of the envelope, and consequently increase this envelope, through innovative HMI design, automatic concepts and flight crew monitoring solutions, procedures and training.

For each HPE component (Workload, Stress, Situations Awareness, Fatigue, Attention, Vigilance, Teamwork, Communication, and Trust) we provided one or more definitions, and some recovery measures and mitigation means currently envisaged in the aeronautical domain. A list of measures/techniques for each factor was also extracted from the review. In particular, two kinds of measures were taken into account: *task-related measures*, linked to subjective assessment and measure of the task execution (i.e., accuracy, duration etc.), and *psychophysiological measures,* related to neurophysiological variation in the operator (e.g., brain, eye, and cardiac activity, respiration, blood flow, and so on).

The results of the literature review [24] show that:

- workload and stress are the most investigated factors in aviation research;
- the frontiers between the concepts of fatigue, vigilance, and attention are quite fuzzy; in particular, these factors are difficult to assess in a flight simulator, although NASA, for instance, was conducted considerable research on fatigue in long haul flights;
- situation awareness is another relevant topic in aviation and several studies were found. However, the distinction between the various levels of situation awareness, and the attention and vigilance factors was often unclear and these factors seem to overlap in most of the cases;
- the impact of communication, teamwork and trust on aviation operators performance is mostly unexplored in the scientific literature although well identified in the operational world.

Workload

Workload refers to the portion of operator information processing capacity or resources that is actually required to meet system demands [14]. This hypothetical construct describes the extent of cognitive resources, required to perform a task, that have been actively engaged by the operator [20]. Workload is not an inherent property of a task, but rather it emerges from the interaction between the requirements of a task, the circumstances under which it is performed, and the skills, behaviours, and perceptions of the operator [22].

On the flight deck the workload is, on a normal day, predictably cyclical for every flight and fluctuations between low and high workload are common both for crews and ATCO (Air Traffic Controllers) teams. Variations in traffic-load, adverse weather, degraded equipment, loss of aircraft and other abnormal situations, may cause workload peaks. It is well known and demonstrated that an increase of workload and task difficulty lead to a performance decrement that reflects in a decrease of accuracy and number of completed tasks, while reaction times and number of errors increase.

There are several measures in literature for the assessment of workload, for example subjective measures (e.g., NASA-TLX), primary and secondary task, and observation from experts of strategy changes, as regards task-related the end measures. For psychophysiological measures, we found studies using the electroencephalography (EEG), electrocardiography (heart rate), electrooculography (EOG), eye tracking, and respiratory activity. Other minor measurements, also included in this group, are the functional near infrared (fNIRS) spectroscopy, electrodermal activity, and electromyography (EMG). Although literature reports the use of several valid methods and techniques for workload evaluation have been used in literature, some of them are more suitable for simulated conditions rather than real cockpit operations. For example, despite EEG is a reliable form of workload measure, it is still not portable/usable in a real cockpit condition. Other measures such as pupillometry, eye tracking, and respiratory activity can be basically used in simulated conditions, even if new advanced devices are being developed to be more adaptable to the real context.

Stress

According to psychological theories, stress is determined by the balance between the perceived demands from the environment and the individual's resources to meet those demands [19], [28]. From a physiological point of view, a typical stress response means that autonomic activity increases. Stress can be categorised into two basic forms: acute stress, relatively short in duration and is often experienced as caused by high taskload; chronic stress, prolonged stress that can result from occupational or non-occupational sources.

Among the main task-related measures used for stress assessment can be mentioned the communication analysis (e.g., using non-standard phraseology), a video camera pointed to the operator (to detect head movement, body position, and facial expressions), and the cognitive observations (e.g., attentional narrowing). Seat foil sensors can be also included in the list for stress assessment. As regards the psychophysiological measurements, particular attention is given to voice analysis, respiratory activity, heart rate variability, and variations in blinking and eye movements. Another interesting measure of stress is the pressure/grip force, measured through specific pressure/grip sensors on seats and tools. Edwards study on ATCOs [11] confirms that facial expressions, head movements, verbal cues, and behavioural changes (e.g., easily frustrated) are good markers of stress. Physiological changes, identified in heartbeat and sweat with negative feelings such as uncomfort, anxiety, nervosity, and tension, can be markers of stress as well. Voice analysis, grip force, scan pattern, electrochemical sensors and observation from an expert can be detected in real flight conditions.

Situation awareness

Situation awareness (SA) is the up-to-the minute comprehension of task relevant information that enables appropriate decision making under stress [37]. SA is a function of several quasi-independent situation types: available situation, perceived situation, expected situation, and inferred situation [7]. Endsley [15] developed a three-levels model of SA: perception of elements, comprehension of current situation, and projection of future status. SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future. SA, related to pilots, involves the operators' perception of different environmental elements with respect to time and space, together with a comprehension of their meaning and the projection of their status after some variable has changed with time [6]. When people are required to make critical choices [15], [29], [35], sometimes at a fast pace, the majority of errors occurring is a direct result of failures in SA. While variety of techniques have been proposed to measure situational awareness for example self-rating and inferential techniques (SAGAT or SART[1]), EEG, EOG, heart rate variability, scan pattern, and expert observation, none of these have been explored fully in terms of their reliability and validity. The multivariate nature of SA significantly complicates its quantification and measurement.

Attention and vigilance

Attention is the ability to attend to information in the environment [17]. It is a multidimensional construct that includes focused attention, divided attention and sustained attention/vigilance. Sustained attention or vigilance is the ability to maintain the focus of attention to a task and to remain alert to stimuli over prolonged periods of time, in order to detect and response to infrequent critical events [10], [34].

Vigilance, attention and situation awareness are closely linked, and difficult to consider in isolation. Whereas vigilance and attention might be measured with physiological indicators (e.g., eye tracking, EEG, EOG, ECG), situation awareness (as an understanding of the situation) might be more tricky to measure especially in a real cockpit. The three factors seem to be at different levels, with attention and vigilance closely related to SA level 1 - perception.

Fatigue

Fatigue is a multidimensional state that includes physical, mental and sleepiness components [1]. It is a gradual and cumulative process associated with an aversion for effort, sensation of weariness, reduced motivation, efficiency, vigilance and alertness, and impairments in task performance [21]. Due to the similar neurophysiological characterization, it is difficult to discriminate between mental fatigue and drowsiness, and they may be considered as transitional states on a continuum. Mental fatigue and sleepiness can be regarded as a consequence of sustained mental activity and lack of resources due to mental task execution, but also as a result of monotonous and boring situations when demand for sustained attention is high but little information is conveyed. No standardized methods for the measure of drowsiness exist, but the more reliable technique seems to be the combination between EEG and EOG.

Teamwork

Teamwork is the organized, collective working methods between an established group of people [2], [16], [36]. Teamwork is a collective and mutual interaction between humans in the system for performance [11]. Improving teamwork is the main focus of Cockpit Resource Management (CRM), addressing among other skills

[1] SAGAT (Situation Awareness Global Assessment Technique), SART (Situation Awareness Rating Technique)

communication, cooperation and task sharing [18]. Only task-related measures can be applied to this factor such as, TARGET (Targeted Acceptable Responses to Generated Events) and BOS (Behavioural Observation Scale), direct observation/simulation study, and analysis of incident reports.

Communication

Communication may be defined as the transfer of meaningful information from one person to another [23] and involves both the production and the reception of messages, although communication is independent from (but related to) the concepts of speech and language [23], [25]. In ATC environment is the exchange of information, including timeliness, accuracy, clarity and receptiveness. As for teamwork, communication can be measured throughout TARGET, BOS, direct observation/simulation study, and analysis of incident reports. Speech recordings are also a good technique for the assessment of communication.

Trust

Trust is a multidimensional construct [9]. One taxonomy of trust [26] used in literature discriminates between dispositional trust and situational trust. The former refers to an individual‘s propensity to trust, based on both predispositions to trust, and subsequent environmental influences; the latter is context specific, arising from the perception of an individual‘s (or machines) trustworthiness.

A second distinction [30], [31] is made between interpersonal trust and trust in technology. The interpersonal (cognitive and affective) trust the willingness to be vulnerable to another party based on the belief that the latter party is competent, open, concerned and reliable; the trust in technology is described as an intervening variable that mediates between the system and an operator‘s interaction strategy with the system.

Edwards [11] reports that ATCOs consider trust as important in their work in terms of their relations with colleagues, pilots and management; as well as with regard to their attitude towards technology [5]. There is no standardised method in literature for the measurement of trust. Usually, trust in colleagues is assessed through questionnaires (i.e., self-assessment) and/or direct naturalistic observations, while trust in automation can be inferred using false alarms and reaction times.

Interaction among factors

The literature review revealed several interactions among the nine factors composing the HPE emerged from the literature review. Three thematic areas seem to arise: workload, stress and fatigue is a group of strictly interrelated factors; situation awareness, attention and vigilance are almost overlapped, with attention and vigilance recognised as crucial components of situational awareness. Finally, teamwork, communication and trust can be seen as the set of “social” factors.

Beyond the three thematic areas, it is shown that high levels of workload affect attention, vigilance and situation awareness. It is also proved [4] that high level of workload affects communication abilities. Stress may affect vigilance, induce monotony, and impair the process of stimuli from environment. Acute stress may also impair decision making, in particular under time pressure conditions, and communication. In addition, fatigue affects attention, vigilance, and situation awareness, and may induce monotony.

Endsley [15] showed that situation awareness (SA) and workload are independent constructs, with four possible combinations:

- low SA and low workload if the operator does not know what is happening and is not actively trying to find out;
- low SA and high workload if the operator is handling too much information or too many tasks, thus he is not able to process and integrate everything;
- high SA and low workload, in which the important information is being presented and correctly perceived and integrated (the ideal situation);
- high SA and high workload, when the operator is working hard, but successfully handling the situation.

SA is also affected by the amount of workload and stress. It was observed that physiological factors, such as sleep loss and high blood pressure, can affect attention and vigilance. Motivation, intrinsic or extrinsic, can affect attention and vigilance too. Teamwork and communication are affected by all the variations of the individual status (workload or stress increase, SA decrease). Finally, a robust positive correlation between interpersonal trust and team working emerged from the analysis of the literature.

All the interdependencies emerged are summarised in table 1 where the bold ticks indicate a correlation or interdependency between two factors that is confirmed by independent studies (for instance, the correlation between workload and SA emerged both in Endsley research and in Nählinder studies on workload [32], [33]). On the other side, the crosses indicate a relation between factors that emerged from literature review, but with a less stable consensus.

	WL	Stress	Fatigue	SA	Attention	Vigilance	Teamwork	Comm.	Trust
Workload		✓	x	✓	✓	✓	x	x	x
Stress	✓		✓	✓		✓	x	x	x
Fatigue	x	✓		✓	x	✓			
SA	✓	✓	✓		✓	✓		✓	
Attention	✓		x	✓		✓			
Vigilance	✓	✓	✓	✓	✓				
Teamwork	x	x						✓	✓
Comm.	x	x		✓			✓		x
Trust	x	x					✓	x	

Table 1. Interdependencies between HPE factors

FROM SINGLE FACTORS TO THE MODELING OF THE INTERACTION BETWEEN RELEVANT FACTORS

Usually, a single factor must be severely degraded to cause a significant deficit and, in that case, most modern aviation systems prevent it (for example through HMI tools, strict rest requirements for the pilots, etc.). However, if two or more human factors start to degrade at the same time (e.g. communication problems, fatigue and decreased situation awareness), then a significant combined decrement in performance can be observed, even if the level of the individual factors alone would not cause a significant deterioration. In this sense, we assume that rather than focusing on one single factor, we have to consider a full range of factors that generally affect the performance and their relative interactions.

In this work, we propose to reveal these potential interactions using *human-in-the-loop* simulation. Three HPE factors were chosen as they appeared as the most prominent measures to consider amongst the nine initially identified. Particularly, situation awareness, stress and workload were selected thanks to their respective importance in aviation domain. By manipulating each factor individually, we propose to measure both the effect of each of these three factors on human performance, but also how the interaction of the different factors could impact human performance envelope. Both simple paradigm and complex human-in-the-loop simulations are proposed. We propose to explore in a first step this question in simple paradigm. Particularly, we have designed two experiments using MATB (multiple attribute task battery) from NASA [8]. In these two experiments, we plan to manipulate independently the three HPE factors selected, and to measure both the independent effect of each factor on human performance and their interaction effect. Both behavioural (reaction time, time on target, error detection) and physiological measures (ECG, GSR, EEG, oculometric measures) are planned to be collected. Together with the identification of the potential interaction of these three factors regarding human performance envelope, the main objective of these two experiments is also to select adequate sensors for real time simulations. Thanks to the results obtained during these initial experiments, a second series of experiments using real time simulations is planned for 2016 in order to confirm the independent effect of each factor on human performance and their interaction effect in a more complex environment. In these simulations, two scenarios will be played and their characteristics (factor manipulated, performance measure) will be defined in collaboration with pilots.

FROM HPE LITERATURE REVIEW TOWARDS INNOVATIVE SOLUTIONS

The third step of our approach consists to propose innovative solutions including adaptive automation, which can provide effective recovery measures if the human performance is compromised. Particularly, we assume that the delimitation of the HPE boundaries, in terms of cockpit operations and design solutions, can be used as the starting point for determining methods to recover the pilot's performance to the centre of the envelope, and consequently increase this envelope, through innovative HMI design, automation concepts and flight crew monitoring solutions (procedures and training). The importance of the design of HMI relies in enabling pilots to be in a situation where they have sufficient cognitive resources to perform their tasks efficiently and safely.

Recovery measures connected with the introduction of HMI and support tools

The human resources (both physical and cognitive) are limited: to perform efficiently and safely in complex working settings, the human performance needs the support of different tools. Task description, training, working methods, procedures, automation, HMI and supporting tools are introduced in the complex working environment to ensure an efficient support to human activity. Particular attention is given to information display, HMI and automation that need to be designed with and around the final users, on the basis of understanding their needs in the various contexts. The system design, and more specifically the automation design, evolved from an engineer driven approach (based on technical feasibility) to a human user centred approach (based on the user requirements and on the need to reduce accidents/incidents and costs) [3]. Thus, to perform efficiently, designers need to ensure that automation, HMI and support systems are as simple and intuitive as possible, by involving the final users in their design. Keeping this in mind, some examples of recovery measures and mitigation means are proposed from literature for high and low levels of workload (Table 2), as both extremes are potential sources of errors. Mitigation is considered as steps taken to control or prevent a hazard from causing harm and reduce risk to a tolerable or acceptable level, while recovery is composed of the actions put in place in real-time to handle the hazard (i.e., to restore the system to its nominal - pre-failure - state or at least to limit the consequences of the failure).

Workload	Mitigation	Recovery
Technical	Automation and information system design Procedures	Alarm and attention getters (combination of light, sound and vibration to alert the pilot) Maximum use of automation in flight and on ground Support system for information filtering, guiding the situation analysis and the decision making (e.g. HMI, Autopilot, FMS)
Organisational	Task definition and repartition (e.g. taskload smoothing, through task allocation and task balance over time and among pilots) Staffing arrangements, scheduling and rostering (e.g. keep consecutive night shifts to a minimum, keep long work shifts and	Operational documentation (FCOM, procedures, check-list for task sharing and reallocation) to guide the pilot in situation handling (e.g. monitor relevant indicators, parameters) throughout the whole process (i.e. until the end of the situation) Break in the current activity (either to break the routine effect or to reduce the overload)

	overtime to a minimum, consider different lengths for shifts, examine start-end times, examine rest breaks) Training on how to handle workload issues (detect and react) Workload monitoring programme (e.g. post flight debrief, issues reporting)	Giving responsibilities to other people within the organization Changing Processes
Individual / Team	Awareness of other's tasks requirements	Assessment (or at least detection) of others' current workload (either in the cockpit or on the ground through party line) Task sharing and/or reallocation • In the cockpit (PF/PNF) • With the ground • With the automation (e.g. auto-pilot) Task prioritisation and changes in strategy (e.g. postpone tasks, reject controllers' requests, reduce communication load)

Table 2. Mitigation and recovery measures for workload

CONCLUSIONS

In this work, we proposed a new approach based on the definition and delimitation of the HPE concept starting from a literature review on nine common human factors that can affect the human performance. Recognizing the need for a multi factorial approach to understand the determinants of human performance and eventually to support it, the HPE concept encompasses not only one single factor, but a set of interdependent factors, working alone or in combination. We reviewed the definitions and possible measures for each of the factors and discussed their interdependencies. We also introduced some examples to mitigate and recover the pilot's performance through innovative HMI design, automatic concepts and flight crew monitoring solutions, procedures and training. Particular attention is put on the importance of designing HMI solutions and automation that relies in allowing pilots to be in a situation where their cognitive resources is enough to perform efficiently and safely their tasks. Future works include pilots' workshops in order to elicit applicable factors and measures, and to define scenarios for validation of the concepts. Preliminary experiments will then be conducted in order to reinforce the hypotheses regarding factors interdependencies (e.g., between workload and stress) and their measure, before performing trials involving qualified flight crews in realistic simulations.

ACKNOWLEDGMENTS

This paper is based on work performed in the Programme Future Sky Safety, which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 640597. The views and opinions expressed in this paper are those of the authors and are not intended to represent the position or opinions of the Future Sky Safety consortium or any of the individual partner organisations.

REFERENCES

1. Åhsberg, E., Garnberale, F., & Kjellberg, A. Perceived quality of fatigue during different occupational tasks development of a questionnaire. *International Journal of Industrial Ergonomics 20, 2* (1997), 121-135.
2. Bailey, L.L., & Thompson, R.C. The effects of performance feedback on air traffic control team coordination: A simulation study. Federal Aviation Administration (Oklahoma City OK, 2000) Civil Aeromedical Institute.
3. Bannon, L. From human factors to human actors: the role of psychology and human-computer interaction studies in system design. In Design at work: cooperative design of computer systems, Hillsdale, NJ: L. Erlbaum Associates Inc, 1992.
4. Berka, C., Levendowski, D.J., Lumicao, M.N., Yau, A., Davis, G., Zivkovic, V.T., ... & Craven, P.L. EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks. *Aviation, space, and environmental medicine 78 Suppl. 1* (2007), B231-B244.
5. Bonini, D. ATC do I trust thee?: referents of trust in air traffic control. *In CHI'01 Extended Abstracts on Human Factors in Computing Systems* (2001) ACM, 449-450.
6. Borghini, G., Astolfi, L., Vecchiato, G., Mattia, D., & Babiloni, F. Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. *Neuroscience & Biobehavioral Reviews 44* (2014), 58-75.
7. Boy, G.A., & Ferro, D. Using cognitive function analysis to prevent controlled flight into terrain. In Harris, D. (Eds), *Human factors for civil flight deck design.* Ashgate, Burlington (2004), 55-68.
8. Comstock, J.R., & Arnegard R.J. The multi-attribute task battery for human operator workload and strategic behavior research. Hampton, VA: National Aeronautics and Space Administration, Langley Research Center, 1992.
9. Costa, A.C., Roe, R.A., Taillieu, T. Trust within teams: The relation with performance effectiveness. *European Journal of Work and Organizational Psychology, 10, 3* (2001), 225-244.
10. Davies, D.R., & Parasuraman, R. The psychology of vigilance. Academic Press, 1982.
11. Edwards T. Human Performance in Air Traffic Control. Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy, January 2013.
12. Edwards, T., Sharples, S., Wilson, J. R., & Kirwan, B. The need for a multi-factorial model of safe human performance in air traffic control. In *Proceedings of the*

28th Annual European Conference on Cognitive Ergonomics (2010), 253-260

13. Edwards, T., Sharples, S., Wilson, J.R., and Kirwan, B. Factor interaction influences on human performance in air traffic control: The need for a multifactorial model. *Work: A Journal of Prevention, Assessment and Rehabilitation 41* (2012), 159-166.
14. Eggemeier, F.T., Wilson, G.F., Kramer, A.F., & Damos, D.L. Workload assessment in multi-task environments. *Multiple-task performance* (1991), 207-216.
15. Endsley, M.R. Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37, 1* (1995), 32-64.
16. Erdem, F. & Ozen, J. Cognitive and affective dimensions of trust in developing team performance. *Team Performance Management: An International Journal, 9, 5/6* (2003), 131-135.
17. Eysenck, M.W. Principles of cognitive psychology. Psychology Press, 2001.
18. Flin, R., Martin, L., Goeters, K.M., Hormann, H.J., Amalberti, R., Valot, C., & Nijhuis, H. Development of the NOTECHS (non-technical skills) system for assessing pilots' CRM skills. *Human Factors and Aerospace Safety, 3* (2003), 97-120.
19. Frankenhaeuser, M. A psychobiological framework for research on human stress and coping. In H.H. Appley & R. Trumbull (Eds.), Dynamics of stress: Physiological, psychological and social perspective 101-116. New York: Plenum Press, 1986.
20. Gopher, D., & Donchin, E. Workload: An examination of the concept. In Boff K.R., Kaufman L., Thomas J.P., (Eds) *Handbook of perception and human performance* Vol2: Cognitive processes and performance. Oxford, England: John Wiley & Sons (1986) 1-49.
21. Grandjean, E.P. Fatigue. *American Industrial Hygiene Association Journal, 31* (1970), 401-11.
22. Hart, S.G., & Staveland, L.E. Development of NASA-TLX (Taskload Index): Results of empirical and theoretical research. *Advances in Psychology 52* (1988), 139-183.
23. Hogg, M.A., & Vaughan, G.M. Social Psychology (3º ed.) London: Prentice Hall, 2002.
24. https://www.futuresky-safety.eu/wp-content/uploads/2015/12/FSS_P6_DBL_D6.1-Concept-for-Human-Performance-Envelope_v2.0.pdf
25. Huttunen, K., Keranen, H., Vayrynen, E., Paakkonen, R., Leino, T. Effect of cognitive load on speech prosody in aviation: Evidence from military simulator flights. *Applied Ergonomics, 42, 2* (2011), 348-357.
26. Kiffin-Petersen, S., & Cordery, J. Trust, individualism and job characteristics as predictors of employee preference for teamwork. *International Journal of Human Resource Management 14 1* (2003), 93-116.
27. Loft, S., Sanderson, P., Neal, A., & Mooij, M. Modeling and predicting mental workload in en route air traffic control: Critical review and broader implications. *Human Factors 49* (2007), 376-399.
28. Lundberg, U. Methods and applications of stress research. *Technology and Health Care 3* (1995), 3-9.
29. Lundberg, J. Distributed Situation Awareness for the Civil Cockpit: Theory and operationalisation. Masters Thesis. Linköping, Sweden: Department of Computer and Information Science, Linköpings universitet, 1999.
30. Mishra, A.K. Organizational responses to crisis. *Trust in Organizations. Frontiers of theory and research* (1996), 261-287.
31. Muir, B.M., & Moray, N. Trust in automation: part II, experimental studies of trust and human intervention in a process control simulation. *Ergonomics 37, 11* (1996), 1905-1922.
32. Nählinder, S. ACES-Air combat evaluation system. Command and Control Systems. Swedish Defence Research Agency, 2004.
33. Nählinder, S. Flight Simulator Training: Assessing the Potential Department of Management and Engineering. Doctoral thesis. Comprehensive summary, 2009.
34. Parasuraman R. In The attentive brain. Parasuraman R. editor. Cambridge, MA: The MIT Press, 1998.
35. Parasuraman, R., Sheridan, T.B., Wickens, C.D. Situation awareness, mental workload, and trust in automation: viable, empirically supported cognitive engineering constructs. *Journal of Cognitive Engineering and Decision Making 2, 2* (2008), 140–160.
36. Rasmussen, T. & Jeppesen, H.J. Teamwork and associated psychological factors: A review. *Work & Stress, 20, 2* (2006), 105-128.
37. Smith, K., & Hancock, P.A. Situation awareness is adaptive, externally-directed consciousness. *Human Factors, 37, 1* (1995), 137-148.
38. Svensson, E. Angelborg-Thanderz, M., Sjoberg, L., & Olsson, S. Information complexity-mental workload and performance in combat aircraft. *Ergonomics 40* (1997), 362-380.