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Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Paola Tomasello/DBL	WP5 Leader	18/04/2018
Stefano Bonelli/DBL	Project Coordinator	20/04/2018
Martina Ragosta/DBL	WP6 Leader	18/04/2018
Gianluca Borghini/Unisap	WP2 Leader	20/04/2018
Nicolina Sciaraffa/UniSap	Project Member	10/05/2018
Gianluca Di Flumeri/UniSap	Project Member	10/05/2018
Piero Aricò/UniSap	Project Member	10/05/2018
Fabio Babiloni/ UniSap	Project Member	11/05/2018
Géraud Granger/ENAC	WP1 – WP3 Leader	18/04/2018
Jean-Paul Imbert/ENAC	Project member	18/04/2018
Fabrice Drogoul/ECTL	Project member	18/04/2018
Uğur Turhan/AU	WP4 Leader	18/04/2018
Birsen Açikel/AU	Project member	18/04/2018
Ali Ozan Canarslanlar/AU	Project member	18/04/2018

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Géraud Granger/ENAC	WP1 – WP3 Leader	18/05/2018
Jean-Paul Imbert/ENAC	Project member	18/05/2018
Fabrice Drogoul/ECTL	Project member	18/05/2018
Uğur Turhan/AU	WP4 Leader	18/05/2018
Birsen Açikel/AU	Project member	18/05/2018
Ali Ozan Canarslanlar/AU	Project member	18/05/2018
Géraud Granger/ENAC	WP1 – WP3 Leader	29/05/2018
Jean-Paul Imbert/ENAC	Project member	29/05/2018
Fabrice Drogoul/ECTL	Project member	29/05/2018
Uğur Turhan/AU	WP4 Leader	29/05/2018
Birsen Açikel/AU	Project member	29/05/2018

Ali Ozan Canarslanlar/AU	Project member	29/05/2018

Approved for submission to the SJU By — Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Stefano Bonelli	Project Coordinator	06/06/2018
Paola Tomasello	WP5 Leader	06/06/2018
Gianluca Borghini	WP2 Leader	06/06/2018
Fabrice Drogoul	Project member	06/06/2018
Jean-Paul Imbert	Project member	06/06/2018
UğurTurhan	WP4 Leader	06/06/2018
Gianluca Borghini	WP2 Leader	17/07/2018
Stefano Bonelli	Project Coordinator	17/07/2018
UğurTurhan	WP4 Leader	17/07/2018
Géraud Granger	WP1 – WP3 Leader	17/07/2018

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

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STRESS

HUMAN PERFORMANCE NEUROMETRICS TOOLBOX FOR HIGHLY AUTOMATED SYSTEMS DESIGN

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699381 under European Union's Horizon 2020 research and innovation programme.

Abstract

STRESS studied the impact of advanced highly automated systems on air traffic controllers' performance.

The project developed a mental states measurement toolbox (also called "neurometrics toolbox") able to provide with high-time resolution neurophysiological indicators of workload, vigilance, attention, stress and cognitive control behaviour, that facilitates understanding, modelling and analysing changes in the Human Performance Envelope in reaction to different automation types and levels.

The STRESS approach is about supporting the SESAR transition to higher levels of automation in Air Traffic Management (ATM), providing guidelines for the design and implementation of future technologies for air traffic control, aimed at ensuring that a balanced human-machine cooperation is obtained and that safe transitions from high to low automation levels (e.g. automation failures), and vice versa, are maintained.

In this document, we provide a summary of the STRESS accomplishments and contributions, along with the feedback obtained and lessons learned, to then conclude with further developments of STRESS in the ATM Community and in the integration of Exploratory Research projects into the SESAR mainstream and future SESAR 2020 Programme.

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1 Executive Summary

This document provides an overview of the STRESS project context, objectives and outcomes.

STRESS (HUMAN PERFORMANCE NEUROMETRICS TOOLBOX FOR HIGHLY AUTOMATED SYSTEMS DESIGN) was a Horizon 2020 project co-funded in the framework of the SESAR Research and Innovation Action (RIA), started in June 2016 and lasting 24 months (www.stressproject.eu).

The project research plan addressed the Human Performance issues, benefits and impacts of the SESAR paradigm shift towards increasing automation levels.

Most of the proposed changes deriving from the implementation of the SESAR solutions are expected to increase the pilot's autonomy in controlling the route of their aircraft, including the requirement to maintain required separation between aircrafts. Flight time, delays and fuel consumption are all expected to profit from such changes. At ground level, this corresponds to a **change in the role of Air Traffic Controllers (ATCOs)**, shifting from active controller to monitoring one. To support Air Traffic Control operations, SESAR is working to introduce higher levels of automation, to the extent that **the new generation of automated systems for Air Traffic Control (ATC) are expected to autonomously (or partially autonomously) manage decision-making and action-implementation tasks**, generally carried out, at the current moment, by ATCOs. The latter are still responsible for running the ATC system safely, but their role would move from active control to monitoring of complex situations and managing unexpected system disruptions. It is vital **to enhance the comprehension of the ATCOs responses to such role changing**. STRESS dealt with it.

In its two years, STRESS has achieved the following technical contributions to tackle the aforementioned problems:

- **Future ATC scenarios** including highly automated supporting technologies, for assessing the changes in human roles in higher automation scenarios.
- **Validated mental states measurement toolbox** and neurophysiological signals fusion-based methodology to monitor with high time resolution the human performance of Air Traffic Controllers in realistic operational environments.
- **Guidelines** for the design, implementation and training of innovative technologies that are compatible with human capabilities and limitations.
- **A White Paper** on follow-up research activities, in cooperation with other SESAR Exploratory Research projects.

The participation in various events has helped disseminate the STRESS approach. Aviation stakeholders provided positive feedback on the project results, and also gave advice for the application of the STRESS approach. In particular, they highlighted that the mental state measurement toolbox developed by STRESS could be applied at several ATM organizational levels, as follows:

- As a training tool, to assess the level of expertise and feed debriefings
- As an automation evaluation tool, useful to assess new systems from a HP perspective and also to compare the HP impact of different solutions
- For research in the area of safety and HP, for example ageing performance

- In operations, to support workers in difficult situations (stress, overload, fatigue, etc)

2 Project Overview

2.1 Operational/Technical Context

STRESS (HUMAN PERFORMANCE NEUROMETRICS TOOLBOX FOR HIGHLY AUTOMATED SYSTEMS DESIGN) is a Horizon 2020 project co-funded in the framework of the SESAR Research and Innovation Action (RIA), started in June 2016 and lasting 24 months [1], [2] (www.stressproject.eu).

The project research plan addressed the Human Performance issues, benefits and impacts of the SESAR paradigm shift towards increasing automation levels. Most of the proposed changes deriving from the implementation of the SESAR solutions are expected to increase the pilot's autonomy in controlling the route of their aircraft, including the requirement to maintain required separation between aircrafts. Flight time, delays and fuel consumption are all expected to profit from such changes. Moreover, at ground level, SESAR is working to introduce higher levels of automation to support Air Traffic Control operations, to the extent that **the new generation of automated systems are expected to autonomously (or partially autonomously) manage decision-making and action-implementation tasks**, generally carried out, at the current moment, by Air Traffic Controllers (ATCOs).

ATCOs are still responsible for running the ATC system safely, but their role would be shifted from active controller to monitoring one [3]. It is vital **to enhance the comprehension of human responses to their role changing**, that is, from active control to monitoring of complex situations and managing unexpected system disruptions.

To tackle this topic, STRESS started from an analysis of the SESAR vision and generated associated future operational scenarios, with a focus not only on automation support types and levels, but also on the ATCOs role changing.

Assuming that all the equipment and pilots perform correctly, the controller's workload would be expected to decrease in nominal situations, since they are interacting with fewer aircrafts. It also seems plausible that the controller's situational awareness of the airspace would decrease as well, since they would not be paying as much attention as they previously did to many of the aircrafts. However, for an unknown period of time, certain aircrafts in the system would be properly equipped to participate accordingly with the new rules, allowing more autonomy, but others would not be and would require the controller to manage their flight path.

As a consequence, ATCOs are expected to operate with very few tactical interventions, strategic planning by exception (only when automation cannot find a solution), need to intervene rapidly to recover disruptions, or unexpected events. As compared to pilots, workload may be even less primary, but with sudden bursts when recovery actions are needed.

Such a monitoring role will probably require vigilance and attention recovery, more than it is required today. Lack of user involvement in automation assisted processes may in fact lead to reduced vigilance and loss of situation awareness. The allocation of certain tasks to the system may also lead to the operators becoming de-skilled, as skills deteriorate when they are not used. The implication of skill loss is that when an operator is forced to manually take over an automated system, he\she is likely to do so with minimal information and skill [4], [5]. This highlights an often-unforeseen problem relating to the impact of the automation in abnormal conditions or in degraded modes of operations. Operators may perform effectively with automated systems during normal conditions, but during abnormal conditions they tend to do not always react appropriately to the failure of automated systems. This has been referred as "out-of-the-loop performance problem" or the "out of the loop unfamiliarity problem". There are several possible reasons for this problem. Loss of skill, poor feedback, and complacency may all contribute to the 'out-of-the-loop' problem.

Moreover, ATCOs will need to deal with very complex system, with many interacting elements, of different typologies (e.g. Remotely Piloted Aircraft Systems -RPAS), moving in 4D trajectories across space. The efficiency of humans in coping with complex situations is largely due to the availability of a large repertoire of different mental representations of the environment from which rules to control behaviour can be generated ad-hoc. In line with this, it is vital to comprehend the level of cognitive control engaged time by time on the various tasks.

As systems become more automated, and humans move to monitoring positions, the weight of stress is likely to grow as well. This applies both in normal conditions (when ATCO will need to rely on automation without having the possibility of controlling it) and in automation disruptions, when humans have to react quickly in highly stressful conditions. In these cases, stress is known to influence performance and impair attention, memory, and decision-making. The relevance of stress is also recognised by EASA, that in the Notice of Proposed Amendment (NPA) [6] addresses the issue of licensing and medical certification of air traffic controllers, considering stress and fatigue management as an essential topic for training [7], [8].

To address the impact of such role changing to human performance, STRESS proposed a multidisciplinary approach intended to apply the high time resolution **neurophysiological measurement** of air traffic controllers' mental status to the execution of operational tasks, within a simulated Air Traffic Control environment reproducing the complexity of future airspace scenarios and associated supporting technologies (Figure 1).

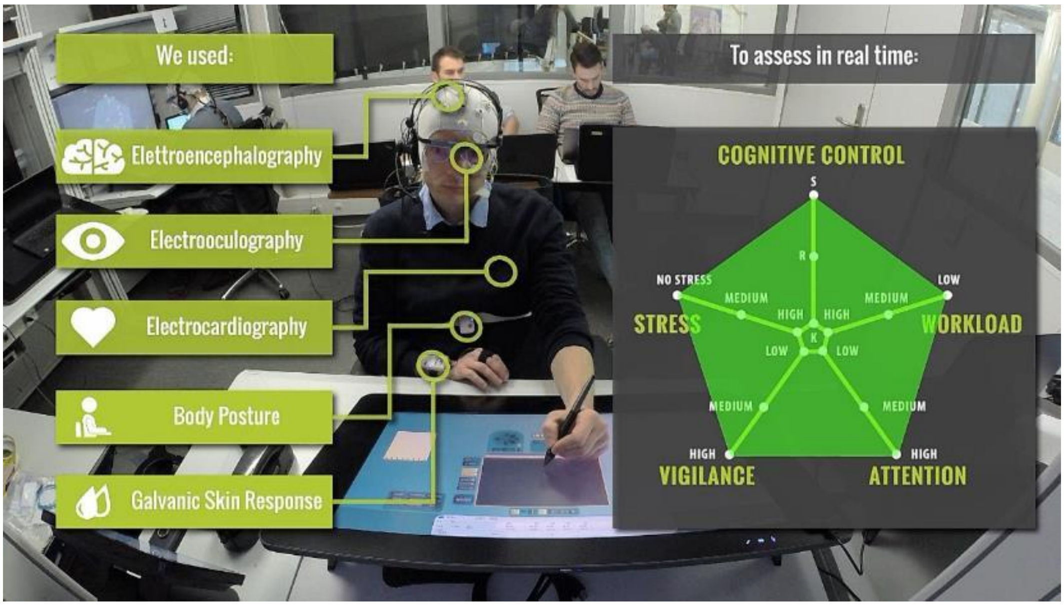


Figure 1 - The STRESS approach

2.1.1 The STRESS approach

The STRESS project approach focused on the following concepts:

- Human Performance Envelope (HPE) configuration.
- Definition of neurophysiologic indicators for the factors composing the future HPE.
- Design of automated systems on the basis of the HPE status.

Each of such concepts is described as follows.

2.1.1.1 Alignment of the HP envelope with the foreseen ATCO role in SESAR

In the recent years, the concept of **Human Performance Envelope (HPE)** [9] has been introduced as new paradigm in Human Factors. Rather than focusing on one or two individual factors (e.g. fatigue, situation awareness, etc.), it considers their full range, mapping how they work alone or in combination to lead to a Human Performance (HP) decrement that could affect the safety. The future ATCO role will share some commonalities with what happened to pilots due to cockpit technological evolution: a prominence of workload and stress; then attention, communication, vigilance, and fatigue issues may be expected. The HPE considered by the Future Sky Safety [10] project was a first good approximation of what may be expected also for controllers: a prominence of workload and stress, then attention, communication, vigilance, and stress (Figure 2).

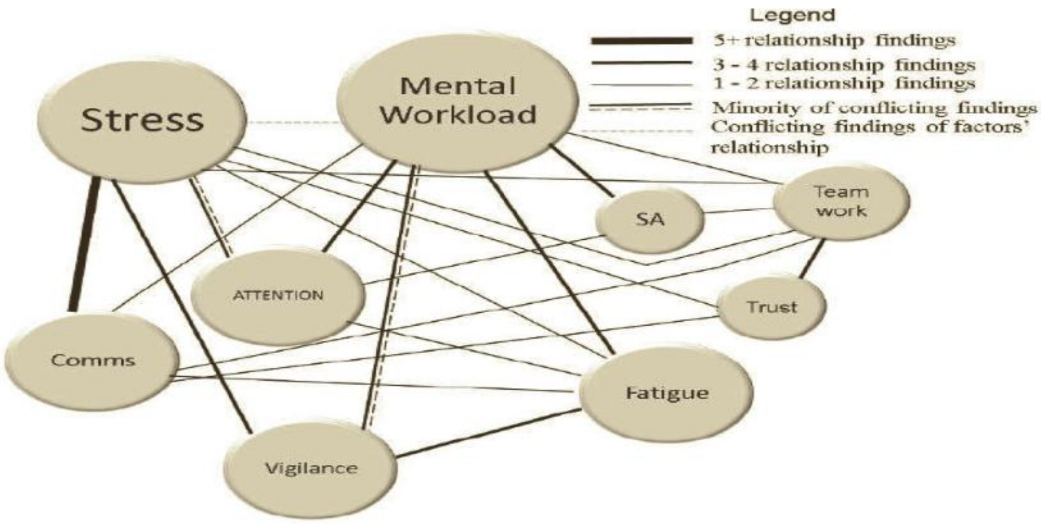


Figure 2 - The HP envelope being considered by the Future Sky Safety project for pilots.

It is reasonable to expect that the future ATCO HPE will be different than the current one. It will have different underlying Human Factors (HFs) concepts, or at least a different combinations among them. Based on the expected future ATCOs role, STRESS chose the following HFs as the most relevant with respect to the HPE future configurations [11]:

Stress;
Vigilance;
Attention;
Mental Workload;

Cognitive control behaviour.

2.1.1.2 Definition of neurophysiological indicators for the future HP envelope

Neurophysiological indicators are quite advanced today, offering a unique opportunity to objectively monitor the HPE. The research gap addressed by STRESS was the customization of these indicators to (future) Air Traffic Control (ATC) tasks. While neurophysiology knows what to monitor to detect stress, **what is called stress in ATC (by using everyday language) corresponds to different patterns of neural activity, as compared to everyday stress.**

This consideration is especially relevant for complex HFs concepts like Stress, Attention and Vigilance. These concepts have an everyday meaning and are being studied in contexts different than ATM. In addition, aviation research on neurophysiological indicators have mostly focused on cognitive concepts, traditionally disregarding the emotional aspects concerning stress perception and management. This oversimplification is hard to justify at the light of current neurophysiological knowledge, where **stress has been shown to play a key-role in "cognitive" processes like decision-making or attentional focus.**

To capture this level of complexity, STRESS tested and validated indexes by data fusion of the following measures: neural patterns of brain activation (EEG) and physiologic indicators (heart activity, galvanic skin response). In particular, STRESS developed neurophysiological indicators of vigilance, attention, stress, workload and cognitive control behaviour. As a result, STRESS provided a **customized neurophysiological measurement toolbox to the future ATM able to measure the HP Envelope.**

2.1.1.3 Design of the automation level on the basis of the HP envelope status

The third concept is about linking the HPE to automation design. A full understanding of the future HP envelope and of the underlying HFs allows the optimization of Human Performance, by identifying human bottlenecks and limitations. This concept is aligned with the ACARE Strategic Research Agenda [12].

This concept applies to nominal conditions, when the HPE analysis would determine the human bottlenecks with reference to higher automation levels, as for instance lack of trust, too high stress level, or lack of adequate attentional patterns. But it is also relevant in degraded conditions, where it will be possible to track the temporal variations of the HP envelope. As a practical example, this could mean predict what will typically happen to the stress and workload levels in case of automation disruptions and when their levels could be considered "back to normal".

STRESS provided different kind of **guidelines to support automation design**:

1. **Very specific ones**, related to the automated solutions tested during the project;
2. **Some related specifically** to the STRESS Neurometrics Toolbox and its use for generating new automated solutions;
3. **Generic ones**, to be used in the concept/design phase of new automations to assess the expected impact on safety (from the HP perspective).

Figure 3 summarises the different types of contributions the STRESS project brought to automations design and validation.

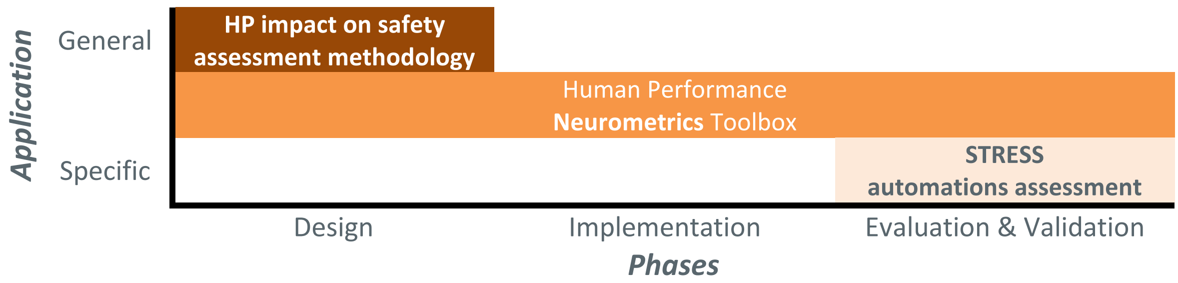


Figure 3 - STRESS contribution to automation design

All the proposed guidelines are related to all the aspects of the SESAR HP argument [13]:

The role of the human is **consistent with human capabilities and limitations** (e.g. how to design the human role within the HP envelope boundaries);
Technical systems support the human actors in performing their tasks, e.g. automation design principles, adaptive automation;
Team structures and team communication support the human actors in performing their tasks, e.g. Team Resource Management and coping strategies during disruption cases;
Human Performance related **transition factors** are considered, e.g. changes in competence.
Requirements, identification of training needs;

2.1.2 The STRESS Consortium

The composition of the STRESS Consortium (Figure 4) reflected the multidisciplinary approach engaged by the project, bringing together five partners with different expertise and competence profiles, as follows:

Company/Institution logo	Description	Role in STRESS
	Deep Blue (DBL) (acting as project coordinator), a research and consultancy Italian Small Medium Enterprise (SME) specialised in human factors, safety, validation and scientific dissemination.	• Coordinator • Dissemination manager • Future scenarios envisioning • Simulations planning and execution • Automation guidelines generation
	Sapienza University of Rome (UNISAP) provided expertise in the measurement and analysis of neurophysiological signals, and definition of indexes of human mental states and cognitive performance.	• Neurophysiological and psychological measurements • Analysis of neurophysiological signals • Definition of experimental protocols • Definition of indexes of human mental states and

		cognitive performance
ENAC	Ecole Nationale de l'Aviation Civile (ENAC), the French National School for Civil Aviation, providing first quality access to ATC simulators and ATM experts, as well as engineers and pilots, and a long-standing expertise in innovative interaction technology.	• ATC expert • ATC automated tools research and development • Research simulation facilities availability
ANADOLU ÜNİVERSİTESİ	Anadolu University (AND/AU), with the Faculty of Aeronautics and Astronautics, providing state-of-the-art synthetic training devices and flight simulators.	• ATC expert • Future ATC scenarios development • Simulation facilities availability
EUROCONTROL	EUROCONTROL, the European Organisation for the Safety of Air Navigation, providing quality experience in the application of Human Performance analysis to innovative concepts and background experience in stress and fatigue management.	• Support to future scenarios generation • Support to Human Performance assessment

Table 1 - The STRESS partners' roles

Figure 4 - The STRESS Consortium

2.2 Project Scope and Objectives

The project had four main objectives (Figure **5**):

1. **Define the characteristics of the HPE for the ATCOs working in future SESAR scenarios**, (e.g. less tactical interventions, high automation support, multi-sector operations, and so on):
   a. Develop future scenarios.
   b. Identify the relevant Human Factors to be investigated.
2. **Develop neurophysiological indexes able to monitor in real-time ATCOs HPE**, during monitoring tasks in different automation levels:
   a. Identify neurophysiologic indexes for the following cognitive and emotional aspects: stress, workload, vigilance, attention, level of cognitive control on tasks.
3. **Study the impact of high and changing automation on controllers' Human Performance Envelope:**
   a. Identify HP envelope configurations specific to automation transition scenarios.
   b. Identify optimal states of the human performance envelope.
4. **Derive guidelines to reach the highest level of automation and support transitions.**

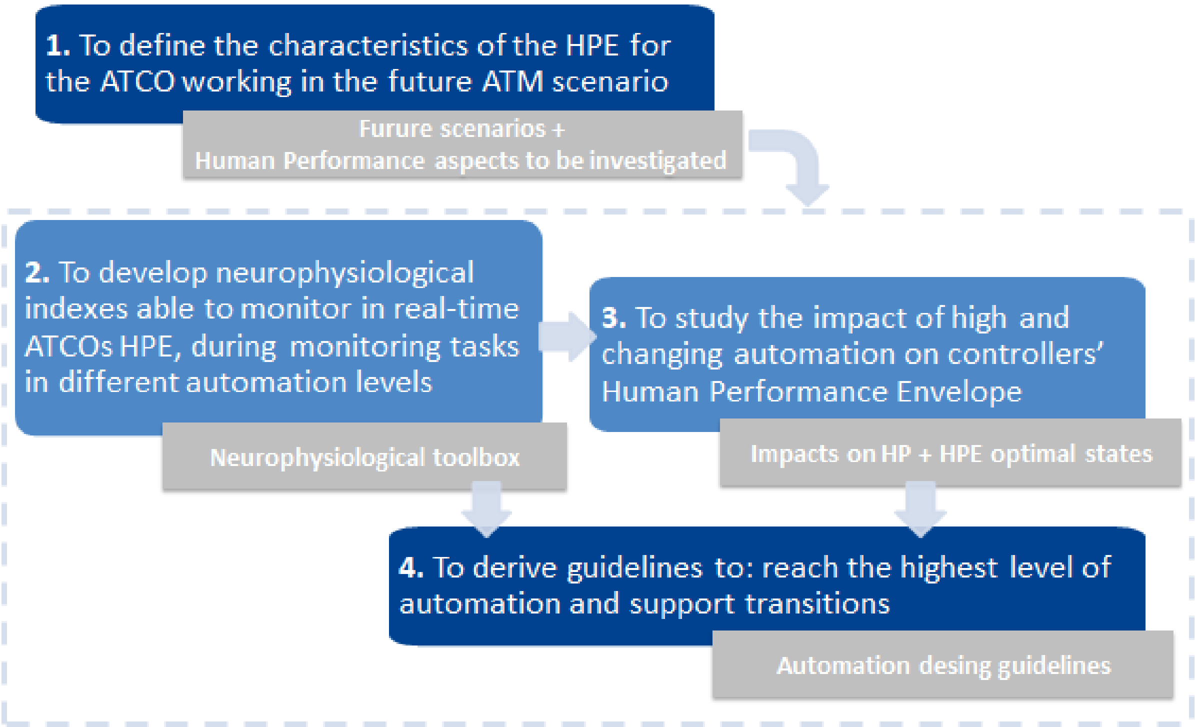


Figure 5 - STRESS project objectives

Mitigation measures were successfully applied for a number of risks that were identified at the beginning of the project, as described in the following table. No risk impacted, no issues to be reported.

Risk number	Description of risk	Probability	Severity	Proposed risk-mitigation measures	Mitigation application	Status
1	Suggested acquisition devices are prone to record artefacts in the different recording sites of the project.	Medium	Medium	A set of simple pre-experimental test will be organized in the different recording locations to anticipate possible recording problems. Suitable techniques to remove artefact exist. We applied one of these techniques in case of needs, at the cost of	Yes	Closed
2	Delay in unlocking funds for ENAC's eyetracker.	Medium	Low	ENAC ordered an additional Eyetracker (to have two and don't need to borrow it from DNSA team)	Yes	Closed

3	Impossibility to connect the eye tracker to ENAC ATC research simulation platform.	Low	Low	ENAC used off-line analysis, synchronized in time with the platform.	Yes	Closed
4	We have difficulties in finding subjects for the experiment	Low	High	ENAC has instructors who are qualified ATCO and experts of the field. Their participation to experimental projects members was part of ENAC's contribution and is standard practice in the ENAC facilities. In case of temporary lack of these resources Deep Blue had Operational Experts as part	No	Closed
5	Output of WP1 (or WP 2) do not pass the first (or second Validation)	Low	Medium	Validation criteria were clear since the beginning of the project, allowing an anticipated control of the performances during measurement and tuning (WP1). This allowed to intervene in advance to improve and refine the	Yes	Closed
6	Lack of consensus within consortium	Low	High	The project coordinator and the members of the management board engaged the necessary skill to resolve such conflicts by adequate negotiation and applying the conflict resolution procedure.	Yes	Closed
7	Results are not delivered timely by partners	Low	High	Regular and detailed monitoring detected any problems early on, making possible a broad spectrum of actions to avoid any knock-on effects. These included re-assigning activities, adjusting the work plan, re-allocating effort	Yes	Closed

Table 2: Risks and mitigations actions

2.3 Work Performed

The work performed during the project lifecycle is elaborated through eight Work Packages (WP) (Figure 6). Each WP describes the main content developed by the Project Team.

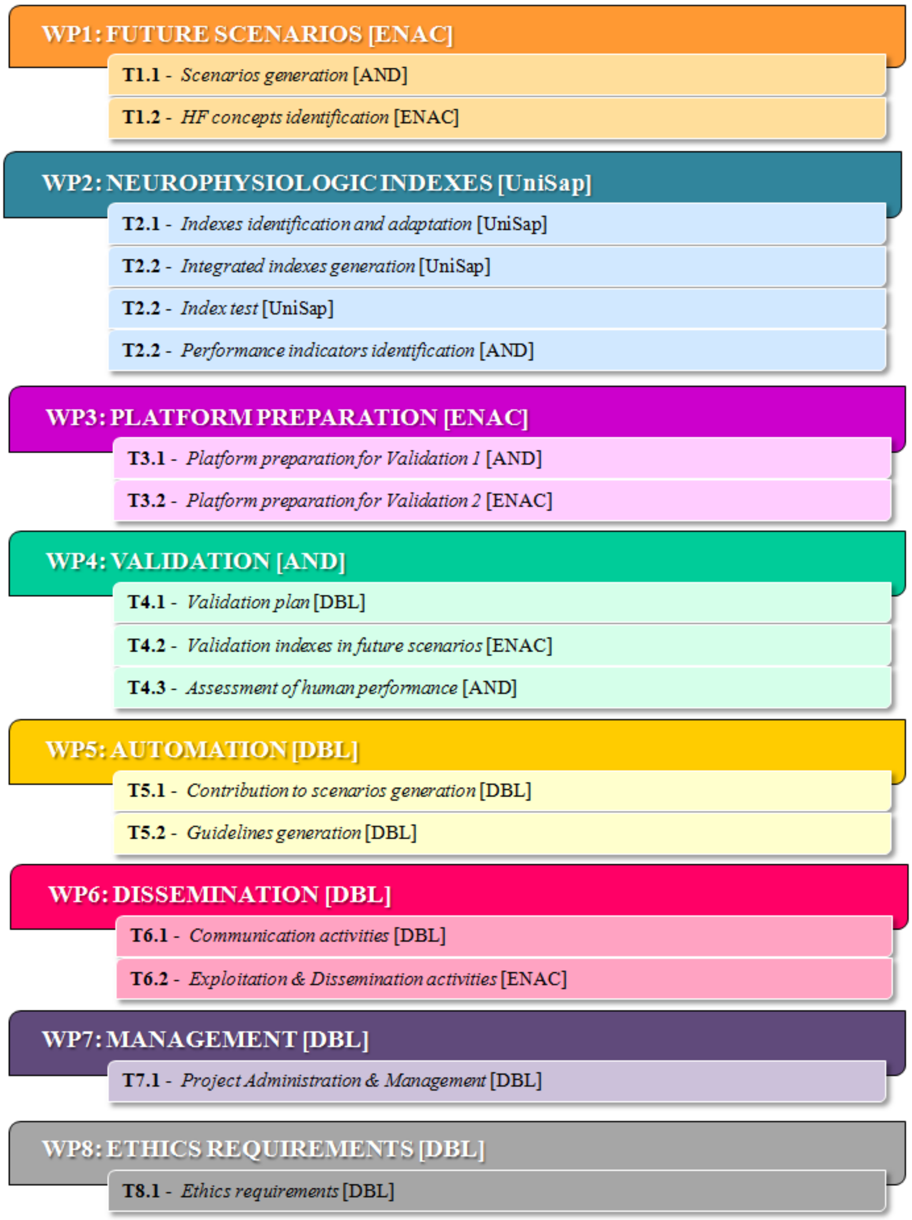


Figure 6 - The STRESS workplan

2.3.1 Work Package 1: Future Scenarios and relevant HFs concepts

The WP1 work was carried out in the first 4 months of the project, as it was meant to lay the basis for the subsequent research activity of STRESS.

WP1 objective was **to develop future ATM scenarios (compliant with the SESAR vision and with a focus on hi-automation) and to identify the related HFs issues, so to select the most relevant**

concepts to be investigated through neurophysiologic indexes (WP2) during the STRESS validation activities (WP4).

To achieve this, WP1 engaged in the following tasks:

- T1.1 Future scenarios generation;
- T1.2 HFs concepts identification.

The methodology used for selecting the most appropriate set of potential validation scenarios included 4 criteria, as follows.

First. Compliance with the lessons-learned derived from the extensive literature review of SESAR future concepts.

The scenarios generation process took into account the SESAR expectation in terms of traffic type and implemented concepts (taking as reference the ATM master plan), a deep knowledge of automated solutions available today and the operational knowledge. The description of the future ATCO role, airspace organisation, traffic load and characteristics, concepts and automated solutions was included as well. To identify the most appropriate scenarios for the project, STRESS browsed several documents and repositories. In particular:

With regard to automation and future changes in ATM, several SESAR, EUROCONTROL, ICAO and EASA reports were reviewed. Furthermore, STRESS considered the latest global demonstration activities, Skybrary Repository and research projects in order to obtain an appropriate and, as much as possible, updated picture of these aspects in relation to Human Performance;
Concerning HFs concepts relevant in future ATM scenarios, STRESS started from the role and significance of stress, attention, mental workload and cognitive control recognised by EASA. Then, each individual factor was investigated taking into account the psychological studies and how the specific factor could impact on the HP and vice versa;
Furthermore STRESS started a fruitful collaboration with different H2020 project dealing with similar topics such as AUTOPACE (Facilitating the AUTOmation PACE) project dealing with psychological modelling to predict how future automation would impact on ATCOs' performance and to identify competences and training to cope with the effects of automation on humans, and MINIMA (Mitigating Negative Impacts of Monitoring high levels of Automation) project aiming at understanding and mitigating "out of the loop" phenomena of ATCOs in highly automated environments especially Terminal Manoeuvring Areas (TMA).

Second. Compliance with the project objectives.

Based on the STRESS objectives, the following requirements were identified:

- Scenarios shall elicit the relevant Human Factors such as stress, workload, attention, level of control in the context of future SESAR framework in which are foreseen less tactical interventions, high automation support, multi-sector operations, and so on;
- Scenarios shall allow to monitor in real-time the controllers' mental state to measure the identified neurophysiological indicators;
- Scenarios shall offer the possibility to deal with different levels of automation to develop specific guidelines for supporting tasks migration or new tasks allocation and so on.

Third. Compliance with the initial operational needs collected during preliminary focus groups with controllers.

To select the most appropriate scenarios for the project, STRESS preliminary discussed feasible scenarios with operational personnel. In particular, Anadolu (AU) contacted the Turkish ATCOs Association (TATCA) and Deep Blue (DBL) contacted the Italian ATCOs Association (ANACNA) for sharing STRESS project objectives and research plans in order to have reliable inputs from operational environment and ATC expert's view and experiences about automation and its effects on human performance when developing realistic scenarios for the project purposes.

Fourth. Assumptions and limitations.

Assumptions are an essential and unavoidable element of each research activity. They are often necessary to provide a frame for the validation process, but they can also have a powerful effect on the conclusions of the analysis that should not be underestimated. The introduction of unmotivated assumptions in analysis and evaluation is a widely recognised issue in the scientific literature. During the project lifecycle and in the planned simulations, STRESS took into account assumptions and limitations from:

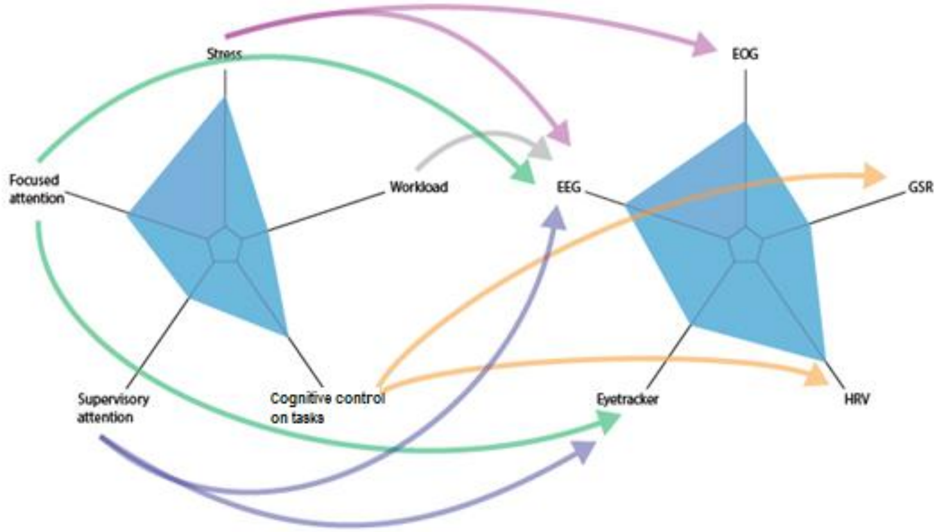
- platform capabilities
- capability to measure the neurophysiological indicators

Both are essential to limit the extent of the analysis at a manageable size. These assumptions have no influence on the validation as long as any comparison (e.g. comparison of the STRESS validation activities outcomes with Subject Matter Experts (SME) or ATCOs feedback) is done with several simulations considering the same portion of the ATM world and involving the ATCOs personally. Besides, the opinion of the SMEs was always used to redefine and evaluate the project activities.

The selected Human Factors were:

- **Stress**: "is determined by the balance between the perceived demands from the environment and the individual's resources to meet those demands"
- **Attention**: "Attention is the ability to attend to information in the environment"
- **Mental workload**: "Mental workload is a hypothetical construct that describes the extent to which the cognitive resources required to perform a task have been actively engaged by the operator"
- **Cognitive Control Behaviour**:
  - skill-based: "the types of activity are usually routine and automated"
  - rule-based: "types of response to known and often rehearsed scenarios"
  - knowledge-based: "behaviour is the result of skill, ability, observation, training and experience".

These would be investigated through neurophysiological indicators in the framework of WP2 (Neurophysiologic indexes) and WP4 (Validation). Neurophysiological measurement tools to assess them included Electroencephalography (EEG), eye-tracker, Electrocardiography (ECG), Electrooculography (EOG) and Galvanic Skin Response (GSR) measurement tools (Figure **7**).



Human Factors	STRESS proposal for assessment
STRESS	GSR, ECG, EEG
ATTENTION	EEG,GSR + Eye-tracker
MENTAL WORKLOAD	EEG
COGNITIVE CONTROL BEHAVIOUR	EEG

Figure 7 - The STRESS proposal for neurophysiological measurement of relevant HFs for future ATM

As WP1 result, the initial features of STRESS validation scenarios were defined, as follows:

Radar environment in Anadolu and En-route environment in ENAC were chosen as operational environments to be simulated.

- The Free Route Airspace was chosen as environment to be implemented in the STRESS simulated airspace.
- Future automations to be simulated included the Agenda of Conflicts (a tool for automatic conflict detection) and the solver (a tool performing automatic implementation of time-based conflict resolution).
- Possible non-nominal scenarios examples included label transfer failure, wrong information on the label and Short Term Conflict Alert (STCA) failure.

2.3.2 Work Package 2: Neurophysiologic indexes

The WP2 objective was to identify neurophysiologic indexes for the relevant HFs identified in WP1, to be reviewed and validated for the ATM environment. Furthermore, this WP intended to generate an integrated index able to monitor the human performance envelope in monitoring tasks.

To achieve this, WP2 engaged in the following tasks:

T2.1 - Indexes identification and adaptation;
T2.2 - Integrated indexes generation;
T2.3 - Indexes test;

T2.4 - Performance indicators identification.

The indexes identification process started with the description of the relevant HFs identified in WP1 in terms of specific cognitive processes and mental states. Afterwards, preliminary neurophysiological evidences of stress, vigilance, attention, cognitive control and workload phenomena were derived on the basis of literature review and previous partners' works. Then, specific and very controlled experiments have been carried out in the Lab by using multimodal approach and collecting several neurophysiological signals (EEG, ECG, EOG, GSR, eye-tracker, Body Posture, Head movements) in order to accurately characterize each of the considered HFs.

As a result, the mapping between HFs concepts and neurophysiological indexes was generated. Indeed, on the basis of the obtained results, different neurophysiological indicators have been defined in order to be univocally related to a specific HFs concept, without any overlap between them (as reported in the following table).

	EEG				ECG		GSR	
	Theta	**Alpha**	**Beta**	**Gamma**	**HR**	**HRV**	**SCL**	**SCR**
Stress			Left and Right Parietal		HR mean		SCL mean	
Vigilance	Occipital		Occipital					
Selective Attention			Midline Frontal and Parietal	Frontal and Parietal				SCR Peaks Amplitude
Cognitive Control Behaviour	Parietal	Frontal Right						
Mental Workload	Frontal	Parietal						

Table 3 - Mapping between HFs concepts and neurophysiological indexes

Different fusion techniques and methods were investigated in order to assess their classification capability in realistic ATM settings. Finally, such index were combined with the aim to obtain a synthetic Human Performance Envelope (HPE) Index.

Indexes test was carried out during the first STRESS simulation, held in Anadolu from the 5th to 9th of June 2017. The indexes were validated against their usability and ATM suitability. Based on the simulation results, the final set of neurophysiological indexes to measure human performance in ATM was developed. These were used during the second simulation of STRESS, held in ENAC from the 12th to 16th of February 2018, to monitor the HPE during the execution of air traffic control tasks in highly automated scenarios.

2.3.3 Work Package 3: Platform preparation

The WP3 objective was to prepare the platforms for the two STRESS simulations, considering the validation objectives and the experimental plan defined in WP4 and the input received from WP1 (scenarios) and WP2 (indexes).

To achieve this, WP3 engaged in the following tasks:

- T3.1 - Platforms preparation for the First simulation;
- T3.2 - Platforms preparation for the Second simulation.

Both tasks performed the same activities, adapting the experimental set up and scenarios to the concerned validation objectives and plan, as follows:

- Set up of the AU and ENAC platforms in order to be able to proceed with respectively the first and the second simulation;
- Integration with additional necessary tools (e.g. EEG);
- Set up of the Controller Worker Positions (CWPs), communication configuration and pseudo-pilot position;
- Implementation of the automation solutions identified;
- Generation of the scenario files (as designed in T1.1) to be run by the platforms (e.g. traffic samples, triggering events);
- System log preparation to provide data for the analysis.

The simulation platform engaged for the **first STRESS simulation** was provided by AU and consisted of **simulator used for the ab-initio training of radar en-route control.**

The AU Radar simulator provides training on approach and en-route control procedures for both radar and non-radar control. The controller positions are multi-functional and can be used for different exercises simultaneously (as illustrated in the following picture).

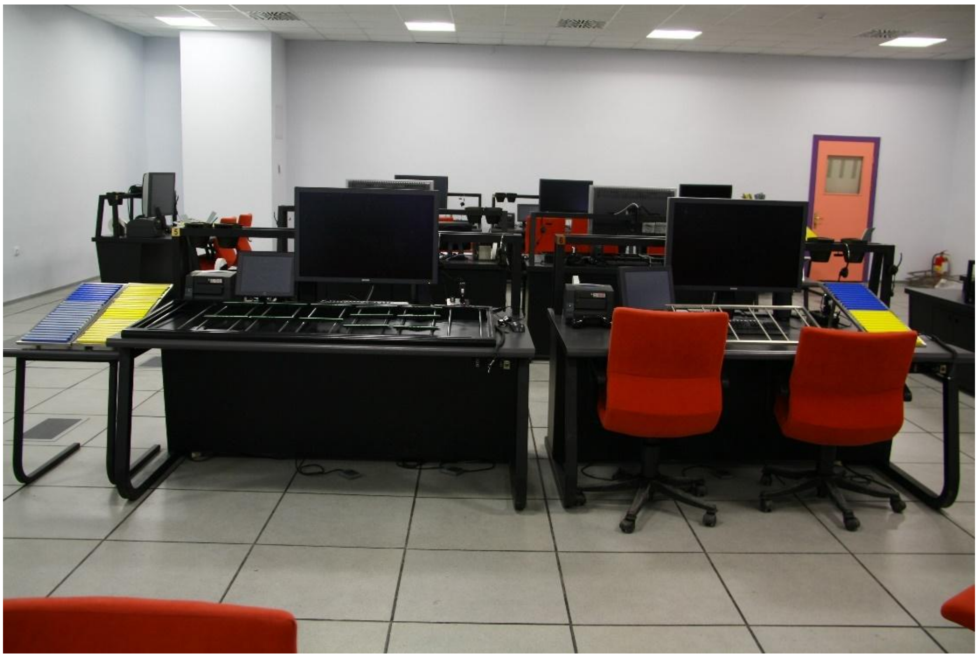


Figure 8 - AU radar simulator working positions

Wind and other meteorological conditions can be modified at any time by the supervisor while exercise program is running. User-friendly interface allows the creation of user-defined airspaces and traffic exercises. The following picture presents a radar simulator at AU.

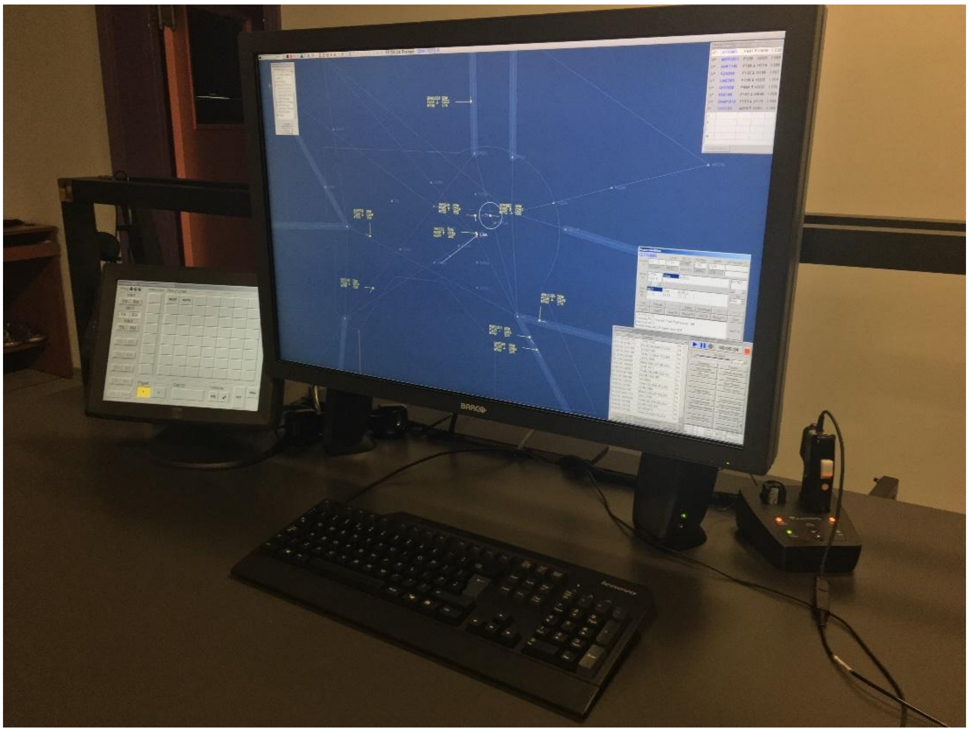


Figure 9 - AU radar simulator CWP

Two CWPs were used for the project experiment purposes. For each of them, one supervisor and two pseudo pilot positions were in charge. **The environment was virtually the same controllers use in real operations.**

The platform set-up allowed the implementation of ad-hoc traffic samples and the introduction of specific events (e.g. system malfunction, aircraft emergency descent, bad weather) enabling the generation of a scenario that **triggered different levels of workload, stress** and **attention resources needs** by the system tools and the pseudo pilot communications. The platform was also able **to provide data to be used to validate the neurophysiologic indexes**, such as system logs, scenario recordings, audio communication recordings.

The simulation platform engaged for the **second STRESS simulation** was provided by ENAC. The available systems were:

- Controller working positions;
- Supervision position;
- Pseudo-pilot position.

Figure 10 - ENAC controllers working position

The platform set-up allowed the implementation of ad-hoc traffic samples and the introduction of specific highly automated systems (e.g. automatic conflict solver) enabling the generation of a scenario that **triggered different levels of automation** as well as **automation failures** whilst keeping traffic volume and complexity stable.

Two kinds of ATM scenarios were implemented: **calibration scenarios** and **simulation scenarios**.

Calibration scenarios were designed to calibrate the machine-learning based neurophysiological indexes of vigilance, attention, cognitive control behaviour, workload and stress for each ATCO before the simulation scenario. Criteria for calibration scenarios were: *i)* to implement ecological tasks, and *ii)* to be as much short as possible. In line with this, target calibration scenarios corresponding to each of the human factors under analysis were designed.

Simulation scenarios were designed to reproduce in a plausible and operationally realistic way future high-level automations, with the possibility to introduce automation failures. Several automated tools available in the ENAC platform, such as conflict solver, conflicts agenda and Controller-Pilot Data Link Communication (CPDLC) were implemented to simulate high automation scenarios.

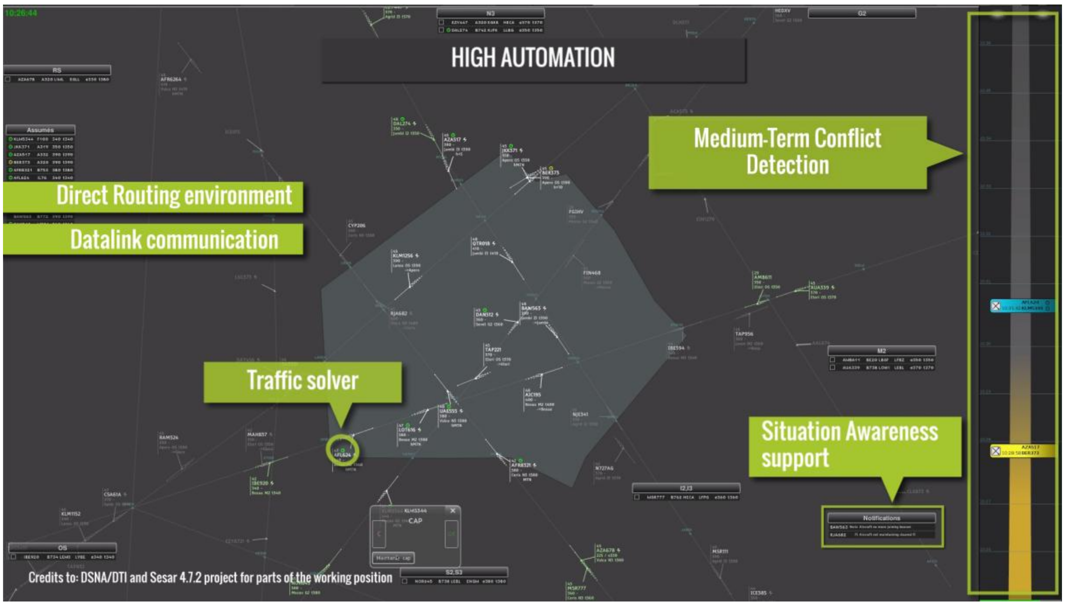


Figure 11 - The automated tools developed for the second simulation

WP3 produced, as a result, two simulation environments, respectively in AU and ENAC, ready to be engaged for the STRESS simulations, including ATC realistic scenarios of nominal and non-nominal situations and future automations.

2.3.4 Work Package 4: Validation

The WP4 objective was to run the simulation activities in order to validate the neurophysiologic indexes identified and tested in WP2 and investigate automation levels and automation disruption impact on HP. The evidences obtained from these simulation activities would be fundamental to generate automation design guidelines (WP5).

To achieve this, WP4 engaged in the following tasks:

- T4.1 - Validation Plan preparation;
- T4.2 - Validation of neurophysiologic indexes for ATM future scenarios (1st simulation);
- T4.3 - Assessment of Human Performance through the validated indexes (2nd simulation).

To generate the planning for the 2 simulations and the related validation objectives, scenarios, experimental protocol, validation methods and techniques, as well as expected results, WP4 took as input:

- The results of the future scenarios generation activity (T1.1);
- The results of the relevant Human Factors Concepts identification activity (T1.2);
- The preliminary results of the platforms preparation activities (T3.1 and T3.2);
- The preliminary results of Indexes identification, adaptation, generation and test (T2.1, T2.2, T2.3 and T2.4).

Two simulations, with different objectives (Figure 12), were carried out (Table 4).

The video of the first simulation is available here.

The video of the second simulation is available here.

	1ST SIMULATION	2ND SIMULATION
Objective:	To validate the HP indexes: Stress Vigilance Attention Workload Cognitive control behaviour	To study the impact on the HPE of: High automation Low-high-low automation transitions Automation failures
When:	05-09 June 2017	12-16 February 2018
Where:	Anadolu University (Turkey)	ENAC (France)

Table 4 - Summary of the objectives and timeframes of the two validation activities

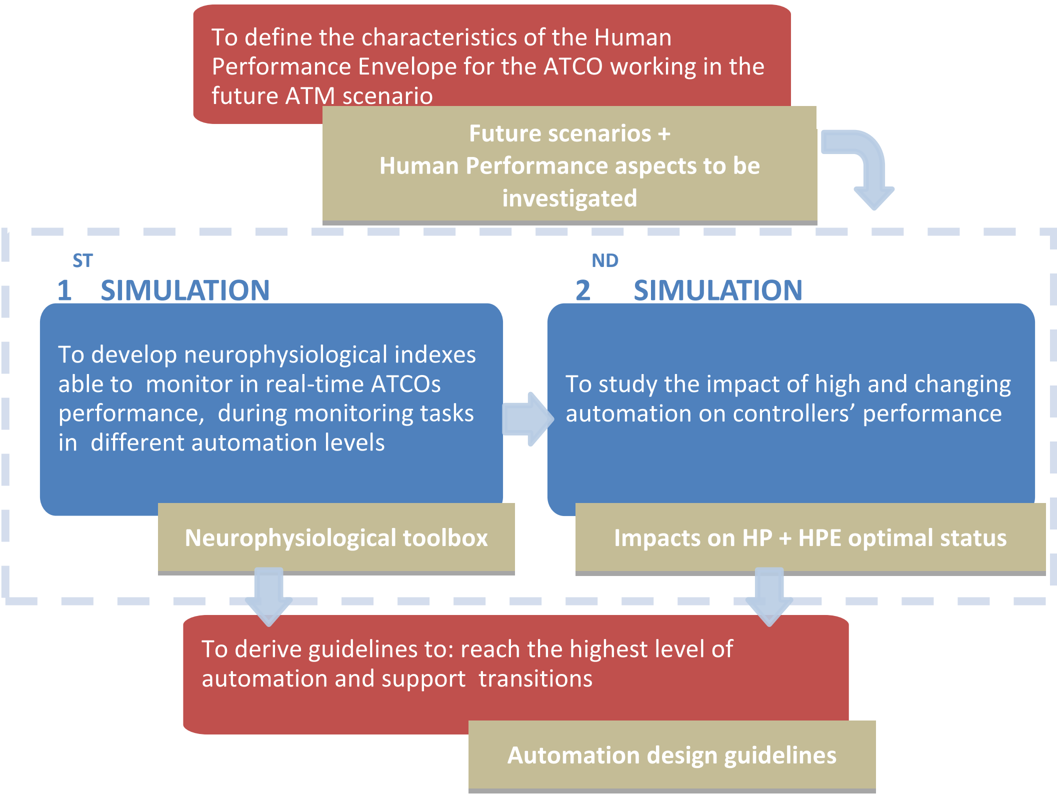


Figure 12 - Relation between first and second validations and STRESS objectives

Both the validation activities in STRESS were divided in four phases:

- Preliminary activities:
    - Future context scenarios.
    - Indexes development and laboratory test.

  - Platforms preparation.

- Simulations preparation:

  - Final scenarios generation and implementation.
  - Experiment subjects' recruitment and training on the experimental platform.
  - Data collection methods and tools set-up.
  - Platform set-up and tools integration.

- Simulations execution:

  - Recording sessions and data collection.
  - Data Analysis and results delivery.

The **first simulation** took place on the platforms developed in T3.1. A group of air traffic control students were involved in different validation exercises which simulated different levels of the human factors concepts investigated by the project (Stress, Vigilance, Attention, Workload, Cognitive control behaviour). Their reactions were analysed using the identified indexes.

A detailed data analysis **provided evidence that the indexes were capable of assessing the human factors concepts in a realistic operational context.**

The consolidated indexes were used in the framework of the **second simulation** to investigate possible configurations of the air traffic controllers' performance envelope in high automation scenarios. The study took place from the 12th to 16th of February 2018, on the platforms developed in ENAC in the framework of the task "T3.2 - Platforms preparation for Second Simulation".

The scope of the simulation was to investigate what is the impact of highly automated system both in nominal and non-nominal (failures, change of the automation level) scenarios on controllers' stress, workload, vigilance, level of attention and cognitive control behaviour.

A group of 20 air traffic controllers, both experts and students, were involved in different exercises integrating different levels of automation as well as automation levels transitions. The stress, vigilance, attention, cognitive control behaviour, mental workload levels, and HPE **were assessed through the neurophysiological indexes validated in the framework of the first STRESS simulation**.

The results of the simulation are summarised in the following table.

ID	SIMULATION OBJECTIVES	SUCCESS CRITERIA	RESULTS
VO2-1:	Assess the **impact of high automation** on ATCOs Human Performance Envelope (stress, attention, workload and cognitive control)	There is a significant difference in controllers' stress, attention, workload and/or cognitive control when working in a highly automated condition respect to a baseline condition	**We measured a significant impact of automation on ATCOs' HPE elements for both students and experts groups.**
VO2-2:	Assess the **impact of the transition** between different levels of automation on ATCOs Human Performance Envelope (stress, attention, workload and cognitive control) in non-nominal scenarios (i.e. automation failures or malfunctions)	There is a significant difference in controllers' stress, attention, workload and/or cognitive control when shifting from an highly automated condition to a baseline condition or to a system malfunctioning condition	**We measured a significant impact of automation levels transitions on ATCOs' HPE elements for students and experts groups, both during high to low level transition and during automation malfunction.**
VO2-3:	Investigate **configurations of the 4 human factors** concepts for nominal and non-nominal scenarios	There is a significant difference in controllers' stress, attention, workload and/or cognitive control levels when providing good performance respect to bad performance moments	**It was not possible to find significant good/bad HPE configurations common to students or experts. However, some single mental states trends have been detected.**

Table 5 - Summary of the results obtained by the analysis of the measures collected during the second simulation for the two groups of ATCOs

WP4 produced relevant results from a methodological point of view, providing an **innovative experimental method** to measure the impact of automation on controllers' mental state through the use of neurophysiological based measurement approach. Through this method, the project was able to gather data on the comparison between two different levels of automation and related transitions in terms of:

- **HPE assessment**: levels of vigilance, attention, workload, stress and type of cognitive control on tasks of air traffic controllers during the execution of operational tasks
- **HPE stability**: how much the levels of vigilance, attention, workload, stress and type of cognitive control vary over time during the execution of operational tasks
- **HPE index**: this is a unique index that combines all the single indexes values providing a synthetic measure of the current mental state of controllers executing operational tasks (to be optimised)
- **Optimum HPE**: HPE configurations to be associated to good and bad performance moments (for individuals)

2.3.5 Work Package 5: Automation

The goals of this WP were to support WP1 in the definition of high level of automation scenarios and to define guiding principles for the maximisation of the benefits and the mitigation of the issues associated to the levels of automations investigated through the WP4 validation activities to provide case-based indications to be used for reaching the highest possible levels of automation whilst maintaining safety and allowing adequate performance.

To achieve this, WP5 engaged in the following tasks:

- T5.1 - Contribution to scenarios generation;
- T5.2 - Guidelines generation.

A theoretical framework, to be used for the identification and definition of levels of automations, was identified to feed future scenarios generation. An already existing classification method, namely the Level Of Automation Taxonomy (LOAT), was used to model the automation scenarios using the experience from the SESAR P16.5.1 (Good Practices for Human Performance Automation Support)[14], [15]. The method helped to define both the higher level of automations scenarios and the transition to lower levels resulting from automation support disruptions and failures. The results were used to support the design of the simulation scenarios for both the first and the second simulation. For the latter, the LOAT was used as reference method to understand the HP implications of the selected automation solutions to be simulated and to identify the concerned HP issues, benefits and impacts.

As anticipated, STRESS provided different kind of automation guidelines (Figure 3), that can be related to three purposes, as follows:

- very specific ones, related to the automated solutions tested during the project (referred below as “STRESS automations assessment”);
- some ones related specifically to the STRESS Neurometrics Toolbox and its use for generating new automated solutions;
- generic ones, to be used in the concept/design phase of new automations to assess the expected impact on safety from the HP perspective (below referred as “HP impact on safety assessment methodology”).

Detailed explanation for each one follows.

STRESS AUTOMATIONS ASSESSMENT

From the experience gathered during the project, we derived some suggestions to be taken into consideration when designing or evaluating new automations or training the operators with automated tools and environments. They are especially valid when dealing with highly automated support to decision-selection and action-implementation, as the automation generated and evaluated during the STRESS project. Suggestions deal with the benefits of high automation and transition criticalities, as follows.

- **High automation benefits:**
  - HPE configuration: decrement of workload, and a more stable HPE configuration (i.e. less peaks of individual human factors).
  - Impact on controllers' work: the high automation improved performances.
  - ATCOs feedback: the tested automations are considered useful and they could bring benefits in real operations (Figure 13).
  - Based on these results, we can conclude that the automated tools tested have a positive impact, in nominal conditions, on both HPE and Performance of the selected audience.
- **Transition criticalities:**
  - The simulated failure (sudden drop from high automation condition to baseline condition) impacted HPE and performance but didn't generate excessive stress.
  - The transition back to a high level condition, with malfunctions, generated more problems to controllers, losing resources and time to verify wrong system alerts and trying to understand if there was a system problem or not (as highlighted by the higher SRK level).
  - It has to be noted, however, that they were able to keep a high HPE index, managing workload and stress and mobilising more cognitive resources when needed (during malfunction).

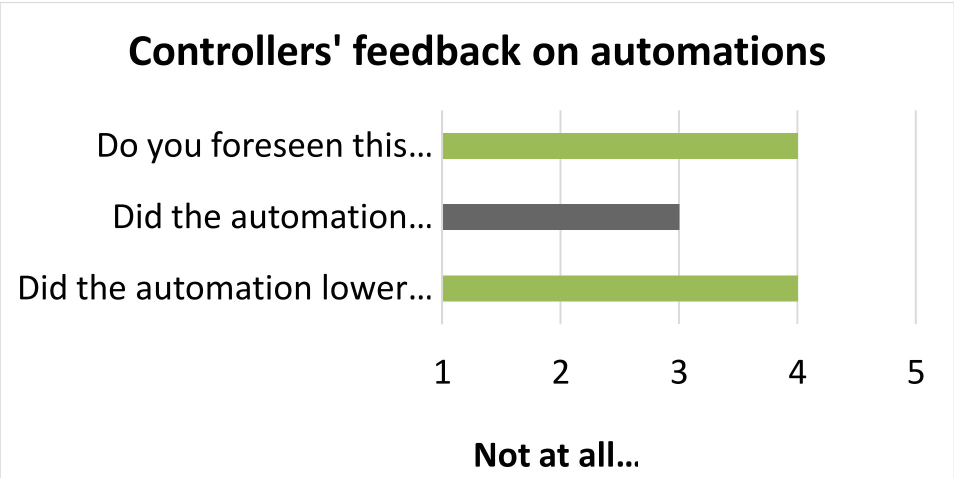


Figure 13 - STRESS automations analysis results

Guidelines for the design of new automated systems for ATC include the following suggestions and key messages (Figure 14):

- **Age/Experience differences should be considered when designing new automation** and to have realistic expectations on automation impact on controllers' work.
- **The aspect of trust should be taken into consideration when introducing new automated tools**, and this is particularly true for high level automation. The personnel's training for automation should always include a detailed explanation of the logic behind the system and should include a part in which the reliability of the automation in different contexts and conditions is proved.
- **The training for highly automated systems should include ways of checking if the proper level of proficiency and confidence is reached even in absence of easy to detect external clues** (e.g. actions of the controller on the HMI).

KEY MESSAGES from ATCOs
Controllers have trust issues in automation as support for safety yet, especially when decision making is concerned
Automation is very well accepted when it lowers workload
When human-machine interface is poorly designed, the users tend to ignore automation, losing its possible advantages
To introduce automation requires key competences (training) and roles
To introduce automation requires a clear and shared liability attribution scheme
Automation can make you passive and gives you a fake feeling of safety; the risk is that you may not be completely in control of the situation and lose attention focus on relevant information
High automation levels may reduce situational awareness
Automation support can be useful if you are experiencing acute stress (support to critical incident stress management) and/or temporary incapacitation

Figure 14 - Key messages about high automation by ATCOs

A toolbox able to assess different mental states (Stress, Mental Workload, Selective Attention, Vigilance, Cognitive control behaviour) and the Human Performance Envelope (HPE) of Air Traffic Controllers has been developed throughout the project by combining several neurophysiological signals. STRESS proposed some applications of this tool for enhancing the research activities related to automation impact assessment and to improve the design, evaluation and implementation of automated systems (Figure 15), as follows:

- In **research**, the toolbox gives the possibility to study the effects of whatever new concepts (e.g. a tool, a working environment, a procedure) on controllers HPE, understanding its impact on workload, stress, attention, vigilance and cognitive control on tasks.
- In more **applicative contexts,** the Neurometrics Toolbox can be used to assess system changes and understand their impact on controllers. For example, the tool can be used to perform the pre-operational validation of tools and procedures (e.g. to understand the capacity of a sector taking into consideration the impact of traffic on controller's workload or to find the better sector configuration in terms of impact on controllers' stress and workload).

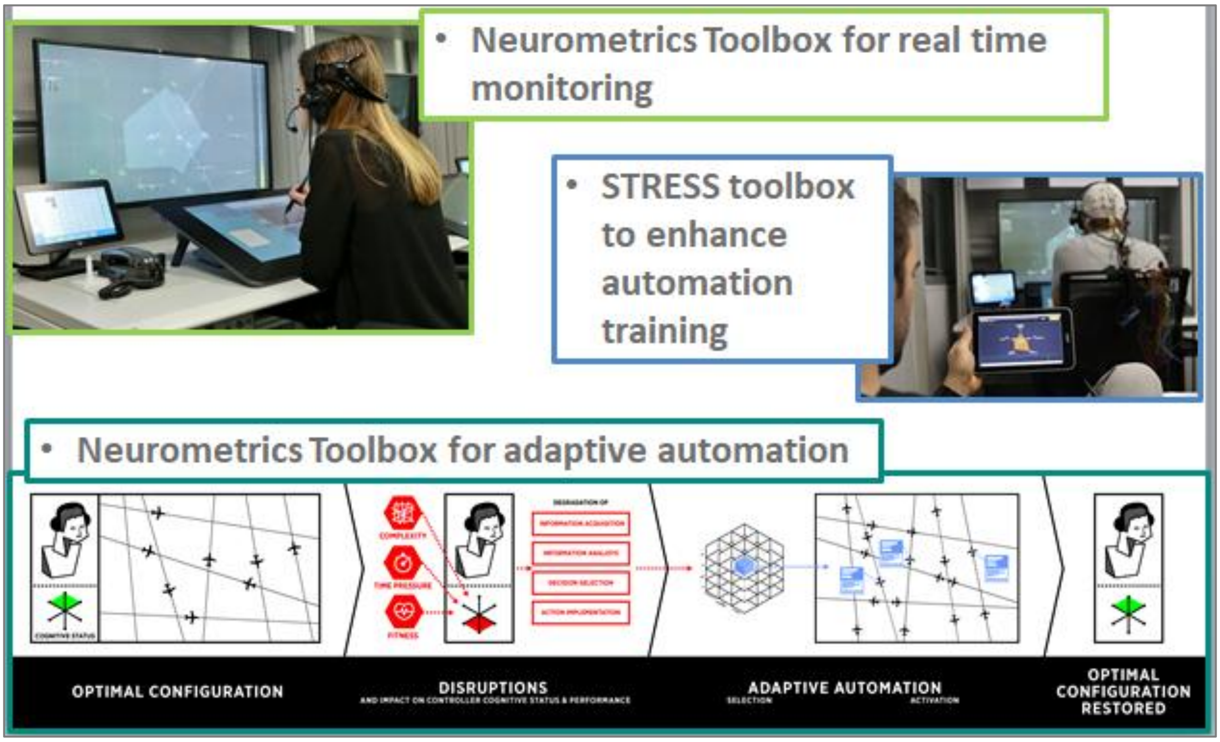


Figure 15 - The STRESS toolbox as an enabler for future automation solutions

HP IMPACT ON SAFETY ASSESSMENT METHODOLOGY

STRESS proposed a methodology, based on the Level of Automation Taxonomy (LOAT), to improve the Safety Reference Material Framework, considering the hazards related to human performance issues associated to the use of high automation (Figure 16).

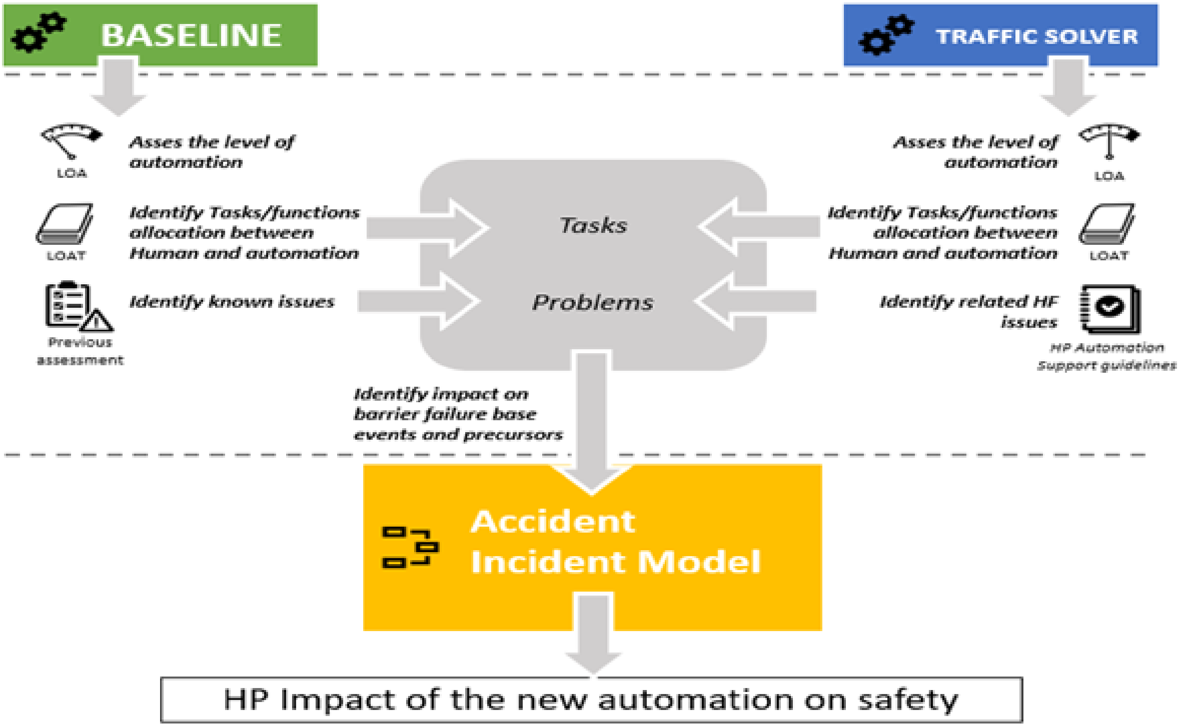


Figure 16 - STRESS guidelines on the assessment of the HP impact on safety

The proposed methodology intends to support the detection of hazards related to HP issues associated to the use of high automation, thus complementing the Safety Reference Material Framework by enriching the initial stages of the change assessment.

The method can be useful to compare baseline vs change. In fact, it integrates critical Human Performance aspects when assessing a change at both service and task level, by using the Accident Incident Model (AIM) as a guidance. Plus, it integrates the hazard identification of the baseline (existing hazards) and the HP automation issues surfacing from the assessed change (gathered from SESAR HP Automation Support Guidelines).

As per the Safety Reference Material (SRM), 4 main stages are foreseen:

- Determining the environment and limitations of the assessed ATM change
- Setting Safety Criteria: measurable criteria that, if satisfied, deem the change is safe
- Setting Safety Objectives: what has to be satisfied in order for the Safety Criteria to be reached
- Safety Requirements: what has to be done at operational level in order to make sure the Safety Objectives are reached.

The proposed methodology is envisioned to cover the first three steps. It is consistent with the general Safety and HP Assessment framework, offering a complementary approach to identifying hazards and their mitigations, eventually leading to a more robust solution design.

2.3.6 Work Package 6: Dissemination

The main objectives of WP6 were: *(i)* definition and implementation of an integrated strategy for communication, dissemination and exploitation, intended to capture the project outputs and detail how to communicate and exploit them within target audiences; *(ii)* maximisation of the impact of STRESS outcomes by communicating results and gathering feedback from the reference communities.

To achieve this, WP6 engaged in the following tasks:

- T6.1 - Communication activities;
- T6.2 - Exploitation and Dissemination activities.

Despite WP6 foresaw a unique deliverable, namely **D6.1: Dissemination, Exploitation, and Communication Report**, containing the evidences and results of all the communication, dissemination and exploitation activities performed during the project, an *Intermediate Dissemination report* was provided at the beginning of January 2018 (as explicitly requested by the Project Officers during the Intermediate Review Meeting).

The maximization of the information usage was based on the identification of groups of stakeholders who might be interested in the project findings, and on the personalization of the communication message for the stakeholder characteristics in terms of content, style and information support.

The STRESS dissemination activities were designed to match the messages to be communicated with the target audience and the means used, with the end goal of achieving awareness across a multi-layered community. Work Package 6 was entirely dedicated to the organization of the dissemination and exploitation tasks, aiming at:

1. Raising awareness, by impacting on the target audience to feed and increase awareness in the project. The main effort was devoted to make the project known, and spread information about the objectives and scope;

2. Generating understanding, by conveying specific messages to the target audience constantly during the two years of the project. To achieve this objective, the communication activities were planned to foster interaction and exchange among the target audience, showing the relevance of our work to their own practices and collecting feedback and comments;

3. Delivering key messages to key decision makers so that the developed methods, tools and best practices have an impact on policies or practices;

4. Promoting and supporting the organisation of cross fertilization exchanges with other projects, by creating and feeding synergies with other co-funded projects, whose research questions, solutions and processes could be shared to improve the quality of the SESAR and European R&D.

From the European Commission point of view, the role of dissemination in research projects is to show the relevance of the research outcomes and making better use of the results, by ensuring that they are taken up by decision-makers to influence policy-making and by industry and the scientific community to ensure follow-up. In this perspective, the STRESS dissemination goals aimed to maximise the communication effectiveness and the exploitation of the project results by decision makers and other relevant stakeholders.

The STRESS dissemination strategy was based on the identification of the desired outcomes of the dissemination, the definition and analysis of the audience that would be targeted by the communication and the definition of the strategy to achieve the desired outcomes.

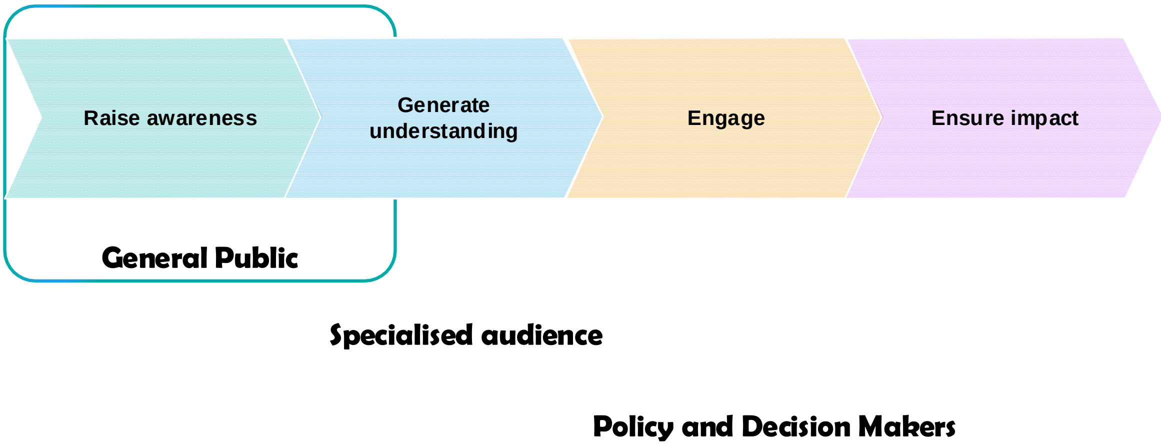


Figure 17 - Mapping between dissemination goals and target audience

A *conceptual use* of information, affecting levels of knowledge or attitude towards a research topic, was expected by the General public. The Specialized audience would use the communication in an *instrumental way*, influencing behaviour and practice. Finally, an effective STRESS dissemination was expected to produce a *strategic use* of the communication by the Decision Makers, affecting the definition of policies and broad research themes. As a result, different roles in the same organisation may require different dissemination means and activities, using different languages, content types and levels of detail for each specific target. In such a way, the dissemination and networking strategy ensured that the dissemination effort touched the target audience and produced a specific type of utilisation.

An effective and efficient communication requires that results are personalised for the different categories of target audience, in terms of content, style, format and information use. The personalisation of the STRESS dissemination messages was not limited to information content, but it also considered the style of the message and the means through which it was disseminated (e.g. document, report, web site, USB sticks, seminar, and forum). Once defined the dissemination goals and identified the target audience of the communication, the dissemination strategy consisted in an accurate matching between:

- the target audience characteristics and needs;
- the selection of the results to be communicated (tailored on the target needs);
- the identification of the proper content, means, formats, and language style to get the desired outcomes from the target audiences.

A key role in the STRESS dissemination strategy was played by the project graphical identity. Each communication from the project had to be clearly recognizable and easily connectable to the project itself. The Consortium designed a dissemination pack for internal and external communication containing the project logo and logotype (Figure 18) to ensure coherence of the communication, that is particularly relevant for the external dissemination.

Figure 18 - The STRESS logo and logotype

The STRESS dissemination activities implemented the dissemination strategy into target dissemination and exploitation actions. Figure 19 summarizes the structure of the STRESS communication and dissemination activities and initiatives undertaken from the beginning to the end of the project.

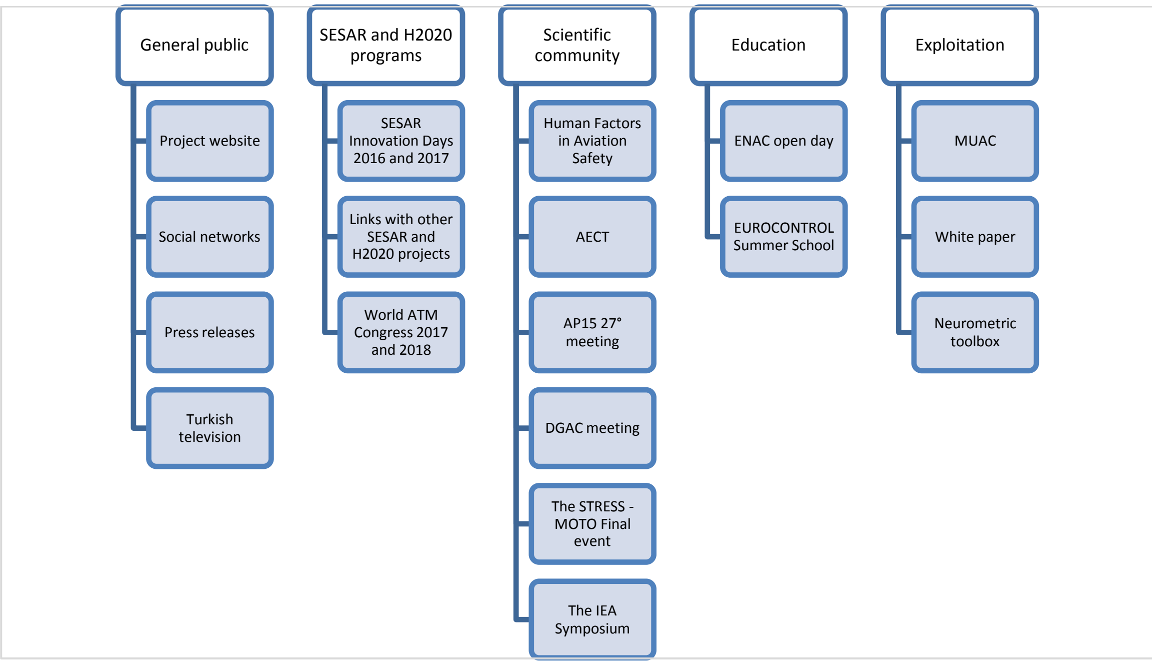


Figure 19 - Structure of the STRESS dissemination activities

The dissemination activities were structured in 5 main strands, as follows:

- Dissemination towards general public including general information on STRESS scope and objectives. Concerned dissemination actions were: i) online dissemination by means of periodic updates of the project website, in order to align it with status and achievements of the project; ii) virtual interaction with and among the followers of STRESS by means of the project social networks (twitter and LinkedIn), that were constantly updated with project materials; iii) press releases; iv) interviews for television.

- Dissemination towards the SESAR and H2020 Programmes. The related actions were organized to establish contacts and possible cooperation opportunities with the other members of SESAR long term research and H2020 projects, who were considered as target network for the cross-fertilization of the STRESS results. Concerned dissemination actions were the participation in the SESAR Innovation Days and in the World ATM Congress;
- Dissemination towards scientific community, including the participation in key Conferences and Events, which were selected on the basis of a dissemination strategy which recognized target audience, defined the aims of the communication and prepared the speeches accordingly;
- Dissemination towards education, representing the scientific value of the research carried out in the project in different academic programs;
- Exploitation of project results.

Table 6 summarizes the dissemination activities carried out for each strand and also gives reference to the concerned sections in this document. More information is provided in deliverable D6.1 Dissemination, Exploitation and Communication Report.

Strand ID	Strand		What we did
S_1	Dissemination towards general public	Project website	We developed the project website. Its structure was designed in order to make it aligned with project status and progress. A wordpress template including a backend section was chosen with the purpose of enabling a smooth and quick website update.
		Social networks	We created the twitter and LinkedIn project profiles and constantly updated with news and materials.
		Press releases	We released 7 international press releases, one french press release and 1 italian press release.
		Interview for Turkish television	The STRESS project coordinator was interviewed in the framework of the first STRESS simulation, held in Anadolu in June 2017
S_2	Dissemination towards the SESAR and H2020 Programmes	SESAR Innovation Days 2016 and 2017	We participated in the sixth SESAR Innovation Days (from November 8^{th} to 10^{th}, 2016) held at the Delft University (Netherlands) with: *i)* a fact sheet about STRESS scope and objectives; *ii)* a poster including the STRESS study in a wider research programme on human performance encompassing the MOTO and TACO projects. We participated in the seventh SESAR Innovation Days (from November 28^{th} to 30^{th}, 2017) held at Belgrade, with: *i)* a paper on the development of neurometrics for selective attention evaluation in ATM; *ii)* a poster

			including the STRESS study in a wider research programme on human performance encompassing the MOTO and TACO projects.
		MINIMA advisory board	We were invited to become a member of the MINIMA Advisory Board, which is foreseen to support the development of the MINIMA research activities. The meeting was held on the 10th of November 2016 at Technical University of Delft, The Netherlands.
		Coordination with MOTO, TACO and AUTOPACE projects	As strongly recommended by SESAR, a fruitful collaboration has been initiated with these projects for sharing information, discussing results and provide a holistic approach on these emergent challenges. In particular, we exchanged information with MOTO and TACO and also attended the AUTOPACE workshop, held on the 7th of November 2016 at Technical University of Delft, The Netherlands.
		The STRESS-MOTO Final Event	With reference to the cooperation and cross-fertilization between STRESS and the other SESAR ER Projects, a special mention should be given to the Final project dissemination event. This was jointly organized with the MOTO project and saw the TACO project as special guest. The event was entitled "Keeping the Human in the loop in the Digital ATM Era" and was kindly hosted by ENAC (Ecole Nationale de l'Aviation Civile) on May 31, 2018 in Toulouse (France). The detailed agenda, as well as the links to the presentations, are provided at http://www.stressproject.eu/final-event/
S_3	Dissemination towards scientific community	Participation in 4 international conferences	We participated in: the Human Factors in Aviation Safety Conference; the AECT (Association for Educational Communications& Technology) - Learning Trough Research In Technology; the FAA/EUROCONTROL AP15 27th Meeting; the DGAC meeting in ENAC (France).
			We published 4 scientific papers, as follows: • A New Perspective for the Training Assessment: Machine Learning-Based Neurometric for Augmented User's Evaluation, Frontiers in Neuroscience, 11, 2017

			• Adaptive Automation Triggered by EEG-Based Mental Workload Index: A Passive Brain-Computer Interface Application in Realistic Air Traffic Control Environment Frontiers in Neuroscience, 10, 2018 • Development of neurometrics for selective attention evaluation in ATM SESAR Innovation Days 2017, 28/11/2017 • Discussion on automation Effects for Human Operator's Performance in the Aviation, 1st International Symposium on Multidisciplinary Studies and Innovative Technologies, 2-4 November 2017 Tokat, Türkiye.
S_4	Dissemination towards education	Open day	We presented STRESS at the ENAC 2017 open day
		Summer school	We presented the STRESS first simulation video at the EUROCONTROL Summer School -2017 edition
S_5	Exploitation	MUAC	We demonstrated the workload assessment during a 45 minutes scenario

Table 6 - Dissemination activities carried out in the first half of STRESS (Jun 2016 - Jun 2017)

2.3.7 Work Package 7: Management

The work planned for this WP ran throughout the entire duration of the project. Its objective was to perform the strategic and operational management, ensuring the accuracy, quality and timeliness of the whole project activities and deliverables.

To achieve this, WP7 engaged in project administration and management tasks.

The delivered Project Management Plan included a MS-Project compatible Gantt chart compliant with the scheduled deadlines. The PMP also integrated a Communication and Dissemination Plan, further detailing the implementation of the foreseen communication activities, and for planning the dissemination of project results. First/Second/Third/Fourth bi-annual technical and financial reports (one for each semester) were also submitted.

Last but not least, this document is delivered in the framework of WP7 as a publishable report of the research activities carried out by STRESS in order to be used for transition to subsequent development stages.

2.3.8 Work Package 8: Ethics

The WP8 objective was to identify "ethics requirements" and provide evidence of the STRESS research activities compliance to them.

To achieve this, WP8 engaged in the ethics requirements identification and compliance tasks.

The list of requirements is provided below:

- Non-European Countries (NEC) - Requirement No. 1. The applicant must provide details on the material which will be imported to/exported from EU and provide the adequate authorisations
- Protection Of Personal Data (POPD) - Requirement No. 2. Detailed information must be provided on the informed consent procedures that will be implemented
- POPD - Requirement No. 3. Justification must be given in case of collection and/or processing of personal sensitive data
- POPD - Requirement No. 4. Copies of ethical approvals for the collection of personal data by the competent University Data Protection Officer / National Data Protection authority must be submitted.
- Misuse (M) - Requirement No. 5. Details on measures to prevent malevolent/criminal/terrorist abuse of research findings must be provided Concrete security plan with risk-mitigation measures under EUROCONTROL Guidance/Advise and with the possible assistance of the utmost experts in this field such as Anti-terrorist Agencies/Units in order to minimize the risk of potential leakage of key data to undesired recipients
- POPD - Requirement No. 6. Detailed information must be provided on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation
- Humans (H) - Requirement No. 7. Detailed information must be provided on the informed consent procedures that will be implemented.
- NEC - Requirement No. 8. The applicant must confirm that the ethical standards and guidelines of Horizon2020 will be applied, regardless of the country in which the research is carried out.
- H - Requirement No. 9. Details on the procedures and criteria that will be used to identify/recruit research participants must be provided This becomes necessary because in p. 48, applicant's themselves admit that one of the main project implementation risks is the risk not to find human subjects for the sought experiments: "We have difficulties in finding subjects for the experiment".

The STRESS documentation provided evidence of project's compliance to all listed requirements.

2.4 Key Project Results

STRESS intended to foster the transition to the SESAR vision towards higher automation levels.

2.4.1 The SESAR vision

The objective of SESAR is to modernise European ATM by defining, developing and delivering new or improved technologies and procedures, namely the **SESAR Solutions**, through funding projects. The SESAR's vision builds on the notion of trajectory-based operations' and relies on the provision of Air Navigation Services (ANS) in support of the execution of the business or mission trajectory — meaning that aircraft can fly their preferred trajectories **without being constrained by airspace configurations**.

This vision is enabled by a progressive increase of the level of automation support, the implementation of virtualisation technologies as well as the use of standardised and interoperable systems. The system infrastructure will gradually evolve with digitalisation technology, allowing Air Navigation Service Providers (ANSPs), irrespective of national borders, to plug in their operations where needed, supported by a range of information services. Airports will be fully integrated into the ATM network level, which will facilitate and optimise airspace user operations.

The latest SESAR Global demonstrations, such as the one regarding the System-Wide Information Management (SWIM), have shown that the development and evolution of the "next" generation of innovative and unconventional ideas, concepts and technologies that define the performance of the future European Air Traffic Management (ATM) system, and contribute to its successful evolution, are already in place. Indeed, as in the case of SWIM, this is no longer a concept on paper, but is progressively becoming a reality that will propel aviation into a new era of global connectivity [16]. This new era not only concerns the introduction of advanced technologies, but it will deal with revised founding principles and building blocks of information sharing, service orientation, federation, open standards, and information and service lifecycle management.

In compliance with the International Civil Aviation Organization (ICAO) and European Aviation Safety Agency (EASA) regulations and directives [17], [18], SESAR is delivering the performance necessary to meet the growing demand for air transport from a worldwide perspective in order to achieve performance ambition levels for 2035 (reported in the following figures).

Key performance area	SES High-Level Goals vs. 2005	Key performance indicator	SESAR ambition vs. baseline 2012: Absolute saving	SESAR ambition vs. baseline 2012: Relative saving
Cost efficiency: ANS productivity	Reduce ATM services unit cost by 50% or more	• Gate-to-gate direct ANS cost per flight - Determined unit cost for en-route ANS* - Determined unit cost for terminal ANS*	EUR 290-380	30-40%
Operational efficiency	-	• Fuel burn per flight (tonne/flight) • Flight time per flight (min/flight)	4-8 min 0.25-0.5 tonne	3-6 % 5-10 %
Capacity	Enable 3-fold increase in ATM capacity	• Departure delay (min/dep) - En-route air traffic flow management delay* - Primary and reactionary delays all causes • Additional flights at congested airports (million) • Networkthroughput additional flights (million)	1-3 min 0.2-0.4 (million) 7.6-9.5 (million) Additional flights, not saving	10-30 % 5-10 %[1] 80-100 %[2]
Environment	Enable 10 % reduction in the effects flights have on the environment	• CO_2 emissions (tonne/flight) - Horizontal flight efficiency (actual trajectory)* - Vertical efficiency - Taxi-out phase	0.79-1.6 tonne	5-10 %
Safety	Improve safety by factor 10	• Accidents with ATM contribution	No increase in accidents	Improvement by a factor 3-4
Security	-	• ATM related security incidents resulting in traffic disruptions	No increase in incidents	

Metrics with monetary value in business view

* Targeted by the Performance Scheme

[1] Additional flights that can be accommodated at congested airports, representing 5-10 % of flights at congested airports (~31 % of 14,4 (million) flights in 2035).
[2] Additional traffic accommodated in 2035 in comparison with 2012 and associated with ANSP productivity gains, enabled by SESAR. Note: Numbers are rounded.

Figure 20 - SESAR performance ambition levels for 2035

These levels are subject to the optimal development and deployment of the Operational Changes made possible through SESAR Solutions [19]. Their realisation follows strategic orientations described by 4 Key Features (represented in the figure below), which evolve through an ongoing Deployment and supporting Research & Development (R&D) programme.

Figure 21 - The four areas of ATM (Key Features)

The operational changes are enabled through improvements to technical systems, procedures, human factors and institutional changes supported by standardisation and regulation. The Master Plan [20] includes roadmaps of the identified changes, ensuring that their deployment is planned in a performance-driven and synchronised way (e.g. between ground and air deployments) to maximise the benefits gained.

For each key area, there are dedicated solutions. In particular, "Advanced Air Traffic Services" and "Optimised ATM network services" concern "Traffic Synchronisation" which covers all aspects related to improving arrival/departure management. It aims to achieve an optimum traffic sequence resulting in significantly less need for Air Traffic Control (ATC) tactical intervention, and the optimisation of climbing and descending traffic profiles" [21]. Free Route Airspace (FRA) Concept of Operations is one of the solutions belonging to these areas. This solution offers additional flight planning route options on a large scale across Flight Information Regions (FIRs), such that overall planned leg distances are reduced in comparison with the fixed route network and are therefore fully optimised. This solution is particularly relevant for cross border control centres located in high and very high complexity environments. Indeed, in current operations, airspace users must follow a fixed route which takes into account sector boundaries to allow for adequate controller support. With the move to a free route environment, airspace users can generate their own optimised route, which is more efficient for them.

One major challenge is that the impact of the envisioned change is hard to understand clearly, because it is different when we consider different aspects of the ATM system such as safety, security, organisation of work, economy, etc. Comparisons between alternatives are difficult to perform because, typically, no obvious "best" alternative emerges (one given solution fares better relative to some performance areas, but worst relative to others). On the contrary, the selection of a "best" alternative requires the consideration of potential limitations and trade-offs.

2.4.2 The STRESS outcomes in the light of contribution to the SESAR vision

The scope of STRESS was to **explore in an innovative and reliable way the Human Performance Envelope configuration in highly automated systems, in order to provide new knowledge and guidelines needed for the design and implementation of higher levels of automation, with the related procedures and humans' roles.**

The project fully took into account the expected future technical and institutional development, and started with the definition of scenarios focused on:

- Automation: scenarios including highly automated systems, and considering both automation failures and automation shifts
- Traffic: scenarios based on traffic with characteristics compliant with SESAR expectation, such as high number of flights, different types of traffic and SESAR concepts implementation (e.g. free-route).

In particular, STRESS produced as outcomes:

- **The HP envelope definition for future SESAR scenarios**
- **Future ATC scenarios** including highly automated supporting technologies, for assessing the changes in the human performance envelope in higher automation scenarios.
- **Validated mental states measurement toolbox** and neurophysiological signals fusion-based methodology to monitor with high time resolution the HPE of ATCOs in realistic operational environments.
- **Guidelines** for the design and implementation of innovative technologies that are compatible with human capabilities and limitations.

The table below documents the STRESS results in a systematic manner.

Results	Criteria to measure achievement	Validation session
Scenarios of SESAR operations	Positive feedback by operational and HP experts on their representativeness	Workshops with experts
Definition of the SESAR HP envelope	Positive feedback by operational and HP experts on its representativeness	Workshops with experts
Validated mental states measurement toolbox (Neurophysiological toolbox for high-time resolution assessment of workload, stress, vigilance, attention and cognitive control behaviour)	Comparison with data collected with established HF methods (e.g. controllers' subjective assessments, observational data, standard questionnaires) Comparison with established brain indicators for workload and level of cognitive control.	First validation session
HP envelope for future SESAR scenarios	Correlation between neuro-physiological toolbox measurements and performance	Second validation session

	indicators	
Guidelines (Automation guidelines in nominal and non-standard conditions)	Positive feedback by operational and HP experts on their fit for the target HP issues	Second validation session

Table 7. STRESS results, criteria to measure their achievement, and corresponding validation session.

In addition, STRESS produced a **White Paper** on follow-up research activities, in cooperation with the AUTOPACE and MINIMA projects.

Such findings are intended to provide insights for the management of the impact of the introduction of new systems for air traffic control, not only in terms of human performance assessment, but also in terms of operational training design and delivery, as well as for the design of optimal competence profiles.

2.5 Technical Deliverables

Reference	Title	Delivery Date[1]	Dissemination Level[2]
D1.1	**Future scenarios and relevant HF concepts**	**22/11/2016**	**Public** available here
This document provides an overview of the operational scenarios to be simulated in the framework of the STRESS validation activities and defines the Human Factors aspects (with related neurophysiological indicators) that are deemed relevant in shaping the Human Performance Envelope in those scenarios. As outcome, the deliverable presents the possible operational environments, the set of highly automated systems and some potential non-nominal situations worth to be simulated in light of the STRESS objectives. The set of possible tools to be used to measure the neurophysiological indicators of controllers mental status are described as well.			
D2.1	**Indexes description (interim)**	**30/05/2017**	**Confidential**
This deliverable describes the set of neurophysiological indexes to be used to measure the relevant Human Factors (HF) concepts, namely Vigilance, Attention, Stress, cognitive control behaviour and Mental Workload, during the first simulation of STRESS. In particular, it highlights: the method through which the indexes have been selected; the description of the experimental protocols, designed uniquely to elicit specific and controlled variations of the considered HFs; the preliminary results of laboratory experiments in which these indexes have been tested before being validated in an operational environment (the first STRESS validation at the Anadolu premises).			
D2.2	**Indexes description (final)**	**18/12/2017**	**Confidential**
This document describes the final set of the neurophysiological indexes of Vigilance, Attention, Stress, cognitive control behaviour, and Mental Workload, to measure the HPE in ATM, on the basis of the results of the laboratory experiments and of the first simulation. The final set of indexes has been defined as a fusion			

[1] Delivery data of latest edition

[2] Public or Confidential

of the neurophysiological features identified in the first part of the project. An example of a possible representation of the Human Performance Envelope concept, as the configurations of vigilance, attention, stress, level of cognitive control and workload, has been generated reflecting the results of the first simulation. A proposal for the development of a combined index is also presented.			
D3.1	First Validation Preparation	25/05/2017	Confidential
This document presents the work done to organise the preparation of the simulation environment that hosted the first STRESS simulation, consisting of *platform* and *experimental setting*. The main objective of the preparatory work was to ensure compliance of the simulation environment with the validation technical requirements. The document describes the characteristics of the technical platform and how it met the needs of the experimental plan, that are basically to be able to simulate, in an ecological environment, different levels of workload, vigilance, level of cognitive control, stress and attention.			
D3.2	Second Validation Preparation	12/12/2017	Confidential
This document presents the validation plan for the second STRESS simulation, that was then held in the ENAC premises from 12 to 16 February 2018. The overall aim of the simulation was to monitor the controllers' mental state during automation levels transitions scenarios, using the indexes validated during the first STRESS simulation, held in the Anadolu premises in June 2017. The plan of the simulation includes: the objectives, scenarios, protocol and schedule; the platform technical preparation; a readiness assessment and an evaluation of risks with mitigation actions as a conclusion.			
D4.1	Validation Plan	02/06/2017	Confidential
This document provides details regarding the experimental plan of the two validation activities foreseen within the STRESS project. In particular, it describes the context of the validation activities of STRESS, including the schedule of simulation 1 and 2, detailing related objectives and reporting the summary of two workshops with Air Traffic Controllers (ATCOs), carried out as scenarios generation preparatory activities.			
D4.2	Indexes Validation Report	30/10/2017	Confidential
This document presents the first simulation of STRESS, carried out at Anadolu University (Eskişehir Turkey) on June 2017, reporting its objectives, how it has been organised and carried out, and its results. The objective of this first validation activity was to verify that the neurophysiologic indexes developed in laboratory were able to assess vigilance, attention, stress and cognitive control in a realistic ATM environment. The simulation results provided evidence that a clear correlation exists between neurophysiological variables and the human factors.			
D4.3	Performance Assessment Report	30/04/2018	Confidential
This document presents the second simulation of STRESS, carried out at ENAC (Toulouse, France) on February 2018, reporting its objectives, how it has been organised and carried out, and its results. The objective of this simulation activity was to assess the automation impact on the air traffic controllers' Human Performance Envelope, measured in high time resolution through neurophysiological indexes of vigilance, attention, stress, workload and cognitive control on tasks during the execution of operational tasks in highly automated scenarios. Findings of the simulation highlight the following results: a significant impact of automation on ATCOs' HPE for both students and experts groups; a significant impact of automation levels transitions on ATCOs' HPE for students and experts groups, both during high to low level transition and during automation malfunction; some trends about good/bad HPE configurations common to students or experts.			
D5.1	Automation guidelines	20/05/2018	Public available here
This deliverable lists the automation guidelines generated through the analysis of the results coming from the STRESS validation activities. The proposed guidelines are meant to work as a means to enhance the benefits related to the automation solutions in future scenarios and to mitigate the related issues. Three kinds of guidelines are presented: the first set of guidelines consist of specific recommendations for the refinement of future systems for Air Traffic Control, and are based on the results of the STRESS second simulation; the second set of guidelines are suggestions for the use of the STRESS neurophysiological measurement toolbox as support tool for three different activities: automation design, automation			

evaluation and training for automation; the third set of guidelines consist of a method to identify the Human Performance issues of new automation solutions and integrate them as hazards into the Accident Incident Model developed by SESAR.			
D6.0	**Intermediate Dissemination, Exploitation and Communication Report**	**09/01/2018**	**N/A**
This document was not foreseen in the Grant. It was submitted upon request made by the Project Officers during the Intermediate Review Meeting. It describes the Work Package 6 communication and dissemination activities carried out in the first year of the STRESS project, namely from June 2016 to July 2017. It also presents some information about the feedback received from the audience following these dissemination activities when available.			
D6.1	**Dissemination, Exploitation and Communication Report**	**12/06/2018**	**Public** available here
This document describes the Work Package 6 communication and dissemination activities carried out in the framework of the whole STRESS project duration, running from July 2016 to June 2018. It also presents some information about the feedback received from the audience following these dissemination activities when available. The main objectives of STRESS WP6 were to disseminate knowledge on the scientific and technical achievements, to build awareness on the project and on its potential impacts. The execution of the Dissemination plan led to good results, as the defined activities contributed to the spread of awareness about project's activities across the reference communities and to a proactive and valuable involvement of external stakeholders.			
D7.1	**Project Management Plan**	**12/12/2016**	**Confidential**
This document presents the Project Management Plan (PMP) of the STRESS project. The document complements the project information provided in the Grant Agreement and its Annex I - Description of Action, integrating in particular more detailed procedures, briefly describing the Communication and Dissemination Plans, addressing the Ethics Requirements and implementing any additional refinement agreed at the Kick-off meeting.			
D7.2	**Project Results Final Report**	**17/07/2018**	**Public** Will be available here after SJU approval
This is the current document. It describes the results of the STRESS project, providing evidence of the work carried out and including: conclusions and lessons learnt; the project maturity assessment; the highlight of the STRESS contribution to the SESAR Operational Improvements.			
D8.1	**NEC – Requirement No. 1**	**24/10/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.1 set out in WP8 Ethics. Such requirement concerns research activities involving Non-European Countries (NEC): "The applicant must provide details on the material which will be imported to/exported from EU and provide the adequate authorisations".			
D8.2	**H - Requirement No. 7**	**11/08/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.7 set out in WP8: "Detailed information must be provided on the informed consent procedures that will be implemented".			
D8.3	**POPD – Requirement No. 6**	**24/10/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.6 set out in WP8 Ethics. Such requirement concerns the protection of personal data (POPD): "Detailed information must be provided on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation".			

D8.4	**H - Requirement No. 9**	**24/10/2016**	**Confidential**
This document presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n. 9: "Details on the procedures and criteria that will be used to identify/recruit research participants must be provided".			
D8.5	**POPD – Requirement No. 3**	**24/10/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethics requirement n.3 set out in WP8: "Justification must be given in case of collection and/or processing of personal sensitive data".			
D8.6	**POPD - Requirement No. 2**	**11/08/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.2 set out in WP8: "Detailed information must be provided on the informed consent procedures that will be implemented".			
D8.7	**M - Requirement No. 5**	**19/09/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.5 set out in WP8 Ethics. Such requirement concerns the misuse of research data (M): "Details on measures to prevent malevolent/criminal/terrorist abuse of research findings must be provided".			
D8.8	**POPD – Requirement No. 4**	**07/08/2017**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.4 set out in WP8 Ethics. Such requirement concerns the protection of personal data (POPD): "Copies of ethical approvals for the collection of personal data by the competent University data protection Officer / National Data Protection Authority must be submitted".			
D8.9	**NEC – Requirement No. 8**	**24/10/2016**	**Confidential**
This deliverable presents the procedures followed by the STRESS Consortium to ensure compliance with the ethic requirement n.8 set out in WP8 Ethics. Such requirement concerns research activities involving Non-European Countries (NEC): "The applicant must confirm that the ethical standards and guidelines of Horizon2020 will be applied, regardless of the country in which the research is carried out".			

Table 8 - Project Deliverables

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

Among the outcomes of STRESS, the mental states measurement toolbox (from now on, referred as "**toolbox**") and the **guidelines** are considered of relevance in the light of the project contribution to the ATM Master Plan.

Due to its capacity to measure objectively and with high time resolution the level of vigilance, attention, stress, workload and cognitive control behaviour, the STRESS toolbox could be engaged in several ways and at different levels of the ATM system, as follows:

- At training level, as an Air Traffic Control training tool, to assess the level of expertise and feed debriefings
- At research and development (R&D) level, as an automation evaluation tool, useful to assess the impact of new systems on Human Performance in the framework of system validation studies and / or to design adaptive automation
- At operations level, to support workers in difficult situations (stress, overload, fatigue, etc)

For example, the toolbox could be used for assessing the airspace configurations' and new systems' impact on workload and attention of air traffic controllers, not only in the framework of validation studies for the assessment of different options, but also in the framework of ATCOs training programmes for the assessment of the their level of cognitive control on concerned operational tasks.

Moreover, through the workload neurophysiologic measurement enabled by the toolbox, STRESS provides additional support to dynamic sectorisation, by providing a measure of sector capacity based on the "mental" capacity of ATCOs to handle traffic volumes and complexity, so in line with human characteristics. In this way, the STRESS approach provides measures and tools to support the collaborative decision-making process, thus promoting the right balance among several stakeholders.

The STRESS toolbox could also support adaptive teamwork organization by providing neurophysiologic high time resolution measures of ATCOs stress, vigilance, attention and workload, thus enabling the recognition of potential needs of support within the team. This aims at facilitating the recognition of particular needs potentially emerging in specific situations, thus facilitating the transition towards new configurations of controllers' teamwork, and associated supporting procedures, as for instance: *i)* that the Planning Controller provides support to several Tactical Controllers operating in different sectors. In this configuration, the Planning Controller ensures suitable coordination agreements between sectors and assists in managing the workload of the Tactical Controllers, thus ensuring that potentially critical traffic situations and the associated workload are manageable for the Tactical Controllers at the time of occurrence; *ii)* that a single controller undertakes both the planning and executive roles for a sector.

These are only examples of possible contexts of application and don't intend to exhaust the applicative potential of the toolbox.

The STRESS automation guidelines could help the design of highly automated systems for air traffic control, as for instance automatic conflict solvers, by identifying possible hazards related to HP issues, thus facilitating the identification of target mitigation measures for critical events management. In this light, the STRESS guidelines on adaptive automation could provide support recommendations for managing such critical situations.

The aforementioned makes evident that the STRESS results make no direct contribution to the ATM Master Plan in terms of Operational Improvements (OIs), since such results are quite transversal and could be applied to several OIs.

For this reason, the STRESS results could rather feed the set of Enablers of the ATM Master Plan. SESAR defines as Enabler a "*New or modified technical system/infrastructure, human factors element, procedure, standard or regulation necessary to make (or enhance) an operational improvement*" (please refer to https://www.atmmasterplan.eu/data/enablers). Currently, *human factors elements* concerning the neurophysiological measurement of mental states as well as automation design guidelines are missing within the set of the ATM Master Plan Enablers.

STRESS intends to bridge this gap by proposing the toolbox and the guidelines as two new Enablers for the ATM Master Plan (Table 9).

Code	Name	Project contribution	Maturity at project start	Maturity at project end
EN_1	Toolbox	Neurophysiologic high-time resolution measurement toolbox, to collect levels of ATCOs workload, vigilance, attention, stress and cognitive control behaviour at training, operations and R&D levels.	TRL0	TRL1
EN_2	Guidelines	Guidelines for the design of highly automated and/or adaptive systems, and for the identification of HP hazards related to hi automation	TRL0	TRL1

Table 9: Project contribution to the ATM Master Plan

3.2 Maturity Assessment

What follows is the maturity assessment of, respectively, the toolbox (Table 10) and the guidelines (Table 11).

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Achieved	The SESAR transition towards higher automation levels entails a change of roles and tasks of ATCOs. At the EU level there are projects currently addressing the research goal of monitoring the impact of such changes on the HPE configurations. However, all these projects share a common assumption (and its consequence). First, that research is mainly being carried out on pilots and cockpits. Second, that there is a clear definition of the future scenario for pilots and of the corresponding Human Performance (HP) implications. A corresponding work on the ATCO role is still to be performed. This was a major research opportunity, which was addressed by STRESS main concepts. In the STRESS public deliverable D1.1 Future scenarios and HF concepts (see section 2.5), STRESS provided **an overview of future ATM scenarios and highlighted the most impacted Human Factors to be taken into consideration** for assessing the ATCOs future HPE through neurophysiological indicators. Neurophysiological indicators are quite advanced today, offering a unique opportunity to objectively monitor the HP envelope. The research gap addressed by STRESS is the customization of these indicators to (future) ATM tasks. While neurophysiology knows what to monitor to detect stress, it may be the case that **what is called stress in ATM (by using everyday language) corresponds to different patterns of neural activity, as compared to everyday stress.** These concepts have an everyday meaning and are being studied in contexts different than ATM. In addition, aviation research on neurophysiological indicators have mostly focused on cognitive concepts, traditionally disregarding the emotional aspects concerning stress perception and management. This oversimplification is

			hard to justify at the light of current neurophysiological knowledge, where **stress have been shown to play a key role in "cognitive" processes like decision-making or attentional focus.** To capture this level of complexity, STRESS **aimed to customize existing neurophysiological indicators to future ATM, in order to measure the HP envelope with neurophysiological indicators.**
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	Partial – Non blocking	The STRESS research on future HPE configurations has **quantified levels of the HFs under assessment**. Each factor, as for instance workload, was given a value (low/high) corresponding to a target range of the neurophysiologic signals scores collected by means of the toolbox.
TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.	Achieved	Some gaps have been identified with reference to the toolbox equipment usability and acceptability. In fact, the sensors are not completely ergonomic and require time to be mounted. Moreover, their calibration phase should also be shortened, to permit the use of the indexes within the compressed timetables of pre-operational validations and, in the future, in operational contexts.
TRL-1.4	Has the concept/technology under research defined, described, analysed and	Achieved	The analysis that STRESS performed throughout the experiments in both controlled (i.e. Laboratory) and ecological settings (i.e. ATM simulator at Anadolu University) provided the **most correlated neurophysiological features to the considered mental states**, namely mental workload, stress, attention, vigilance and cognitive control

	reported?		behaviour. The neurophysiological features have been **properly combined in order to define indexes able to track and objectively measure the controller's mental states while dealing with ATM activities.** Such indexes have been tested and validated on the ATM scenario designed for the First Validation experiments. A summary of the definition of the Fusion-based Indexes is described as follows: • Mental workload: EEG • Stress: EEG, ECG, GSR • Attention: EEG, GSR • Vigilance: EEG, GSR
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Partial – Non blocking	The STRESS toolbox provides contribution to Safety and Capacity of the SESAR performance framework (Figure 20). As already anticipated, through the workload neurophysiologic measurement enabled by the toolbox, STRESS provides additional support to dynamic sectorisation, by providing a measure of sector capacity based on the "mental" capacity of ATCOs to handle traffic volumes and complexity, so in line with human characteristics. In this way, the STRESS approach provides measures and tools to support the collaborative decision-making process, thus promoting the right balance among several stakeholders. Moreover, through the vigilance and attention neurophysiologic measurement enabled by the toolbox, STRESS provides additional support to the HP and Safety analysis of new automated systems for conflict detection and resolution.

TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	Achieved	The STRESS neurophysiological measurement toolbox may be applied to the following: *(i)* the evaluation of the automation impact on the HPE in the framework of validation and evaluation activities of new systems for ATM; *(ii)* ATCOs training programs to support the learning objectives related to the use of new ATM automated systems; *(iii)* airspace capacity, airspace design and other pre-operational evaluation activities; (iiii) adaptive automation; (iiiii) real time monitoring of controllers' mental state. More information is reported in the STRESS public deliverable D5.1 Automation Guidelines (see section 2.5).
TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	Not applicable	
TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	Achieved	Aviation stakeholders provided positive feedback on the project results. They highlighted that the mental state measurement toolbox developed by STRESS could be applied at several ATM organizational levels, as follows: *(i)* as a training tool, to assess the level of expertise and feed debriefings; *(ii) a*s an automation evaluation tool, useful to assess new systems from a HP perspective and also to compare the HP impact of different solutions; *(iii) f*or research in the area of safety and HP, for example ageing performance; *(iv) i*n operations, to support workers in difficult situations (stress, overload, fatigue, etc). On the other hand, they highlighted as possible drawbacks: *(i)* the neurophysiological measurement equipment dress-up process (too long, intrusive); *(ii)* a possible misuse of measurements results (for hiring or discrimination). These aspects are taken into consideration by STRESS as recommendations and lessons

			learnt.
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	Achieved	STRESS published four research papers: • A New Perspective for the Training Assessment: Machine Learning-Based Neurometric for Augmented User's Evaluation, Frontiers in Neuroscience, 11, 2017 • Adaptive Automation Triggered by EEG-Based Mental Workload Index: A Passive Brain-Computer Interface Application in Realistic Air Traffic Control Environment Frontiers in Neuroscience, 10, 2018 • G. Borghini, M. Ragosta, P. Aricò, S. Bonelli, G. Di Flumeri, N. Sciaraffa, P. Tomasello, D. Mancini, A. Colosimo, F. Babiloni (2017), Development of neurometrics for selective attention evaluation in ATM SESAR Innovation Days 2017, 28/11/2017 • U. Turhan, B. Açıkel, T.Güneş (2017), Discussion on automation Effects for Human Operator's Performance in the Aviation, 1st International Symposium on Multidisciplinary Studies and Innovative Technologies, 2-4 November 2017 Tokat, Türkiye.
TRL-1.10	Have the research hypothesis been formulated and documented?	Achieved	The STRESS public deliverable D1.1 Future scenarios and HF concepts (see section 2.5) **identified the most impacted Human Factors to be taken into consideration** for the STRESS experiments assessing the ATCOs future HPE. These were: stress, vigilance, attention, cognitive control behaviour and workload.

TRL-1.11	Is there further scientific research possible and necessary in the future?	Achieved	Stress and fatigue are among the current hottest topics in ATM. Stakeholders are keen to learn about frameworks, approaches and mitigations, and the STRESS dissemination results provided further evidence of the great interest in such topics. The STRESS methodology and approach could be applied to fatigue: neurophysiological indicators of fatigue for ATM may be derived in the same way as the ones of vigilance, attention, workload, stress and cognitive control behaviour were.
TRL-1.12	Are stakeholders interested about the technology (customer, funding source, etc.)?	Partial – non blocking	Initial exploitation of the STRESS results was carried out at the Maastricht Upper Area Centre (MUAC). In this perspective, the STRESS toolbox was used to assess airspace capacity on the basis of a real-time measurement of ATCOs workload. Feedback gathered during the activity demonstrates a pretty high interest in this kind of approach for capacity assessment.

Table 10: Toolbox Maturity Assessment

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Achieved	The European research agenda is working to introduce higher levels of automation in air traffic control. These are expected to autonomously (or partially autonomously) manage decision making and action implementation tasks currently carried out by human operators and/or to support humans in making decisions that the operators will hardly be in a position to question. Such a monitoring role will probably require even more vigilance and attention than it is required today. Lack of user involvement in automation assisted processes may in fact lead to reduced vigilance and loss of situation awareness. The allocation of certain tasks to the system may also lead to the operators becoming deskilled, as skills deteriorate when they are not used. The implication of skill loss is that when an

			operator is forced to take over an automated system manually, he or she is likely to do so with minimal information and skill. This highlights an often unforeseen problem relating to the impact of the automation in abnormal conditions or in degraded modes of operations. Stress and workload may be prominent in this light. The STRESS guidelines aim to support the design of future technologies and ensure they are in line with human capabilities and limitations. They are based on the results of the STRESS experiments and are extensively presented in the STRESS public deliverable 5.1 Automation Guidelines (see 2.5).
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	Partial – Non blocking	The LOAT (see 2.3.5) was used in the project to assess the levels of automation provided by future ATM technologies, and the corresponding impacts on the division of tasks between humans and machines, **thus acting as key framework for the development of automation guidelines**. The LOAT structure is a matrix. Reading horizontally, the taxonomy proposes four cognitive functions: information acquisition (A), information analysis (B), decision-making (C) and action implementation (D). Reading vertically, each function groups a number of automation levels that was deemed suitable for each cognitive function. All columns start with a default level '0' corresponding to manual task accomplishment, without any technical support. The levels increase up to full automation. At Level 1 the human accomplishes a task with 'primitive' technical support, not involving automation. Any non-automated means that support the human mind, e.g. using flight strips to compare parameters of different aircraft and to pre-plan future traffic, could correspond to this intermediate level. From level 2 on upwards, 'real' automation is involved.

			The classification of the level of automation of any new operational concept is provided according to the concerned cognitive function. This means that a certain technology may have different levels of automation according to whether we look at the information acquisition (A), information analysis (B), decision-making (C) or action implementation (D) fields. Examples of technologies are included in the LOAT, to facilitate the reader in understanding how to interpret and use the table for the classification of a technology. Detailed information on the LOAT is presented in the STRESS public deliverable D1.1 Future scenarios and Human Factors concepts (see 2.5). **The main reasons for using the LOAT to develop the STRESS guidelines were the following:** • *Supporting conceptualisation*. The LOAT expresses varying levels of interaction between the human and the technology. In the first instance, it is used to understand technology better. It provides an accurate account of human-machine interaction and serves as a tool to refine the concept of automation, by providing a human factor based conceptualization of automation. Secondly, the LOAT helped to define baseline and future levels of automations, providing a reference tool to assess future increasingly automated systems. • *Embedding and connecting the Safety assessment with human factor research*. In addition to providing a better conceptual analysis of technologies from a human factors perspective, the LOAT can foster the definition of HF issues acting as safety hazards, thus linking the terminology of the Safety assessment methodologies to the framework of human factor based research projects.

TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.	Partial – Non blocking	Some gaps have been identified with reference to the STRESS guidelines. STRESS designed high-level guidelines to broaden the scope of its recommendations. This requires pretty much time and effort when they are customized to real applications.
TRL-1.4	Has the concept/technology under research defined, described, analysed and reported?	Partial – Non blocking	In the STRESS public deliverable D5.1 Automation Guidelines (see 2.5) the guidelines developed by the project were applied to a case study, namely related to the automatic conflict solver, an air traffic control tool that automatically implements conflict resolution through speed adjustment. The aim was to show how the STRESS guidelines could complement the safety assessment when considering a change in the ATM system implying a remarkable transition towards higher automation support levels. This is mainly because the human operator can be influenced or impacted in ways that are safety critical, but not necessarily captured by a traditional Safety Assessment. In order to do so, use has been made of the LOAT (see 2.3.5) in order to identify appropriate levels of automation and the implied change in terms of automation levels. Relevant Human Performance Issues were listed, arising either from the new system or identified as improvement areas of the part of the system being changed. These issues were then grouped and a few categories of interest emerged: Workload, memory, situational awareness and time management. These Focus

			Areas are then considered when assessing the HP impact on the Mid-Air Collision Accident Incident Model, which is generally used in the Safety Assessment. The results are HP considerations, questions and trade-offs that can potentially influence the mitigations design or the operational implementation of the new tool.
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Partial – Non blocking	With reference to the SESAR performance framework (Figure 20), the STRESS guidelines mainly contribute to Safety. In fact, the STRESS guidelines provide a method of analysis aimed to **detect hazards related to human performance issues associated to the use of high automation.** **Detailed information is available in** the STRESS public deliverable D5.1 Automation Guidelines (see 2.5).
TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	Partial – Non blocking	The STRESS guidelines provide high level recommendations that can be followed when designing new technologies to support air traffic control tasks. **Detailed information is available in** the STRESS public deliverable D5.1 Automation Guidelines (see 2.5).
TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	Not applicable	

TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	Partial – Non blocking	Aviation stakeholders provided positive feedback on the project results. In line with this, interest was shown towards the STRESS guidelines. Nevertheless, these should be further tested and validated.
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	Partial – Non blocking	The STRESS guidelines have not been published on Conference proceedings or scientific journals. Nevertheless, the STRESS deliverable D5.1 has been made publicly available via the project website (www.stressproject.eu/outcomes).
TRL-1.10	Have the research hypothesis been formulated and documented?	Not Achieved	No hypotheses on possible applications of the STRESS guidelines have been formulated yet.
TRL-1.11	Is there further scientific research possible and necessary in the future?	Partial – Non blocking	The STRESS guidelines may be applied in the framework of future technologies validation projects.
TRL-1.12	Are stakeholders interested about the technology (customer, funding source,	Not Achieved	Even if the stakeholders feedback on the STRESS guidelines was positive, no hypotheses on possible exploitations have been formulated yet.

	etc.)?		

Table 11: Guidelines Maturity Assessment

4 Conclusion and Lessons Learned

4.1 Conclusions

STRESS **explored in an innovative and reliable way the Human Performance Envelope configuration in highly automated systems, in order to provide new knowledge and guidelines needed for the design and implementation of higher levels of automation, with the related procedures and humans' roles.**

The innovative aspect of the project was to apply the neurophysiological approach to the ATM domain, by providing new methods and tools for the assessment of the human performance. To achieve this, STRESS brought together neurophysiological experts (the partners from Unisap), ATM experts (the partners from AU, ENAC and EUROCONTROL) and Human Factors Experts (the coordinator, DBL). The human factors knowledge was used to select relevant HF concepts for future ATM: the ones selected were vigilance, attention, stress, workload and cognitive control behaviour. The subsequent step was to derive, test and validate neurophysiological indicators for each of the identified HFs. A mental states measurement toolbox was developed as a result. This was engaged to measure the impact of automation on ATCOs mental states during the execution of air traffic control tasks, in a simulation environment reproducing the complexity of future scenarios and highly automated systems able to carry out decision making and action implementation tasks.

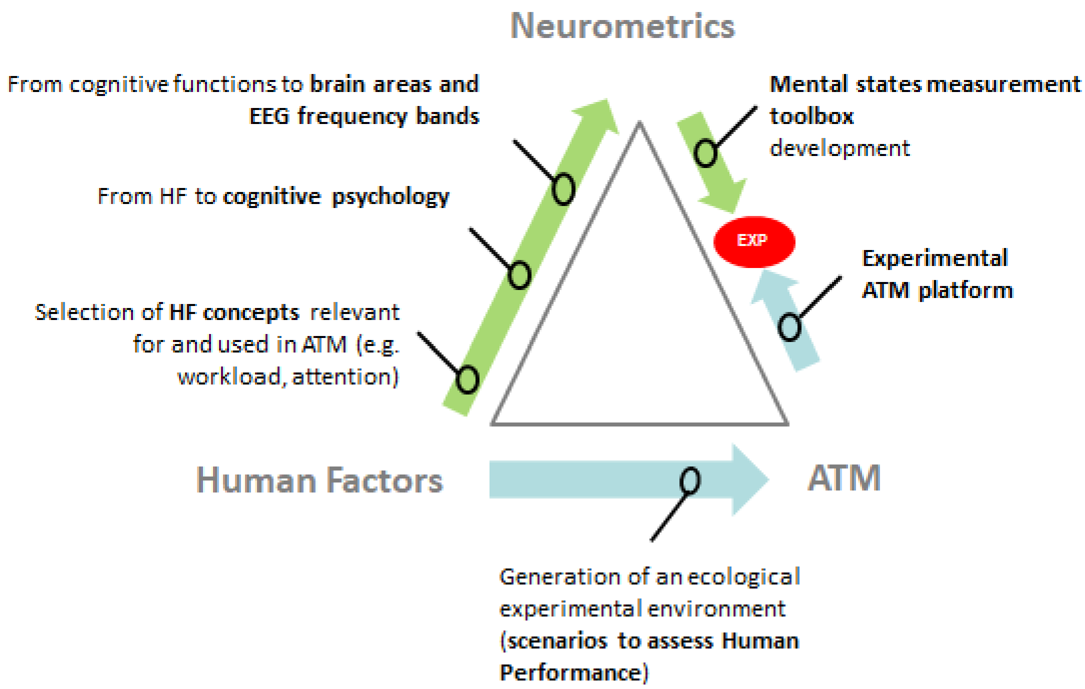


Figure 22 - Multidisciplinary approach

The key outcomes of STRESS are:

- **A validated mental states measurement toolbox** and neurophysiological signals fusion-based methodology to monitor with high time resolution the HPE of ATCOs in realistic operational environments.
- **Guidelines** for the design and implementation of innovative technologies that are compatible with human capabilities and limitations.

The continuous interaction within the Consortium as well as with external operational experts supported the whole process, aligning the neurophysiological approach with the domain-specific terminology, and in exploiting already available taxonomies and knowledge bases.

Stakeholders provided positive feedback on the project results, and also gave advice for the application of the STRESS approach. In particular, they highlighted that the mental state measurement toolbox developed by STRESS could be applied at several ATM organizational levels, as follows:

- As a training tool, to assess the level of expertise and feed debriefings
- As an automation evaluation tool, useful to assess new systems from a Human Performance perspective
- For research in the area of safety
- In operations, to support workers in difficult situations (stress, overload, fatigue, etc)

This feedback will be taken onboard by STRESS to design possible follow-up research activities. On the other hand, they highlighted as possible drawbacks:

- The neurophysiological measurement equipment dress-up process (too long, intrusive)
- A possible misuse of measurements results (for hiring or discrimination)

These will be taken into consideration by STRESS as recommendations and lessons learnt.

4.2 Technical Lessons Learned

From WP1	**Lessons Learned from Future Scenarios and HF concepts**
Engaging in the envisioning of detailed future scenarios, in terms of automated systems and innovative procedures, was not an easy task. STRESS addressed this challenge not only through an extensive SESAR literature review, but also by providing insights on automation levels transitions, based on reliable automation frameworks and theories. The LOAT developed by SESAR was a very effective tool to catch the operational character of future systems, even without envisioning in detail their technical features. Based on LOAT levels it was possible to anticipate future challenges and needs related to human-machine interaction. In this light, the LOAT could be used also in the future as a tool to envision and design future ATM scenarios, based on SESAR vision and expectations.	
The involvement of ANSP in the design of future scenarios and validation of the hypotheses on relevant Human Factors was carried out to feed the design of validation scenarios to be engaged in the framework of the STRESS experiments. ATCOs and operational experts were invited to dedicated workshops, in which their feedback was collected, and then analysed. In particular, the	

Turkish ATCOs Association (TACTA) and the Italian ATCOs Association (ANACNA) were involved. Such involvement revealed very useful for the realism and effectiveness of the experimental design of STRESS, thus preventing the risk related to late identification of bugs and problems.	
From WP 2	**Lessons Learned from Neurophysiologic indexes**
Capability and reliability of neurophysiological of indicators: the neurophysiological measures demonstrated the capability to provide additional and very useful information for a better assessment of the operator. However, depending on the task and environment, high attention should be paid on the kind of sensors and neurophysiological signals to consider and collect. In fact, if the sensors are not comfortable and ergonomic, they could be rejected by the operator. The calibration phase should also be shorten, to permit the use of the indexes within the compressed timetables of pre-operational validations and, in the future, in operational contexts.	
Usability and acceptability of neurophysiological measurement tools: both ATC Experts and Students reported high interest on the neurophysiological measures throughout the STRESS experiments. However, the knowledge and use of neurometrics in operative environments is not common yet. This could be probably due to the lack of communication, unfamiliarity with such technology, and advantages in terms of economic, social, and professional outcomes in employing the neurometrics. More effort will be done for making the neurometrics commonly used in order to better support both the Instructors and the Operators.	
From WP3	**Lessons learned from Platform preparation**
The platform proposed must be robust and realistic enough to provide a working environment that correspond to controller’s usage.	
Communication between partners ahead of the development is essential to anticipate the needs and have a mutual understanding of the capability of the platform.	
Both platform preparations, at Anadolu University or at ENAC, are based on existing technologies. This requires people having an excellent knowledge of their software to fit the project expectations and get around limitations.	
From WP4	**Lessons learned from Validation**
Users involvement in scenario design and implementation: the **inclusion of the ATCOs** already during the design of the simulation scenarios has been one of the pillars of the project. This feature of the project was already recognised during the preliminary Workshops of STRESS as a key strength point with respect to the so called “V shaped” project scheme, that includes the stakeholders only at requirements and final validation stages. In particular, operational experts where involved: before the simulation, to support the scenario design; during the simulation, as experimental subjects; after the simulation, to support human performance data analysis. Such an **iterative approach** proposed in the design and development of the scenarios has been very helpful in the implementation processes identifying more easily bugs and problems which have been	

timely solved. Plus, this involvement promoted also interest among ANSPs in the exploitation of project results. The MUAC experience demonstrates the ANSP willingness to use the project results.	
Impact on controllers: The participant air traffic controllers acknowledged the value of the project and were motivated to contribute to all processes by providing positive feedback. As end-users for future automation, they understood that their performance can be measured with new combined methodologies and will support their future performance by upcoming automated technologies. Their performance in validation studies were very unique and have potential for the future automation awareness in their job and training environment.	
Length of scenarios: a word of caution should be given with reference to the scenario length. The STRESS experience demonstrated that longer scenarios are needed to provide reliable results on the impact of automation transitions.	
Robust methodology: the STRESS approach provides a robust methodology to assess HPE via neurophysiological indexes in highly automated scenarios.	
Different background and expertise affect: The validation studies were performed by the different experts who contributed to validation studies in line with a multi-disciplinary approach. The shared knowledge of ATC, human factors, neurophysiology, safety and efficiency by different expertise collaborations are very useful for the realistic human performance measurement in ATM field.	
From WP5	**Lessons learned from Automation**
Future scenarios envisioning: to prevent issues related to the difficulty of catching in detail the future systems features and capabilities, STRESS chose to apply consolidated automation classifications and frameworks able to model the type of automation support provided to end-users. This allowed to envision future automatic decision-making and action-implementation supporting technologies, thus facilitating the design of the project experimental scenarios.	
Guidelines generation: STRESS designed high-level guidelines to broaden the scope of its recommendations. This allowed to identify stages of systems development and design target guidelines for each of them.	
From WP6	**Lessons learned from Dissemination and Exploitation**
STRESS dissemination strategy was based on the **identification of groups of stakeholders** who may be interested in the project findings, and on the **personalization of the communication message** for the stakeholder characteristics in terms of content, style and information support. This strategy allowed us to customise and adapt the messages for a particular target audience and create different communication channels to properly distribute it.	
Among the communication channels it is believed that web and social networks have been the most successful media to distribute information and updates among particular ATM members that were identified during project activities.	

The exploitation plan proposed was pretty ambitious. However, it is considered that the results achieved at the prototype level will still require a long journey to pursuit the evolution of the STRESS toolkit within the SESAR framework. The true engagement of consortium members has allowed to identify a clear path for the joint and individual exploitation not only at academic level but also at organizational one.	
Among the dissemination actions particular mention should be given to the effort spent for the cooperation with other SESAR ER projects, that revealed very fruitful and effective. The final dissemination event, jointly organized with MOTO and TaCO, provided a unique opportunity to maximize the impact of the STRESS dissemination and exploitation of results.	
From WP7	**Lessons Learned from Project Management**
Small consortia with all the consortium members fully engaged in the successful implementation of research objectives creates a friendly atmosphere during brainstorming sessions that foster the identification of most prominent solutions to academic problems. Needless to say, that a small consortium is easy going from the financial and accountability aspects. Moreover, the STRESS partners had already been working together in the previous NINA project, thing that made coordination and interactions very smooth and effective.	
From WP8	**Lessons Learned from Protection of Personal Data**
The interaction with ATCOs through the various simulations required gathering both personal and professional data, as well as their opinions and domain expertise, which helped analysing data about the automation impact on the human performance envelope. Already in the beginning of the project, we have taken into account the requirements for the protection of personal data as required by the latest European privacy regulation, General Data Protection Regulation (GDPR).	
The project could profit from the long-term experience related to ethic issues about research on humans. The involvement of experts in this field helped complying with the requirements and is recommended when dealing with ethics.	

4.3 Recommendations for future R&D activities (Next steps)

STRESS developed a White Paper in cooperation with other two SESAR Exploratory Research projects, i.e. AUTOPACE and MINIMA, to provide ideas and recommendations for further R&D activities. The paper is presented below.

4.3.1 AUTOPACE – MINIMA – STRESS: White Paper on the exploitation of results

4.3.1.1 Purpose of the document

The purpose of this document is twofold:

first, to present the main achievements from AUTOPACE, MINIMA and STRESS projects, that are all SESAR Exploratory Research projects, addressing the first research call on Automation;
second, being all of them fundamental scientific research projects aiming at achieving TRL1, to identify the opportunities for common areas of further investigation given by their complementarily.

4.3.1.2 AUTOPACE MINIMA and STRESS achievements at a glance

Through the investigation of an Air Traffic Controller (ATCo) Psychological Model and based on established attentional theories, *AUTOPACE* has performed basic research on effects of automation on ATCo along with the identification of new competences and training strategies for a safe operation in highly automated environments.

The main achievements of AUTOPACE are:

- The definition of AUTOPACE ConOps and future automation Scenarios in nominal and non-nominal situations identifying new roles and responsibilities for ATCo with the system-human function allocation foreseen at 2050 time horizon.
- The research of an ATCo psychological model based on established attentional theories to predict the effects of automation on the ATCo performance. Based on this model:
- the identification of the ATCo performance drawbacks due to the risk of the "out of the loop (OOL)" and "fear of automation" whose consequences are especially severe in case of automation failure;
- an estimation on how the ATCo cognitive system structure changes with automation as the future ATCo shall focus his/her cognitive effort in mainly comprehension and projection processes for situational awareness acquisition;
- some hypotheses are identified regarding the effects of automation on ATCo level of activation and engagement and an experimental plan is outlined to validate these hypotheses in future research.
- A list of new ATCo competences and the training strategies addressing not only the system interaction aspects but also the psychological (cognitive and non-cognitive) aspects to mitigate the performance drawbacks.
- This research has also provided a feasibility Study on a Validation Platform to emulate future ATCo and system responsibilities to be used for validation of the ATCo Psychological Model and new training strategies.
- A preliminary Safety Hazard Assessment (PHA) in uncertain scenarios to provide a set of automation risks that should be mitigated by modifying ATCo training or refining the automation design. Based on this analysis, training strategies have been refined to mitigate those related hazards.
- A Qualitative Performance Assessment (CAP, CEFF, HP) to show the benefits brought by AUTOPACE concept elements.

The general objective of *MINIMA* project is to improve the comprehension of the OOTL performance problem especially according to a future air traffic scenario. Further, in MINIMA tools have been developed in order to detect and compensate the negative impact of this phenomenon and a carefully selected allocation of tasks between the human agent and the automated system for the use case of a highly automated Terminal Manoeuvring Area (TMA) is proposed.

In particular, the main achievements of MINIMA are:

The identification of out of the loop effects through a literature and expert based research in order to define:

- The classification of the OOL effects;
- The methods to identify and measure the OOL effects;
- The methods to mitigate such OOL effects.
- The development of a Vigilance and Attention Observer that allows measuring the OOL effects through the observation of vigilance and attention decrements by means of neurophysiological parameters.
- The conception of an OOL mitigation strategy based on the adaptation of the level of automation triggered by low levels of vigilance.
- The validation of the Vigilance and Attention Observer and of the adaptive automation strategy in a Task Environment based on a TMA (Terminal Manoeuvring Area) simulator to be operated by means of an automated Radar Display.

The vigilance and attention observer has been developed in order to be able to measure both vigilance aspects, which refer to the alertness component of attention, and the selective aspects, which refer to the capacity of controlling the focus. To this aim, the measure of the loss of vigilance and attention is performed by means of psychophysiological recording, such as EEG (ElectroEncephaloGraphy) and Eye tracking. Both decrease in vigilance and not adapted focus of attention are integrated in the MINIMA Task Environment, a highly automated TMA (Terminal Manoeuvring Area) simulator, in order to continuously monitor the level of vigilance and attention and, if a decrease is observed, to lower the level of automation and therefore bring the operator back in the loop.

STRESS wants to enhance the comprehension of the human response to this role changing, in order to generate knowledge able to support the design of the technologies which will be used by controllers to manage the future air traffic scenario. Specifically, the project **provides guidelines to be followed to design future systems that are compatible with human capabilities and limitations**, ensuring that the right balance between humans and automations is obtained.

STRESS has developed:

- Future ATM scenarios and related human factors issues, based on the SESAR expectation in terms of traffic type and implemented concepts. The project identified **highly automated operational scenarios, featured by technologies able to support in a semi or totally automated way controllers' decision making** (e.g. how to solve conflicts) and action implementation tasks (e.g. giving orders to aircraft). Stress, vigilance, attention and workload have been recognized to be the human factors issues mostly impacted by the transition to higher automation levels.
- **Neurophysiological indexes of Stress, Vigilance, Attention, cognitive control behaviour and Mental Workload**. The indexes have been tested in an ecological environment and validated against usability and ATM suitability. These indexes were used to assess the impact of high automation on the human performance in air traffic control tasks and derive optimal automation design strategies.
- **Automation guidelines** for the design and implementation of innovative technologies that are compatible with human capabilities and limitations.

4.3.1.3 Areas of commonalities and complementarities

AUTOPACE, MINIMA and STRESS projects present strong commonalities and complementarities since:

- All projects deal with long term automation.
- All projects are focused on the human/system relationship in highly automated scenarios.
- All projects try to reduce the risks of the negative effects of automation.
- All projects identify different levels of automation but for different purposes.

Furthermore, the complementarities identified are:

Complementarity #1: HF assessment

AUTOPACE provides a model to predict the mental workload as a relationship between demanded resources and available resources with some hypothesis to be validated regarding the effects of automation on available resources (Level of activation/arousal and engagement with the task)

MINIMA provides tools and methods to measure the available vigilance and attentional resources (available resources).

STRESS provides a mental state toolbox for the human performance assessment based on the fusion of neurophysiological signals.

Complementarity #2: Prevention and mitigation of automation drawbacks

AUTOPACE focused on Training Strategies for future ATCo to mitigate ATCo performance drawbacks with automation

MINIMA is focused on system adaptation to mitigate the abovementioned performance drawbacks.

STRESS supports a better design of technologies by ensuring the consistency between automation support and human capabilities and limitations

Complementarity #3: Support to the innovation process

AUTOPACE provides a catalogue of training techniques for future ATCo not validated yet addressing not only the technical aspects but also the psychological ones

MINIMA develops a method for mitigating the negative effects of automation regardless the ATCO Competencies and Strategy

STRESS delivers automation guidelines for achieving the highest possible level of automation and for supporting safe transitions from higher levels of automation to lower levels of automation, and viceversa.

Complementarity #4: Experimental setting

MINIMA provides a simulation platform and an experimental plan

AUTOPACE provides the requirements for a simulation platform and an experimental plan to validate hypothesis on psychological aspects and training strategies

STRESS provides a simulation platform integrating the neurophysiological measurement tools for the analysis of human performance during the execution of ATM tasks at different level of automation support

Complementarity #5: **Envisioning of future scenarios**

AUTOPACE considers a complete ConOps for en-route, the nominal and non-nominal situations for 2050 along with the roles and responsibilities expected for future ATCo

MINIMA focuses on a simulation platform of TMA that includes aspects of the AUTOPACE ConOps, such as the AMAN in a dense traffic airport

STRESS considers current expectations of ATM stakeholders towards automation, which are related to the introduction of innovative concepts and increased automation levels and to a change in the roles and tasks of air traffic controllers as a consequence

4.3.1.4 Further objectives built upon the areas

Research opportunity #1: Automation drawbacks mitigation

Main area to keep on researching is the validation of combined solutions (training and system design and adaptation) to mitigate ATCo performance drawbacks at high automated environments. These validations should cover not only the nominal situations but also the cases of system failure where controller has to recover the active control.

Among the catalogue of training techniques to keep the level of activation (arousal), biofeedback technique[3] could be validated by using psychophysiological measures to train controllers to maintain a high attentional level.

To reach a higher level of maturity of the concept of mitigating the negative effects of automation through:

a combined approach based on a system adaptation and a training/competences control.
The demonstration of the applicability to a number of key areas in the SESAR 2050 ConOps through the already selected in the AUTOPACE 2050 ConOps.

Research opportunity #2: Training design and management

As the context and the tools change, ATCo training should adapt. The training techniques and strategies developed in the MINIMA project could be validated using Human Factors neurophysiological indexes in realistic future scenarios simulation environments, not only testing envisioned technological concepts but also expected future roles and procedures.

[3] Biofeedback is a technique in which one or more psychophysiological parameters (heart rate, respiratory rate, brain waves ...) are recorded and automatically displayed scientifically and objectively on screens to be seen by the ATCo. The research shows that is possible to train him/her to identify and to relate body signals for level of activation to those values.

Research opportunity #3: Validation of future technological and organisational concepts

Simulation environments are available which are able to simulate in a realistic way future technologies, procedures and roles. These concepts can be tested and validated through the use of Human Factors neurophysiological indexes to assess their impact on human and system performance.

Research opportunity #4: Adaptive automation

Knowledge is available among the three projects to propose and validate adaptive automation concepts (e.g. able to prevent/reacts to performance degradation or anticipate errors) and tools able to provide different support depending on controllers' status (e.g. more automation in high workload conditions).

5 References

5.1 Project Deliverables

[1] D1.1 Future scenarios and relevant HF concepts, edition 00.02.00, 2016. This document is public, available at http://www.stressproject.eu/outcomes/

[2] D2.1 Indexes description (interim), edition 00.01.00, 2017

[3] D2.2 Indexes description (final), edition 00.02.00, 2017

[4] D3.1 First Validation Preparation, edition 00.02.00, 2017

[5] D3.2 Second Validation Preparation, edition 00.02.00, 2017

[6] D4.1 Validation Plan, edition 00.01.00, 2017

[7] D4.2 Indexes Validation Report, edition 00.01.00, 2017

[8] D4.3 Performance Assessment Report, edition 00.02.00, 2018

[9] D5.1 Automation guidelines, edition 00.01.00, 2018. This document is public, available at http://www.stressproject.eu/outcomes/

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6 Appendix A

6.1 Glossary of terms

Since technical terms have been explained in the text, the Glossary of Terms is not applicable.

6.2 Acronyms and Terminology

Term	Definition
AND/AU	Anadolu University
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
CPDLC	Controller-Pilot Data Link Communication
CWP	Controller Working Position
DBL	Deep Blue
EATMN	European ATM Network
ECG	Electrocardiography
EEG	Electroencephalography
EOG	Electrooculography
ENAC	Ecole National de l'Aviation Civile
GDPR	General Data Protection Regulation
GSR	Galvanic Skin Response
H	Human
HF/HFs	Human Factors
HP	Human Performance
HPE	Human Performance Envelope
HR	Heart Rate
HRV	Heart Rate Variation

KPA	Key Performance Areas
LF	Low Frequency
LOAT	Level Of Automation Taxonomy
M	Misuse
M	Maastricht Upper Area Centre
NEC	Non-European Countries
OI	Operational Improvement
PMP	Project Management Plan
POPD	Protection Of Personal Data
R&D	Research and development
RPAS	Remotely Piloted Aircraft Systems
SCL	Skin Conductance Level
SCR	Skin Conductance Response
SESAR	Single European Sky ATM Research Programme
SID	SESAR Innovation Days
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SME	Subject Matter Experts
STCA	Short Term Conflict Alert
UNISAP	La Sapienza University
WATMC	World ATM Congress
WP	Work Package

Table 12: Acronyms and terminology