The bottom line on Human Factors Engineering in ATM change

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Contents

Introduction

As we navigate our way out of the current pandemic, air navigation service providers are accelerating the search for opportunities to generate new revenue, reduce costs, and create long-term stakeholder value. In the possible mix will be changes such as digital tower, virtual data centres, ATM data service providers, unmanned air traffic management, single pilot operations, increased automation and even artificial intelligence solutions.

These exciting developments involve major changes, and whenever change happens Human Factors Engineering (HFE) is an essential element to de-risk the change and ensure benefit realisation. The aim is to ensure that a solution can be used safely and effectively by the target end user. Yet, despite the value delivered by the discipline in the aviation domain, and its recognition by institutions such as EUROCONTROL, EASA, CANSO, and ICAO (also through their recent Manual on Human Performance for regulators (ICAO, 2021), HFE is not uniformly adopted across the ATM industry, with many ANSPs not realising the benefits HFE can deliver.

So, why is HFE important? What are the business impacts? Do the benefits justify the costs? This paper attempts to answer these questions and show how Human Factors Engineering can benefit the bottom line.

WHAT IS HUMAN FACTORS ENGINEERING?

Human Factors Engineering (HFE)

Human Factors Engineering is an engineering discipline concerned with the application of knowledge about human abilities, characteristics and limitations to the design of tools, machines, systems, jobs, and environments for safe, comfortable, and effective human use. When we integrate HFE early in ATM change planning we minimise the risk of design-induced human performance issues, thus ensuring that the performance of the end user is kept to the same level as before the introduction of the change, or improved ~~b~~ut not degraded.

Human Performance (HP)

Human Performance (HP) refers to how people perform their tasks. People design, build, maintain and operate every aspect of the global aviation system. The performance of the aviation system, including its safety performance, depends on HP.

Human Centered Design (HCD)

Human-centred design, also called user centered design, is an approach to system development that focuses specifically on making systems usable. It is a multi-disciplinary activity which incorporates human factors and ergonomics knowledge and techniques. The application of human factors and ergonomics to interactive systems design enhances effectiveness and efficiency, improves human working conditions, and counteracts possible adverse effects of use on human health, safety and performance.

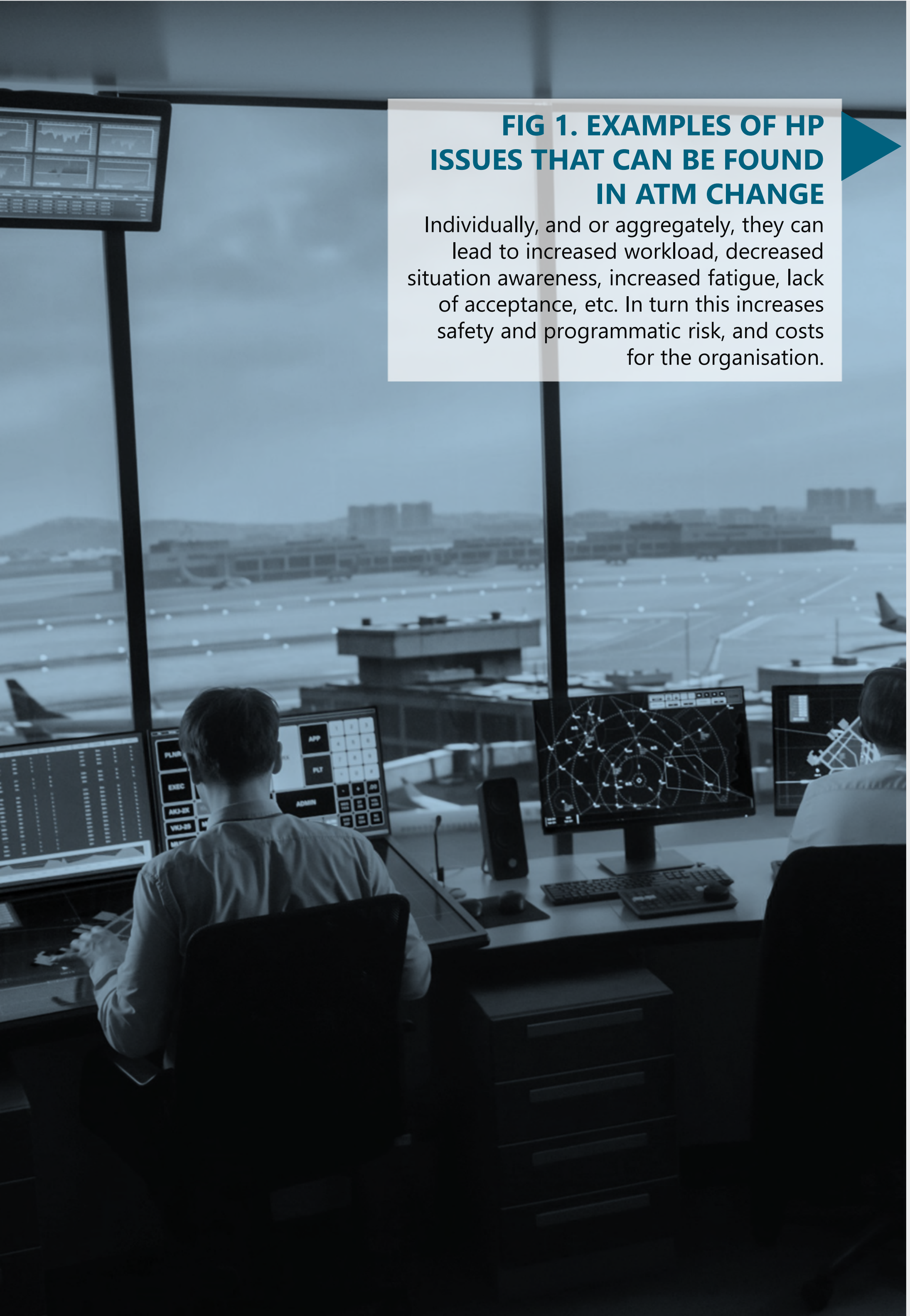
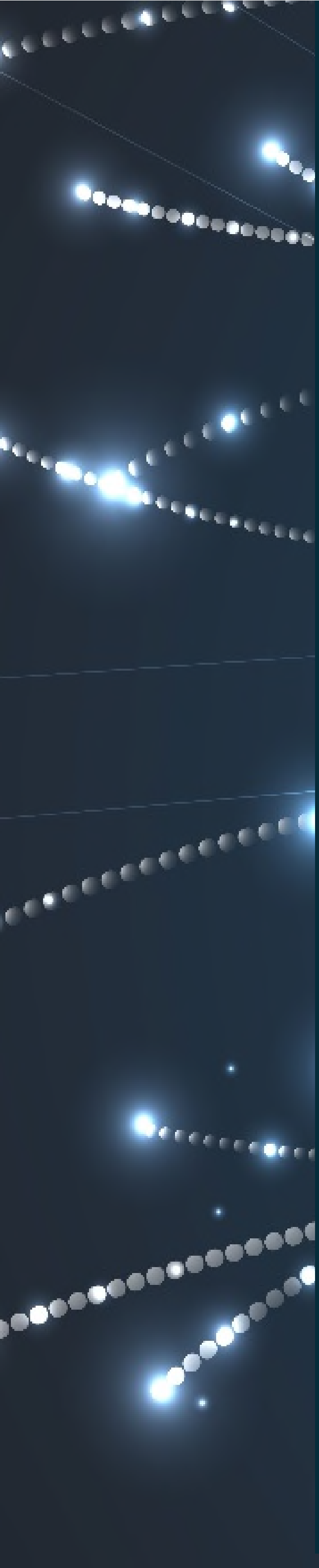


FIG 1. EXAMPLES OF HP ISSUES THAT CAN BE FOUND IN ATM CHANGE

Individually, and or aggregately, they can lead to increased workload, decreased situation awareness, increased fatigue, lack of acceptance, etc. In turn this increases safety and programmatic risk, and costs for the organisation.

Cognitive	▪ Exposure to frequent nuisance alerts ▪ Trajectory prediction algorithms having the potential to surprise ATCOs ▪ Ambiguous, conflicting alerts
HMI aspects	▪ Excessive n. of clicks needed to access secondary menus and windows, flight plans requiring long/cumbersome manipulations to edit ▪ Confusing/inconsistent colour coding schemes, error messages ▪ Display objects hard to read/discriminate
Physical	▪ Frequently used equipment placed in faraway, hard to reach locations ▪ Operators having to use several mice when one could be used instead ▪ Viewing distances exceeding minimum recommended values ▪ Control room layout not supporting movement of personnel
Environmental	▪ Noise from equipment (e.g., HVAC and/or computer hardware) ▪ Poor air circulation ▪ Poor lighting resulting in glare and reflections, demanding extra visual effort to extract the relevant information from the radar display ▪ Control room layout defined with poor consideration of walkways, sight lines, 'useful' overhearing and yet also noise reduction
Organisational	▪ Lack of clarity in roles and responsibilities ▪ Unspecified working methods preventing safe and effective system usage ▪ Incomplete training



Why Human Factors Engineering

HFE replaces intuition and gut feeling about end user behaviours, needs and performance with actual data, increasing confidence in stakeholder decisions.

Poor consideration of end users leads to reduced operational performance, increased risk and higher costs - as the rest of this paper will show.

Reducing safety risk

Historically safety has been the major driver for HFE in aviation as well as air traffic control, and this trend is going to remain for the foreseeable future. A study by the Mitre corporation identified that at least 30 catastrophic accidents which occurred between 1970 and 2013 (Gawron, 2019) were due to human factors issues, such as cockpit automation and usability induced problems. Specific to ATC, a recent study (Lyu, Song, & Du, 2019) identified that 13.6% of aviation accidents and incidents occurring worldwide over the period 1980-2019 involved ATC Human Factors issues. Indeed, learning from these lessons, smart ANSPs are now integrating HFE end-to-end across the entire lifecycle to promote the early identification of sources of human error and maximise the positive human contribution to safety.
HFE is essential to maintain, and when possible improve, aviation safety.

FIG 2. COMMON MISCONCEPTIONS ABOUT HFE

FICTION	FACT
Human factors focuses only on the individual	Human factors focusses on the individual, the team and the organisation
Involving end users is sufficient for user centred design, there is no need for Human Factors specialists	For successful change, end users need to be involved in a structured way and integrated with human factors expertise and processes, so that the change is driven by end user needs (which are stable) and not end user opinions and preferences (which are more volatile).
Human Factors analysis can be done when at least a prototype is available	It is when the design has not been developed, or the system has not yet been procured that HFE delivers most benefits, by providing data about user needs, informing and improving design decisions
Human factors addresses problems by teaching people to modify their behaviour	HF enables us to design or modify solutions, so that they meet human strengths and limitations
Human Factors consists of a set of principles that can be learnt during brief training	Human factors is a scientific discipline that requires years of training; most human factors professionals hold relevant graduate degrees. (Russ et al., 2013)
HF is used as a 'cover' to post-rationalise a design decision	HF informs design decisions before they are made

Reducing programmatic risk

Back in 1980, the FAA initiated a complete modernisation of its major air traffic control computer systems through its Advanced Automation System (AAS) programme. The aim was to provide new communication equipment as well as modernised controllers tools and displays (DOT, 2005). In 1994 the agency finally abandoned the programme after encountering significant delays and increased costs. Of the $2.6 billion spent, $1.5 billion were invested in unusable software and hardware (Cone, 2002). The programme came with several Human Factors limitations, which lead to limited acceptance from air traffic controllers. A lesson learnt was that these limitations could have been alleviated by early and continuous integration of HFE into the programme (Small, 1994).

One of the problems, for instance, was that while the new Human Machine Interface (HMI) design came with an advanced customisation capability, the same capability could render a flight invisible against the background of the radar display . The solution would have been to revert to a simpler HMI design. However, the software vendor had committed to deliver these functionalities and felt that simplifying the design would risk non-compliance. This case underlines the importance of involving HF early in the procurement phase of ATM systems to avoid early "lock in decisions" over aspects that require the integration of end user and HF analysis.

Taking another ATM example, initial attempts to introduce ground safety nets in Europe were "plagued" with nuisance alerts, ie, the frequent generation of unnecessary alerts (due to inadequate tuning). This was annoying for air traffic controllers, and increased the risk that a desensitised controller ignored a true alert (Rozzi, Amaldi, & Kirwan, 2010; EUROCONTROL, 2005). These systems were frequently switched off after the first implementation, so that the intended safety benefits was not realised.

Other notable failures where poor consideration of human performance aspects played a part include:

- The cancellation of Aquila, a programme aimed at the development of a remotely piloted vehicle programme, which costed over $1 billion (Steward, 1989);
- The "disastrous" opening of Heathrow Terminal 5 in 2008. The human performance aspects involved included the poor consideration of staff input, lack of staff training, and an error by a technician that introduced a software filter intended for testing purposes into the operational baggage handling system. The crisis led to stranded passengers, 15,000 bags piled up around the airport, 430 flights cancelled, and a total cost to BA of an estimated $50 million (Clarke, 2008);
- The grounding of the Boeing 737 Max, following two crashes that resulted in the loss of 346 lives five months apart. The accidents were caused by a common human automation interaction hazard which was left in the system, due to invalidated assumptions about crew responses to flight deck automation. On top of the tragic loss of human lives, the grounding resulted in increased costs, loss of sales and revenue as orders and production were suspended, loss of reputation, victims' litigation, client compensation, decreased credit rating and lowered stock value.

These types of programme failures can be avoided through early and continuous HFE integration.

"New technologies, digitalisation and artificial intelligence (AI) are considered as a reliable source for more capacity and efficiency.

However, confidence in technology alone without further investment in HF/E will likely result in less safety, capacity and efficiency."

(EUROCONTROL, 2019).

Cost benefits and the bottom line

When the focus in hard-hit aviation is on cost reduction, the question has to be asked whether it is worth investing time and money on HFE when planning ATM system changes?

To answer the question, we need to start by characterising and quantifying the benefits of assuring the operational experience through proper HFE. These can be broadly separated into a) cost savings and b) risk reduction benefits (with associated potential costs).

FIG 3. COSTS AND BENEFITS OF HFE

HF costs

HF expert(s)
Internal resources

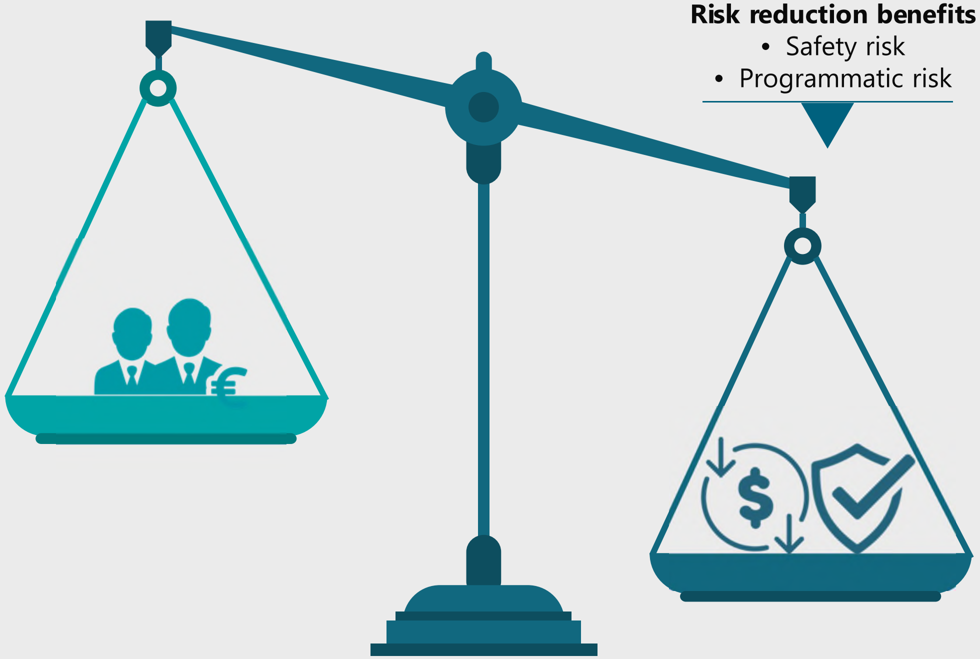
HF benefits

Cost saving benefits

- corrective costs
- procurement costs
- development/customisation/V&V costs
- lost productivity
- training costs
- maintenance costs

Risk reduction benefits

- Safety risk
- Programmatic risk



Corrective costs

Back in 1999, EUROCONTROL identified that compared to the definition phase, it costs 1.5 to 6 times more to correct a defect in the development phases, and 60-100 times more in the operational system. The cost of correcting the design increases exponentially depending on how late we detect and correct the problem. Thus, it is more cost effective to address HF issues early in the lifecycle of a change as opposed to implementing design changes when the system has been finalised and delivered to the end users.

Which curve is your organisation on?

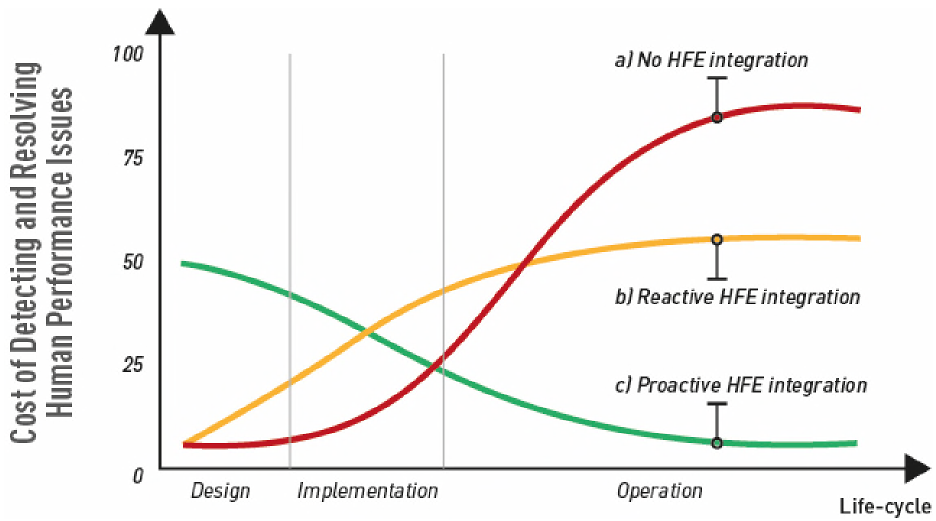


FIG 4. COST SCENARIOS ACROSS THREE DIFFERENT LIFECYCLE STRATEGIES
(SOURCE: EUROCONTROL 1999)

Procurement costs

In the procurement phase, HFE integration can help teams to discard HMIs, functions or sub-systems that are unnecessary or immature for operational use. For instance, HFE integration in a Canadian defence acquisition programme led to a $2M saving from the elimination of an unnecessary on-board display system for military helicopters (Greenley, et al., 2008).
Similar benefits are possible in ATM when vendor solutions that are not needed or immature for operational use are identified in good time. For instance, there is little value in having four competing conflict detection capabilities, each vying for the user's attention. Through early identification and tracking of end user problems and requirements, it is possible to determine which function is needed and which is not, thus improving the quality of the experience for the end user and avoiding expenditure on superfluous functionalities.

Design/customisation/and V&V costs

The benefits to end users are clear, but what about indirect users like the operational experts, developers, engineers and stakeholders involved in the project? Here too, early HFE involvement pays off. For instance, usability tests alone have proved to reduce development time by 30-50% (Donahue, Weinschenk, & Nowicki, 1999; Weinschenk, 2005).

How are these gains possible? The answer is that HFE optimises stakeholders and team decision making. First, it provides them with the right information about end user problems and needs, something that in turn (1) facilitates prioritisation decisions, definition of road maps, training and validation objectives ; (2) protects teams from spending time on unneeded features and iterations; and (3) reduces the risk of unforeseen and unmet end user requirements.

Second, it provides clear guidance regarding when and how to involve end users in the development/evaluation process. Note that identifying end user needs goes beyond asking for opinions and user preferences!

And finally, it avoids costs associated with "reinventing the wheel", because integrating available HF knowledge from relevant standards saves ANSP teams from having to second guess problems for which relevant reference solutions or guidance already exist (Schaffer & Lahiri, 2013).

"HFE minimises the risk of design-induced human performance issues."

FIG 5. EXAMPLES OF RELEVANT STANDARDS IN HFE

ISO 9241 Parts 1-17 Ergonomic requirements for office work with visual display terminals (VDTs)
ISO 9241 Parts 20-920 Ergonomics of Human-System Interaction
ISO 11064 Parts 1-4 Ergonomic Design of Control Centre
MIL-STD-1472 Human Engineering
FAA HF-STD-01 Human Factors Design Guidance (HFDG)
SESAR Human Performance Assessment process (HPAP)

Lost productivity

All too often, cutting corners in the consideration of end user needs leads to a variety of inefficiencies in the operational environment, such as, excessive clicks needed to access secondary menus and windows, flight plans requiring long or cumbersome manipulations to edit; operators having to use several mice, so that their workflow is split across physically distinct systems when one could be used; glare and reflections on screens oriented towards direct light sources, thus reducing contrast and demanding extra visual effort to extract the relevant information from the operational displays.

These elements might be easily dismissed as "nice-to-haves" by cost-conscious decision-makers, but besides increasing the potential for human error, they contribute to daily operator frustrations, and, most importantly, they really add up when you multiply the staff involved and the predicted lifespan of operations (more than 20 years for a major system overhaul). An extra click here or there hourly or daily across the whole organisation, could amount to thousands of hours of lost productivity per year.

Note that these considerations are not limited to front end personnel. For instance, a tool for FAA safety inspectors delivered savings in labour time of about 19.2% of an inspector workday, which equals labour cost savings of $16M over four years (Hastings, Merriken, & Johnson, 2000).

Maintenance & training costs

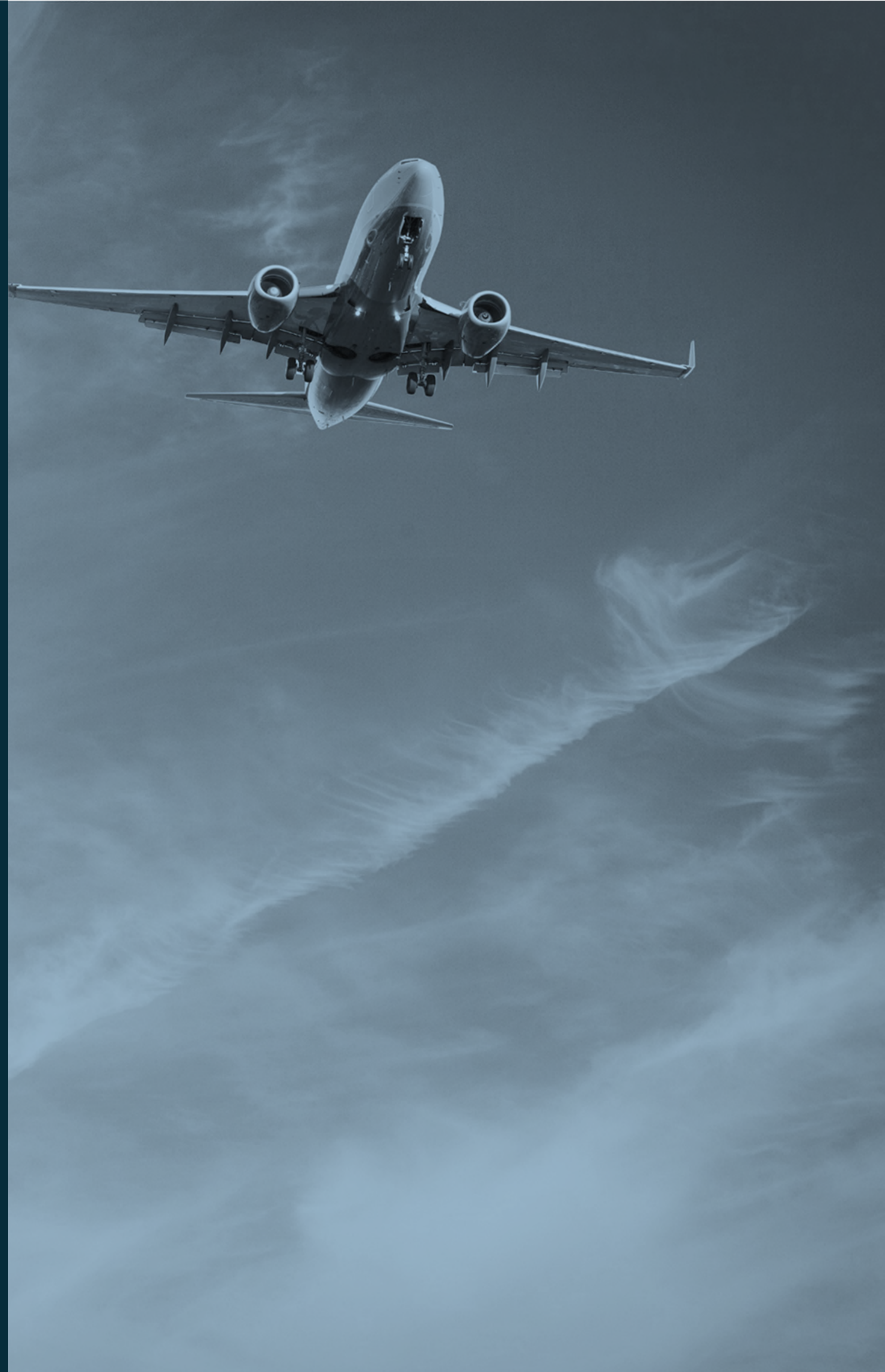
Control rooms, working positions and systems are often designed without due consideration of the cognitive and physical needs of maintenance engineers, so that for instance opportunities for reducing maintenance man hour costs are not exploited. On the other hand, best in class ANSPs have learnt that HFE can reduce the risk of maintenance error (for example, accidental unplugging of critical equipment), reduced risk of injury and/or miscommunications, faster maintenance interventions and reduced system downtime (for instance by permitting access to the back of the working position, so that minor maintenance interventions can be done without having to close a working position).

With the growing complexity of ATM systems and the introduction of new concepts such as ATM data service providers and virtual centres, more attention needs to be paid to assuring the performance of Air Traffic Safety Electronic Personnel (ATSEP). HFE provides the perfect means to achieve this goal.

Poorly designed systems also lead to increased training costs, because operators have to put more effort into learning a system that ignores basic HF principles and end user requirements. The FAA cites research stating that well-designed systems through effective HFE integration can reduce training time by as much as 35%. (Bias & Mayhew, 1994).

"HFE moves human related aspects from an afterthought to a forethought in ATM changes, whether system, procedures, control room or controller working positions ... and this results in safer, easier and more cost efficient implementations."

Targeting success



If ANSPs want to realise the target business outcomes of change projects—increased efficiency, capacity, and safety—they need to assure that change from an HFE perspective. Proactively targeting human performance outcomes is key and it needs to happen early in the planning process and follow through each phase of the change programme.

Applying HFE to change projects generates lifecycle cost savings, and the earlier the investment the greater the savings. As a reminder, it is 1.5 to 6 times more expensive to fix a user problem in the development phases, and 60-100 times more in the operational phase. Development time can be reduced by HFE, and figures of 30-50% have been cited. Savings can also be realised in procurement, during the development, customisation and validation phases, as well as during operations, through improved productivity and reduced maintenance costs. In addition to these are the risk reduction benefits of reduced safety and programmatic risks.

"To achieve the anticipated benefits through more technology, it is all the more important to understand the overall system with its complex interactions and dependencies. Who, if not HF/E can provide a significant contribution to this?" (EUROCONTROL, 2019)

Benefits realisation depends not just on a new technology, but also on the ability of end users to successfully use it. Digitalisation, artificial intelligence and other upcoming solutions need HFE integration now, or risk negative impacts in safety, capacity and efficiency.

The bottom line is, with ATM modernisation and change projects typically costing anywhere from €1 million for a minor change to as much as €800 million for a major overhaul, can ANSPs afford not to invest early in HFE?

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ABOUT

About our HF expertise

Established for over twenty years, the Egis Human Factors Engineering (HFE) team comprises 20 HF experts with a deep understanding of HFE integration in the aviation, air traffic control, energy generation and rail industries. We work alongside colleagues with complementary expertise in software and infrastructure engineering, safety, cybersecurity, ATM and airport operations, and economic analysis.

From the introduction of remote towers, en route and approach systems to cockpit certification projects, our teams have been involved in methodology development, such as the SESAR human performance assessment process (HPAP), to promote safety and benefit realisation through proper end user consideration in ATM change. We understand the practicalities of making HF work in real life contexts and in a cost-effective way. Clients rely on us for technical expertise and for support with developing their HF maturity. Egis core HFE expertise covers:

- ATM and airport system development and validation
- Cockpit design and certification
- ATM and aircraft maintenance
- SESAR projects
- HFE training
- Safety assessment
- Control room and working position design
- HD development strategy

Clients include: Airbus, Avinor, CAAS, DGAC, DSNA, EASA, EDF, ENAC, Hong Kong Civil Aviation Department, PANSA, Skeyes, Skyguide, Transport Canada.

About the author

Simone Rozzi, PhD, UX-PM L3, is a Senior Human Factors consultant at Egis, based in Toulouse, France, with more than 15 years of international experience in ATM and aviation.

He brings value to clients by delivering critical insights about end user needs, by integrating HF in projects and programmes in a cost effective way, and by providing strategic advice enabling clients to grow their own HF capability. He works with ANSPs, airports, aircraft manufacturers, and institutions.

Simone holds MSc degrees in Industrial Design and Ergonomics, both from the Polytechnic University of Milan, and a PhD in "Human Automation Interaction and Organisational Safety" from Middlesex University.

In 2019 he joined the CANSO Human Performance Management Task Force.

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