Human Integration in the Lifecycle of Aviation Systems

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Abstract. While Human Factors is perhaps the most critical discipline to improving aviation safety, research and development is disproportionately small-scale, fragmented and unsustained. The key issue is the delivery of Human Factors knowledge throughout the system to improve design, operation or monitoring. A systems integration approach to technology development and innovation incorporates user requirements at all stages of the system life-cycle. The goal of the HILAS project is to develop and demonstrate such an integrated model of Human Factors research, practice and integrated application, linking design and operation – in a 'system life-cycle approach'. A central challenge is to demonstrate how to integrate models of the human operator, which demonstrate the influences on human performance, with wider system models that encompass the influences on system performance.

Keywords: aviation, Human Factors, safety, research capability, operational performance, system improvement, system life-cycle, innovation, system models.

1 Introduction

In a complex 'system of systems' like aviation, the human operator (pilot, cabin crew, ATC, maintenance technician) plays and will continue to play a critical role both within and between systems. The requirements of this role cannot be simply specified in a set of guidelines – as a recipe for 'human centred-design'. Human Factors has moved beyond analysing human fallibility and related performance deficits. It is increasingly addressing how people behave in normal operational contexts and how performance in such contexts can be better supported by design for use, by better planning and operational management and by quality and safety management systems. As new information technologies make possible the increasing integration of the 'systems of systems' of aviation, it becomes urgent to understand more comprehensively the human role in the system context. This inevitably extends the scope of what has traditionally been regarded as the domain of 'Human Factors'.

This requires an integrated approach, which systematically generates knowledge about the human aspects of the system at the operational end and transforms this 'knowledge about' into an active knowledge resource for more effective management and operational systems and better, more innovative, design. The challenge is to develop and demonstrate an integrated model of Human Factors research, practice

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and integrated application, linking design and operation – in a 'system life-cycle approach'.

The overall goal of the HILAS project is to develop and evaluate such a model of Human Factors integration. The project contains four parallel strands of work that concern: integration and management of Human Factors knowledge; flight operations performance monitoring and process improvement; the Human Factors evaluation of new technologies applications on the flight deck, and the monitoring and assessment of maintenance operations.

This paper examines the background and rationale for the project.

2 Human Factors RTD Capacity and the Challenge of Aviation Safety

2.1 The Aviation Safety Challenge

In the European strategy for air transport set out in, "European Aeronautics: A Vision for 2020" a target of an 80 per cent reduction in aircraft accidents is proposed as necessary to support the expected growth in traffic with a reduction in the number of accidents. Following the publication of these targets the Advisory Council for Aeronautics Research in Europe (ACARE) produced a Strategic Research Agenda (SRA) which identified that ensuring effective and reliable human performance would be a key contribution to the required accident reduction.

Analysis of accident data has shown that for 70 per cent of aircraft accidents human error on the flight deck is cited as the primary cause. In a further 15 per cent of accidents human error on the flight deck is cited as a contributory cause. While it has been accepted for the last 30 years that Human Factors are perhaps the most critical discipline to improving aviation safety, the verifiable evidence that RTD in Human Factors has made a significant difference to aviation safety during this time is not strong. This is not to deny the considerable achievements of Human Factors in the introduction of crew resource management and in its increasing impact on the design of new technologies, for example. While these have had an impact, it is hard to quantify how much, and it undoubtedly the case that Human Factors remains the central area where verifiable progress has to be made if substantial gains in safety are to be achieved.

2.2 Weaknesses in RTD Capability

This lack of measurable impact can be attributed to several factors. Research and development in Human Factors is disproportionately small-scale, fragmented and unsustained in proportion to the scale of the problems that need to be addressed. The knowledge infrastructure is undeveloped for ensuring the availability of appropriate Human Factors knowledge precisely when and where it is needed to ensure its greatest impact. There has been a lack of learning by the industry from examples of good Human Factors implementation.

Thus, the following characteristics have generally been typical of Human Factors research in aviation:

- Fragmented in discrete, relatively isolated projects, rather than large scale integrated programmes.
- Sector-specific research and development predominates, rather than research which spans different aviation sectors (e.g. design, flight ops, ATM, maintenance) or which concerns the interfaces of these sectors.
- There is little integration of Human Factors research across the CADMID cycle (concept, assessment, development, manufacture, implementation, disposal).
- There is a serious lack of evaluation studies, particularly longitudinal studies of programme implementation.
- Competence in Human Factors is poorly developed and distributed around critical regions of the aviation community.
- There is little appreciation of what it takes to manage Human Factors knowledge and the activities it supports. Differences between Human Factors and technical knowledge are not generally well understood.
- There are few clear requirements standards. Most of these are at an operational level.
- Demands to manage and regulate complex issues concerning organisations and culture have not been matched by an appropriate research effort.

In summary, the implementation of existing Human Factors knowledge and methodologies is inconsistent, poorly monitored and evaluated and not transferred. Research has not been undertaken on a systemic basis across the sector and along the life cycle of systems. There is a poorly developed infrastructure to manage the effective generation, deployment and implementation of Human Factors knowledge across the aviation system.

2.3 Research and Development Needs

The JAA-FAST prioritisation of research needs have identified Human Factors and system change as strategic research priorities for aviation. If this priority is to be fulfilled with a commensurate impact on the aviation sector, then it will have to be based on an approach to Human Factors which is

- systemic, being fully integrated within each system component of the aviation sector (including technology, organisational systems and social processes),
- starts from design but extends throughout the operational lifecycle, including maintenance,
- addresses operational performance in a valid way,
- creates the basis for using Human Factors knowledge for improving technologies systems and processes.

All these requirements point to the need to address the way in which Human Factor knowledge is generated, distributed, implemented, and evaluated. The urgency of this task is emphasised by the projected growth of the aviation system over the next 20 years, with unprecedented demands for improving quality and safety while increasing capacity. Reconciling these goals will only be possible if the human and social contribution is addressed in a coherent and systemic manner.

3 Human Factors and System Change

Several developments of Human Factors research and practice point the way forward, but none on its own provides an adequate model.

3.1 Normal Operational Performance

LOSA (line operations safety audit), developed by the University of Texas in collaboration with NASA, represents a qualitative leap forward in providing a methodology to capture the normal processes of flight operational performance (2). This has led to the development of a 'new view' of human errors in which they are accepted as a normal and inevitable part of operational performance. Thus, what is critical to professional performance is both the capacity to recover from error and manage successfully the recurrent threats that are typical in normal operations. The ADAMS 2 project has demonstrated the feasibility of adapting this approach to aircraft maintenance operations.

While there is increasing evidence of LOSA as a performance monitoring methodology, there is little evidence about the impact of its use by airlines on the improvement of operational systems and procedures. Furthermore LOSA is administratively cumbersome, expensive and takes time to achieve feedback. This demonstrates the necessity to link performance assessment to a systematic feedback mechanism which can lead directly to system improvement. Such a mechanism does not exist at present, but achieving this is a specific goal of HILAS.

3.2 System Improvement

Process analysis and redesign methodologies are being adopted by airlines that are striving to reduce costs and improve operational performance. The basic principles of process analysis are well known (3) if not always well applied or properly validated. At the same time the introduction of information technologies in the form of 'electronic flight bags' or cockpit integration technology provides the opportunity to consolidate this approach into a 'lean aircraft' systems approach (4).

So far, in aviation, the development of process redesign methods and cockpit integration technologies has developed independently of performance management systems. Thus there are no models for a system of continuous improvement, which integrates these two approaches. In order to make this integration possible, it is necessary to develop analytic methods and identify requirements for the human characteristics of processes as well as performance, so that feed back from performance addresses the psychological realities of those processes which condition and influence performance. The ADAMS 2 project has been developing this approach in the context of aircraft maintenance processes (processes involved in maintenance checks, planning and supply chains, quality and safety management). The HILAS project provides the opportunity to further develop this approach and extend it to flight operations.

3.3 The Lifecycle of Aviation Systems

Research on the integration of Human Factors across the lifecycle of systems has really only just begun. From an engineering design perspective, the demand for Human Factors commonly emerges as a request for a checklist or written guidelines which specify how to address the human requirement of new system design. From this perspective, Human Factors, no matter how early in the design cycle, can only play the role of an evaluation metric for an already existing idea. User-centred and participatory design processes have become more accepted and more formalised as processes. In these processes, representative groups of users contribute directly to the design process. When done well this can provide a much more in-depth appraisal of user needs.

However, this does not address the experience of actual users of the design, once it has been developed, manufactured and implemented. This kind of feedback, when systematically done, provides a much more robust basis for designing out the operational problems in the next generation of operational systems. The work on normal operational performance demonstrates the prevalence of informal, unofficial patterns of behaviour (often including routine 'violations' and non-compliance with procedures) which has been demonstrated in a variety of domains in aviation and elsewhere (5). Considering this, it becomes obvious that the kind of links with the customer that are being fostered by aircraft manufacturers (amongst others) are not a sufficient mechanism for capturing ecologically valid feedback from the reality of everyday operations. What is required is a much more structured system for routinely gathering such everyday information and making it available *in the appropriate form* to those responsible for current designs and future systems.

This is not a trivial task. The AMPOS project has demonstrated the difficulties of providing and using feedback to maintenance organisation and manufacturer for operational and procedural improvement. The ADAMS 2 project has developed a set of tools and methods for managing Human Factors at different stages of the aircraft maintenance lifecycle, from design to operational performance. However these remain to be integrated in a fully functional manner. HILAS will provide the opportunity to develop an empirically based model of the transformation processes necessary to make operationally derived knowledge usable at the design stage.

4 The Aviation System and the Management of Human Factors Knowledge

4.1 The 'System of Systems'

Aviation is a complex 'system of systems' in which the human is the critical interface between the different sub-systems. Achieving the Strategic Research Agenda targets for European aviation will inevitably require redrawing the boundaries and roles between such subsystems – between flight deck and ground control of air traffic, between maintenance and dispatch, for example. This requires an integrated 'system of systems' approach to research and development if dysfunctional interactions between poorly co-ordinated systems are to be avoided. Despite this, human factor research and development has been almost exclusively focused within each subsystem – flight operations, flight deck design, air traffic management, ground operations and maintenance. HILAS will provide the opportunity to develop and demonstrate a seamless approach to Human Factors integration across system boundaries. It will have a particular focus on the system boundaries between maintenance, dispatch and flight operations, and between the operational aspects of both maintenance and flight operations and technology and process design.

4.2 Knowledge Management

It has become obvious that the key to unlocking the potential of Human Factors to contribute to the robustness and error resistance of complex system does not reside solely in the domain of human-machine interface design (though this remains an important component). Rather, the issue is the delivery of the appropriate Human Factors knowledge (and the competence to use it) in the appropriate form, throughout the system to all those who are in a position to implement it to improve design, operation or monitoring. Currently there is an uneven distribution of Human Factors expertise between research institutes and universities on the one hand and industry (manufacturing and operation) on the other. The expertise deriving from research is imperfectly put in the service of design development and operation. Human Factors has been slow to develop a capability to thoroughly engage in the everyday realities of operational performance and organisational processes in an ecologically valid manner (the ADAMS 1&2 and AMPOS projects have pioneered this approach in aircraft maintenance). It therefore is necessary to learn from and apply some of the models of knowledge management, which have been developed in other domains.

It is important to recognise that Human Factors deals in tacit and implicit knowledge as well as explicit declarative knowledge, and that the pathways for managing Human Factors knowledge will often be different from those for 'technical' knowledge. The role of organisational memory and the capacity of organisations to learn from experience and put right the mistakes of the past are critical. Unfortunately the evidence suggests that organisations' capacity to learn in this way is very limited. It is clear that organisational culture plays an influential role in the development and institutionalisation of Human Factors in practice, yet very little research has seriously explored the parameters of this influence. The role of active social processes, like communities of practice, in fostering the development and interchange of knowledge are critical. Very little research has been done on the constraints and requirements for the sharing of knowledge between organisations despite the fact that many Human Factors initiatives have been founded on the premises that Human Factors is about safety and that the sharing of safety information is in everybody's interests (for example, GAIN, MEDA). Unfortunately these initiatives have not often delivered on their initial expectations, precisely because these constraints have not been understood. HILAS will explicitly address these issues and will develop a model of good practice in the management of Human Factors knowledge in the complex system of aviation.

5 A New 'Business Model' for Human Factors

5.1 Human Factors as Technology

Human Factors is a unique science and technology, which systematically represents the user or operator of technical systems and processes, not just at the proverbial 'sharp end' but at all stages of the process. As such, more than any other discipline, it should be fully integrated into the system lifecycle. In aviation, Human Factors falls short of this ideal model and plays a very imperfect role in a systems integration model of innovation and development. The challenge for Human Factors is to develop a more comprehensive model, which can effectively integrate a variety of methodologies along the life cycle for example, from new technology/operational/product concepts through simulation and testing in their development to naturalistic research in operational environments and system modelling. This will require a greater interaction between research and development organisations (which can deliver applied research, technological research and basic research functions) within networked clusters of industrial organisations from design and development to operation and maintenance.

Through its workprogramme and through the user-support activities of the Knowledge Integration strand, HILAS will develop in practice the notion of an active innovation cluster of industry-research partnerships. This will work both on a European level and at a regional level, where synergistic partnerships can be formed between research and industry – for example in Ireland and the UK, in the Scandinavian region, in Italy and Spain.

5.2 Systems Integration Innovation

What is proposed is a systems integration approach to technology development and innovation, which would drive the incorporation of user requirements at all stages of the life-cycle of systems. What does this mean? The traditional business innovation model has a hierarchical linear sequence from basic research to developmental research to applied research to product development to marketing. Concurrent engineering and lean production have transformed this sequence by integrating design and manufacture. Design for manufacturability and continuous improvement driven by production requirements have driven down the time and cost of bringing new products to market. Lean production has led to agile production systems which flexibly meet customer needs. What is being proposed in the HILAS model is an analogous process of systematically building the user into not just the design process but also the whole life cycle of systems. In recent years there has been some growth in Human Factors capability in the aviation industry – amongst manufacturers, in ATM, in some airlines, maintenance organisations and national authorities. Thus, Human Factors do contribute to the development, operation, maintenance and regulation of aviation systems, but not in a coherent and integrated way across the life-cycle. Aircraft manufacturers are increasingly involving the user in the design process, but this represents the first steps in what should be an integrated systemic process, addressing user needs across organisations. The great bulk of the research and development capacity in Human Factors is in the research institutes and universities. While the research institutes, in particular, have strong industry links, this is not well integrated along the system lifecycle.

Developing this ‘new business model’ will enable the better design and implementation of new technologies, which are developed with a sophisticated and valid appreciation of user requirements and characteristics. This will foster trust and acceptance in the introduction of new technologies. It will generate new and demonstrably valid methods and criteria for the certification and regulation of systems for human use. It will provide the tools and methods for the better management of quality and improvement of aviation operations and maintenance, which can lead to synergistic step improvements in both safety and efficiency. However, the fundamental argument is that this ‘new business model’ for integrating Human Factors in the lifecycle of European aviation represents a potential step change in competitiveness for the European aviation sector.

This analysis is based in part on Best (6), whose capabilities and innovation perspective (CIP) sees innovation and growth as being dependent on the production and organisational capabilities of clusters of organisations. For example, where the pull of the production system is towards innovation in new product development (NPD), “The NDP pull, interactive model seeks to permeate R&D throughout the organisation in a way that draws the customer / user into the definition of the problem and the solution”.

In the open systems model of innovation, technology integration teams “’dip-down’ into the scientific and technological bodies of knowledge that are available in the universities and ‘industrial districts’” in order to solve the challenges of rapid technical change. “Companies form long-term relationships with university research groups and other technology oriented firms to access [specialised knowledge and expertise]”. This contrasts with the hierarchical and linear model in which basic research in separate R&D labs drives technological development in a ‘trickle –down’ manner.

HILAS will adapt the open systems model of innovation to the large complex system of aviation where the user (the human operator), at all levels of the system, plays the key role in the different subsystems.

5.3 Modelling the Human in the System

If this vision of Human Factors as a driver of systems innovation is to be realised, then Human Factors has to develop the research capacity to play its role in understanding existing operational systems in a way which enables the human-centred design of future systems. Fundamental to this is the issue of modelling the role of humans in the system. If one wants to intervene in any way to change a system, one needs a model of that system which describes its underlying functionality and causal structure.

Models of ‘humans in the system’ can crudely be classified at different levels in terms of the extent to which they enable understanding and support intervention, as illustrated in Table 1, below. Many organisations manage Human Factors simply with a set of checklists, and this is often what design engineers say they want from Human Factors. However the level of inference that such taxonomies support is very weak. Cognitive psychology has spawned many models of the human operator, either as an individual or in a small group, which can sometimes include tools as agents or actors. While such models can have great inferential power within their theoretical scope, they often do not address those factors which are critical to change if the operation is to be enabled to work better or designed to function more effectively in its environment. Therefore it is necessary to develop 'leverage' models which seek to address precisely these issues.

Table 1. Models of humans in the system

Level of model	**Characteristics modelled**	**Operational functions enabled**	**Design functions enabled**
Descriptive classification of Human Factors	Factors which potentially affect performance	Taxonomies for incident analysis, performance reports	Checklist for design support
Analytic model of human operator(s)	How Human Factors affect performance	Analyse / diagnose problems & events with respect to human operator	Evaluate HMI from user perspective
'Leverage' model of operational system	Functional relationships which support system outputs	Managing system & implementing change	Design and evaluate new system concepts

A model that provides leverage over the design and management of socio-technical systems has to be able to represent those factors that potentially causally influence the system's functioning. Most especially it should seek to model those factors that are amenable to modification, change or re-design in such a way as to transform the pattern of causal relationships that influences the required output of the system. This is perhaps the central theoretical challenge for the HILAS project – to demonstrate how to integrate models of the human operator, which are critical to understanding the influences on human performance, with wider system models which are critical to understanding the influences on system performance.

If this is possible, it will help to solve some fundamental problems of regulation. Not only will it provide the methodologies necessary to support certification of new technologies, from a human performance point of view, but it will also inform better models for the approval of airline and maintenance operators. If these two goals are separately possible, it makes realisable a third goal – to demonstrate a seamless human systems approach to both certification and operator approval. This integration is essential if we are to support the industrial goal of design for 'operability' – design to maximize the effective operational use of the technology to be manufactured. This, of course, depends on being able to integrate cognitive models of the human operator with models of the human in the operational system. Thus system innovation to meet human needs requires radical transformation of the scope of Human Factors.

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