E S S A I

Enhanced Safety through Situation Awareness Integration in training

A validated recurrent training programme for Situation Awareness and Threat Management

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Summary

It is currently widely believed that situation awareness and threat management skills are a significant factor in (avoiding) aircraft accidents and incidents and play a major role in a crew's ability to cope with hazardous situations. In the ESSAI (Enhanced Safety through Situation Awareness Integration in training) project the roles of situation awareness and threat management skills were investigated. In the first project phase a literature review and a state-of-the-art investigation was carried out in order to find the most promising approach. In the second phase, incidents and accidents were analysed and specific attention was paid to what (lack-of) situation awareness and threat management skills were contributing factors in the accident or incident. In the third phase, the results of the first and second phase were combined and submitted to operational pilots. During two workshop sessions, the list of situation awareness and threat management skills was refined.

This resulted in a set of situation awareness and threat management skills that were considered most relevant for effective situation awareness and threat management, from both a theoretical as well as an operational point of view. More specifically, they were considered as potential candidates, suitable for inclusion in training. The list of skills was re-structured into a so-called ESSAI Competency Structure, in which the interrelationships between the skills were made clear. The situation awareness and threat management skills could both be further decomposed into four 'competencies'. Situation awareness competencies are 'Prepare & Review'; Notice and Perceive'; 'Understand & Interpret' and 'Project & Think Ahead'. Four threat management competencies can be distinguished: 'Anticipate & Avoid', 'Detect & Trap', 'Diagnose' and 'Recover'.

In the fourth phase the training was developed and tailored around these concepts. The concepts were translated into aviation terminology, and clustered in the following training modules:

- to think ahead into the future phases of flight in order to maintain situation awareness, instead of simply noticing events
- to avoid threats instead of waiting to trap or mitigate their consequences
- to perceive loss of situation awareness and act on that knowledge
- to perceive weak signals, indicative of potential dangerous situations
- applying situation control, i.e. the skill to effectively balance (mental as well as flying) workload between crew-members

This division offered a very effective means of training the required skills. The proposed training consisted of a DVD, exercises and simulator sessions. The effectiveness of the training was then evaluated in a (level D) simulator experiment, where 8 crews received the ESSAI training and 8 reference crews did not, whereas the simulator sessions for both groups were otherwise identical.

The results indicate that situation awareness and threat management increased as a result of the training across all methods of measurement. Observations have shown that especially the briefing quality, the approach and landing phase and the management of distractions can be significantly improved by the ESSAI training.

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Abbreviations and Acronyms

A320/A330	Airbus type 320 or 330
AEF	Aero Lloyd
AISS	Arnett Inventory of Sensation Seeking
ATC	Air Traffic Control
AZ	Alitalia
BA	British Airways
CB	Cumulus nimbus
CFIT	Controlled Flight Into Terrain
CFTT	Controlled Flight Towards Terrain
CLSA	China Lake Situation Awareness Scale
CRM	Crew Resource Management
DDL	Dedale
DLR	Deutsches Zentrum fuer Luft- und Raumfahrt
EOI	Enhancing Operational Integrity
ESSAI	Enhanced Safety through Situation Awareness Integration in training
FAA	Federal Aviation Authorities
FASA	Factors Affecting Situation Awareness
FDR	Flight Data Recorder
ITMS	Index of Threat Management Strategies
JSAT	Joint Safety Analysis Team
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory)
KSA	Knowledge, Skills, Attitudes
LOFT	Line oriented flight training
Q_Q	QinetiQ
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SOP	Standard Operating Procedure
TM	Threat Management
TUB	Technische Universitaet Berlin
WL	Workload

1. Introduction

It is currently widely believed that situation awareness is a significant factor in aircraft accidents and incidents, playing a major role in a crew's ability to cope with hazardous situations. The ESSAI (Enhanced Safety through Situation Awareness Integration in training) project seeks to investigate that role and to offer potential training solutions for improved safety by enhancing situation awareness and threat management capability on the flight deck. As air transport operations have become more reliable, aircrews are less exposed to aircraft and system failures. However, the growth in the complexity of highly integrated systems has made the task of identifying developing problems much more difficult. How to train flight crew for these very low probability events is clearly a challenge for the aviation industry.

The goal of the ESSAI project is to provide workable training tools and techniques for 1) maintaining and recovering Situation Awareness and 2) performing Threat Management should the situation deteriorate and become potentially hazardous.
For the training programme, several requirements were set. In the first place, it should be based on both scientific as well as operational data. The second requirement for the ESSAI training was that it should be possible to integrate it within existing operator recurrent training practice. Moreover, it should be possible to be integrated not only by e.g. flag carriers, but also medium and small operators. In the long-term, it is possible that adaptations of the ESSAI training solutions could be applied in *ab-initio* and/or transition training. Potential customers for such an application of the training would be flight schools, and possibly aircraft manufacturers and regulators.
Thirdly, in order to aim for as large a safety increase as possible, the developed training should be *generic*, meaning that the training is not limited to one specific aircraft type or operating philosophy (eg Boeing versus Airbus, glass-cockpit versus conventional).

The training tool was developed in 5 phases (see Figure 1), which varied widely in perspective, that of scientists or pilots and abstraction level - theoretical or applied. Since the current document reports on all phases, it reflects this variance. We have aimed to write the report in a manner that should be readable to both practitioner as well as scientist. However, if the reader should wish to consider skipping parts of the report, we suggest this be done according to the guidelines given in this Introduction. It is indicated there by whom the phase was carried out, and whether it carried a theoretical or applied emphasis. This should help decide whether the chapter is of particular interest.
This document reports on a project involving 14 man-years of effort carried out within 3 years. Given the nature of the project - research – a large amount of information was gathered in phases 1 and 2 that was later, for different reasons, not used in the training or experiment. We do think however that some of that information is relevant to report here since it enables the reader to make his or her own judgement or make use of that information for own purposes. However for clarity, all approaches, theories, and concepts etc that were re-used in later phases (phase 3-5) are indicated in the margins of the text.

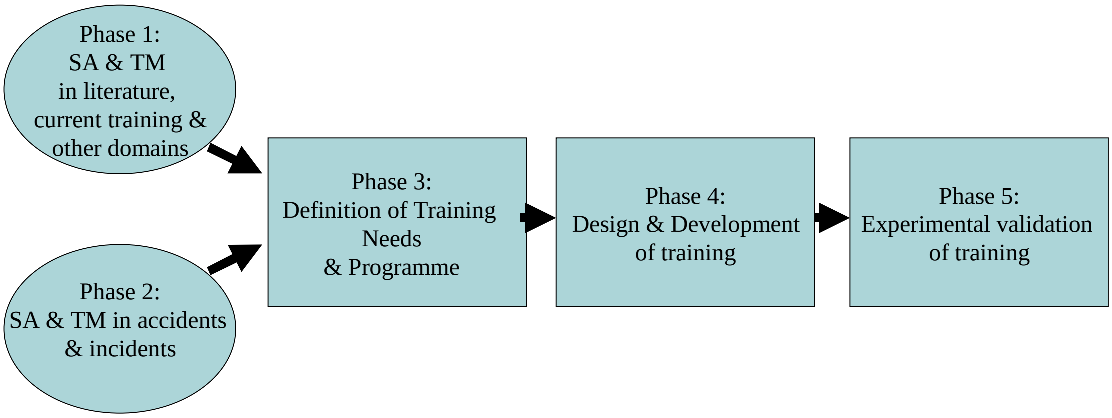


Figure 1: Phases of the ESSAI project

In the first phase a literature review and state of the art investigation were carried out in order to find the most promising approach. This phase was a theoretical phase, carried out by mainly researchers. In the second phase, incidents and accidents were analysed to se to what extend (lack-of) situation awareness and threat management skills were a contributing factor in the incident or accident. This phase was carried out by both scientists as well as pilots, and carried out from a scientific as well as an operational perspective. This resulted in a preliminary hot-list of skills to be considered for inclusion in the training. In the third phase, the results of the first and second phase were combined and submitted to operational pilots. During two workshop sessions, the list of situation awareness and threat management skills was refined. This resulted in a list of situation awareness and threat management skills that were considered most relevant for effective situation awareness and threat management from both a theoretical as well as an operational point of view. More specifically, they were considered as potential candidates for inclusion in training. The list of skills was re-structured into a so-called Competency Structure, in which the interrelationships between the skills were made clear.
The situation awareness and threat management skills could both be further decomposed into four ‘competencies’. Situation awareness competencies are ‘Prepare & Review’; Notice and Perceive’; ‘Understand & Interpret’ and ‘Project & Think Ahead’. The four threat management competencies ‘Anticipate & Avoid’, ‘Detect & Trap’, ‘Diagnose’ and ‘Recover’. The competencies and respective behaviour strategies through which they become effective would constitute the contents of the proposed training solution. They would be formulated in a concrete and clear manner, such that they could be related to the operational context and used by pilots.
Although operational information was gathered from the pilots during this phase, the results from this phase were mostly of a scientific nature. This was necessary in order to make a comparison and link to the earlier phases and projects visible and to avoid making design decisions too early on in the process. Generic (psychological) terms can be interpreted in various ways, whereas concrete terms often implicitly nudge towards a specific solution.
In the fourth phase the ESSAI training was developed and tailored around these concepts. The generic concepts were translated into aviation-terms and the training focused on the following four concepts:

- to think ahead into the future phases of flight in order to maintain situation awareness, instead of simply noticing events
- to recognise clues that one is losing situation awareness
- to avoid threats instead of waiting to trap or mitigate their consequences
- to apply situation control, i.e. the skill to effectively balance (mental as well as flying) workload between crew-members

Three major ESSAI training principles were stated: an integrated and joint approach, realistic context and a supportive learning environment. Based on these principles, the training was set up in 4 different parts.

First, DVD was selected as the means to transfer knowledge on situation awareness and threat management. Design involved an iterative process lasting four months, transposing the competency structure created into more manageable units for delivery in a DVD format. During this time, a further refining process took place sub-dividing the competency structure into *knowledge* and *skills*. This structure had been shown to resonate well with the practical training aspirations but it required close scrutiny in order to ensure that all the essential elements found their place in the ESSAI Training Solution. The second part of the training was a Tactical Decision Game, providing a situation in which the pilots could practice the skills that were introduced in the DVD. The third and fourth parts of the training consisted of simulator training sessions and a final debriefing.

In the last phase of the project, an experiment was carried out on a level D A330 simulator to assess the effectiveness of the ESSAI training. The ESSAI experiment was designed to find out whether the exposure to the advanced training tools can significantly minimise pilot's' loss of situation awareness and improve their effectiveness of threat management strategies. An experimental design was chosen which allowed the comparison of differences between two groups of pilots: one group (the experimental group) trained with the ESSAI training solution, the other group (a control group) trained in a normal LOFT session. In addition, quantitative and qualitative measurement was administered prior to and after the training allowing to test differential performance gains within the two groups during the whole training experiment. In line with the hypotheses, it was expected that the pilots of the experimental group show higher levels of situation awareness and threat management after the training. The gain of performance in the control group should be significantly lower.

2 Phase 1 - Orientation on Situation Awareness & Threat Management

In phase 1 of the programme, the major objective was to define the scope of the project. Although the Top Level questions were known, they needed to be elaborated in order to narrow the field of investigation. Therefore, the following questions were addressed:

1. What exactly are situation awareness and threat management? What factors affect them?
2. What do we mean by ‘threat’ and what type of threats do we consider in the project?
3. What is the relationship between situation awareness and threat management?
4. How are situation awareness and threat management dealt with in other domains?
5. What is state of the art in respect to training (development)?

Three sources of information were consulted. In the first place, a vast literature study was carried out to answer questions 1 – 3. The literature study supplied the theoretical background and constructs for the key-concepts of the project - situation awareness and threat management. These are discussed in sections 2.1 and 2.2. Question number 4 was answered by holding interviews with experts in 6 different domains. The results are reported in section 2.3. To ensure the most novel and up-to-date answers to the last question, current programs in research institutes and universities were analysed. The results are discussed in section 2.4.

2.1 Situation Awareness

The literature on situation awareness is overwhelming and can be roughly divided into two viewpoints on situation awareness. The most common viewpoint is that situation awareness is a ‘mental state’, in a particular context, at a particular point in time. Such a view on situation awareness however does not provide any anchors for training, since it does not specify what a pilot needs to do in order to achieve and maintain situation awareness. The other viewpoint in literature approaches situation awareness as an activity, a skill. Such a viewpoint offers the possibility to treat situation awareness as concrete tasks, which can be instructed, practised and evaluated. The definition chosen for the project reflects this last viewpoint:

Endsley's definition of situation awareness

> Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. (Endsley, 1988)

The acquisition and maintenance of situation awareness is affected by many factors. These factors can be classified as internal or external factors, as well as direct or indirect factors. The internal / external dichotomy can be made to represent those factors that are related to the cognition of the individual, and those that are related to the task environment respectively. The direct / indirect dichotomy refers to factors that affect situation awareness directly, versus those that affect situation awareness via an indirect route, i.e. via other mental processes closely related to situation awareness. The processes closely related to situation awareness are decision-making and group processes. A provisional list of factors for further consideration is presented below (Table 1). They are organised into those that affect situation assessment directly, and those that affect situation assessment indirectly via decision-making and group processes.

Divided attention

Confirmation bias

Overconfidence

Team co-operation

Situation Awareness	Decision Making	Group Processes
• Top-down processing (e.g. on depth perception) • Divided attention • Automatic processing • Selective perception • Perceptual biases (e.g. confirmation bias) • Mental imagery • Cognitive dissonance • Prospective memory • Self-fulfilling prophecies • Task interruptions • Situation Complexity	• Estimating probabilities (e.g. decision-making under uncertainty) • Framing bias • Overconfidence • Anxiety (i.e. reduction) • Stress (i.e. reduction) • Expertise	• Non-verbal communication • Polarisation • Group think • Team relationships • Team co-ordination • Cultural aspects

Table 1: List of factors grouped by those processes that they impact upon

All factors are thought both to have robust effects on performance and be generic enough to be applicable to a wide range of scenarios. In addition, it is thought that they are relatively easy to devise training regimens for.

Lastly, a variety of measures was investigated which can be used to assess the level of situation awareness. Subjective techniques (e.g. questionnaires) are by far the most common form of situation awareness measurement. However, without knowing the exact processes leading to sufficient situation awareness for safe flight, it is difficult to determine the training needed to enhance situation awareness. Until now, only a small number has attempted to objectively measure the processes, the traits and behaviour and conditions that underlie the building and maintenance of sufficient situation awareness. This meant that objective measures needed to be developed for the ESSAI project. These will be treated in Chapter 6.

2.2 Threat Management

Literature on threat management was much scarcer and surprisingly focussed almost exclusively on skills necessary to cope with hazardous yet predictable and familiar situations (e.g. engine flameout). Such situations are usually dealt with in recurrent training and proficiency checks. Although most researchers acknowledge the need for different coping strategies in unfamiliar situations and have described such behaviour, none have tried to develop a training programme for such behaviour.

Before continuing, a step back in time needs to be taken. Initially, the key-concepts of the ESSAI project were situation awareness and **Crisis** Management. It soon became clear that pilots interpreted the term crisis as an unrecoverable situation whereas the project team's definition was: *"A crisis is an unexpected, unfamiliar and potentially life-threatening chain or combination of events, causing uncertainty of action and time-pressure."* The project goal was not to train pilots for unrecoverable situations, yet train them to prevent such situations from occurring. The term 'threat' seemed to cover the intended meaning better, and the term 'threat management' was adopted to describe the techniques that are essential for avoiding and/or coping with possible internal and external threats to a flight (-crew), such as regaining control after loss of situation awareness.

A threat can be considered to be a surprising or unexpected combination of events for which the crew is not prepared or trained. The crew can be trained for certain aspects of the situation, but there is no clear course of action for the combination of events. The implication is that the outcome may be uncertain and that there is a lack of (or failure of) established procedures (SOP's) to cope with the developing situation. The crew has to engage additional resources to resolve the problem. However, sometimes, their resources are insufficient and workload becomes so high that they are unable to monitor the developing situation or other crewmembers. From this viewpoint, Threat Management is directly associated with loss of situation awareness.

The following key areas were defined for threat management:

(a) Avoiding the threat
(b) Preparing to manage the threat
(c) Recognising the potential threat
(d) Troubleshooting / Decision-Making / Problem Solving
(e) Taking action when necessary
(f) Communicating through stages a-e

Note that the process of threat management is cyclical and adaptive, and also that threat management is affected by a number of factors, which originate from either individual sources or from the task environment. Next to that, factors can impact on threat management either directly or indirectly. Examples of external direct factors are situation complexity, time pressure, workload and high associated risks. One of the clearest internal factors that have an impact on threat management is the crew's expertise or experience.

2.3 Threat Management in other domains

While literature on situation awareness is endless, there is much less literature on threat management. Therefore, threat management was more closely investigated in other domains. Literature was studied and domain-experts were interviewed. By interviewing practitioners and trainers, practices were examined for potential application within the ESSAI project. Domains were selected on common task-characteristics (e.g.

complexity) or common characteristics of the environment in which they have to be carried out (e.g. team settings). The domains investigated were 1) medicine, 2) fire-fighting, 3) nuclear power industry, 4) offshore oil industry, 5) Airforce and 6) Navy.

In the literature, a distinction was made between routine, familiar situations on the one hand, and novel, unfamiliar situations on the other hand. Although most researchers acknowledge the need for different coping strategies in the two circumstances, it was surprising to find that most emphasis was placed on behaviour witnessed in the routine situations.

The central aspects of threat that the six domains share with civil air transport are the life-threat, the induced stress and perceived time-pressure, and the aspect that threat management must be achieved in a team setting. Next to that, it could be established that in each domain the threat management task of the actual responsible person in command could be classified as a 'high performance task'. In general this is characterised by (1) more than 100 hours of specialist training being required, (2) substantial numbers of individuals failing to develop proficiency, and (3) the performance of the expert being qualitatively different from that of the novice. In fact, many operators in the investigated industries operate and are trained today on the implicit notion of the threat management task as being a high performance task. Depending on the domain, those high performance tasks require technical skills such as system handling and manual control (as in the military cockpit) and non-technical skills such as social and communication skills. To perform the threat management task, knowledge is needed that is typically acquired in education and training, but also the knowledge that builds up through operational experience, such as insight in operations, procedures and processes and the knowledge to keep track of the situation and to 'read the game'.

2.4 State of the art in Training

The last part of phase 1 was an investigation of the state of current research and practice in the aviation training system in order to identify a conceptual framework for phase 2, in which incidents and accidents were analysed and phase 3, in which the training analysis was carried out. Several training initiatives are discussed. In the first place, British Airways' Enhancing Operational Integrity (EOI) programme focuses on increasing crews' understanding of the loss of situation awareness and introduces the concept of *error management* (EM) following Reason's model. Secondly, Helmreich's Line Operation Safety Audit (LOSA) integrates Error Management into safety programmes (Helmreich *et al* 1995, 1999). An overall assessment of crew behaviour is made on line flights by independent observers using rating parameters. Data from the audit are fed into a database for analysis and feedback to the airline concerned. Thirdly, the Airbus Industry Type Transition training involves interactive sessions with trainees discussing their own experiences and pooling ideas about detection of loss and restoration of situation awareness. Next to traditional techniques such as 'fly the aircraft first' are backed up by more sophisticated suggestions such as 'assess the situation from a different perspective' (Orasanu, 1995 a & b), 'consider a change in the level of

Helmreich's model

Rating Parameters

Different perspective

automation' and 'avoid fixation on the last problem' are also given. The last initiative is carried out under the auspices of the Federal Aviation Authorities FAA and NASA. A multi-faceted approach to improve safety is in progress co-ordinated by the Commercial Aviation Safety Team. At present the work has evaluated the important area of Controlled Flight Into Terrain (CFIT) and the Approach and Landing phases. Many of the recommendations from the Joint Safety Analysis Team (JSAT) chartered by the Commercial Aviation Safety Team refer to situation awareness and threat management as do those from the Flight Safety Foundation.

Historically training in aviation had been oriented towards technical and operational skills but modern insights into human behaviour led to the establishment of Crew Resource Management (CRM) concepts. The latest generation of CRM training currently includes issues such as the updating of Situation Awareness, decision making strategies and coping with the environment (time pressure, stress). In this way Situation Awareness and Threat Management issues are being integrated into CRM training.

LOFT scenarios

Training for threat management in aviation has traditionally been centred on the intensive use of various levels of simulator sophistication, including emergency procedures, LOFT-type (Line Oriented Flight Training) scenarios, abnormal attitude recovery and wind shear training. It offers the opportunity to confront complex situations in a relatively realistic operational setting without, in theory at least, instructor intervention. Decision-making in a dynamic and unpredictable environment can thus be practised without risk.

For phase 3 Training Analysis, trends and ideas for training analysis and development were studied. A classical task analysis was rejected in favour of cognitive task analysis. Cognitive task analysis seeks to understand how expertise actually manifests itself in a particular work domain by considering the relationships between knowledge and actions for the entire job. Cognitive task analysis can thus assist in understanding how a skill is actually learned in practice. Next to that, a common held belief in the aviation industry is that good decisions are the result of a natural quality granted to good pilots through experience. Modern decision making theories now acknowledges that good decisions can be reached through situation assessment and experience, aided by mental simulation of potential solutions and 'decision strategies.' Lastly, training in aviation is dominated by the acquisition of handling skills and the search for adherence to procedures.

A complete overview of the results of this phase can be found in ESSAI (2000).

3 Phase 2 - Identification of factors affecting Situation Awareness and Threat Management

In the previous phase the main focus was on the processes of situation awareness and threat management themselves. In this phase, the purpose was to identify how hazardous states affect situation awareness and threat management and by what specific factors this is caused. The results are reported in section 3.1. Subsequently in section 3.2 threat management strategies are discussed which are currently used in operation. Relevant material in both normal and non-normal operations was investigated. In particular, accident data obtained in previous research projects were screened for relevant events to help define training requirements in phase 3. Further, data from normal operations were collected to capture flight-crews' knowledge of critical threat management and situation awareness skills. Finally, in section 3.3, airline-training practices in threat management and situation awareness were identified from a high-level perspective.

3.1 Hazardous States related to Situation Awareness and Threat Management

By screening accident and incident data, especially regarding Controlled Flight Into Terrain (CFIT) and Controlled Flight Toward Terrain (CFTT), the nature of hazardous states relating to situation awareness and threat management were identified. Three complementary approaches were adopted. Firstly, reports from the Joint Safety Analysis Teams (JSAT) provided a useful data source for analysing hazardous states of flight relating to situation awareness and threat management. In these reports use is made of so-called problem statements, which are defined as those statements that describe what went wrong and why it went wrong, that define an overall deficiency, or that describe a potential reason something did or did not occur. Secondly, structured interviews with UK-based aircrew produced self-reports of safety-critical incidents, which were linked to the JSAT information. Finally, using flight data recorder (FDR) systems installed on an UK-based operator, it was possible to examine flight performance that resulted in potentially hazardous states of flight.

JSAT

JSAT is one of the initiatives of the Commercial Aviation Safety Team. The Commercial Aviation Safety Team is responsible for the co-operation of the US Safety Co-ordination Program under which the industry and government combined their forces. The objective of JSAT is to find the most dominant safety problems in CFIT, Approach and Landing, Loss of Control, and Runway Incursion accidents, and subsequently to specify the most effective intervention strategies that will mitigate these safety problems. Three are included in this study: CFIT, approach and landing, and loss of control.

One of the products of the JSAT analysis is a list of standard problems defining causal or contributory factors in the incidents and accidents. For the purpose of this study, only

standard problem statements relating to situation awareness and threat management were selected. This resulted in a list of 70 problem statements.
After this, safety analysts, aviation experts and A320/A330/A340 Flight instructors rated all of the 70 problem statements with respect to their relevant situation awareness and threat management level. After grouping the problem statements according to their respective importance towards situation awareness and threat management is was possible to identify the main hazardous states. Summarising the following states were identified:

Inability to respond to warnings

Workload / time pressure

Inappropriate crew co-ordination

- Crew preoccupation and complacency with modern flight deck automation.
- Crews' lack of system situation awareness and mode awareness.
- Crews' inappropriate level of automation skill and knowledge.
- Crews' inability to handle information being displayed to them and to respond to warnings or alerts.
- Crews' workload and workload increase under time constraint.
- Inadequate crew training and procedures.
- Inappropriate crew co-ordination.

Interviews
In combination with the JSAT analysis, group interviews with 36 operational crews were conducted related to safety-critical incidents they had experienced. The interviews also included questionnaires related to situation awareness, threat management and CRM. For each reported incident it was evaluated which JSAT problem statements applied to that particular case. As a result it was possible to examine the frequency in occurring of particular "situation awareness and threat management" JSAT problem statements in the available incident reports. The evaluation showed that the most frequently occurring JSAT problem statements appearing more than 15 times in the crew incident reports grouped according to their relevance, were:

Preoccupation under time constraints

Failure to recognise

1. **Inadequate situation awareness** (spatial). Failure of flight crew to identify correctly aircraft position over the ground (PS-12)
2. **Flight crew preoccupation** with inappropriate tasks or failure to prioritise correctly the critical tasks under time constraints (PS-28)
3. **Failure to recognise** and take appropriate action to mitigate combinations of circumstantial factors, hazards, and/or non-normal system conditions (PS-42).
4. Flight crew **failure to maintain aircraft systems status awareness** (PS-47).

Next to that, the crew incident reports indicated that the following categories are highly relevant for SA:

- Abnormal situations
- Communication
- Complacency
- Display information
- Incorrect or conflicting mental models
- Equipment failure
- Experience
- Fatigue/stress/illness

- High/low workload
- Panic; Procedure
- Training
- Attentional tunnelling
- Visibility/weather.

FDR data
Data gathered from a major operator's FDR recording system between July 1995 and August 2000 were assessed. This system records a wide range of flight parameters that can be extracted to examine the behaviour of an aircraft around the time of a safety critical incident. Software tools can be used in conjunction with these systems to reconstruct and visualise the events that lead to a safety critical situation. Thus, it offers an enormous database that could potentially be interrogated to address a wide number of unstable flight configurations or critical incidents that may result from a loss of situation awareness.

Currently the system is used only to describe hazardous situations, not how those situations came about, or how they were solved. Obviously, it is not easy to relate the FDR data to the experiences of the pilot although some crew reports exist that indicate that they are sensitive. This may reduce the impact of the use of these data for situation awareness training, and may produce the chance of misinterpretation of these results. However, the analysis of the data provided identification of significant flight contexts for work in the training development and validation (e.g. possible scenarios and environments) and would provide a potential methodology to assess the impact of the ESSAI training were it to be incorporated in an FDR operator's training. Finally, the FDR data provided an opportunity for operationally relevant measures of situation awareness related to crew performance to be assessed, e.g. measuring gate bust on approach with varying manipulations of workload.

3.2 Flight deck Situation Awareness & Threat Management strategies

The objective was to identify situation awareness & threat management strategies currently in practice on the flight deck, in both normal as well as non-normal situations. Thirty-four crews were asked to respond to questions relating to the strategies that they use to manage threats.

A number of cognitive factors are thought to affect the acquisition and maintenance of Situation Awareness. Based on factors identified in the first phase a novel scale was developed– the Factors Affecting Situation Awareness (FASA) scale. Some factors were excluded because the participants would not be able to have insight into their own psychological processes. The FASA scale is divided into five sub-scales and pilots were asked to rate how important they felt these factors were. The scales are:

- **Attention Management –** Questions pertaining to participants' ability to attend to more than one task and resume a task successfully after being interrupted.

- **Information Management –** Questions pertaining to participants' desire to acquire appropriate information to make rational decisions.
- **Cognitive Efficiency –** Questions pertaining to participants' ability to ignore distractions and maintain Situation Awareness despite external stressors.
- **Automaticity –** Questions pertaining to participants' experience of performing routine tasks in an overly practised, automatic way.
- **Inter-Personal Dynamics –** Questions pertaining to participants' knowledge of non-verbal communication and their views on what team membership entails.

Analysis of the FASA sub-scales indicated that participants felt they were especially susceptible to factors affecting situation awareness in Information Management and Automaticity.

Confirmation Bias

The Information Management scale relates to the participants' desire to acquire appropriate information to make rational decisions. Participants appeared indifferent to the notions of seeking evidence that refutes their current beliefs; trying to pose the same problem in different ways; trying to articulate reasons for and against each of the alternatives before making a decision. On this evidence, it seems that confirmation biases (i.e. seeking only data that support the current hypothesis) are likely to affect the acquisition and maintenance of sufficient levels of situation awareness for safe flight.

There was a high level of agreement by respondents with the definition of situation awareness put forward by Endsley. Specifically, respondents thought that understanding the situation and anticipating future outcomes were important aspects of situation awareness.

Respondents reported a number of situations in which they had experienced a loss in SA. Generally, these losses in situation awareness occurred during periods of high workload, during periods of multi-tasking, while preoccupied with other tasks, inadequate feedback from crewmembers, during periods of stress and during interactions with automated systems. In addition, there was a large degree of overlap between these responses and the factors that comprise the FASA scale: Attention Management (i.e. multi-tasking), Cognitive Efficiency (i.e. attentional narrowing under stress), Automaticity (i.e. interacting with automated systems), and Interpersonal Dynamics (i.e. poor interpersonal feedback and communication).

Furthermore, participants were asked to indicate their agreement or disagreement with a number of statements (developed for the FASA scale from WP1) in light of a recent event they had encountered that fitted the description of a threat. They were asked to rate agreement on the following range: Strongly Disagree, Disagree, Neutral, Agree and Strongly Agree.
In addition, participants were asked what factors (identified in phase 1) they thought are necessary for effective skills in Hazard Management by indicating their agreement or disagreement with a number of factors. Again, pilots were asked to indicate their agreement: Strongly Disagree, Disagree, Neutral, Agree and Strongly Agree. Following

this, participants were asked to rate the importance of each factor as High, Medium or Low.

Finally, participants were asked what factors they thought could be trained to make for effective skills in Threat Management by indicating their agreement or disagreement with a number of factors (Table 7), using the same scaling and rating as mentioned before.

Analysis of the participant responses to what factors made for effective threat management indicated that there was most agreement with Systems Assessment and Teamwork. There were also agreements, albeit to a lesser extent, with Communication (both inter-personal and with air-traffic control) and Option Selection. However, the respondents did not think that Risk Taking was a positive factor in TM. However, the crews had demonstrated risk-taking tendencies on the Arnett Inventory of Sensation Seeking (AISS, Arnett, 1994), a scale that measures risk-taking attitudes.

Non verbal communication

Finally, analysis of the participant responses to what factors can be trained indicated that there was most agreement with Situation Knowledge and the least agreement with Non-verbal Communication.

3.3 State of the Art in airline practices

The objectives of the second activity in this phase were to identify current formal practices at airlines with respect to situation awareness and threat management. Also, for several European airlines, it was envisaged how new technologies incorporated into airline practices and flight-deck procedures contrasted with current airline practices.

Situation awareness has recently been identified at many levels within the safety hierarchies and the regulatory bodies, as a crucial area for research and further training. There is therefore a potential for threat management to be investigated as an extension of flight deck situation awareness. Many practising pilots believe that a concentration on situation awareness issues and an increase of that awareness would actually resolve many of the problems that can arise during the development of a potential threat situation.

One example of a relevant training programme is BA Enhancing Operational Integrity (EOI) course that is aimed at the whole BA pilot and flight engineer community. The conceptual base of the programme, according to Robinson (2000), was that CRM had been seen to encompass two main areas, namely cognitive processes and interpersonal skills. Since ‘perfect’ crew situation awareness is an unlikely goal in a highly dynamic aviation environment, a natural link into an Error Management strategy could be forged to help compensate for situations when situation awareness was low or threats appeared with minimal warning.

Lufthansa has included situation awareness training into its initial CRM course since 1994. However, Lufthansa does have some difficulties with the concept due to the diversity of definitions, the question of how to really provide training in it, and the problems of observing or measuring it.

For crisis management, the company provides a security course during the upgrade training for becoming a captain. The security training covers such topics as hijacking and bomb alert.

Swissair has been running an Emergency Situational Awareness programme for flight crew and senior cabin crew since 1997. In 2001 a significant joint venture with Austrian Airlines and Lufthansa will be introduced. This will involve a two-day CRM course featuring a “policy-discussion” session with flight crew and fleet chief pilots regarding the grey area of decision-making when checklist procedures or SOPs that do not cope adequately with the given emergency (cf. Swissair MD-11 accident in Halifax, Nova Scotia). A computer-simulation is used to train specific topics such as workload management, communications, stress management and SA. Cockpit-cabin mock-ups are then used to address crew co-operation problems during emergencies.

Up to now, situation awareness and threat management were both investigated in the project both conceptually and as found in current airline practice and other domains. It was evident that much of the theory and current practice was somewhat outdated and largely based on the early CRM courses conceived nearly three decades ago. Even the more modern training courses such as BA’s EOI and Continental’s Decision-Making and Leadership programme hark back to many earlier concepts of training.

It was found that threat management *per se* was not taught at any of the training establishments studied. Remedies are sometimes implied within threat management strategies, and often Error Management techniques contain reference to mitigating the effects of potential crises. The then joint-Swissair/Austrian Airlines/Lufthansa initiative described above comes closest to addressing the subject but the issues raised clearly require further study in the subsequent work packages within ESSAI.

A complete overview of the results of this phase can be found in ESSAI (2001) and Banbury, Dudfield & Lodge (2002).

4 Phase 3 - Training Analysis

The goal of the preceding phase of the ESSAI project was to provide an analysis of scenarios of accidents and incidents in terms of loss of situation awareness and threat management and to analyse threat management strategies during normal operations. Effective situation awareness and threat management techniques that had been identified in that phase served as the input for the Training Analysis.

The approach to identify the training needs and to develop operational applicable solutions to these needs is called Training Analysis. Training analysis is the determination of:

- Training-needs analysis - determine the training that a person requires to perform a job or task satisfactorily.
- Training-program design - the best way in which this training can be given.
- Training-media specification - by what media can the training best be given.

In parallel, Training Design & Development can be initialised, effort increasing towards the end of the TA process. This is depicted in Figure 2.

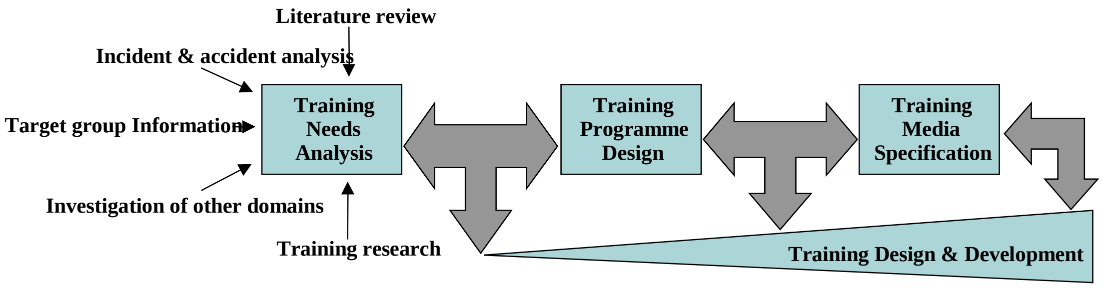


Figure 2: Phases of Training analysis and their relation to other activities within the ESSAI project

The training-needs analysis will be discussed in section 4.1. The training-program design is discussed in section 4.2. Note however that the training-media specification is not discussed in this chapter: separate specification of the training media would be theoretically correct, yet would not necessarily result in an effective and applicable media specification. It was therefore carried out during the Training Design & Development, and will be discussed in chapter 5.

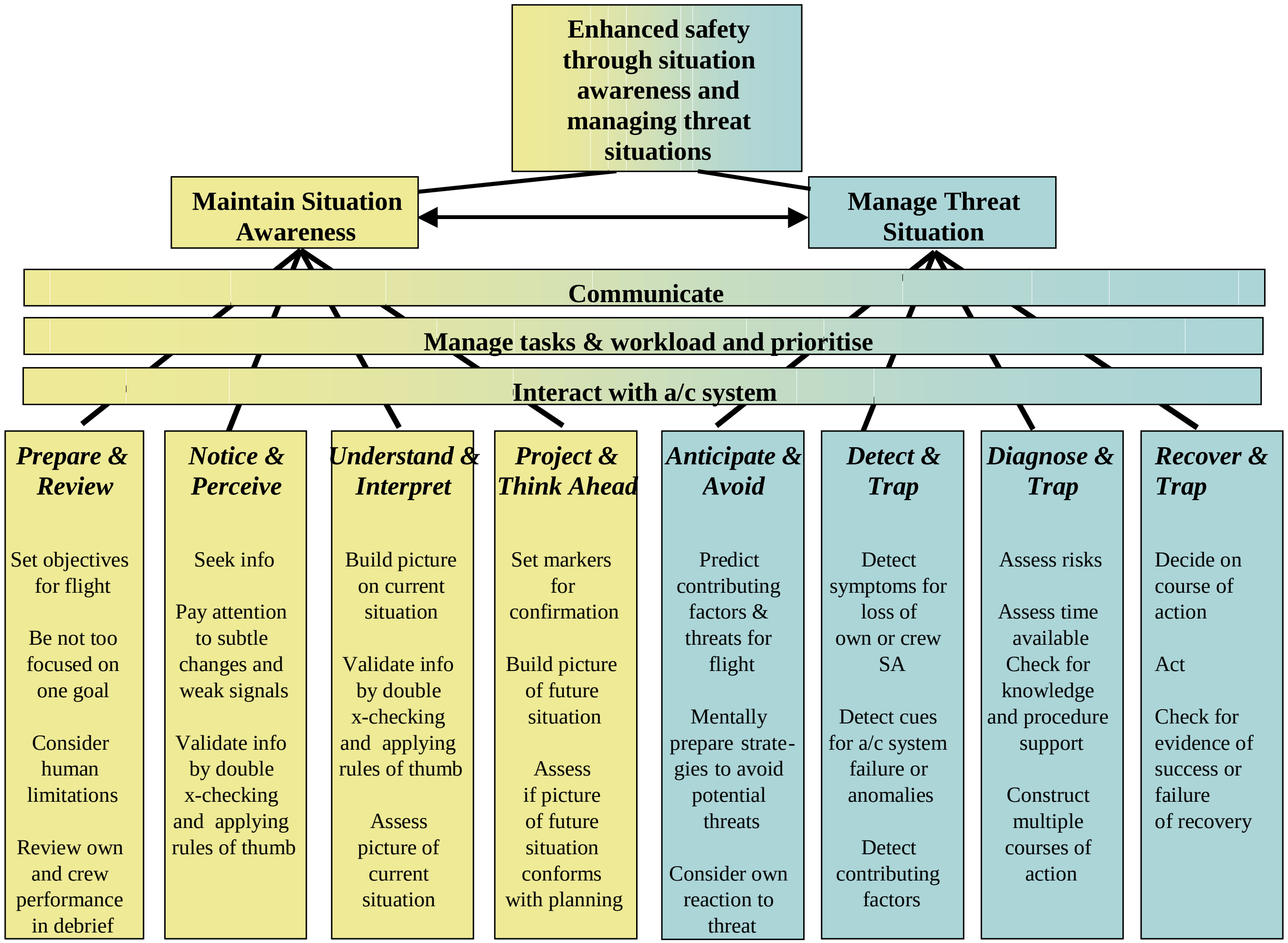
4.1 Training Needs Analysis

The training-needs analysis determined *what* should be trained. In classical training needs analysis approaches, training needs are expressed in terms of knowledge, skills and attitudes (KSAs). This has the disadvantage of resulting in long lists of isolated KSAs, which are difficult to incorporate into a coherent training program. In real life, it is difficult to distinguish between aspects of knowledge, skills and attitudes as they are too closely linked to each other to be separated. Therefore, in the ESSAI project, an alternative approach was chosen: the so-called activity-based approach. With this approach it is possible to search directly for competencies or behavioural strategies, which are seen as successful coping techniques in relevant situation awareness/threat management scenarios. Firstly, the training objectives identified in the previous phases were extracted. Next, these objectives served as input for two workshops that were held with pilots. In the first workshop, a list of behavioural strategies and competencies for effective situation awareness and threat management was generated. Next to knowing what strategies are relevant for situation awareness and awareness/threat management, it was also necessary to define the training needs for such strategies. For this, a second workshop was organised to determine specific training needs for the identified behavioural strategies and competencies and define corresponding training objectives. Next, via questionnaires pilots were consulted with regards to the importance of these behavioural strategies for situation awareness and threat management and how trainable they thought such strategies were. In Table 2 the results are summarised.

		IMPORTANCE		
		Low	Medium	High
TRAINABILITY	high		• Setting objectives prior to flight phase • Not being too focused on one goal • Checking for contradictory facts • Double cross-check • System knowledge	• Recognising personal signals for loss of situation awareness • Recognising other crew members signals for loss of situation awareness • Workload management
	medium	• Health maintenance • Automaticity • Interpersonal dynamics	• Being critical and interrogative • Being self-critical • Attention mgmt • Information mgmt	• Accepting own errors and communicating them • Interpersonal communication • Cognitive efficacy
	low	• Experience		

Table 2: Cross-tabulation of importance by trainability of behavioural competencies for situation awareness and threat management

Figure 3: Competency Structure



4.2 Training Program Design

The training-program design determines *how* the training best can be given (method and program), taking into account constraints and other pre-conditions. Additionally it gives an initial indication of the training media that may be suitable.

Before this step could be taken, the interrelationships between the strategies identified in the training-needs analysis and others not mentioned needed to be made clear. This was necessary since in real-life the strategies are not carried out in isolation but integrated with other task and skills, which might not be skills of primary interest for the ESSAI training. Firstly, to emphasise this interrelationship and the expertise necessary, the strategies were called competencies. The approach taken hereby was to walk through relevant scenarios with pilots. The pilots were asked to indicate which skill in combination with other skills was needed. The resulting ESSAI Competency Structure is presented in Figure 3.

In order to maintain situation awareness and manage threats the crew needs to communicate, manage the tasks/workload and interact with the aircraft systems. These activities take place continuously. The four blocks under situation awareness (Prepare, Notice, Understand, and Think Ahead) and threat management (Anticipate, Detect, Diagnose, and Recover) reflect the 'phases' of the thinking process. These phases are not open loop, but occur in an iterative process. The items indicated under each phase are the strategies that can be used by the crew in that particular 'thinking phase' (e.g. set objectives for each phase of flight or set markers for confirmation).

Having determined what competencies should be trained, the training program was defined. The ESSAI competency that the crew needs to acquire is characterised by the fact that it is mainly cognitive in nature and rather complex. The training approach for ESSAI should be tailored to this complex cognitive competency. Because more and more complex and cognitive competencies are needed, recent trends and developments focus on providing or developing training strategies for preparing personnel for their job.
Three major principles in training the complex cognitive competency in ESSAI can be derived from these trends:

1. *Integrated and joint approach*: Take the totality of the complex cognitive competency into account, reflecting the way as it is applied in the operational situation. Integrate theory (knowledge) and practice (skills) and integrate technical and non-technical abilities.
2. *Realistic context:* Take the actual operational situation and the way in which the competency is applied in the real world as a starting point for training. Scenario-based learning is a good example where hands-on practice of the competency in an operational situation is achieved.
3. *Supportive learning environment*: Provide the learner with the appropriate instructional support (explanations, information, feedback on performance, briefings, debriefings etc.) at the right time, tailored to the needs in the learning

process, the individual learner and the crew. Decrease the support as the learner gains more experience during practice.

Moreover, the training should comply with several criteria. These were:
- Aim for recurrent training, complementary to existing training programs
- Operationally applicable and realistic, meaning that the training is designed as if to be used in a company environment
- The training should be usable and payable for by not only a large airline, but medium and small airlines also. Next to that, the training should be flexible and adaptable for specific needs within operators
- The training should focus on skills and not on knowledge

The training took the operational situation as a starting point, by linking the underlying theory to operational situations. In addition, the training should focus on the application of the underlying theory (the knowledge) in these situations and not only providing the knowledge or theory. Further, there should be some form of test or assessment in the training before going to the simulator.
Therefore, different elements are needed in the training: Examples of operational situations, explanations of the underlying theory/knowledge, exercises to apply the theory/knowledge and an evaluation to assess whether the objectives had been reached and to provide feedback.
By explaining the necessary information in the form of examples, explanations and exercises, a supportive learning environment is provided. In addition, evaluation should provide a supportive learning environment with effective assessment and feedback of performance.
The framework presented in Figure 4 was proposed for ESSAI. This framework was derived from CAST (1999) and Van Bavelgem, Schuver-van Blanken & Van Avermaete (2000).

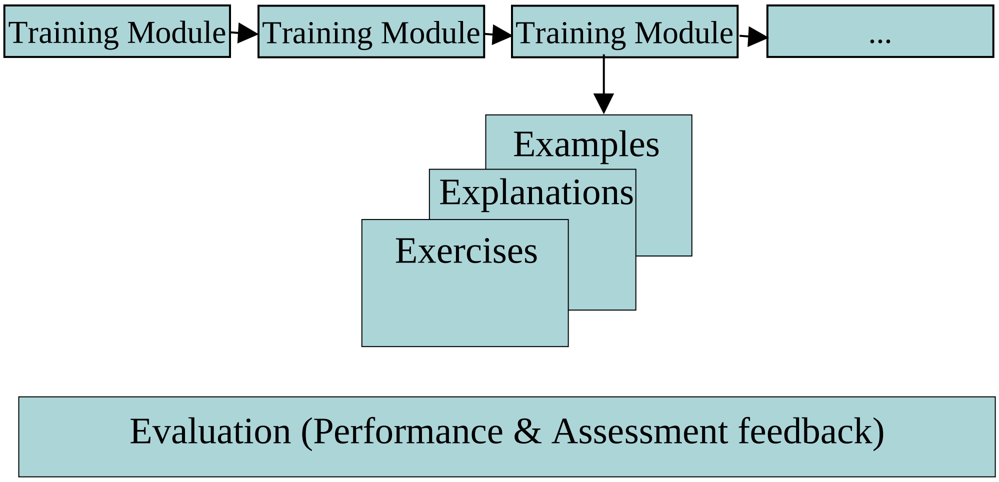


Figure 4: The four E's: ESSAI Training Framework

It should be emphasised that this sequence is not fixed. However, the 4 E's (explanations, examples, exercises, evaluation) should be systematically present in the training. Each of the elements shown in Figure 5 is explained below.

Explanations

The explanations provide a description of the underlying theory/knowledge. The explanations should be linked to the examples (analysis of the examples by means of the theory).

Examples

For each training cluster examples are given in which the theory/knowledge depicted in the explanations are applied. The examples should be related to the explanations. This should be both positive and negative examples of operational situations (e.g. on paper, video) as well as examples from other non-aviation related domains. The examples should include a description or discussion of what actually happens (both physically as well as cognitively).

Exercises

Next to examples and explanations, exercises are a very important part of the training. Exercises have to be provided in which the trainees can learn to apply the theory/knowledge addressed in the explanations and exercises. The exercises are problem- or scenario-based.

Evaluation

Some sort of test or assessment should be included (at the end of a cluster or at the end of the training), focusing on the application of the knowledge. This test or assessment can be similar to the exercises, but then providing a different situation. In addition, feedback mechanisms (e.g. de-briefing, on-line feedback) and the content of feedback should be specified.

A complete overview of the results of this phase can be found in ESSAI (2002).

5 Phase 4 - Training Design & Development

The criteria for the practical context of the ESSAI training were identified in WP3 as being:

- Focused primarily on recurrent and transition Airline training but sufficiently generic to be used in other training roles.
- Operationally applicable and centred on crew competency in situation awareness and TM.
- Modular and flexible allowing for variations in airline size and resources.
- Complementary to existing CRM/non-technical training programmes and progressing beyond imparting knowledge so as to improve skills.

A critical ingredient in the design of the Training Solution was the Competency Structure elaborated in phase 3 (see Figure 3). The complex cognitive nature of those competencies demanded carefully tailored training strategies that were firmly rooted in an operational context. Three major ESSAI training principles were stated: an integrated and joint approach, realistic context and a supportive learning environment. Based on these principles, the training was set up in 4 different parts (see Figure 5).

Figure 5: ESSAI Training Sequence

First, DVD was selected as the means to transfer knowledge on situation awareness and threat management. Design involved an iterative process lasting four months, transposing the competency structure created into more manageable units for delivery in a DVD format. During this time, a further refining process took place sub-dividing the competency structure into *knowledge* and *skills*. This structure had been shown to resonate well with the practical training aspirations but it required close scrutiny in order to ensure that all the essential elements found their place in the ESSAI Training Solution.
The contents of the DVD are discussed in section 5.1. The second part of the training was a Tactical Decision Game, providing a situation in which the pilots could practice the skills that were introduced in the DVD and that will be discussed in section 5.2.

The third and fourth parts of the training consisted of simulator training sessions and a final debriefing; this will be discussed in section 5.3.

The whole ESSAI training was carried out in a supportive environment, meaning that no feedback was given in terms of 'good' and 'bad' performances. On the contrary, emphasis was placed on effective operating strategies. Trainer intervention was thus limited to highlighting potential opportunities to improve crew and individual performance by utilising techniques suggested earlier during the tactical decision game and DVD sessions. Where appropriate these training inputs were underlined during the debriefing sessions.

5.1 The DVD

The DVD was aimed at delivering the required knowledge in a compact, interactive manner, enabling the participants clearly to understand the methodology, concepts and vocabulary that they would encounter during the ESSAI simulator-training phase. The medium would allow for flexibility in customising the product at a later stage should it be proved successful. Greater depth and further sub-routines could be added with relative ease to the base content.
The DVD main menu consists of three central sections preceded by an Introduction and concluded by a Summary and a section on the Key Learning Points.
The central sections concentrated on three concepts. Two of those were situation awareness and threat management, the third was 'Situation Control', which was introduced to provide insight as to how situation awareness and threat management are influenced by high workload and how to help cope with such situations as an individual and as a crew. Lastly, the training addressed how pilots can recognise that they or their crewmember are losing SA, and strategies to try to recover it. All concepts were explained with concrete examples using video material specifically filmed for the project in an A320 simulator using crews from the ESSAI partner airlines. The three concepts are discussed below.

Situation Awareness
Due to the large correspondence of the competency structure discussed in section 4.2 and Endsley's definition for situation awareness discussed in section 2.1, Endsley's definition was used:

> Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. (Endsley 1988)

The three most important aspects of this definition are underlined. The words Perceive, Comprehend and Project were changed into more every-day language i.e. Notice, Understand and Think Ahead. The first and most basic level of situation awareness is noticing, for example an area of CB activity on the weather radar. The next level of Situation Awareness is reached understanding what that means. In this example, the thunderstorm equates to turbulence, lightning strikes, etc. Having understood the implications of the CB, we move on to the higher level of situation awareness - thinking ahead, which in the example could mean to negotiate a re-route or different approach with ATC. Tips are given on how to focus SA: on aircraft status -*Plane*, the *Path* of the aircraft and *People* -cockpit- and cabin-crew, ATC (see Figure 6).

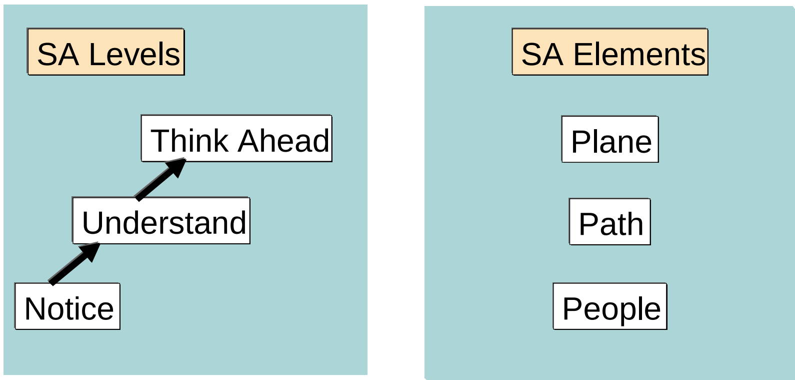


Figure 6: Levels & Elements of SA

Threat Management
For TM, the concept of a layered defence towards threats developed by Helmreich corresponded most closely with the ESSAI Competency Structure in section 4.2. Using his model (see Figure 7), perhaps the first and most effective defence is to identify potential threats and avoid them.

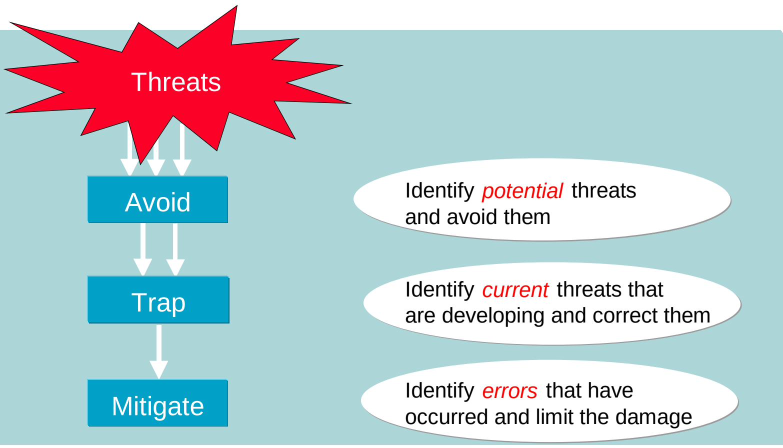


Figure 7: Layers of TM

However, not all threats can be predicted in advance so another level of threat management must be used when they slip through the avoid layer. In these circumstances current threats that are developing can be trapped and corrected. If a threat slips through the trapping layer, then the final strategy is to mitigate their effect. This involves identifying threats that have occurred and limiting the damage.

Situation Control
The concept of Situation Control (Amalberti, in preparation) aims to help pilots "picture" how they apply their "brain power" in different situations. So, Situation

Control helps us to prioritise the allocation of our mental resources. It is a conceptual model, not an exact envelope. In this model is shown in Figure 8.

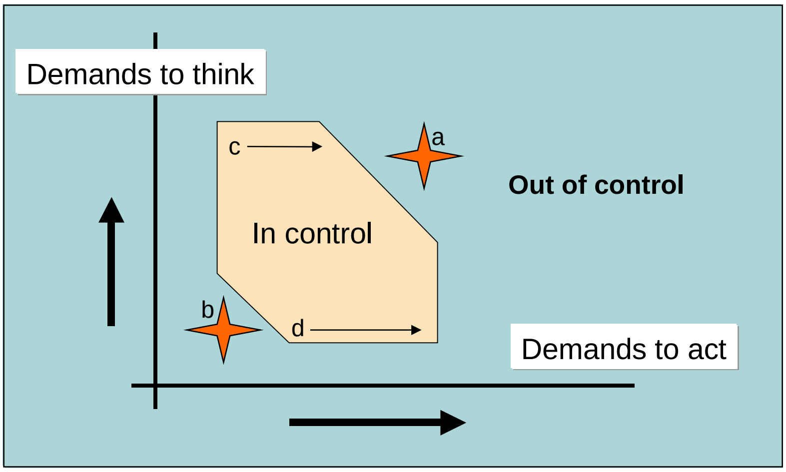


Figure 8: Model of Situation Control

The vertical axis can be called *demands on resources to think* (for example, SA). The higher up this axis, the greater the demands on the mental resources used to gain better SA. Similarly, on the horizontal axis the *mental demands on resources to take action* (for example, fly the aircraft) are plotted. The farther along this axis, the greater the demands on the mental resources used to operate the aeroplane. Within these axes, a conceptual workload envelope can be plotted, which shows where sufficient mental resources are available to deal with thinking AND flying. This represents the "in control" or "ahead of the aircraft" region, where the demands on mental resources can be met by the brainpower that is available. Looking at a point above and to the right of the envelope ('a' in the figure), this would be a situation of overload or being "behind the aircraft". Looking at a point below and to the left of the envelope ('b' in the figure), this represents an area of under stimulation. The size and exact shape of the envelope are different for each person and each situation.

Recognising Clues for loss of SA

Perhaps the first stage in dealing with higher workload situations is to recognise what is happening. Sometimes there are very large and unmistakable cues that the threat is present, for instance instruments or warning systems that tell you something is happening. These are strong external cues. However this is not always the case. When trapping and mitigating threats, then we are probably reacting more immediately to events. Workload is liable to be somewhat higher which will lead to characteristic ways of crew thinking and behaving. Relating back to situation control model (see Figure 8), there is a transition layer between the "In Control" zone and the "Out of Control" zone, which can be called the "Turbulent Layer". This is where it is possible to be aware of impending overload. This turbulent layer is of variable thickness and constantly changing. In this layer there are signals that one is starting to get behind the aircraft. These turbulent signals will vary between individuals and will depend on a large number of factors, for example, fatigue or emotional state. However there are some general clues for getting behind the aircraft. Some examples are:

- Confusion or uncertainty not being resolved

- A fixation on a single task
- Failure to communicate effectively
- A disagreement between two sources of information
- Failure to adhere to SOP's
- Failure to comply with minima

5.2 The Low Tech Exercise

This tactical decision game was called the Low-tech exercise and could be undertaken by two pilots under observation with subsequent feedback by the trainers. The concept and further background of tactical decision games is described in Chrichton & Flin (2001). Such tools are known to be cost-effective and relatively simple to design and execute. It was also felt that a change of pace would be beneficial to the participants following the demanding CBT and questionnaire sessions. The opportunity to reinforce the messages of the DVD could be taken in a low-key environment whilst also demanding some degree of physical activity prior to the simulator phase. The game consists of a grid marked out on the classroom floor, each square to represent a move needed to be traced by one of the participants from a given 'waypoint' to the 'destination' via various intermediate stops verbally guided by the other pilot. 'Obstacles' en route would cause loss of time and 'fuel penalties' requiring recalculation of the routing. As an added stressor a task demanding manual dexterity would be superimposed on the overall workload. Lessons derived from the DVD would then be facilitated from the pilots by the Instructor during the short debrief. No formal observations were to be taken whilst the exercise was in progress. The Low-tech Exercise provided the possibility to practice and illustrate the concepts introduced in the DVD presentation under facilitation by the trainers before further higher level skill development would begin in the level D A330 research/training simulator at TU Berlin. It also introduced the opportunity for crews to identify some of their personal clues to loss of situation awareness, or the "weak signals" that indicate they or their colleague are losing situation awareness.

5.3 Simulator Sessions & Debriefing

In order to create a realistic setting for the training and put the concepts of the DVD into practice, two simulator sessions followed. The scenarios were specifically designed to expose crews to situations that called for situation awareness and threat management. Since the ESSAI training tool should not be 'type-specific' but rather generic in its potential applications, the scenarios did not to have a high technical content. However because it is mandatory for an effective transfer of training and reliable results of the experiment, the level D A330 simulator was chosen because all participating pilots in the experiment flew A319/A320 aircraft.

The simulator training sessions were concluded with an extensive debriefing, using video footage taken during the simulator sessions. Relevant excerpts of the video were reviewed during the debriefing to illustrate instances where important situation awareness and threat management lessons could be learnt. Relevant instances for situation awareness and threat management were recaptured and discussed by the trainers to underpin the interventions made during the LOFTs and to re-inforce examples of good performance. Uniquely for most of the participating crews, this included the use of forward facing camera views so that non-verbal communication could also be captured and related to individual and crew situation awareness and threat management behaviours. An example of a LOFT scenario can be found in Appendix A.

A complete overview of the results of this phase can be found in ESSAI (2003a).

6 Phase 5 - Experimental validation of the ESSAI training

After the training development was complete, its effectiveness was measured by carrying out an experiment, in which the performance on situation awareness and threat management competencies and skills of two groups of pilots, one having received the ESSAI training and another having flown a conventional LOFT scenario, was compared. Specifically, performance on the key concepts of the ESSAI training was analysed.

The experiment started with a Benchmark Scenario for both groups. It was expected that the effectiveness of both groups would not be different during this scenario. Next, the procedure was different for the control group and the experimental group. The experimental group received the ESSAI training, whereas the control group received a conventional LOFT training (i.e. without specific ESSAI situation awareness and threat management training interventions). Both groups then concluded their trials by flying an Assessment Scenario. It was expected that the experimental group would be more effective in situation awareness and threat management during this scenario than the control group. The set-up of the experiment and the measures taken is given in Figure 9.

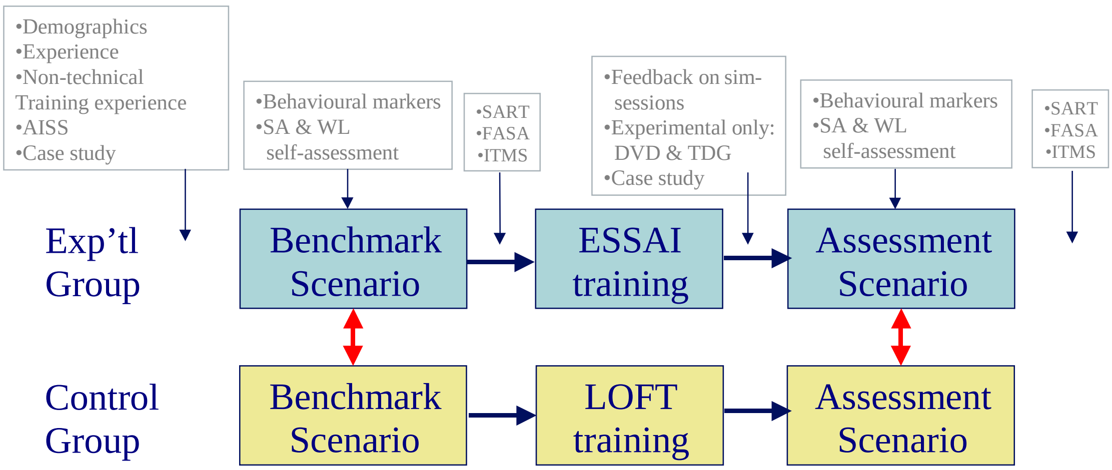


Figure 9: Overview of experimental set-up & measures

The training effectiveness was measured by looking at the performance of the pilots on the four key concepts of the training: situation awareness, threat management, Situation Control and recognising clues for loss of situation awareness.

Measures for situation awareness

Several measures for situation awareness were taken. In the first place, during the Benchmark Scenario and Assessment Scenario, an instructor and a Human Factors expert marked visible crew-behaviour on a predefined marking-sheet. Target behaviour was defined for relevant events, and allowed operator-specific procedures. An example of two events can be found in Appendix B.

Next to that, if situation awareness skills increase as a result of the training, this should also become visible in subjective ratings of the pilots during the Benchmark Scenario and Assessment Scenario. Pilots were asked to rate their own and their fellow crewmember's perceived level of situation awareness on a three-point scale (Notice, Understand and Think Ahead). Situation awareness ratings should be higher for the experimental group in the Assessment Scenario that in the Benchmark Scenario and in the control group.

Next to measuring situation awareness *in situ*, two questionnaires were filled out after the Benchmark Scenario and Assessment Scenario, SART and FASA. SART, Situation Awareness Rating Technique, (Taylor, 1990) is a subjective measurement technique that concentrates on assessing an operator's knowledge in three areas: (1) demands on attentional resources, (2) supply of attentional resources, and (3) understanding of the situation. Thus, it considers pilots' perceived workload as defined by attention capacity (supply minus demand) in addition to their perceived understanding (awareness) of the situation in question. The FASA questionnaire was developed in an earlier phase of the project and focused on a number of cognitive factors that are thought to affect the acquisition and maintenance of sufficient situation awareness for safe flight. Pilots answered questions generated to elicit a response from individuals as to how important they felt these factors were for situation awareness (actual and ideal). It was expected that both groups would score equally on both the questionnaires after the Benchmark Scenario, but that after the Assessment Scenario the experimental group would score higher on the SART and lower on the FASA scale that the control group.

Lastly, in a case study before the Benchmark Scenario, pilots were asked to state their opinion regarding an incident caused by lack of situation awareness. The same case study was repeated for both groups after the training and LOFT sessions and pilots were asked whether they could think of anything to add to their previously written answer. It was expected that the groups would score equally in their responses in the first case-study, and that the experimental group would be able to come with more additions than the control group for the second case-study.

Measures for threat management

TM was measured during the Benchmark Scenario and Assessment Scenario in the same manner as was situation awareness: visible crew-behaviour was marked on a predefined marking-sheet an instructor and a Human Factors expert. Target behaviour was defined for relevant events, and allowed operator-specific procedures.

Next to that, after the Benchmark Scenario and Assessment Scenario together with the SART and FASA the ITMS or Index of Threat Management Strategies questionnaire was filled out by the pilots. It was expected that both groups would score equally after the Benchmark Scenario, and that the experimental group would score higher after the Assessment Scenario.

It is thought that sensation-seeking tendencies affects threat management, i.e. a sensation seeking correlates negatively with threat management. To control for these effects and to check whether there were no differences between the control and the experimental groups, the Arnett's Inventory of Sensation Seeking (AISS: Arnett, 1994) was filled out by both groups. The concept of Sensation Seeking can be defined as the need for varied, novel and complex sensations and experiences, and the willingness to take physical and social risks for the sake of such experiences (Zuckerman, 1979). Previous research has found a relationship between Sensation Seeking and risk behaviour (Arnett, 1994). Of particular interest to this study is the relationship between Sensation Seeking (or risk behaviour) and threat management. For example, an individual who scores high on a measure of Sensation Seeking may be more likely to commit themselves to a riskier course of action in a threatening situation than an individual who scores low on this measure.

The present study used the Arnett Inventory of Sensation Seeking (AISS) (Arnett, 1994) to measure this concept as an aspect of the subject's personality.

Measures for situation control and recognising loss of situation awareness
The concept of situation control addresses the interrelationship between situation awareness and workload and attempts to explain how situation awareness is affected by workload, and vice versa. If pilots become more proficient at maintaining situation awareness, this should also have an effect on perceived workload, which should decrease. Therefore, pilots were also asked to rate their perceived level of workload (and that of their fellow crewmember) on a three-point scale (*Underloaded*, *Just Right* and *Overloaded*). Both ratings were done at predefined moments during the Benchmark Scenario and Assessment Scenario. The ratings took a few seconds and therefore the simulator was not frozen. Next to being able to rate one's own level of situation awareness, pilots should also become more proficient at recognising the crew-member's level of workload and situation awareness and detecting clues that s/he is losing it. Therefore, the pilots were asked to rate the level of situation awareness and workload for their fellow crew-member at the same moment. The experimental group, having more solid understanding of situation awareness and workload and their interaction, and having been trained to recognise clues for loss of situation awareness with themselves and their crew-member, should be able to judge the level of situation awareness and workload of their crew-member more consistently than the control group in the Assessment Scenario. In the Benchmark Scenario they should score equally.

In Table 3 the measures of the four concepts of the training are summarised.

CONCEPT	**MEASURE**
Situation Awareness	Behavioural Markings Subjective situation awareness Ratings Case Study SART FASA
Threat Management	Behavioural Markings ITMS (Confounding variable: AISS)
Situation Control	Subjective situation awareness & workload Ratings
Recognising clues for loss of Situation Awareness	Subjective situation awareness & workload Ratings

Table 3: Measures for Training Concepts

6.1 Subjects

Thirty-two pilots from Aero Lloyd (16), British Airways (8) and Alitalia (8) participated in the experiment. All participants are A319/320 type rated. Average age was 33.17 years. Sixteen of the 32 pilots were captains, the other 16 first officers. The pilots were randomly assigned to the experimental and control Group, respectively. None of them was aware to which group (experimental or control) (s)he had been assigned.

6.2 Experimental Procedure

The sessions for the experimental group took three days, the sessions for the control group took two days. This was because the DVD, Low-tech Exercise and Debriefing for the experimental group took in total approximately 2-3 hours, which were not required for the control group. The three additional hours on the training days required the experimental group to complete the Assessment Scenario on a third days, whereas the control group could complete their sessions in two days.

Participants stayed two days (Control Group), or three days (Experimental Group).

Control group schedule, day 1:

After arrival the crew was generally briefed about the facilities, the procedure, the schedule, etc. Then the first part of questionnaires was handed out in the same room. This part took about 60 minutes on average followed by a briefing for the BS (40 minutes). After the briefing the pilots flew this scenario in the A330 training simulator. Flying time for this took about one hour. However, two hours simulator time was scheduled to avoid time pressure in case of unexpected problems. After leaving the simulator the crew had half an hour debriefing time and half an hour for another set of questionnaires. The crew finished the first day with a general LOFT-session as part of their training accompanied by a briefing/debriefing.

Control group schedule, day 2:
The second day consisted of the Assessment Scenario with a preceding briefing and followed by the auto-confrontation debriefing and a short questionnaire.

Experimental group, day 1:
After the arrival the crew was generally briefed about the building, the procedure, the schedule, etc. Then the first part of questionnaires was handed out in the same room., which took about 60 minutes on average followed by a briefing for the BS (40 min.). Subsequently this scenario was flown in the A330 simulator and took about one hour. Another questionnaire part after the Benchmark Scenario finished the day one.

Experimental group, day 2:
The second day began with the DVD training followed by the Low-Tech exercise and a questionnaire package. After that part the first training scenario was briefed, flown and debriefed. The simulator briefing, second training scenario, and the debriefing closed day 2.

Experimental group, day 3:
Day 3 began with a short general briefing followed by the briefing for scenario 4 (Assessment Scenario). This session was debriefed afterwards. The auto-confrontation interview and the final questionnaire package represented the last parts of the experiment for the experimental group.

During the experiments efforts were taken to avoid direct contact between participants of the two different groups (experimental and control group) to eliminate “cross fertilisation” of the two groups. Additionally, no participant knew in what groups he or she had been assigned.

6.3 Results

The different methods of measurement of situation awareness and threat management applied in the ESSAI experiment can be distinguished according to whether they relate to Meta-knowledge, attitudes, or behavioural skills and strategies. In order to avoid certain methodological bias, the experiment did not only rely on questionnaires, but also used behavioural observations, self- and peer-ratings, knowledge and reasoning tests as well as quantitative and qualitative methods.

It appeared that the subjective training satisfaction of the participating pilots with the different training components in general was very high. The majority of the ESSAI trained pilots (62.5%) strongly agreed that they have learnt a lot from the Low Tech Exercise and the simulator training sessions. Most found them stimulating and interesting (75% agree strongly for the Low-tech exercise and 68.8% for the simulator). In the control group only 25% agreed strongly that the simulator session was stimulating and interesting and 37.5% that they have learnt a lot from the DVD. The DVD primarily seems to have provided the pilots with certain knowledge and concepts about situation awareness and threat management. While it was rated by the majority as interesting and stimulating (68.8% strongly agreed) only 25% agreed strongly that they learnt a lot. However, due to sequential effects the three ESSAI-training components cannot be evaluated separately. Certainly, the effectiveness of the Low-tech exercise as well as of the simulator exercises depend to a high degree on these concepts embedded in the DVD computer-based training part.

Further evidence for positive ESSAI training outcomes were found in two written tasks. Being asked to re-analyse a case study, at the end of the training, experimental group participants produced a greater variety and number of causal factors and possible preventive measures in relation to situation awareness and threat management concepts than the control group. The results demonstrated that the pilots in the experimental group were able to systematically apply training contents conveyed in the DVD to the analysis of a given scenario. In comparison to the control group they came up with more general safety enhancing attitudes and intentions applicable also to other operational contexts.

A significant shift in attitudes and self-reflected behaviours can also be deduced from with questionnaire techniques. As a result of the ESSAI training the experimental group pilots revealed more favourable attitudes towards Information Management, Automaticity, and Interpersonal Dynamics (see also Banbury et al., in prep.). In order to maintain more adequate levels of situation awareness, experimental group pilots put an increasing emphasis on these factors, while the attitudes of control group pilots seemed unchanged. Effects on self-rated threat management strategies were also affected by the ESSAI training but less prominent than the situation awareness measures. However, the overall trends for threat management strategies are consistent and also statistically significant. The spread between the two groups is increasing in relation to the training events. Experimental group pilots perceived their own threat management strategies and those of their fellow crewmember as being more effective after the training, while the scores in the control group remained unchanged or even slightly decreased in the second test scenario.

The most crucial test of the effectiveness of the ESSAI training is the comparison of crewmembers' actual behaviour in a full-flight simulator before and after the training events. The tasks embedded in the scenarios were twofold: First, in relation to situation awareness, the pilots had to notice, understand and project flight related information appropriately in order to maintain situation control and "being ahead of the aircraft". Secondly, in relation to threat management, overt and hidden threats like disruptive passengers, high terrain, weather, or human error had to be detected and managed effectively.

The results of the data analyses do provide convincing empirical evidence that the ESSAI training solution substantially enhances situation awareness. During the training experiment the majority of experimental group crews improved their situation awareness-level from Understanding to Projection, while control group remained on the level of Understanding. This can be demonstrated especially for the briefing phases during the simulator missions. The effectiveness of threat management strategies does also significantly increase; however, the incremental gain of the ESSAI training compared to a "normal" LOFT-mission is visible but not statistically significant. For both, experimental group and control group crews, more effective threat management strategies were observed at the end of the training. Consequently, ESSAI seems to have had a larger and more specific impact on situation awareness than on threat management.

A complete overview of the results of this phase can be found in ESSAI (2003b).

7 Conclusions from the experiment

The ESSAI experiment was designed to find out whether the exposure to the advanced training tools can significantly minimise pilot's' loss of situation awareness and improve their effectiveness of threat management strategies. An experimental design was chosen which allowed the comparison of differences between two groups of pilots: one group (the experimental group) trained with the ESSAI training solution, the other group (a control group) trained in a normal LOFT session. In addition, quantitative and qualitative measurement was administered prior to and after the training allowing to test differential performance gains within the two groups during the whole training experiment. In line with the hypotheses, it was expected that the pilots of the experimental group show higher levels of situation awareness and threat management after the training. The gain of performance in the control group should be significantly lower.

Overall, the consistency of the data trends was very high. If in some cases the effects fell short of the significance threshold, it has to be kept in mind that the sample size for this kind of training experiment is quite small. As shown in the power analysis the probability that actually significant differences are being "overlooked" is between 30% and 50% depending on the definite size of the respective effect. In addition, as all participants are well-trained pilots of some leading European airlines, the crewmembers in both groups performed considerably high in terms of situation awareness and threat management from the beginning of the experiment. Therefore, effects of reaching the end of the evaluation scales ("ceiling effects") reduced possible gains attributable to the training.

In conclusion, it can be stated that there is enough empirical evidence in this study to prove the effectiveness of the ESSAI training for enhancing the quantity and quality of pilots' knowledge, skills and attitudes related to situation awareness. The positive effects of training can be demonstrated across all modalities of measurement: knowledge tests, self-ratings, peer-ratings, behaviour observations and general questionnaires. Scores for situation awareness and threat management were observed as increasing during the experiment as a result of the training across all methods of measurement. A difficulty of the statistical comparison is that also the control group showed an increase in performance in some areas. Therefore, performance gains cannot always be attributed solely to the ESSAI training solution. The extra benefit of the ESSAI training tools compared to a regular LOFT-type training was more evident for situation awareness than for threat management. In summary, it can be confirmed here that with the ESSAI training tools, loss of situation awareness is in fact minimised. Effective strategies for threat management can be acquired through ESSAI but also through other training means (e.g. conventional LOFT).

8 Using the ESSAI results & contact information

The ESSAI training solution consisting of the DVD, low tech exercise, simulator sessions and (de)briefing is available to the public. The training can be adapted to specific needs and requirements of the operator including translation to other languages (English and Italian currently available). Possibilities include:

ab-initio training (feasibility study is being undertaken)
MCC training
TRI training

Preliminary results indicate that the training can also be adapted to fields outside the aviation industry, such as medical emergency surgery (see **Practical exploitation below)** or command and control.

You can contact the consortium for information or consultation on any of the subjects below:

Situation Awareness
Threat Management
Training Analysis (training needs analysis, training program design, training media specification)
Training design and development
Experimental validation

Email: essai@nlr.nl

All reports resulting from the project and most of the publications and presentations on ESSAI can be found on: www.essai.net.

To give the reader an idea of the different possibilities of the ESSAI project results, an overview of the presentations and publications is given below. Next to that, the partners are also using the results of the project for other activities. Some of these are also listed below.

Practical exploitation of the ESSAI Project results

All Aero Lloyd crews (110) will receive the ESSAI training in the period January - June 2003 as part of the Company training programme. In addition, questionnaires are filled out by the crews to provide additional feedback to the ESSAI consortium.

Aero Lloyd will do a Feasibility demonstration in February 2003 for a major operator and an ab-initio Pilot school.

Aero Lloyd has held an ESSAI workshop for mixed fleet operation. The follow up is in spring 2003.

BA is adding the Low-Tech exercise and elements from the ESSAI DVD for Command CRM Training "Essentials for Command".

BA has started a project with potential to integrate ESSAI training into a hardware/software simulator training aid for Briefing/Debriefing, initially on B777 fleet for Re-current and Transition training.

QinetiQ has used the experiences gained in the ESSAI experiment in a case study to explore measures of performance in human in the loop simulation.

The WP1 “Review of SA the state of the art literature review” has been exploited in the UK MOD research programmes for the development of implicit measures of SA

Alitalia will possibly use the ESSAI training in Advanced CRM or Command course, the MCC training, LOFT facilitators training and TRI training.

Alitalia will present the results to different Italian airline companies, the military and governmental organisations.

Alitalia has assessed a large group of pilots on the Arnett’s Inventory of Sensation Seeking test, which was also used in the ESSAI experiment. This was done during the CRM recurrent training in the Fall/Winter 2002, results will be available in 2003.

Aero Lloyd in collaboration with a medical faculty will carry out a feasibility study in the spring 2003 in which the ESSAI training is adapted for an operating theatre training programme.

Aero Lloyd has started another Feasibility study to integrate the ESSAI training structure into a child education programme.

NLR will use the results for further study of implementation of objective training measurement in training analysis.

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Development andvalidation of novel measures of Situation Awareness to assess the effectiveness of commercial airline pilot threat management training. International Journal of Aviation Psychology.

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Appendix A Example ESSAI-Training LOFT

This training LOFT involves a departure from Basle and flight to Lyon. A high crew workload is structured into the exercise with a time management issue for the Instructor. To expedite the start, engines are running and the set-up can be assisted if desired.

1. The aircraft is to be dispatched with two MEL items: FMGC 1 U/S and a Pack 2 fault. (SA) Instructor should select "FM to BOTH ON 2" and ensure Pack 2 switched Off
2. The clearance given is 'to Lyons Satolas HOC 2C' from Runway 16. This SID is not in the TUB simulator database and requires a manual input by the crew (SA). Route entered: HOC-R13-WIL-G5-ARGIS Flight Level 220
3. The take-off is flown with a low QNH and an initial SID restriction of Flight Level 80. (The crew has been given a temporary note in the AIS briefing that the Transition Altitude is 6000'.) The Instructor instigates an ATC distraction approaching Transition via a frequency change (SA).
4. ATC gives direct routings to the waypoints FRI and then SPR, direct Lyons for arrival.
5. En route under Geneva Control with Minimum Safe Altitude of 12,800' (FRI-SPR) other Pack gives an Overheat warning. Due to the low QNH the crew must adjust their minimum Flight Level to ensure terrain clearance. (SA,TM).
6. Once aircraft is established in the descent the Pack Overheat warning is cancelled by the Instructor.
7. A severe thunderstorm with Micro-burst is set directly overhead Lyons airfield.
8. On arrival at Lyons weather is passed to crew: Wind 020/15 in showers of rain and hail with broken cloud at 1500' and cumulonimbus at 2500'. Temperature 9, dewpoint 5, and QNH 980.
9. Crew are advised of thunderstorms approaching the airfield.
10. Radar vectors are given towards Runway 36Right but then told that a lightning strike has caused damage to the tower and the airfield is closed until further notice.
11. Instructor ensures a diversion to Geneva is considered and offers clearance to waypoint CBY for an ILS-approach to runway 05. (SA+TM).
12. Radar vectors are given but clearance below Minimum Safe Altitude is offered with possible terrain conflict (SA+TM).

Exercise ends when crew has dealt with the unsafe radar vectoring as time allows.

Appendix B Example of behavioural scoring sheet

Two events for threat management and situation awareness (different scenario).

Event:	Threat Management			
Taxi Out: Faulty ATC taxi instruction		**Ineffective**	**Partially effective**	**Effective**
		Fail to notice problem	Start taxiing with uncertainty	Decline taxi clearance / question routing
	Capt	1	2	3
	F/O	1	2	3
	Crew	1	2	3

Event:	Situation Awareness			
Descent Brief: Arrival weather close to VOR minima		**Notice**	**Understand**	**Think Ahead**
		Not notice at all OR cursory mention	Notice and talk about it / no specific discussion	Discuss plan of action of VOR approach unsuccessful
	Capt	1	2	3
	F/O	1	2	3
	Crew	1	2	3