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Proceedings of the First EUROCONTROL Human Factors Workshop Cognitive Aspects in ATC

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Abstract

This report contains the proceedings of the first EUROCONTROL Human Factors Workshop held in Luxembourg in May 1996. The workshop addressed "Cognitive Aspects in Air Traffic Control (ATC)" in four areas: model, selection, training and automation. The report includes the presentations of the speakers, summaries of the working groups and the workshop evaluation.

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EXECUTIVE SUMMARY

The European Air Traffic Harmonisation and Integration Programme (EATCHIP) Human Resources Team (HRT) has initiated the organization of annual workshops on topics concerning Human Factors (HF) in Air Traffic Management (ATM).

This report contains the proceedings of the first EUROCONTROL HF workshop held in Luxembourg in May 1996. The workshop addressed “Cognitive aspects in Air Traffic Control (ATC)” in four areas: model, selection, training and automation.

Chapter 1 introduces background, scope and purpose the HF workshops and their relevance for the work of the Human Resources Domain (HUM) in EATCHIP.

Chapter 2 of the document includes the text of the presentations given during the plenary session:

- “Cognitive Aspects in ATC” (Mr. V. David Hopkin);
- “Model for Cognitive Aspects in ATC” (PD Dr. K. Wolfgang Kallus);
- “Issues in the Selection of Air Traffic Controller (ATCO) Candidates” (Pr Brendt Brehmer);
- “Cognitive Trends and Training” (Sylvie Figarol);
- “Cognitive Aspects and Automation” (Marcel Leroux).

Chapter 3 provides the summaries of the working groups held on four themes: “Model for Cognitive Aspects”, “Cognitive Aspects in the Selection of ATCO students”, “Cognitive Aspects and Training in ATC”, “Cognitive Aspects and Automation of ATC”. During the working groups participants were asked to identify, in each of those four domains, the critical issues which require further research and development.

Chapter 4 gives an overview of the results of the evaluation made by the participants.

A list of all participants can be found at the end of the document as well as an evaluation form and the list of definitions and abbreviations used in this report.

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1. INTRODUCTION

The need to invest in and study human aspects was part of the early steps within EATCHIP. In the EATCHIP HUM it was agreed to regard HF as the Research and Development branch which attempts to integrate human aspects related knowledge and methods into the current and future ATM system to ensure the overall compatibility with the human operator. The results of this activity find their application in the fields of job description, manpower planning, selection, training, licensing and human performance.

1.1 Scope

The EATCHIP HRT, at its 4th meeting in September 1995, has initiated the organization of annual workshops on topics concerning HF in ATM. The goal is to provide a Centre for ATM HF expertise in Europe. This will encourage researchers and practitioners to exchange the results of current research, development trends and practice, to share their experiences and to consider the evolution of new concepts for the changing ATM environment.

1.2 Purpose

This report contains the proceedings of the first workshop on “Cognitive Aspects in ATC” which was conducted in May 1996 at the EUROCONTROL Institute of Air Navigation Services (IANS) with 60 participants from 10 States. It included plenary sessions (technical notes) and working groups covering cognitive issues in modelling, selection, training and automation in ATM.

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2. TECHNICAL NOTES

On the first morning, the workshop commenced with a plenary session during which a keynote address and four technical notes were delivered.

2.1 Cognitive Aspects in Air Traffic Control

(key note address)

by V. David Hopkin - Human Factors Consultant, ‘Peatmoor’, 48 Crookham Road - Church Crookham, GB-Fleet GU130SA

2.1.1 Introduction

Cognitive principles and concepts have been applied to ATC for nearly fifty years. The original emphasis was on the extrapolation of laboratory findings to real life but latterly the main emphasis has been on the application to ATC of cognitive methods and constructs.

2.1.2 Cognitive Concepts

Among the cognitive concepts and processes directly applicable to ATC are the following:

– perception,
– attention,
– learning,
– memory,
– information
– processing,
– understanding,
– planning,
– problem saving,
– decision making,
– prediction,
– motivation,
– human error,
– communication.

Psychological theories which have been developed in relation to the above cognitive constructs are generally applicable in ATC and attempts have been made to apply many of them. However, although they are useful, they usually do not transfer directly to ATC but often they require considerable interpretation and interpolation before they can fit ATC contexts when they can then help to illuminate and explain ATC processes. For example, taxonomies of types of memory, of human error or of cognitive style derived from psychological theories do not always fit real ATC activities very well until they have undergone some modification.

Conversely, cognitive concepts that have originated from practical ATC such as the old concept of the controller's picture and the much newer concepts of readiness to perform, Situation Awareness (SA) and cultural ergonomics do not have exact equivalents in the terminology of orthodox cognitive theories.

Attempts to link theory and practice nevertheless seem worth persisting with and they have an honourable history. If a direct connection can be made between a cognitive theory and a practical ATC finding, this can benefit both. It can strengthen the theory by providing independent confirmation of its correctness and it can reinforce the finding by demonstrating its compatibility with other findings and by reinforcing it at a more fundamental theoretical level. From time to time, concepts with a theoretical basis such as fatigue and levels of information processing have been employed successfully as tools in ATC, usually to identify variables, to furnish explanations, to provide measures or to suggest methodologies.

Inappropriate forms of cognition that are also of theoretical interest include wrong cognition in the form of errors, irrelevant cognition in the form of disruptions or distractions, absence of cognition associated with omissions, insufficient cognition leading to boredom and free association inducing inappropriate exploratory behaviour when there is too little work.

All can be potentially unsafe.

2.1.3 Cognitive Implications of Computer Assistance

Many of the commonest HF effects of computer assistance are mostly cognitive. They include:

- the allocation and matching of human and machine functions,
- human adaptability,
- monitoring and passivity,
- observability,
- reported loss of mental picture or model,
- the disguising of human inadequacy,
- the curtailment of team functions,
- restrictions on the forms and efficacy of supervision,
- the development of professional norms and standards,
- human comprehension of system functioning,
- human initiatives,
- potentially incompatible human roles.

2.1.4 System Effects on the Controller

Effects of the system on the controller's cognition include:

- the accumulation of professional knowledge and experience,

- task demands and human workload,
- the presentation of the current traffic scenario,
- sources of stress and fatigue,
- sources of boredom,
- the formation of attitudes towards the system and the work,
- the development of trust,
- job satisfaction.

2.1.5 External Influences

ATC can seem simple at first but is actually quite complex as many have found when they have tried to write software for it. The cognitive aspects of ATC are influenced by numerous external influences. Notable recent and pending ones are occurring in communications with the advent of data links and satellite derived data, in technology with the introduction of colour displays and in computing with the provision of decision aids such as ghosting.

2.1.6 Functional Complexity

Electronic flight progress strips have provided a good illustration of the functional complexity of paper flight progress strips and have raised the issue of which aspects of this functionality have to be captured on electronic strips or, in other ways, if electronic strips replace paper ones. A discernible and increasing trend is the progressive introduction into ATC of machines possessing attributes hitherto treated as exclusively human, machines that can be intelligent, adaptable, flexible or innovative. Efforts to match the human and machine optimally when both possess these attributes have not yet led to a set of applicable rules and practises but without them there could, for example, be instability as the human tries to adapt to the machine while the machine is trying to adapt to the human. Existing sets of rules about the allocation of functions to human or machine clearly become irrelevant. The associated cognitive issues are challenging.

2.1.7 Tacit Understanding

ATC often relies heavily on forms of collaborative decision making that depend on tacit understanding between controllers. Each knows what the others are doing and each acts on the supposition that colleagues are performing their tasks in their normal ways and to their normal standards of achievement but there may not be many overt interchanges between them. Indirect measures of tacit understanding therefore have to be developed if there is a requirement to study it. Its importance has often been underestimated, particularly when forms of computer assistance for cognitive tasks have been introduced into ATC without taking account of it.

2.1.8 Teaching and Learning

There is a big difference in ATC between what is taught and what is learned.

What is taught is the product of training and is the body of knowledge and skills which the professional controller possesses. However, much of what is learned is learned on-the-job and is never formally taught. This learning includes much tacit understanding and also covers:

- The professional standards that must be achieved to earn the respect and trust of colleagues;
- Activities in which the controller can be independent and autonomous and those in which consultation with colleagues is expected;
- Attitudes towards management, conditions of employment, pilots and colleagues that the controller is expected to hold and support;
- The professional ethos and norms of conduct;
- Local practises which are sanctioned and universally followed within the workspace;
- The social mores and camaraderie within the working group.

All this learning depends on team roles, mutual observability and active supervision, all of which are being changed for other reasons, often without recognition of their cognitive implications.

2.1.9 Training Issues

Future cognitive requirements such as the progressive evolution of ATC from the tactical control of single aircraft to the strategic pre-planning of traffic flows have cognitive implications not only for ATC training and practice but also for selection since some of the envisaged requirements are not featured in current selection batteries. An associated issue is whether changes in training can compensate for any deficiencies in selection.

ATC training and research both employ simulation techniques. There has been a natural but unfortunate tendency to equate the fidelity of the simulation with the validity of its findings or products. Consequently, some simulations have been unnecessarily complex and costly while others have tackled issues that cannot be resolved validly by simulation because certain crucial real life influences or variables cannot be simulated. Cognitive analysis, task analysis and transfer of training principles are among the cognitive techniques that could resolve this issue.

2.1.10 Workload

There is considerable misunderstanding about some cognitive aspects of workload, particularly in attempts to equate task demands with the controller's workload. Task demands are a system derived concept and not a human cognitive one. They refer to the amount of work that has to be done, which does not depend on the controllers who happen to be on duty. The workload is a function of individual controllers because their knowledge, experience, skill and training partly determine the human effort and functions required to meet the task demands and how well the task will be done. In ATC a main influence on most cognitive studies has been the need to ensure that the cognitive demands on the controller do not become excessive. Much emphasis has therefore been on high workload and its reduction though high workload can be satisfying can provide opportunities for esteem and may be essential for the maintenance of professional knowledge, proficiency and skill. Low workload can also be a cognitive problem in ATC.

2.2 Model for Cognitive Aspects in Air Traffic Control

(first technical note)

by PD Dr. K. Wolfgang Kallus

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2.2.1 Introduction

To begin with, some basic definitions will be given for ‘mental model’, ‘mental picture’ and ‘SA’. The second part of the paper presents a brief structural model based on four core elements. Elementary aspects of a process model for cognitive aspects in ATC will be outlined in the third part. Finally, factors which impose stress on the cognitive system will be used to discuss advantages, limits and practical implications of the proposed model.

2.2.2 Basic Definitions

The importance of cognitive factors in ATC has been widely accepted. Unfortunately, different aspects of cognitive factors and different concepts were used in the various areas and disciplines dealing with ATC. The use of common expressions with different meanings is some kind of inevitable consequence of a common interest of different disciplines. Our model for cognitive aspects in ATC is based on the following definitions :

Mental Model

The term ‘mental model’ is used according to Rouse and Morris (1986). Their definition has only slightly been modified by replacing ‘mechanisms’.

‘Mental models are the cognitive processes/representations whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states and predictions about future system states’.

Mental Picture/Traffic Picture

The term ‘mental picture’ is defined as the actually used mental model which has been adjusted thoroughly to the actual situation input.

‘The actual mental picture of a situation represents a moment to moment snapshot of the actual situation based on the mental model and the actually perceived external cues. A series of mental pictures represents the actual mental model including the actual parametrization’.

The term ‘mental picture’ is used within the ATC domain to denote the mental representation of an air traffic situation and the necessary actions that should be taken. The above definition of 'mental picture' is in harmony with the everyday use of this term. In theoretical texts mental pictures are sometimes defined as more general mental models (Wilson & Rutheford, 1989). The situation-oriented definition, which has been agreed upon by the HRT of EUROCONTROL, is in accordance with the use in the ATC community.

SITUATION AWARENESS

Several definitions of 'Situation Awareness' were reviewed by Domingues (1994). He suggested the following definition which was adopted for the current model:

'Continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture and the use of that picture in directing further perception and anticipating future events'.

Endsley (1995) tries to line out different levels of SA:

'It does not only encompass an awareness of specific key elements of the situation (Level 1 SA) but also a Gestlat comprehension and integration of that information in the light of operational goals (Level 2 SA) along with an ability to project future states of the system (Level 3 SA)'.

2.2.3 Structural Model

The 'structural model' has been developed with reference to Baddeley's (1986) conception of working memory. The working memory metaphor was introduced by Baddeley and Hitch (1974) with close reference to the architecture of modern computers. In correspondence with this metaphor an input/output-system, a long-term memory structure and a process control unit were added to the working memory in order to obtain the basic elements of a cognitive model of ATC.

Working Memory

The working memory according to Baddeley and Hitch (1974) consists of three parts: central executive, visuo-spatial sketch-pad and the phonological loop. The working memory is a short-term buffer with limited capacity. It can only handle a set of about four to seven elements or combined elements (chunks) at the same time.

Without active rehearsal procedures the memory traces fade within a few seconds. The limited capacity of the working memory along with a high susceptibility to interference explains why there is a wide range of deficiencies in human information processing.

'Loosing the traffic picture', one of the greatest concerns of an ATCO, may also be attributed to the limited capacity and/or the proneness of the working memory to interference. The mental picture as well as the mental model of the air traffic situation in one sector contain more informational units than 'seven ± two'. Thus, a close interaction between working memory and active long-term memory has be considered.

Long-term Memory

The mental model of ATC is stored in the long-term memory. The mental model of ATC can be conceived as schemata (Norman & Rumelhart, 1975) and scripts (Schank & Abelson, 1977). The selection of a specific script can be viewed as the activation of a network of action-related knowledge (Oesterreich, 1994).

Long-term memory structures can be subdivided into different structures. One should differentiate between knowledge, which is actually accumulated (epistemic knowledge) and the knowledge, which enables us to solve problems and adjust to new situations (heuristic knowledge).

Epistemic knowledge encompasses at least three important domains:

1. Rule-based knowledge how to do things and how things work;
2. Language-based knowledge about things;
3. Knowledge which is related to concrete episodes from experience.

Knowledge based on episodes is also termed analogue knowledge, which implies a primarily visuo-spatial knowledge representation.

For the current model it is feasible to differentiate between general knowledge structures and ATC-specific knowledge structures:

a) In specific epistemic knowledge structures rules and conventions of ATC, sector-specific rules and the like are represented;

b) ATC specific heuristic knowledge structures contain rules and procedures how to derive solutions for new, unexpected traffic situations. It has been shown that the capacity to derive these solutions depends on the experience of the controller.

The ATC-specific knowledge structures are part of the mental model. The mental model is dynamic, primarily visuo-spatial and a least four-dimensional time-space cluster. It can further be characterized by epistemic background knowledge, strong episodic influences and it encompasses general as well as sector/task-specific components. It includes action routines and is responsible for the selection of adequate zooming parameters as a function of traffic density.

Input/Output (I/O) System

The I/O system is closely integrated in functional loops. Most of the activities of the I/O system can be conceived as top-down processes. These top-down processes are determined by the mental model and the mental picture. The I/O system is governed by interacting feedback-loops according to the principle of reafference. The activity of the I/O system, i.e. the selection of information and responses, is controlled by the process control system.

Process Control System

The process control system of our model is a functional extension of the central executive proposed by Baddeley. Taking into account the continuous (self-)monitoring of the process of ATC and at the same time including SA in the model, we decided to extend the central executive to a process control system. This process control system allows for including different aspects of attention, planning processes and concepts of goal-directed action into the model.

The process control system organizes the interaction of working memory, long-term memory and I/O system. It serves as a short-term planning unit and depends on the capacity of the working memory. The tasks of the process control system include:

- Controlling the back-up rate of the mental picture;
- Attentional focus (selection of zooming-parameters);
- Setting of interruption-thresholds (thresholds to switch from one task to a different one or to attend to environmental stimuli);
- Allocation of controllers' activation and attentional resources;
- Controlling the sequencing of actions;
- Checking the correct execution of short-term plans;
- Organizing intentional forgetting and termination of tasks.

2.2.4 Process Model

The ATCO has to use different mental functions in order to fulfil the various task and jobs of ATC simultaneously.

The basic assumption of the process model is that ATCOs follow a precise, pre-formatted and situationally adapted mental model when doing their job. This mental model of the situation is used to organize the received input information to plan traffic flows routinely, to structure ATCOs' activity, including the Radio/Telephony (R/T) communication and to check necessary feedback.

According to this conception, ATC is primarily organized and conducted in a top-down mode. This does not exclude regular checks for irregularities and unexpected information nor does it mean that bottom-up signals are irrelevant for the ATC process. It does imply, however, that the threshold for incoming signals is higher during the "non-check" intervals.

The process model conceives ATC as a special case of goal-directed action. Basic parameters for the execution of goal-directed action will be taken from Dörner's (1993) model of action regulation and they will be adjusted and supplemented to the case of ATC.

In addition, conditions of non-routine decision making have to be considered. A basic assumption is that unexpected information or changes in a situation are a prerequisite of non-routine decision making.

In some instances non-conforming information can be assimilated to the actual mental model. In these cases the model remains unchanged and no change in the course of action will occur in spite of changes in the situation. This can be a major source of error. Repeatedly experienced technical errors and the resulting "mental error model" can be an easy means of assimilating non-conforming information. It should be noted in this context that low-base rates and negative evidence are often biased by the human cognitive system.

On the other end, unexpected information can induce changes in the mental model (accommodation processes). In this case the course of action will be changed according to an active decision process. Principles derived from the work of Janis and Mann (1977) on emergency decision making will be used to describe risks and possible errors in the decision process within the process model of ATC.

Changes in the mental model can also occur when the situation (and accordingly the mental picture) changes drastically (e.g. changes from high to low traffic density).

The mental functions which are activated during ATC are not restricted to the running of a mental model. The ATCO has to use his cognitive functions to conduct his tasks.

These cognitive functions include:

- perception,
- encoding of information,
- information integration,
- appraisal of evidence,
- weighing of evidence,
- categorizing,
- structuring (e.g. prioritization),
- storing,
- retrieving information,
- comparing expected and received information,
- decision making (selecting alternatives),
- logical reasoning,
- problem solving,
- the anticipation, planning and preparing of actions.

At the same time, cognitive resources are required to handle the devices of the work environment for the self-regulation of the ATCOs' activation, emotions and attention and for the communication in the team to maintain a shared mental model.

The structural model and the process model will be presented and discussed for the cases of extremely high traffic density under time pressure and long lasting low traffic density. Both of which can be considered as stress conditions for the controller.

2.3 Issues in the Selection of Air Traffic Controller Candidates

(second technical note)

by Berndt Brehmer - Dept. of Human Sciences - National Defence Research Establishment, S - 172 90 Stockholm

2.3.1 Introduction

To see an ATCO at work is an impressive sight. The ATCO, seemingly without effort, keeps track of a large number of aircraft, steering them towards their destinations and keeping then well apart in the process. Those of us who are not controllers know that we could never do what the controller is doing. It is therefore easy to jump to the conclusion that the controller must be a very special person. Certainly the controller must have traits that most of us do not have! Clearly, this should be a situation for which selection by means of psychometric methods ought to have a lot to give.

However, there has always been an alternative to this view, as V. D. Hopkin reminds us. I quote the following from one of his papers:

> *One contention is that the would-be controller should be young, physically fit, mentally stable, articulate, considerably above average in intelligence, and educated to college entrance standards or thereabouts. These are not stringent criteria - many people could meet such requirements.*
>
> *Another contention is that, to be selected, a future controller must possess a combination of particular skills and attributes, such as manual dexterity, reliability in decision making, spatial reasoning ability, task-sharing ability, and the like. Quite a long list can be compiled of factors thought to have positive predictive value for ATC performance. A selection procedure must therefore seek out small numbers with this unusual combination of desirable attributes, since training alone could not compensate for their absence. Few people would pass such a stringent selection procedure.*
>
> *In practice, the evidence tends to favour the first contention, rather than the second, with the implication that success as an ATCO depends primarily on training and that many people given adequate training could become satisfactory controllers* (Hopkin, 1988, p. 648-649).

That is, it may well be that controllers do not have any very special set of character traits. Instead, they are simply people who have learned certain skills.

An argument against this view is that, in most countries there are very high failure rates in ATC training, suggesting that some people have “the right stuff” while others do not, despite the fact that they have been brought a rigorous selection process.

Assuming that the selection process is a good one, we would have to assume that the failures are due to inadequate training methods rather than to inadequate selection. And this is what happens.
Nevertheless, our first question must be whether we are in reality facing a selection issue. Selection is possible only if ATCOs possess some characteristics which set them apart from people in general, or if they are just ordinary people who have had special training. An answer to this question can only be found if we find a selection process that really works, or that it is possible to make most, if not all, of a group of candidates that have not been selected succeed in ATC training.

Neither of these alternatives has any strong support in the results. Yet, we should not lose sight of the alternative that we are not facing a selection issue. For example, in Sweden, we have found that our previous selection procedure probably did not have an appreciable validity (Brehmer, 1993a) and that the number of candidates who passed has increased from year to year (from an average of 54% in the 1970’s to 66% in the 1980’s to 73% during 1990-93, Haglund, Andersson, Backman & Sundin, 1993a), without any change in the selection procedure (Backman), lending support to the argument that ATCOs are, perhaps, not a special group of people but people who have been well trained to do a complex job.

2.3.2 What do we select for?

The selection of ATCOs is made difficult because the selection is not aimed directly at the ATC profession. In between the selection procedure and the actual performance on the job, there is a long training period, often three years or more, if one includes the on-job-training which takes up a considerable part of the total training time. Even if one is able to select people for the actual job, the selection procedure may still be useless if the candidates who have been selected do not pass the training stage. A good selection procedure, therefore, will have two goals:

– to select people who can do the controller job,
– to select people who are trainable.

If the no-special-characteristics theory is correct, all we can do is select candidates who are trainable. But then the selection procedure would, of course, not be specific to the ATC job. In so far a general intelligence measures correlate with success in training, this may well be because such measures predict the extent to which people can be educated rather than their ability to do the ATC job. After all, that was what they were designed to do in the first place.

This creates problems when we come to the job analysis that should precede the development of a selection instrument. Should this job analysis include an analysis of the demands that training makes or should it be concerned only with the demands made by the job?

Even though it is true that the training must be assumed to be designed to prepare the ATC candidates for their future job, a considerable part of that training is spent in on-the-job training (OJT). That is, the relationship between the more academic training and the subsequent OJT is not necessarily direct. The kinds of study skills that are required to pass the academic part are not necessarily those which are required to make a good controller, or those that help the controller carry out his job.

I have never found a job analysis that has taken this into account. Instead, such analyses focus on the actual controller job. This may be one reason why the selection batteries which are developed on the basis of such an analysis fail to predict who will succeed in training and who will not.

We will return to this issue.

2.3.3 Two Approaches in Selection

Traditionally, there have been two approaches to the selection of ATC candidates. The first involves some form of pre-training screen, where candidates are hired for a number of weeks. The final selection then takes place after this pre-training screen. Such a pre-training screen is not a substitute for the use of traditional selection batteries. The candidates are usually admitted to the pre-training selection period on the basis of their performance on such batteries.

This form of selection is used in the Netherlands and in the United States and perhaps in other countries as well.

I am told that the Dutch experience with a pre-training screen is very good in that the candidates who pass this screen in most cases also complete ATC training (Kraneveldt, personal communication). In the US, the number of failures was approximately 38% in field training and occurred 2.1/2 years into training before the pre-training screen was introduced. After the introduction of a 9-week pre-training screen, attrition in field training was 8% with a 30% failure rate during the first three months of Academy training. Current failure rates in the 9-week pre-training screen are about 45% (ASI, 1991). It is not clear what kind of people are eliminated by this pre-training screen.

This approach to selection thus seems to work fairly well in that it cuts down the failure rate in field training. On the other hand, it has a number of undesirable features for the trainees, who must leave their family and perhaps their current job for a rather low chance of succeeding in becoming ATCOs. The Federal Aviation Administration (FAA) has therefore started developing new tests which are to serve as a substitute for the pre-training screen.

The other approach is to make the selection of ATC candidates directly on the basis of a set of psychometric tests.

This is the dominant approach, and it is therefore surprising that there are so few published data on the effectiveness of this form of selection. The selection batteries tend to be what are best characterized as tests of general intellectual ability, with tests on reasoning, memory and so on. What published data there are suggest that the validity of standard test batteries varies with the criterion used. In general, the validity coefficients are higher when the criterion is a measure of training success rather than a measure of actual success in work (see Table 1 in Eißfeldt & Maschke, 1991). The former measures are in the .45 to .55 range while the latter are in the .30 -.35 range. Eißfeldt and Maschke (1991) also found in their study of 201 ATC candidates that it was easier to predict their success on the theoretical parts of the training than of the more practical parts.

Eißfeldt and Maschke (1991) also found some interesting differences between candidates who quite training voluntarily and those who were forced to resign because of unsatisfactory performance. Specifically, they found differences in the sign of the correlation between the success-failure criterion and a number of selection measures. For the former group, the correlation was positive (in the .14-.21 range) while, for the latter, it was negative (in the same range). As a consequence, only two of the selection variables showed significant correlation with the overall pass-fail criterion (knowledge of English, r = .14 and the clearance test (a test requiring the testee to take note of acoustical messages and their match to subsequent acoustical messages, r = .20). These results are based on a small sample (201 candidates overall with 19 candidates leaving voluntarily and 17 being forced to leave) but they nevertheless point to the need a little more sophistication in the pass-fail criterion than just counting the number who pass and the number who fail.

These results show that it is important to distinguish between the problem of predicting success in training and success in the ATC profession. However, they do not necessarily show that the predictor variables are worse for predicting success in the job than in training. Instead, the explanation for the difference in predictive performance for the two kinds of criteria may well be due to differences in the reliability of the criterion measures.

This points to one of the most difficult problems when developing selection instruments: that of finding a good criterion. Recently, there has been a tendency to use well defined criteria, e.g. in the form of measures from simulation (e.g. Ackermann). While such measures may well be reliable and the studies involving such measures may give us insights into the various aspects of the controller’s job, they can hardly be used for validation purposes. Without good criterion measures, it is not possible to develop good selection procedures (or, at least, one cannot know if one has good selection procedures). The most important task for research on selection of ATCOs is to develop reliable and valid criterion measures.

In the MRU (Marketing, Recruitment, Selection and Training) project we have started the process of developing such measures. We have collected from ATCOs a set of descriptions of behaviours that characterizes good and not so good ATCOs. On the basis of these behaviours, we have constructed a set of scales:

1. Attitude to one's own limitations;
2. Flexibility and ability to adapt to prevailing conditions;
3. Concern and loyalty;
4. Attitudes to colleagues;
5. Ability to do the controller job.

These scales are now being refined and their reliability will be tested before they are used in validation studies.

What is interesting about the list is that it shows that the successful ATCO is more than a person who can do the job. When measured against criteria of this kind, we cannot expect very high correlation with cognitive ability tests of the kind commonly used for selection of ATCO candidates.

2.3.4 Job Analysis

A valid selection procedure presupposes that we know what demands the job actually makes. This raises the question of how a job analysis should be performed for the ATCO's job. Specifically, it raises the question of what would be the appropriate level of analysis.

Traditional forms of job analysis for selection aim at a description of the job in terms of a set of character traits and abilities that can be measured by psychometric tests. The test battery is thus the end product of the job analysis. Presumably this is the form of analysis which is behind many of the traditional tests batteries that are used for selection of ATC candidates. In some cases, like the former battery used in Sweden for selecting pilots, they have been taken over directly for the selection of ATC candidates, perhaps based on the observation that many ATCOs are former pilots. In Sweden, this kind of selection battery did not work well: its validity in predicting success in training was close to zero (Brehmer, 1992).

Most test batteries resulting from this kind of analysis comprise a set of a rather traditional ability test for measuring intelligence and reasoning, supplemented with tests for short-term memory, spatial ability and, perhaps, tests measuring the testee's ability to perform many tasks at the same time. There seem to be no new tests on the horizon which would add anything interesting to what we already have, so we must conclude that we have come to the end of the road here. We cannot expect to exceed the .35 limit found in earlier studies of these kinds of tests.

Recent job analyses have been inspired by modern cognitive psychology and aim at describing the ATCO's job in terms of a set of elementary cognitive processes such as short-term memory, visualization and the like. A good example of such an analysis is that of Broach (1990) which identified 14 critical sensory/cognitive attributes:

Table 1. Critical sensory/cognitive attributes (After ASI, 1991).

Attribute	Definition
Coding	Transformation or translation of information for entry into system
Decoding	Translation of transformation of information received
Deductive reasoning	Ability to reach a conclusion that follows logically from own facts or data
Filtering	Selection of inputs on which to focus attention in the presence of distracting stimuli or high workload
Image/pattern recognition	Perception of spatial patterns and relations among static or dynamic visual inputs
Inductive reasoning	Generation of an explanation for a set of specific data or instances, giving structure and meaning to the information
Long-term memory	Mental storage of knowledge over a period of time and selective recall of items relevant to a situation
Mathematical/probability	Translation of uncertainty into probability reasoning
Movement detection	Recognition physical movement of a visual object; estimation of its direction or speed
Prioritizing	Ordering events in sequence
Short-term memory	Mental storage and selective recall of relevant information over a brief period of time
Spatial scanning	Rapid identification or detection of objects or events displayed in a wide or complicated visual field
Verbal filtering	Same as filtering but limited to voice communication
Visualization	Observation of spatial patterns and subsequent mental transformations into other spatial patterns

The problem with such a list is that it is not specific. It is like a general description of human mental abilities and fits almost every occupation. One certainly would not like to see anyone without any of the abilities listed above.

A more general problem, which pertains to both of the two approaches above, is that they tend to analyse the job in terms that make it impossible to distinguish the result of human abilities from the result of training. If an ATCO showed higher scores on abilities in Table 1 than, say, the average applicant for ATCO training, this may well be the result of learning to perform the ATCO job (if it demands characteristics of the kind listed above). All the candidates would need to be at some reasonable initial level but this may not need to be very high.

Recent applications of this type of theory have changed from thinking only in terms of single processes. There is a growing realization that human abilities do not exist in isolation but that most tasks require the person to use a set of abilities, and the person's abilities may interact in complex ways. An example is the so-called multiple resources theory (e.g. Wickens, 1984). This kind of thinking had led to rather different tests where one does not aim at finding pure tests that measure well defined abilities. Instead, tests in this tradition tend to be work sample tests that require the person to use a number of abilities to perform well on the items in the test.

At least two recent tests for selecting ATCOs have been developed along these lines. The FAA has constructed a test battery with some novel cognitive tests and a work sample test to serve as a substitute for the pre-training screen, and Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) has constructed a similar but more complex test to be used in its ordinary selection procedures. The latter test is still under validation but, for the FAA tests, we have some validation data.

The FAA test presents a screen on which there are two 'air ports', called E and F. On each of the sides there is an exit. The exits are called A, B, C and D. Aircraft coded in terms of their destination (an airport or an exit), their attitude and their speed appear at random on the screen. The tests must then acknowledge each aircraft by clicking on it with the mouse after which it will accept commands. Commands are given by pointing and clicking on symbols to the right of the screen and enable the testee to change the direction (8 directions), altitude (4 different altitudes) and speed (3 different speeds).

The rules are simple: to direct the aircraft to their destination while maintaining separation between aircraft and making sure that aircraft exit at the exits (if one of the four exits is their destination) at the highest speed and highest altitude, and that they land against the direction of the wind and with the lowest speed and lowest altitude if their destination is one of the airports. The subjects are first trained on 16 practice scenarios varying in complexity and then tested on six test scenarios.

The test has high face validity as attested by experienced ATCOs. The testees are scored on safety (their ability to maintain separations between the aircraft) and efficiency (low waiting times).

The test has satisfactory reliability.

Our data show that the test discriminates between experienced ATCOs and applicants for the ATCO job, at least when the ATCOs are aged 30 and under (there is a strong age effect). The FAA's concurrent validation of the test shows that it has a significant but low (about .2) correlation with success in training. Thus, this seemingly very promising test has very low validity. Obviously, a work sample test with high face validity does not capture the essential characteristics for success in ATCO training. This may be because the controller's high performance is not based on any stable abilities or character traits. Instead, it is the result of years of practice.

A third approach to job analysis relies on critical incidents. This has been one of the methods used in the MRU project where critical incidents were collected in a series of focused group interviews. This resulted in a number of problem clusters:

- collection of information,
- decision making,
- communication,
- social relations,
- high goals,
- technical environment,
- variation in workload,
- theoretical knowledge.

Again, we find that the results are hardly specific to ATC. Additionally, an analysis in terms of critical incidents tends to focus on the unusual and difficult aspects of the job while ignoring routine tasks, which, for ATCOs as for everyone else, tend to take up most of the time on the job.

In the MRU project we have therefore combined the analysis of critical incidents with a normative and theoretical analysis. It is based on an analysis of ATC as a form of dynamic decision which involves the control of complex systems.

There are four prerequisites for the control of a complex dynamic system:

- There must be a goal (in ATC the controller's goal is to make sure that the aircraft arrive at their destination safely);

- It must be possible to observe the state of the system (in radar control, the controller observes the positions of the aircraft on his two-dimensional radar screen and constructs a three-dimensional picture from that. In procedural control, he must construct a three-dimensional picture from radio messages);

- There must be a possibility for changing the state of the system (in ATC one changes the state of the system by issuing verbal commands);

- There must be a model of the system that makes it possible to ascertain what will happen if one does something to the system (including if one does nothing). In ATC, there are at least three kinds of models: the momentary *awareness* of the current positions of aircraft and where they are likely to be in near future (‘SA’), the *mental model in short-term memory* that the controller constructs when he or she solves problems, and various models in long-term memory that encode aircraft’ characteristics and the like.

The ATCO’s goal cannot just be a question of controlling traffic. He or she must also learn to control their own workload, calling for reinforcements of changing strategy when the workload increases.

To test this model, the responses of controllers to a questionnaire in which they indicated the importance of a number of critical behaviours were subjected to a principal components analysis. This analysis yielded a number of dimensions congruent with the model. However, while there was a dimension that could be interpreted as ability to regulate one’s own workload, there was no dimension that could be interpreted as ability to regulate one’s one workload, there was no dimension related to goal formulation as such, presumably because there were no critical behaviours related to this factor. Apparently, controllers have little problem in directing their activity to the goals of safety and efficiency. Nor was there any factor that related to observability. But there were components relating to using adequate means for control ‘using correct phraseology’, ‘sounding firm’), and components relating to the three kinds of mental models.

In addition to the components relating to the prerequisites for control, there was a social component having to do with social skills in handling students and in showing empathy with the pilot.

In the MRU project, these results were used to construct a situation interview to be used for selection. The interview yields three kinds of scales. The first is constructed from items that measure the interviewee’s ability to form three dimensional representations and solve problems using these representations (the send kind of model discussed above).

The second was designed to measure social attitudes that could be important for the ATCO’s job. The third was made up of items designed to measure attitudes to education, in an attempt to acknowledge that the testee’s ability to survive training is an important aspect of the prediction problem.

The situation interview has been subjected to a discriminatory validation where its ability to discriminate between qualified ATCOs and applicants to ATCO training. The results showed that the scales produced by the interview were reliable with high Cronbach alphas.

Two of the scales discriminated significantly: the scale representing the ability to form three dimensional representations, and the social attitudes. The educational attitudes scale did not discriminate significantly between controllers and applicants.

Interestingly, there was no correlation between standard tests of spatial ability and the score on the three dimensional problems scale of the situation interview, nor did these spatial tests discriminate between controllers and applicants. This suggests that the three-dimensional problems scale measures a spatial ability different from that measured by standard spatial ability tests. There was significant correlation between a test of reasoning ability (ship's destination) and the three-dimensional problems scale as would be expected since reasoning is required to solve the three-dimensional problems. However, the reasoning test also contributed significantly to the discrimination between the controllers and the applicants, as did their mathematics grade.

Even though the three dimensional problems scale and the social attitudes scale discriminated between candidates and ATCOs there was enough overlap between the two groups to demonstrate that having ATC experience is not a prerequisite for achieving high scores on the situation interview.

2.3.5 Summary and Conclusions

This paper has discussed a number of issues in the selection of ATCO candidates.

The first and most fundamental is whether this is a selection issue at all. It may well be that selection is not as important as we have thought, and that the successful ATCO is not distinguished by any specific set of character traits. The rather disappointing results from the validation studies of selection procedures lend support to this view, as expressed earlier by Hopkin (1988).

The second issue has to do with the problem of what is to be predicted. Selection is for training, and passing training may well required certain skills and traits that are not required by the ATC job itself. The results suggest that it is easier to predict training criteria than job success but this may reflect differences in the reliability of the training and job success criteria.

The third issue pertains to the appropriate level of job analysis. I have argued that traditional forms of the job analysis in the psychometric tradition and the cognitive psychology tradition tend to underestimate the role played by training, and the analyses based on critical incidents lead to an overemphasis on what is unusual and difficult at the expense of what is simple and routine. An analyse based on a more theoretical and normative approach used in the MRU project is suggested as an alternative.

A fourth issue related to the kinds of tests that should be used. Traditional psychometric tests have limited validity, and work sample test have also been disappointing. A new approach based on a situation interview is illustrated.

A fifth issue relates to the choice of criteria for job success. Cognitive aspects are only a part of the total criterion, and we should, perhaps, not expect very high validities using only cognitive tests. On the other hand, personality tests do not seem to give any better predictions.

A general conclusion seems to be that it may not pay off to put much more effort into selection. Perhaps a rather simple selection procedure may be sufficient. Such a procedure should aim at insuring that we have candidates who exhibit stability and above average intelligence and, perhaps also, the ability to process three-dimensional spatial information.

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2.4 Cognitive Trends and Training

(third technical note)

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2.4.1 Introduction

The purpose of the presentation is to start a discussion on the relevance of using cognitive task analysis in ATC training: French approach to training will be offered as a basis for discussion as some experience in cockpit training.

We will make a distinction between AB Innate training and AS upgrade training where cognitive task analysis will be used in two different ways.

- training in ATC: AB Innate and upgrade training,
- AB Innate training: French experience,
- upgrade training: French experience,
- discussion: cognitive modelling and training.

2.4.2 Training: Different Approaches

As we find different approaches to automation design, we can distinguish three main approaches to training design.

The first one tends to forget main HF competence; the second one derives from a deep hierarchical analysis of the task and may emphasize some HF competence (ex: Cockpit Resource Management (CRM) in Aeronautics) plus it considers the necessity to adapt to the trainee; the last one fully takes into consideration the cognitive bottlenecks of the task, the complexity factors and the types of significant working situations; it includes a model of learning :

1. Technology-driven approach: cockpit type rating.
2. Function-driven approach: Advanced Qualification Program (AQP), French AB Innate ATCO training.
3. Cognitive approach: upgrade course.

2.4.3 What is the Problem ?

- AB Innate training: from task analysis to training objectives;
- Upgrade system training:
  - cognitive task analysis: competence modelling,
  - competence acquisition and transfer: cognitive biases,
  - variety of people to be trained.

2.4.4 AB Innate Training in France

HF specialists have been working since 1965 in France (at the “Centre d’Etudes de la Navigation Aérienne” (CENA)). Their first objective was to understand controllers’ task and activity through several data processing models. They clearly discovered the variety of strategies in relation with resources management and with personal human styles. This allowed to avoid some technology-driven choices in ATC automation process and issued in the design of AB Innate training.

- Objectives: cognitive task analysis (Bisseret and Sperandio);
- Students' model of competence acquisition;
- Training program (MICUP):
  - From knowledge to skills,
  - Training technique or method,
  - Training supports: booklets, Computer Based Training (CBT), presimulator, simulators.

2.4.5 Upgrade Training

- Main objective: help people to appropriate new environment;
- Issues are:
  - What evolution in competencies ?
  - How to get people to be motivated ?
  - What kind of training method ?

2.4.6 Main Basis

Our approach was to review the different tasks analysis and cognitive modelling: one made with “Model of Activity for Design” (MAD), from INRIA, another one made through “Le Cours d’Action” (I. Gaillard), last one being the “En-Route Air Traffic Organizer” (ERATO) cognitive model.

I. Gaillard had studied the required new competence during the experimental design process.

We then analysed the evolution of competence through the “Cognitive Competence Modelling” (COROM).

Finally, we had to consider some other sociologic studies besides cognitive task analysis in order to bear in mind the way controllers operate in the ops room (collective dimension and attitude towards technical evolution).

From cockpit experience we knew how much the variety of trainees could impact on competence acquisition (from Airbus COSYNUS database, C. Pelegrin) and how important it was to define the working method (philosophy of human-machine interaction and of human-human task sharing) before going into the training process.

- operational and experimental studies from design process,
- assessment of PHIDIAS impact on controllers' job (COROM, 1992, 1994),
- HF studies on controllers' job,
- lessons from cockpits.

2.4.7 Lessons from Cockpits

- Evolution of complexity: evolution of competence
- Issues in type rating: anticipation and CRM
- Variety of trainees: towards adaptive training (AQP)
- Importance of working method (philosophy of use of automatism): learning from ops experience

2.4.8 Theoretical Material

- Competence model from COROM
- Cognitive modelling from ERATO: complexity and human-machine bottlenecks
- Impact of PHIDIAS on competence typE
- Evolution of cognitive bottleneck
- Competence acquisition models

2.4.9 Impact of PHIDIAS on Controllers' Job

We finally ended up with a few basic hypotheses on the impact of PHIDIAS on controllers' job. From COROM model it seems there will be a slight evolution from the "adaptation" mode to a more intensive "application" mode, specifically regarding Human-Machine Interface (HMI). This could derive in some decreased job satisfaction but all the cognitive problem solving activity would remain.

PHIDIAS will definitely change the data acquisition process and the co-operation between the two controllers and within the ops room, mainly due to the fully electronic environment (no more strip paper).

- data acquisition process: SA,
- Human-Human co-operation and human-machine co-operation,
- job satisfaction,
- consequence of errors,
- evolution of complexity.

2.4.10 Training Basis

Our cognitive approach led us to the definition of the whole training approach: we rejected the objective-oriented approach as it is used in AB Innate training to go to a more problem-oriented approach. As in ERATO model, we emphasized the importance of qualified controllers' expertize and we designed our training objectives from the assessment of the impact of PHIDIAS. We though concentrated on this data acquisition process used with the default reasoning and on the co-operative process. We added a module on human-machine co-operation with the objective of making sure that the controllers would build a simple but realistic mental model of the machine.

The training approach mainly consists in having controllers learn by working on natural control situations:

- training approach based on **case studies** (not hierarchical);
- training tools: CBT and pre-simulation tool, demonstrator, large scale simulator;
- special training for the first trainers;
- designing a working method.

2.4.11 Evaluation : 50 Controllers

- Hypo: there are several classes of trainees
- Data collection on learning acquisition (progress), as COSYNUS
- Pre-test with controllers from Brest
- Participation of all (ACC) for the wide evaluation (sampling issue)

2.4.12 Expected Results

- To validate the efficiency of the training program
- To determine the training parameters:
  - training duration,
  - training approach, tools, ops procedures,
  - classes of learners
- Important feedback from the trainers
- Corrections of the training program

2.4.13 Some Limits

- Few results on the learning "persistence"
- Limited results on training rate of success
- Few elements on training process for the whole staff (supervisors, AB Innate).

2.4.14 Discussion: Cognitive Approach and Training

In order to deal with training, it seems that we need at least three points:

1. Quite a deep cognitive task analysis.
2. A wide job analysis (with sociological aspects).
3. A competence acquisition model.

But do we have to make a training-oriented task analysis or can we use a quite universal cognitive task analysis?

- What kind of cognitive task analysis?
- What kind of competence acquisition model?
- How to use a cognitive task analysis?
- What is missing?
  - social dimension,
  - motivation,
  - working method,
  - awareness of variety of trainees.

2.5 Cognitive Aspects and Automation

(fourth technical note)

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2.5.1 Automation or Cognitive Tools?

The question we have to answer is how to increase both capacity and safety in ATC.

It is obvious that major technology improvements (FMS, Data Link, 4D-Navigation, computational power) must be used intensively. However, in the meantime, full automation cannot be a solution, at least for the next two or three decades. Human controllers must remain in the decision-making loop. As automation cannot replace human operators, it must assist them. This is one of the paradoxes of automation, as needed by the ATC system: as long as full automation feasibility and efficiency are not proved, i.e. as long as we need controllers to make decisions, even in an intermittent way, *it is essential to preserve the controllers' skills.* Whatever tools are designed, human controllers must exercise their skills continuously.

Human operators are a factor of flexibility, of capability to deal with unexpected situations, of creativity, of safety, thanks to their ability to compensate for the failures or inadequacies of machinery. To preserve these capabilities, we may have to automate "less" than possible from a purely technological point of view.

However, the human operators are also a factor of error. From this observation and for years, system designers thought that the more human operators are put on the fringe, the more the risk of error will decrease. In fact technology driven automation adds another kind of difficulty to the supervision of the initial system: the difficulty of understanding the behaviour of the automatisms that partly monitor the system. Thus, it creates additional sources of error; the consequences of such errors are much more important than the previous ones. Rather than eliminating human operators and consequently depriving the joint system of major benefits and increasing the risk of errors, it seems more sensible to design a system which is error-tolerant. Such a system cannot be designed only by using technical advances; we must automate in a different way from that suggested by technology alone. Thus the word "automation" seems inappropriate, "cognitive tools" or "computer assistance to cognitive tasks" appear to be more suitable.

The task that we have to consider is to assist the controller in processing information: the controller's activity consists of real-time and co-operative data-processing so as to "produce decision" under risk pressure.

Up to now the objects presented on the interfaces (paper flight progress strips and radar display) are the aircraft while the controller mainly processes the interaction between the aircraft. Can computers assist the controller to perform this task? The aim is no longer to show the results of radar tracking but to use these results as well as all technological advances in order to present the relationship between aircraft in a more manageable way. In this paper we present the cognitive engineering approach as an alternative to technology driven approaches.

2.5.2 The Cognitive Engineering Approach

We present this approach using the example of ERATO, a project from CENA. This project is aimed at specifying and designing decision aids for En-Route ATCOs. It will result in a Controller's Electronic Assistant. We will describe how we have been able to specify a new philosophy of man-machine co-operation thanks to this approach.

Cognitive Engineering

Cognitive engineering has arisen from the expression of a need by numerous system designers: the need to understand what really makes the task difficult for the operators and how this difficulty impairs human performance so as to define the most effective aids (Rasmussen 1986, De Montmollin & De Keyser 1985, Hollnagel 1988, etc.).

Cognitive engineering is about the multidimensional, open worlds which are the effective working context of the operators. Its aim is to understand and describe the present mental activity of operators, given their present tools, and how these mental mechanisms decay under time pressure, fatigue and stress. Cognitive engineering also enables anticipation of how new technologies will modify the activity of the operators.

We must not only elicit the knowledge of operators but, first of all, we must understand how this knowledge is activated and utilized in the actual problem solving environment. The central question is not to identify the domain knowledge possessed by the practitioner but rather to point out under which conditions this knowledge is (or is no longer) accessible. This is the problem of defining a validity domain for human performance. Cognitive engineering must also identify and predict the sources of error and the mechanisms of error.

When several agents can act on the system, under which conditions can they co-operate efficiently under time pressure? What are the mental resources that are involved? What is the cognitive cost of co-operation?

We then have to point out how the present tools are inadequate. How do the operators compensate for the deficiencies of their tools? So, we have to examine how tools provided for an operator are really used by that operator.

All these analyses enable us to explain the cognitive model of the operator. Such a model is central to defining a global approach to design effective decision aids.

The Case of ATC

We can identify eight steps in the process of designing cognitive tools:

- Explanation of the Cognitive Model

  This model demonstrates the mental mechanisms which are common to all controllers and which enable them to process data and to make real time decisions. These mental processes are analysed for the executive controller, the planning controller and then for both controllers together, so as to assess the consequences of co-operation on mental load as well as on global performance. The main goal remains to describe the mental mechanisms involved in the decision-making process and how these mechanisms evolve and decay under time pressure.

- Bottlenecks Assessment

  Decaying processes become bottlenecks in data processing and decision making. This step is a diagnosis phase: we have to point out the sources of good and bad performances of the ATCOs, given their actual working context. As long as the situation is not too demanding, controllers can compensate for these bottlenecks but, in very demanding situations, these bottlenecks may severely impair the controllers' performance.

- Functional Specifications of Decision Aids

  The assessment of bottlenecks enables us to specify the basic functions of effective decision aids.

- Interface Specification

  This specification also depends on the cognitive model. We need to know in which context these tools will be used so as to optimize their operation on effectiveness.

- Definition of a Logical Representation of the Model

  Some tools may need knowledge-based components. We need to combine different laboratory logics to build a logical tool adapted to formalize the controller's knowledge.

- Encoding Expert Systems or Knowledge-based Systems

  The design of function defined during step 3 may involve the use of expert systems which model large subsets of the controller's knowledge.

- The Design of Cognitive Tools

  The expert system provides the cognitive tools with relevant data. So we have to face the problem of the integration of expert system to real time "classical" software.

- Evaluation, Verification and Validation (V&V) of the joint man-machine system

  Of course, each of the previous steps includes a local V&V phase. The feed-back concerns any of the previous steps up to the cognitive model.

2.5.3 The Cognitive Model of the Controller and the Assessment of Bottlenecks in Decision-making Mechanisms

Mental mechanisms as well as the use of mental resources are described along four dimensions:

1. Those that are involved in the management of the physical process (i.e. maintaining sufficient separation between aircraft).

2. Those that are involved in co-operation between controllers working on the same control position.

3. Those that are involved in interface management.

4. Those that are involved in their own cognitive resources management.

Mental Mechanisms involved in the Management of the Physical Process

Below is a brief overview of the controller's cognitive model as it is used in ERATO.

- Making Decision in a State of Partial Ignorance

  The controller anticipates according to a "normal" routine behaviour of the aircraft, called the “default world” with reference to the "default logic" which models this kind of reasoning. This default behaviour is illustrated by controllers when they use sentences such as "normally this aircraft going to Paris Orly will start descent about 30 Nautical Miles (NM) before this fix". The controller does not know the height of descent but from his experience, he knows that "this will normally happen about here”. So he will ignore all potential conflicts that should happen if the given aircraft should start descending earlier in order to focus all his activity on the most probable conflicts. This is an efficient means of narrowing the range of contingencies to be examined and to increase efficiency: at first all the aircraft are processed as if their behaviour always remains consonant with the "normal" behaviour.

  But to process exceptions, that is to guarantee safety, controllers monitor "sentry parameters". As long as these parameters remain in a "normal" range, all the previous diagnoses or decisions that are inferred from the default world remain valid. However, if a sentry parameter drifts outside the expected range, all the previous plausible inferences have to be revised: some additional conflicts can be created due to this abnormal behaviour. In normal situations, this way of reasoning is an efficient and safe means to make decisions in a state of partial ignorance. We can observe that, in very demanding situations, the monitoring task may no longer be performed by the controllers. Thus, when outside its validity domain, i.e. in over-demanding situations, this mechanism may become a major source of error.

- Making Decision in a Fuzzy and Uncertain Environment

  Very often, diagnosis is the result of an ambiguity elimination mechanism. Even when remaining in the default world, the controller is often unable to assess a definite diagnosis. Controllers spend a large amount of time in ambiguity elimination processes. Allowing himself to doubt is a luxury for a controller; the mastery of doubt is an art. This is performed by associating one (or two) relevant parameter(s) to each undecided situation. To avoid a scattering of resources, these parameters will remain the only ones monitored.

  Each conflicting situation, certain or potential, triggers several resolution frames. These frames are a part of the knowledge base common to all controllers. A part of the activity of the controller is devoted to choosing the best frame. Each of these frames may be more or less demanding. In demanding situations the cognitive cost becomes a basic criteria to choose a frame. Of course, while resolving a problem, the controller may have to shift from an inoperative frame to a more relevant one.

  According to the assessment of his workload, the controller can instantiate a resolution frame in a more or less efficient way. He can also abandon a more elegant frame to shift to a more efficient one: this is the consequence of his own resource management policy, according to the problems he has to face at any one time.

  All these mechanisms are a part of the real time data process. This process results in a problem-driven organization of the raw data set which enables the processing of large data flows.

- Memorization Problems are Twofold

  All these mechanisms may be interrupted at any time: the controller has to keep in his memory the cognitive process which has been interrupted as well as the context in order to restore it later.

  To solve a given conflict, the controller may have to perform actions within far-off time intervals. These time intervals may be very short. If a controller misses the right time span to act on traffic, the very nature and complexity of the problem may change rapidly.

  The only means of avoiding this is to monitor very frequently the position of the relevant aircraft. Obviously this mechanism is very costly. The controller must shift frequently from one problem to another. At each shift he has to restore the resolution context. When conflicts are complex and occur under time pressure, this may become a critical task.

Co-operation

Most of the previous tasks can be performed by the two controllers, successively or in parallel. Mental mechanisms involved in co-operation are an essential part of the model. Efficient co-operation between the two controllers relies on three factors. They must have:

1. The same skills, knowledge and training;
2. The same representation of effective traffic requirements;
3. Simultaneously available cognitive resources to exchange information.

When demand increases, these two latter conditions may deteriorate so much that co-operation may no longer be effective. Numerous airmisses have been reported which were due to co-operation failure in over-demanding situations. One controller did not even know that some tasks were urgent and important while the other controller thought that these tasks were performed normally. This points out the limits of co-operation based on implicit tasks delegation and allocation.

Interface Management

The interface can be thought of as a window through which the operator can get only a partial and distorted view of the real world. Mental mechanisms enable the controller to build the effective mental representation i.e. the representation that enables him to take action.

Cognitive Resources Management

All these mechanisms conflict with one another. As controllers have limited cognitive resources, they have various techniques and mechanisms that enable them to manage their own cognitive resources. The description of these mechanisms is central in the model. The model describes three different strategies in cognitive resources management which are currently used by controllers:

1. "Be elegant first";
2. "Be efficient first”;
3. "Safety first".

These strategies have observable consequences in conflict detection and resolution.

Mental mechanisms have a validity domain. We can easily observe how their efficiency deteriorates under stress, time pressure or fatigue. For example, in demanding situations, the sentry parameters are less frequently monitored and this may lead to errors when abnormal behaviour is not detected soon enough. We can also observe that the assessment of a given conflict, including conflict detection and resolution assessment, needs a few tenths of a second when the number of aircraft is low while it can take 7 to 8 minutes in very demanding situations; in this case, the controller is confronted with problems associated with numerous shifts from this conflict to concomitant ones, as described earlier and the risk of error (forgetting a relevant aircraft, choosing the wrong resolution frame, etc.) is high. The validity domain of the mental processes directly depends on the number of aircraft which has to be processed by the controller. This is the reason why we have focused on a problem driven presentation of the information.

The efficiency of the mental processes also depends on the capability of the operator to focus his attention on the relevant problem at the right time.

2.5.4 Decision Aids Functional Specification

Cognitive tools can be specified:

- to improve (or save) efficiency of cognitive resources;
- to manage these in a more efficient way.

The justification of the tools is a key point of the approach. It explains the reasons why each function has been designed and the improvements of the joint human-machine system that are expected. It also defines the criteria to experiment this system. At this level, there must be a deep symbiosis between theoretical work on the cognitive model, design and validation.

This implies that the design team must be multidisciplinary and multilevel, i.e. it should include researchers and practitioners in each discipline.

2.5.5 Improving Efficiency of Cognitive Resources

This can be made using information filtering techniques or by fitting as closely as possible cognitive needs through the interface.

Task-driven Data Presentation

At any time we can identify the very few data that are useful to a given task; the electronic environment enables to make cuts in the raw data set so as to show relevant data in a way that enables us the controller to perform this task more efficiently.

Problem-driven Data Presentation

The aim of problem-driven information filtering is to reduce the number of aircraft to be considered at any one time. By splitting a very demanding situation into several subsets of aircraft, we can expect that the controllers will have the ability to process these subsets of aircraft very efficiently. As we do not provide the controllers with the results of automatic conflict detection and resolution, they will have to operate all their mental mechanisms to assess the situation. This should preserve their skills and their ability to deal with any unanticipated situation more correctly. The expected gain is that, as they will be working on appropriate subsets of aircraft, these mental mechanisms will be much more efficient than they are now.

Fitting as closely as possible Cognitive Needs through the Interface

Below is an example of how the cognitive model is used to specify the interface in ERATO.

It is commonly admitted that operators spend a significant part of their activity in compensating for tool deficiencies. An ill-adapted interface can significantly devalue the results of information filtering. The extrapolation function of ERATO allows the substitution of a graphical representation for an alphanumeric one. It is our experience that, most of the time, the referential used by the controller is not a temporal one but a spatial one: the question ‘when will you act on this aircraft?’ is answered ‘there’ so the interface will enable the controller to drag an aircraft along its trajectory with the mouse; all the other aircraft will move accordingly. This interface meets the way the controller anticipates. However, if this interface had a temporal referential, the controller should have had to mentally convert distances into time intervals; in demanding situations this could represent a significant additional workload.

Improving Management of Cognitive Resources

We see how difficult it may become for the controller to focus entirely on the right problem at the right time. The solution proposed in ERATO is a new function called the reminder. The reminder consists of a specific window of the electronic assistant where each problem will be tagged. A problem is defined as a conflicting situation involving two or more aircraft. The labels are positioned according to the urgency of resolution, and the display of the relative urgency of the problems should enable the controller to avoid wasting cognitive resources on non-urgent and unimportant tasks while the short-term situation deteriorates. In normal operations, this should allow the controller to objectively manage all cognitive resources and avoid tunnel vision errors.

The aim of the reminder is to show the traffic requirements and their urgency to the two controllers.

Thus it should enhance co-operation between them. There are several ways of splitting a given situation into relevant problems. This variability can be observed for many different controllers as well as for any given controller, according to his cognitive resources management philosophy. The more the situation is felt to be demanding, the more the controller will split it into “little” problems and solve these problems in a very tactical way with short term solutions. If the controller feels that the situation is mastered, he will consider these elementary problems as a part of a whole and solve them in a more strategic way. Thus, the problems that are proposed by the machine must be considered as a draft by the controller. He can modify the labels so as to adapt them to the effective needs of the executive controller and, particularly, he can adjust the target resolution time. At resolution time, the relevant aircraft are highlighted on the radar display. The reminder should be used by both controllers as a safety net based on intentions of action.

2.5.6 The Role of Expert Systems or Knowledge-based Systems

The Expert Systems as a Default Representation of the Knowledge of the Operator

Information filtering techniques are under dispute (De Keyser 1988). The question is how to make sure that the operator will not need data which are hidden by the system. Such data retention would be an unacceptable source of error. The basic answer lies in providing the operator with functions that enable him/her to access extended sets of data or even the whole set of data. This solution is not relevant when using a problem-driven filtering system.

The discussion on the exhaustiveness and the relevance of data filtered by the filtering module is central.

The knowledge elicited in the filtering module of ERATO defines a set of "normal behaviours" of the aircraft as well as of the controllers. It is, however, impossible to represent the total knowledge of all the controllers. Should we be able to do this, we would have to deal with controllers' errors or creativity. The solution defined in ERATO lies in the consideration of the filtering module as a default representation of the controllers as well as of the aircraft.

To avoid the consequences of human error or creativity (i.e. unexpected behaviour), a monitoring process has been connected to the filtering module; this process is inspired by the natural sentry parameters monitoring process of the controllers. It detects any discrepancy between the actual position of all aircraft and any of the possible positions that could result from a "normal" behaviour of the controller. When necessary this process triggers an alarm so as to advise the controller that the previous information filtering is no longer relevant and has been updated. This monitoring process connected to the filtering module allows the electronic assistant to adapt very smoothly to the operator's error and creativity. Such information filtering is error tolerant.

Expert Systems: Solving the Problem Vs Formulating the Problem properly

The role of expert systems or knowledge-based systems as defined in ERATO is not to solve the problem (detect conflict and/or solve them). The problem-driven information filtering allows the controller to focus all his activity on well-formulated problems so that he can operate all his mental mechanisms in a more efficient and creative way. This function substitutes a set of easily manageable problems to the initial complex situation. The role of expert systems is "just" to assist the controller in formulating the problem in a more efficient way. Operators no longer feel progressively expelled from the decision-making loop but feel more powerful thanks to the machine.

2.5.7 Evaluation, Verification and Validation

Classically we define dependability as that property of a computing system which allows reliance to be justifiably placed on the service it delivers (Laprie 1987). We can point out four classical methods regarding dependability-procurement or dependability-validation:

1. Fault avoidance;
2. Fault tolerance;
3. Fault removal;
4. Fault forecasting.

These definitions can be applied to a complex heterogeneous man-machine system like the ATC system as well as to any of its machine components. In the first case, the users are the airlines (or their passengers) while, in the second case, the user is defined as the controller or any subsystem.

The specification of decision aids relies on a philosophy of future man-machine co-operation, whether this philosophy is clearly defined or not. The central question is to make sure that this co-operation fulfils the initial requirements regarding capacity and safety.

The cognitive model provides a guideline for evaluating the joint man-machine system. It enables the transformation of high-level validation requirements into relevant criteria to test the joint man-machine system. It determines which aspects of the machine or of the human-machine interaction must be verified closely so as to guarantee effective performance of the whole system or to prevent error. One can then determine or assess the gains along these dimensions.

We must ensure that the new joint man-machine system preserves the sources of good performance and actually improves the weak points from both a safety and a capacity point of view. This suggests that we must assess the performance of the new system with reference to the previous one under real conditions i.e. whatever the variability of the real world is, in demanding and very demanding situations.

The experiments should enable one to determine how the joint man-machine system evolves, how the bottlenecks in the operator's activity evolve, disappear, deteriorate or are created; what kind of problems are solved and created by the new system and what are the consequences on the operator's training. The experiments should also address questions such as:

- How is this man-machine co-operation philosophy accepted by controllers?
- Does it enable them to work in a more efficient and creative way?
- Does it provoke a loss of vigilance or skill?
- Does it improve the global performance from capacity and safety points of view?

- Does it enable a progressive and "soft" integration of technological advances in avionics?

The design of decision aids implies an analysis, either implicit or explicit, of the operator's deficiencies and of the most effective means to compensate for these deficiencies. The ultimate step of the verification/validation process should be the verification of these initial assumptions.

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3. SUMMARY OF THE WORKING GROUPS

Four working groups were held in parallel after the technical notes. The first session took place during the first afternoon and the second on the following morning. Each working group was conducted twice, allowing participants to choose two of the four themes. The working groups have been run according to a structured teamwork method. Results and conclusions of the working groups were presented to all participants at the end of the workshop followed by panel discussion.

3.1 Model on the Cognitive Aspects of Air Traffic Control

The topics of the two working groups on 'Model on the Cognitive Aspects of ATC' are summarized in the following paragraphs. They are presented in a logical order which does not reflect the importance or the critical level of the issues.

The following clusters were identified at the end of the workshop:

– purpose of the model,
– scope of the model,
– structure and content of the model,
– influencing factors,
– application of the model.

3.1.1 Purpose of the Model

Under this topic the following question was posed: 'What is the goal of a cognitive model?" In the widest sense a model could be used to advance theory, to explain and predict data, or for application in selection, training, design of HMI and other areas. In a more specific sense it could help to specify the controller's tasks and the associated mental workload as well as the interactions between cognitive processes and the environment. In all cases the view was expressed that a model for cognitive aspects in ATC should be practical, useful and applicable.

3.1.2 Scope of the Model

In this context, the nature of a model was discussed. Models can be defined as programmes, diagrams, sets of equations or hypotheses. It was also seen as important to determine the level of detail and accuracy of a model, whether it is generic or specific, whether it is a single model or a set of models. Another critical factor for a model is its timely relevance for prediction and application, whether it is describing the situation today or in the future.

A major concern for the use and application of a model for ATC was expressed by the question as to whether it can be verified and validated, and be used to evaluate new developed cognitive tools.

3.1.3 Structure and Content of the Model

The development of a model also requires consideration of its structure.
A model for ATC could include the sequence and networks of mental presentations and describing the process to build up the mental picture. This comprises the question to determine whether it is designed for individuals or teams, whether it is dynamic or static and whether it allows adaptation at a later stage of development. The choice of the components (gender, age, emotions, etc.), which should be part of the model, was seen as another critical aspect under this topic.

3.1.4 Influencing Factors

During discussions several factors were identified which might influence the model. These comprise possible cultural and gender differences, team characteristics, different levels of professional experience and local working practices. The development of tools aimed at enhancing ATM (datalink, Automatic Dependent Surveillance (ADS), etc.) will have an impact on the cognitive model and conditions when choosing between proactive and reactive control of air traffic.

3.1.5 Areas of Application

This topic reflects the discussions about possible areas of application for a model of cognitive aspects in ATC. The common view was expressed that the model should help to identify the role of the controller in the future ATM environment. It should facilitate the learning of cognitive skills (e.g. mental training) and help to understand strategies to cope with unusual situations. Within the concept of teams in aviation it should clarify the nature of shared mental models between pilots and controllers and amongst controllers in order to use the effects of the teamwork in the most efficient way.

3.2 Cognitive Aspects and Selection

3.2.1 Abstract

The critical issues discussed in both groups covered more than just the ‘typical’ selection problems. In fact the experts were aware of the critical relation between selection and training and selection and the technical evolution in the job of ATCOs. Therefore the issue of a new and better task and job analysis was considered as a critical issue. More focused on the cognitive and team-related demands of evolved systems it should provide the necessary information for developing better selection methods and also training content and strategies.

From this perspective, the discussion concentrated on cognitive and social skills and personalities that might be critical in the training of and in the job of ATCOs. In particular the training- related issues and the coherence of training and job were considered to be of high importance for selection. In this respect the experts shared the view that the validity of the instruments used in selection depends not only on the identification of the demands of the ATCO's job which should be clarified. The concern was in particular that there was no agreement in regard to selection criteria which should be established and lead to 'good' performance criterion measures either in training and in the job. This was seen as the fundamental critical issue as regards better development and harmonized selection methods and tools.

The following paragraphs aim to give a more detailed picture of the discussions in both groups of experts.

3.2.2 (New) Skills in Automation and Training?

The leading question in regard to technical evolution was how measurements of the selective ability of applicants to work in harmony with the automation could be developed. Three aspects were seen to be of importance in this respect:

Automation impacts: Controllers possibly need to manage their own resources. Is there any attribute for which a successful measurement could be devised as part of a selection procedure? Some measurements of 'adaptability' and 'resource management' already exist. A particular concern was whether candidates should have special abilities for maintaining monitoring activities. Selecting people who are more tolerant of boredom and whose performance is not adversely affected by it would then be a critical issue in future selection. Referring to controller training, coping strategies for both high and low workload conditions should be taught.

Trainability: With technical evolution in future ATC systems the determination of the evolution potential or adaptability of a student could be a critical issue in training. The question then would be whether one should first select (stepwise) candidates who are trainable and in a later stage select for the different ATC functions (Aerodrome Control Tower (TWR), Approach Control Service (APP) and Area Control Centre (ACC)) and for the level of automation. Training will always precede job allocation. The critical issue in this respect is that selection should ensure that a candidate is both "trainable" and can retain the job without personal or system (e.g. productivity, safety) compromise. But how to measure trainability in an appropriate way? Can it be determined by the rate of learning and can the rate of learning be predicted? Some methods that aim at identifying the preferred learning style of candidates as well as the rate of learning have been developed. These issues are important also in regard to instruction and training. For example, it has to be established whether there are individual differences in the ability to respond effectively to guidance or instructions provided by different training means (e.g. by CBT).

Teamwork: The concern in this respect is that the ability to work harmoniously as an ATC team member could decrease in importance in selection as automation is progressively introduced. This could bring into question whether the ability to share tasks is still an important attribute of the successful controller. In an highly automated system it could also be suspected that candidates do not really know or understand what they will do as ATCOs. This might reduce their feeling of responsibility and the empathy with which they are doing the job. All this could require more research on "group-testing" on team performance before a final selection of candidates is carried out. To give direction as to what are the critical skills in this respect one could, for example, try to observe and measure important Team Resource Management (TRM) issues during selection.

3.2.3 Cognitive Aspects

First of all it was felt that cognitive aspects play an important role in selection but the job also demands social skills and attitudes, self-esteem and motivation.

Mental Models: When it comes to cognitive demands the main question discussed was how an applicant's aptitude to create mental models could be measured or tested. Some methods to measure this important cognitive ability are emerging or are under development.

Cognitive Processes: Generally it was felt that the measurement of cognitive processes was a problem that deserved a more focused research. How, for example, does skill acquisition work? Answers to this question are important because cognitive issues are most often dealt with as if they were a "black box". Following approaches of differential abilities, the measurement cognitive capacities are often measured separately by different tests. But what is required in training and in the job is the ability to integrate these capacities. Information processing, for example, will be faster if these capacities are well integrated. The extent to which cognitive abilities are affected by stress should be established.

3.2.4 Task and Job Analysis

The first question was whether there was a need for another task and job analysis. A positive answer was given.

New Demands in the Job: It was felt that selection is currently geared too much towards characteristics which are important for training but less important for the job. New demands in the future ATC system should be identified by regular updates in task and job description. Of considerable concern was the fact that selectors select for a current existing ATC system.

But a currently 'good' controller will perhaps not be as good in the future system. This could even require the selection among ATCOs due to technological evolution. However, current selection systems are not developed in this respect.

Task and Job Analysis Methods: The critical question was : How should a proper task and job analysis be done? The feeling was that different approaches should perhaps be compared in the same analysis and that a training needs analysis should be done either at the same time or separately. The aim should also be to find methods which allow to distinguish traits from what is learned or from what can be learned in training.

Task and Job Analysis and Selection: A gap between controller task/job and selection exists: what are "the bridges" between task analysis and selection instruments and how can task and job analysis and allied techniques be applied to selection procedures?

Different Jobs within the ATCO Profession: Different jobs in the ATCO profession exist which are currently not considered in selection. Instead, selection is still aiming at an non-specific controller. Is it at all possible to identify the different requirements concerning skills/aptitudes/personality for different ATC tasks? For example, is TWR/APP the same work as En-route work or are these two different jobs requiring different skills? It was noted that the early identification of candidates for different ATC jobs is hampered by a serious lack of quality within the manpower planning of Air Traffic Services (AS) organizations. Currently, this does not allow for an early job allocation of trainees or an assignment to different jobs right from the beginning of training.

3.2.5 Training Issues

The basic critical training issue is to determine whether the skills required in the controller job are based mainly on a specific trait or whether they can be learned. Methods that allow one to distinguish traits from what is learned would help to decide whether or not controllers have special characteristics and whether differences between experts and beginners are a result of human abilities (traits). From this one could further identify what it is relevant to possess before the training starts or what can be trained.

The Gap between Theoretical and Practical Skills: However, the gap between the ability to learn the theory of ATC and to practice is still a major challenge for selection. Selection is currently geared to characteristics that are more important for training but less important for the job. Most selection systems in fact aim at and are better in predicting training success but are less successful in predicting job performance. The experts felt that what is finally expected in the job has not developed in a linear approach during training. How can this difference be tapped in selection? Should job analysis include an analysis of the demands made by training?

3.2.6 Training Failures

Identifying the causes for training failures could help in this respect. A well structured 'check-list' or scale that can be used to follow trainees in training could perhaps help. But the general observation is that rarely two trainees fail for the same reason. This highlights to some extent the problems met in establishing clear validity criteria for selection. The relationship between selection and training is obvious but adequate co-ordination between “selectors” and “trainers” is lacking. Experts stressed the point that training failures are not automatically attributable to selection. It is well understood that much more potential for improving success rates can be achieved through improvements in training. But it is unclear as yet what criteria should be employed to decide when to stop trying to improve selection batteries further and when to start to improve training. The percentage of suitable candidates in a non-selected sample or the success rate of a random selection would help to establish this criteria but these figures are unknown.

3.2.7 Selection Issues

Selection Criteria: The critical issue of validity is at the heart of any selection system. The experts were concerned about the identification of criteria that should be used in validation of selection data. It was felt that data from knowledge tests and judgements from subject matter experts are not enough. Possibly, the validation of the selection methods could also be established by a subsequent history as a controller rather than by scores during or at the end of training. Experts agreed that, without good criterion measures, it was not possible to develop good selection methods and tests or even to improve existing ones. The pass/fail criterion in training is used in most validations as the sole criterion. This is neither a valid nor an appropriate ‘measure’ in regard to the aim of selection to try to predict job performance. In fact, experts felt that it was necessary to find appropriate measures that can capture individual differences in training and job performance. In order to overcome the restriction of range problem in the criterion these measures need to have sufficient variance.

Validity of Selection Criteria: The selection criteria themselves need to be valid in order to be justified for use in any decision to stop the career of trainees. Experts agreed that the search and development of a reliable and valid criterion for ATC performance should not be restricted to success in training. The performance in the actual job of the controller was seen as the ultimate criterion. However, more and clearer ideas are needed also as to whether selection should for example be directed towards ‘competence’ or ‘productivity’ or both. It was felt that simply to continue to try to identify ‘the best’ in selection was more and more inappropriate. Several measures of performance are available and should be collected during every phase of training.

Validity and Reliability of Assessments in Training: The poor quality of the training scores used for validation purposes limits on what the selection procedures can obtain. The reliability problems with subject matter experts judgements (e.g. in OJT) are well known and must be solved at the same time. The quality of ratings made by instructors or supervisors or other persons knowledgeable of the trainees’ performance should be improved.

3.2.8 Future

Experts considered the current status achieved in selection in Europe as more or less stagnant. The critical issues discussed showed that a co-ordinated approach both in the development and the validation of selection methods and tests would be important to overcome the situation. Communal efforts would be beneficial and could lead to the necessary improvements. To what extent harmonization of selection methods/procedures is feasible is not clear yet but should be identified.

The harmonization of selection criteria in different countries could be a first step in the right direction. Developments and improvements of the current situation will benefit from communal efforts that are underway in the selection area within EATCHIP.

3.3 Cognitive Aspects and Training

3.3.1 Introduction

The text below reflects at best the issues discussed during the two working groups on Cognitive Aspects and Training in ATC. Many problems were mentioned but, due to the time constraint, few solutions were proposed and the prioritization and urgency of the problems have not been set up.

The different subjects are now presented in a logical order which does not at all reflect the importance or the critical level of the issues. The following clusters were identified at the end of the workshop:

– the trainers,
– training design and evaluation,
– coping with interfering factors,
– transition,
– difficulties in upgrade training.

3.3.2 The Trainers

Many questions about the trainers were asked such as:

- Do the trainers need specific training in cognitive aspects?
- Should their background be the HF or ATC?
- How can recognition of cognitive processes be improved?
- Could a method aimed at analysing the student's cognitive process be developed?
- Is one single operational model appropriate?

Some ideas were also expressed such as:

- Training is an interactive process;
- Instructors can learn about themselves as an instruction tool, for example, through trainees' reactions (not judgements);
- An analysis of the cognitive process of trainers and how it influences their training style and methodology was also considered.

3.3.3 Training Design and Evaluation

The model could be used to derive training objectives from task analysis and should stimulate the coping process rather than the theoretical part.

The need for development of appropriate pedagogic models at all levels of training was expressed, particularly in CBT.

The question to determine the stage at which the cognitive aspects should be introduced in the Ab Initio Training was posed, and whether the model provides a sequence in learning, like today's sequence, TWR, APP, ACC, or whether there are different cognitive aspects for each ATC discipline.

It was expressed that the transition from 'school'-learning to operations should be improved.

In order to follow a structured program, evaluation of cognitive skills acquisition should take place. However how can, for example, one measure the level of accuracy of his/her decision making?

Many ideas for training of specific skills were mentioned such as:

- coping strategies to handle stress,
- recreation/relaxation techniques,
- memory span training,
- planning and organizing strategies,
- dealing with the workload,
- problem solving,
- knowledge of one's limitations,
- motivation,
- unusual/emergency incidents,
- heuristics and shortcuts,
- team training.

3.3.4 Coping with Interfering Factors

The culture of international training programmes was considered as having a major impact. The model has to be highly adaptable to different cultures.

Furthermore, these cultural differences between controllers could be used to highlight the importance of taking ‘cognitive’ aspects into consideration.

Common understanding of training methods and tools will have to be ensured.

How will training tools and techniques develop to meet the requirements of different ages, experiences and skills of individual controllers? Would, for example, an age-based training method be workable? Experienced controllers lack sometimes motivation to participate in additional training, or worse, they do not apply new techniques in their job. This problem of “ATCO’s already know” should be taken into account.

Better integrate training in design and better integrate design in training.

3.3.5 Transition

Current traditional teaching is out of touch with today’s technology. Training techniques must be set up to work on cognitive aspects with trainees (debriefing, video support, etc.), including demands of the next generation of systems like the free flight concept. Issues like automation, passive monitoring roles and their drawbacks on coping have to be defined.

Major changes are difficult because it is difficult to give up ingrained attitudes and behaviour.

The duration allocated to academic classroom training is in imbalance with OJT and simulation. Suitable description of new systems and concepts is necessary to allow prediction/anticipation (upgrade) of their impact. Special warning was given for “the Nintendo-syndrom”, a blib-drivers mentality amongst the new generation of controllers. Introduction of new systems may degrade skills in some areas. Therefore, training, with and without systems, is needed.

Proper training of cognitive aspects is considered as being expensive because it needs more simulation.

3.3.6 Difficulties in Upgrade Training

Controllers are bad at working on radically new systems as upgrading the training does not mean being able to erase long-practised habits. This leads to inability to use the ‘system’; the tools cannot be used intuitively.

Operational concepts, not only in relation to the HMI (to help trainees) but also in relation to cognitive aspects, have to be designed.

Training techniques, aimed at making people aware of changes in their cognitive activity, is one way of helping them to change.

New triggering clues to mental activity need to be determined and applied/integrated to people's training because they need such clues to remain skilled.

3.4 Cognitive Aspects and Automation in Air Traffic Control

3.4.1 Introduction

The text below reflects at best the issues discussed during the two working groups on Cognitive Aspects in ATC. Many problems were mentioned but, due to the time constraint, few solutions were proposed and the prioritization and urgency of the problems have not been decided.

The different subjects are now presented in a logical order from general to specific which does not at all reflect the importance or the critical level of the issues.

A need for a taxonomy of automation has been pointed out. The harmonization of the terms used would avoid misunderstanding and misinterpretation.

In addition, as different types of concepts have different consequences on the ATC tasks, harmonization of the underlying principles of different concepts is required.

The words: 'automation', 'to automate', 'automated systems' were often used during the discussion despite the fact that they seemed to be inappropriate due to the different levels of computerization in today's ATC. In a partly automated system, it is better to talk about aiding systems, added functions, computer-assisted control, computerized systems, etc.

3.4.2 What to Automate?

Before going into the process of automation some leading questions should be asked:

Is it useful to automate? - What should be automated? - What should an automated system provide? - Where is the ATC system going? - Which cognitive skills of controllers would be damaged most by computer assistance? - Which cognitive skills of controllers would benefit most from computer assistance? - Which weakness of the human processor should be automated?

What should we automate?

– What is easy, fun, understandable or possible for the developer?
– What is useful for the controllers?

It was deplored that technical driven and top-down approaches are more often used than human centred and bottom-up approaches.

Why should we automate?

The aims of automation from the cognitive point of view must also be defined.

Do we automate ATC:

– to improve SA,
– to aid decision making,
– to reduce workload,
– to improve reliability of the ATS?

Some subjective aspects of the ATCO job also deserve special attention when automating because cognitive performance relies on them and because humans are not only "cognitive"; in particular, it has to be ensured that:

– we leave the human with a worthwhile role and cohesive task,
– we maintain or increase job satisfaction and avoid boredom,
– we optimize workload (reduction is not always the ideal).

The impact of automation should then be evaluated in particular on:

- The teamwork;
- The work organization;
- The work roles;
- The allocation in workload within the team and between the system and the controller;
- The mental workload;
- The decision-making process;
- The understanding of the situation.

For example, in terms of workload, it has to be considered that adding the system monitoring tasks to the ATC tasks can greatly increase the operator's mental workload.

3.4.3 Properties of the System

We need a coherent task systems analysis framework for specifying the human/automation allocation of functions (includes methods and tools) because the automation component needs to be built and integrated with human procedures. In this respect, it is necessary to understand how the present resources are used and represented in order to achieve successful performance.

An adaptive automation should allow dynamic re-allocation of load between the controller and the system because the operator has to be able to define his/her individual level of capability/competence.

3.4.4 Methodological Aspects

The ideas expressed about methodology were formulated in three different ways. There were:

- Questions on the kind of methodology that should be used in the HF domains;

- Some worries about the lack of HF concern in the development of the current project (technical-centered approach Vs human-centered approach);

- Recommendations about what should be done in order to better integrate HF into the automation of ATC.

The methodological aspects concern all the life-cycle phases of an automation project: the specification, the design, the validation/evaluation. For each phase, human-oriented methods are needed to include HF aspects into the project: cognitive aspects as well as psycho-sociological ones.

We need methods and effective criteria to evaluate and/or predict:

- effectiveness and performance of the whole “man-machine system”,
- human response efficiency to various self-assistance systems or methods,
- the impact of the introduction of the system,
- correctness of cognitive recommendations,
- the underlying cognitive models.

Cognitive models should provide effective criteria for the evaluation of the system because validating the software and the HMI is not enough.

3.4.5 Development Approach

For each project, a multidisciplinary team should be set up as each specialist has a contribution to give. The lead designer must be omniscient with a spark of genius and a unifying brain.

From the human point of view, this team should include ergonomists, psychologists and representatives of the final users. The involvement of controllers in soft specifications is a key for success.

In order to improve the efficiency of the team, each member should receive a common training both in ATC and aircraft operations.

An iterative design process is required to specify and evaluate working methods, interfaces, algorithms, etc.

3.4.6 Human-Machine Interface Design

The importance of the presentation of the information was stressed. The computerized system should present the right information, at the right time, in the right format.

'The right information' means all which is necessary and useful depending on the situation and allowing the controller to make the right decision. It also means that an unnecessary piece of information should not clutter up the screen.

'At the right time' means that the information must be available whenever it is needed by the traffic situation.

'In the right format' means that the information should be readable, without any ambiguity, and furthermore, it should help the human operator to build a 'picture' of the situation.

The interface should not match with the designer concepts but with the controller's mental model, otherwise the information presentation may not be adequate because of a lack of operationality.

The next generation of interfaces must be 'fun' to use because our children will expect all systems to be good. They will not tolerate 'kludges' as we do.

3.4.7 Introducing New Systems in Real Work Situation

The way automation is introduced is critical because controllers will reject it if it is not properly introduced.

To ensure a better acceptability of the system, all aspects of human activity (ethnography, social, etc.) must be taken into account.

In particular, understanding job satisfaction at a microlevel is a key issue in avoiding automation related problems.

Cultural attitudes in Southern and Eastern Europe are important because these regions must move fastest to catch up.

A lack of trust in the computerized system can also jeopardize its acceptance. In this case, it is important to prove that the new system can comply with the complexity of the real world.

3.4.8 Training

Training is one of the most critical issues in introducing a new computerized system.

The purpose of training should not only be teaching "how to use the system" but mainly "how does the system work".

The training should then include:

– the model of the system,
– the technical process behind the system,
– the functioning of the system,
– its strengths, weaknesses and limits,
– its failure modes.

Training should also help the controllers to build a relevant image of the system.

Particular attention should be given to training controllers on how to handle the situation in case of system failure.

When introducing a new system older people seem to be much less adaptable and less able to retrain. Special attention should be given to help people to forget previous habits, old skills and knowledge which are no longer relevant, and to become confident with the new tool.

3.4.9 Reliability of the Man-Machine System

The realistic capability of the tasks that the automation can perform (100% reliable, in real-time) will determine which human cognitive functions can be reliably allocated to the automation.

To ensure the reliability of the man-machine system, a high level of human understanding of what is happening must be retained.

It should be ensured that the operator is still able to make decisions, otherwise he will be unable to handle changes in the situation.

A reversionary procedure to enable the switching off of the automation should allow the controller to continue to train and maintain his skills and confidence in case of equipment failure.

3.4.10 Legal Responsibility

Operators should not be blamed for processes they cannot control. In case of incident or accident, the operator should not be the only human agent against whom legal actions are taken. The developer should also be involved if the system was not properly designed.

3.4.11 Last Warning

We must do it all now because it is later than you think.

4. EVALUATION OF THE WORKSHOP

Participants were asked to complete an evaluation form (see annex B) concerning the workshop.

The topics of the evaluation are: the strengths and weaknesses of the workshop, the duration and time allocation of presentations and working groups, the appreciation of the workshop and the subjects of interest for future workshops.

A summary of the results based on the 30 forms we have received is provided below.

4.1 Strengths of the Workshop

The main strength (40%)[1] was the opportunity to exchange ideas between different fields of expertise (HF, Computer sciences, engineering, research, practice) and countries (10). Very closely related to this (13.3%) was the chance to meet experts from different HF domains (selection, training, ergonomics).

The second most important strength (20%) was the place given to working groups and the interest of their discussions.

4.2 Weaknesses of the Workshop

The main weakness of the workshop was the lack of time (40%):

- for questions and discussions after the presentation;
- for the conclusions session;
- to address the most critical issues identified in the working groups;
- to get to know better what the other participants were doing in the different fields of HF.

For some participants (10%), the workshop was not sufficiently practice-oriented, it was too theoretical and lacked a clear vision as to how to deal with the practical constraints of an organization. The link between theory and practice was missing.

Finally there were too many presentations (10%) one after the other on the first morning which made it difficult to concentrate and to assimilate the content and concepts presented.

[1] percentage of answers

4.3 Duration and Time Allocation

The total duration of the workshop ranged from just right to too short. Many people would have liked a three-day event.

The time allocation for presentations and working groups was mainly considered as just right but some participants would have liked to spend more time in working groups.

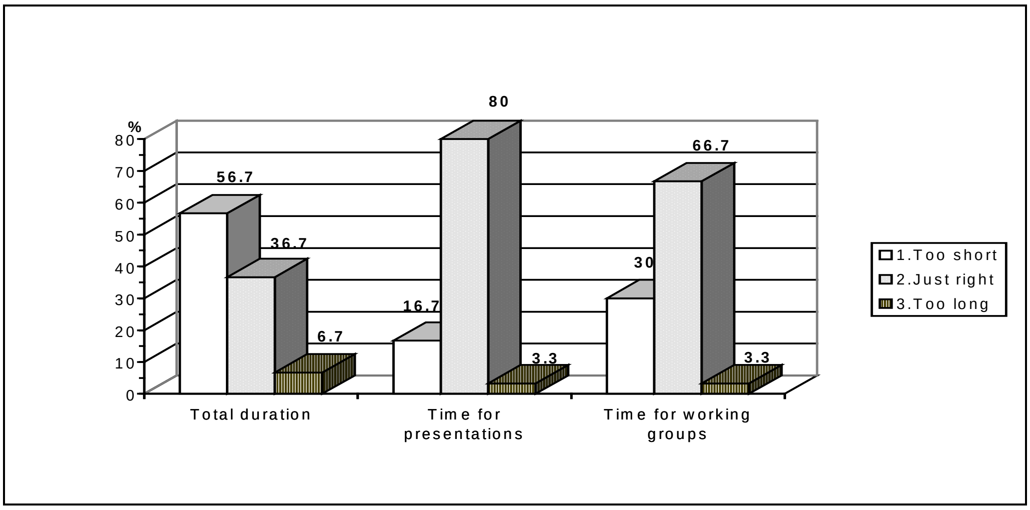

Figure 1: Duration and time allocation between presentations and working groups

4.4 Appreciation of the Workshop

4.4.1 Global Appreciation of the Workshop

Globally the workshop appears to have been appreciated positively by participants, about 85% of whom rated this item from fair to very high.

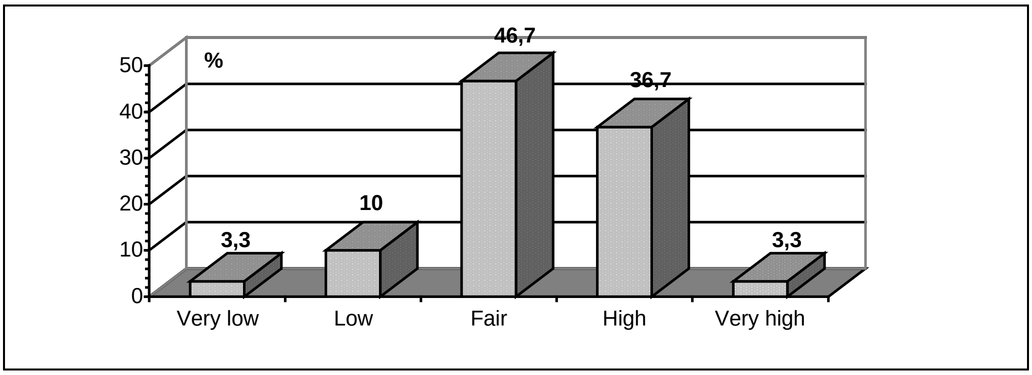

Figure 2: Global appreciation of the workshop

4.4.2 Combination of Presentations and Working Groups

The time sharing between presentations and working groups appears to have met the needs of participants, 92 % of whom rated this item from fair to very high.

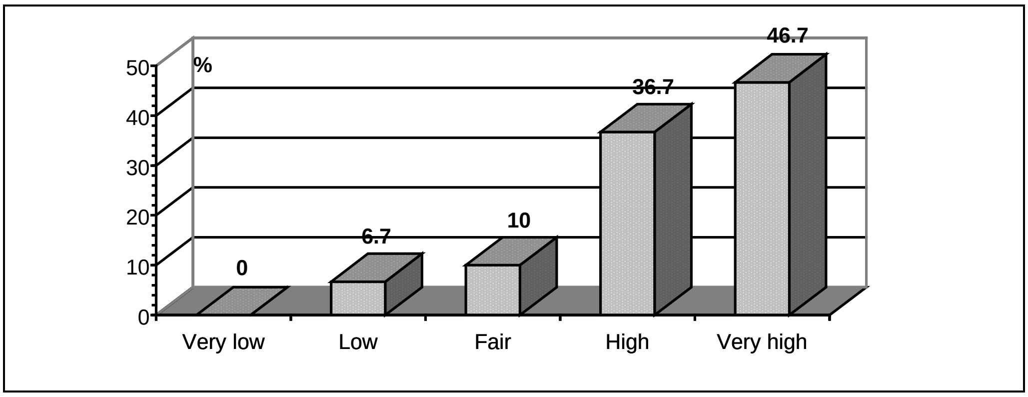

Figure 3: Appreciation of the combination of presentations and working groups

4.4.3 The Content

The content of the workshop (presentations and working groups) met participants' expectations despite the fact that some of them signalled a scarcity of practical aspects. 97% of the participants rated this item from fair to very high.

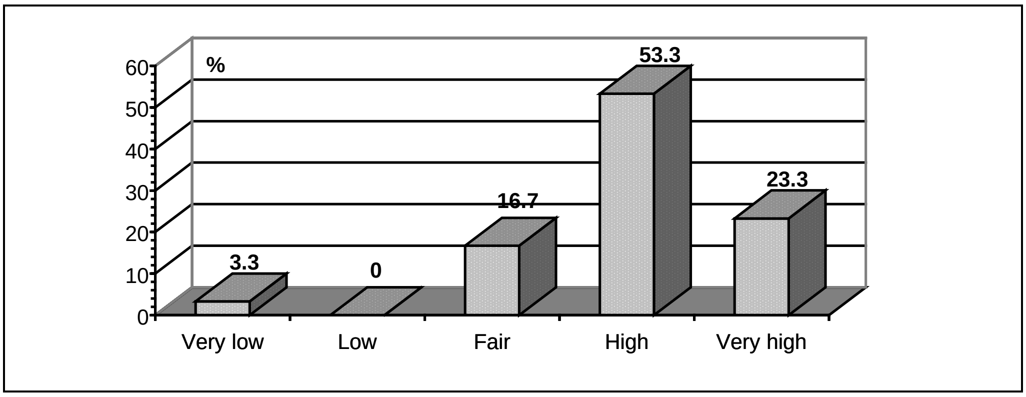

Figure 4: Appreciation of the content

4.4.4 Relevance to the Expertise

Although there was a wide variety of domains of expertise among the participants the relevance of the subject to their expertise was important. 92% rated this item from fair to very high.

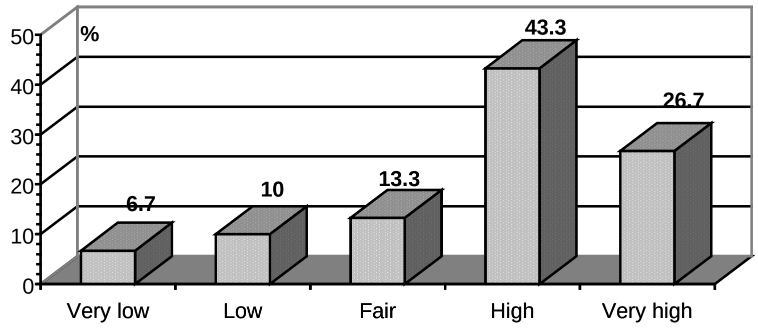

Figure 5: Appreciation of the relevance to the expertise

4.5 Topics of Interest for Future EUROCONTROL Workshop

A very large number of topics was suggested, nearly one per participant. The following are given as examples:

- same subject but more detailed,
- workload,
- stress,
- accident and incident investigation,
- ATCOs/pilots,
- teamwork,
- HMI design,
- workstation design,
- job and task analysis,
- impacts of automation on organizational issues and selection procedure and criteria,
- transition in ATM evolution and coping with change.

4.6 Lessons for the Future

From the evaluation of the workshop and the comments of the participants we can conclude that:

- The idea to create a network of HF experts in ATC responds to a real necessity;
- The workshop concept allows experts from different fields and countries to share experiences. This is obviously lacking in the current situation;
- Mixing presentations and working groups should be retained;
- The working groups should be more oriented towards application;
- A two-day meeting appeared to be too short for some participants and an optional third day could be foreseen for future workshops;
- Subjects for future workshops are not lacking. It seems to be more difficult to find one of common interest to human resources experts and HF experts.

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ANNEX B: EVALUATION FORM

The first EUROCONTROL Human Factors Workshop **COGNITIVE ASPECTS IN ATC**

1. What were major strengths and weaknesses of the workshop?

1.1. Strengths: ....

....

....

1.2. Weaknesses: ....

....

....

2. How was the total duration? ☐ too long ☐ too short ☐ just right

3. Was the time allocation to each part of the workshop adequate?

Presentations	☐ too long	☐ too short	☐ just right
Working groups	☐ too long	☐ too short	☐ just right

4. Could you indicate your appreciation for the workshop? (1 = low, 5 = high)

Your appreciation of the workshop in general	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The combination of speeches and working groups	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The content	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The relevance to your expertise	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5. Which subjects could be of interest for future EUROCONTROL HF Workshops?

....

....

6. Name (optional): ....

Field of expertise: ....

Organization: ....

7. Any other comments: ....

....

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ANNEX C: DEFINITIONS

For the purposes of this document, the following definitions shall apply:

CORUM	Training and Human Resources Consultancy Company
COSYNUS	AIRBUS Training Database
EUROCONTROL	European Organization for the Safety of Air Navigation

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ANNEX D: ABBREVIATIONS AND ACRONYMS

For the purposes of this document, the following abbreviations and acronyms shall apply:

ACC	Area Control Centre
ADS	Automatic Dependent Surveillance
APP	Approach Control Service
AQP	Advanced Qualification Program
ASI	Aerospace Sciences, Inc.
ATC	Air Traffic Control
ATCO	Air Traffic Controller / Air Traffic Control Officer *(US/UK)*
ATM	Air Traffic Management
ATS	Air Traffic Services
CBT	Computer-Based Training
CENA	Centre d'Etudes de la Navigation Aérienne *(France)*
CRM	Cockpit Resource Management
DEL	DELiverable
DED	Directorate EATCHIP Development *(EUROCONTROL)*
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt *(Germany)*
EATCHIP	European Air Traffic Control Harmonization and Integration Programme
ERATO	En-Route Air Traffic Organizer
ET	Executive Task
EWP	EATCHIP Work Programme
FAA	Federal Aviation Administration
FMS	Flight Management System

HF	Human Factors
HMI	Human-Machine Interface
HRT	Human Resources Team
HUM	Human Resources Domain
IANS	Institute of Air Navigation Services *(EUROCONTROL, Luxembourg)*
INRIA	Institut National de Recherche d'Informatique et Automatique *(National Institute for Computer Science and Automation Research - France)*
MAD	Model of Activity for Design
MICUP	Méthode d'Interaction Constante des Unités Programmées *(computerized unit constant interaction method)*
MRU	Marknadsföring Rekrytering Urval and Utbildning *(marketing, recruitment, selection and training for ATCOs)*
NM	Nautical Mile
OJT	On-the-Job-Training
PHIDIAS	Position Harmonisant et Intégrant des DIAlogues InteractifS *(harmonizing and interactive dialogue integrating position)*
REP	Report
R/T	Radio/Telephony
SA	Situation Awareness
SDOE	Senior Directorate Operations and EATCHIP *(EUROCONTROL Headquarters, Belgium)*
ST	Special Task
TRM	Team Resource Management
TWR	Aerodrome Control Tower
V&V	Verification and Validation