CIVIL AVIATION AUTHORITY

CAA PAPER 2000/9

THE DEVELOPMENT OF GUIDANCE ON THE DESIGN, PRESENTATION AND USE OF ELECTRONIC CHECKLISTS

CIVIL AVIATION AUTHORITY, LONDON

Price £5.00

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THE DEVELOPMENT OF GUIDANCE ON THE DESIGN, PRESENTATION AND USE OF ELECTRONIC CHECKLISTS

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REPORT PREPARED BY R M CONSULTANTS LTD, HITCHING COURT, ABINGDON BUSINESS PARK, ABINGDON, OXFORDSHIRE, OX14 1RA
AND PUBLISHED BY
CIVIL AVIATION AUTHORITY, LONDON, DECEMBER 2000

ISBN 0 86039 805 6

Printed and distributed by
Westward documedia Limited, 37 Windsor Street, Cheltenham, England

Foreword

The research reported in this paper was funded by the Safety Regulation group of the UK Civil Aviation Authority. The work was undertaken by RM Consultants Limited and was in response to Recommendation 4.2 of the Air Accident Investigation Branch (AAIB) report 3/95 (accident to Vickers Viscount 813, G-OHOT near Uttoxeter, Staffordshire on 25 February 1994.

The report details how the guidance material in CAP 708 (Guidance on the Design, Presentation and Use of Electronic Checklists) was derived.

The publication of this report, together with CAP 708, concludes the work undertaken in response to the above AAIB recommendation. CAP676 (Guidelines for the Design and Presentation of Emergency and Abnormal Checklists) was published in 1997 and is primarily concerned with paper checklists.

Executive Summary

Background

Checklists are used by pilots as an aid to configuring the aircraft safely for the phase of flight and any specific conditions that may have arisen. They provide a check that routine actions have been correctly accomplished (normal checklists), or assist pilots in handling less familiar situations (abnormal and emergency checklists).

In response to an Air Accidents Investigation Branch (AAIB) recommendation, the Safety Regulation Group of the Civil Aviation Authority (CAA) has already produced guidance on the design and presentation of manual (i.e. mainly paper-based) checklists for abnormal and emergency conditions. This guidance has been published as CAP 676. The present study was intended to enable the CAA to publish parallel guidance for electronic checklist (ECL) systems, which are becoming increasingly common on aircraft flight decks.

Objectives

The study was required to develop guidance which would assist UK aircraft operators in improving flight safety when specifying, evaluating and selecting ECL systems, in the operational use and modification of such systems and in the associated education and training of pilots.

Remit and Scope of the developed Guidance

The study was intended to develop guidance that would promote best practice, not to prescribe the only method of providing a safe system, nor to supersede regulatory standards and guidance on the design and production of ECL hardware and software. Overall responsibility for providing a safe system remains with the operator.

The study covered the design, presentation and use of checklist information but specifically excluded consideration of functional content (i.e. what actions a checklist prescribes). Operators need to ensure that the functional content is consistent with the Flight Manual, especially when making modifications.

The original AAIB recommendation referred only to emergency and abnormal checklists, but it was apparent that compatibility between emergency/ abnormal checklists and those for routine actions was an important requirement, and that many of the issues and suggested solutions were the same for all types of checklist. The original scope of study was therefore expanded to include normal checklists.

Methods

With a paper checklist, the information is fixed on the printed page. Electronic systems can allow the presentation to change, in response to inputs from the pilot or the aircraft systems. As a simple example, the colour of an item may change to indicate that it has been completed. ECL systems therefore present wider and more complex research questions than those related to paper checklists. In addition, there is not such extensive experience in their use.

It was therefore evident that, in order to maximise the potential safety benefits of ECLs and minimise potential disbenefits, the study needed to take a broader approach than mere desk-based editing of the text of CAP 676. The approach was therefore designed to involve, and ask open-ended questions of, a wide range of stakeholders in the provision and use of ECLs, including line, training and management pilots. Industry liaison was also recognised as being important in ensuring that recommendations were practicable.

Numerous aircraft operators provided information, made pilots available for discussion and arranged for observations of simulator training sessions on ECL-equipped aircraft. Aircraft manufacturers and ECL equipment suppliers provided information on their products and related human factors research.

The study began by identifying the various types and uses of ECL, to ensure completeness of the study, and categorising them to provide a structure for the subsequent work.

The next stage comprised a comprehensive identification of the safety issues (potential hazards and benefits) associated with ECLs, including a structured brainstorming session with pilots and other specialists.

Human factors and risk management principles and requirements were applied to identify measures by which the hazards associated with each identified safety issue could be minimised and the benefits maximised. These measures were then collated and translated into a set of concise recommendations, which formed the basis of the guidance document.

The study was also informed by a literature review and by observations of the use of normal checklists (both paper and electronic) during commercial flights.

Structure of the Resulting Guidance

Optimal solutions to the human-machine interaction problems associated with ECLs depend on numerous factors, such as the overall flight deck display design and automation philosophy, stress and workload at the time, and the training and experience of the pilot. In general, therefore, the guidance could not be as straightforward and definitive as that in CAP 676; the 'right answer' will often vary from one aircraft type and operator to another. Generic principles and requirements were therefore identified, against which the operator can test the advantages and disadvantages of the various options. Factors which operators should take into account in making any particular decision were also pointed out.

At the highest level, the structure of the guidance document reflects the 'lifecycle' of an ECL; i.e. the order in which operators will generally acquire, use and modify ECLs. Consequently, the chapter headings are broadly aligned with the main interests of readers having particular roles in aircraft operating organisations.

Some of the issues raised may also be of interest to aircraft and system manufacturers and have implications for other types of flight deck display.

Contents

GLOSSARY

Checklist	The written instructions that describe the set of tasks to be carried out or confirmed.
Drill	A set of tasks to be carried out.
Electronic checklist (ECL)	Electronic checklist – written instructions which describe a drill displayed on an electronic system.
ECL system	The technical system which delivers an electronic checklist (ECL), accepts input from the flight crew, and responds by changing the presentation of the ECL.
Flight crew	Normally refers to two pilots, where either pilot may be interacting with the ECL system. In some cases there may be three members of the flight crew (including the flight engineer) or only one pilot.
Flight Manual	The set of procedures provided by the manufacturer and approved by the appropriate regulatory authority. This forms the basis for the functional content of all checklists (both paper and electronic).
Paper checklist	Written instructions which describe a drill, provided on paper (or in other permanent form, for example printed on the central panel of the control column).
Quick Reference Handbook (QRH)	A handbook containing checklists which may need to be referenced quickly or frequently, including emergency and abnormal checklists. The checklists may be abbreviated, for ease of reference (although they must reflect the procedures contained in the Flight Manual).
Risk reduction measures	Measures to minimise disbenefits and maximise benefits.

ABBREVIATIONS

AAIB	Air Accidents Investigation Branch
ASRS	Aviation Safety Reporting System
BA	British Airways
BMA	British Midland Airways
CAA	Civil Aviation Authority
CHIRP	Confidential Human Factors Incident Reporting Programme
ECAM	Electronic Centralised Aircraft Monitoring
ECL	Electronic Checklist
EFIS	Electronic Flight Information System
EICAS	Engine Indicating and Crew Alerting System
MORS	Mandatory Occurrence Reporting Scheme
PF	Pilot Flying
PNF	Pilot Non-Flying
RMC	RM Consultants Ltd
SRG	Safety Regulation Group

1 INTRODUCTION

1.1 In the investigation report on the accident to a Vickers Viscount near Uttoxeter in 1994, the Air Accidents Investigation Branch (AAIB) recommended (Recommendation 94–40) that the Civil Aviation Authority (CAA) should commission research into the most effective form of presentation of emergency reference required on the flight deck, including both manual (i.e. mainly paper-based) checklists and electronic displays.

1.2 Guidance for manual checklists, covering the emergency and abnormal requirements has already been published by the CAA, as CAP 676 (CAA, 1997). This report describes research carried out by RM Consultants Ltd (RMC) in order to assist the CAA in developing parallel guidance on electronic emergency, abnormal and normal checklists.

1.3 The guidance material resulting from this research is published in CAP 708.

2 OBJECTIVES AND SCOPE OF STUDY

2.1 Objective

2.1.1 The objective of the research was to assist the Safety Regulation Group (SRG) of the CAA in developing guidance for the design, presentation and use of electronic checklists (ECL).

2.2 Intended Readership

2.2.1 This guidance was written principally for aircraft operators, to assist them in:

- knowing what design and presentation features to look for when evaluating, specifying or selecting ECLs, and
- installing ECL systems in the aircraft and writing or adapting the checklists as required, setting up effective training and education in the use of an ECL system, and developing procedures for operational use, obtaining pilot feedback and managing modifications.

2.2.2 ECL systems currently available range from simple hand-held devices, as used by private pilots, to sophisticated systems linked with electronic aircraft management systems on commercial public transport aircraft. It is at the latter end of the scale – where there is perhaps most scope for user input to design and presentation and for user modification – that the guidance is principally aimed. Further detail of how the various parts of the guidance relate to particular roles and responsibilities within an operator organisation is given in Section 7.1.

2.2.3 The guidance, and this research report, may also raise issues of interest to manufacturers.

2.3 Remit and Status of the Guidance

2.3.1 The guidance only addressed the way in which checklists are designed, presented and used. 'Design and presentation' has been taken to comprise:

- The human machine **interface**: 'classical' ergonomic issues related to displays such as colour, typeface, layout, symbology and phraseology. These are generally analogous to the issues for paper checklists.
- Wider issues of human-machine **interaction**: i.e. the functioning of the ECL system and how pilots interact with it. These include, for example, how pilots select the required checklist, whether completed items should be deleted from the display, and to what extent the reasons behind the required actions should be shown. ECLs generally provide the opportunity for greater flexibility than paper systems with regard to such issues, because the information displayed is not necessarily fixed.

2.3.2 The guidance summarised requirements, standards and other authoritative material on the design and production of hardware and software design. This summary covered only those aspects that might be of interest to operators and other non-specialists in these fields, and was not intended to supersede such material.

2.3.3 The study did not consider the functional content of checklists, i.e. what actions are listed. Operators are responsible for ensuring that any changes they intend making to functional content do not conflict with the Flight Manual.

2.3.4 The study aimed to develop and promote best practice guidance, but not to prescribe the only acceptable means of providing safe systems and procedures – overall responsibility for this remains with the operator and manufacturer. The study sought and obtained industry views on the proposed guidance at all stages, but it is for the operator to evaluate any particular system with a representative user population.

2.4 Types of ECL System Considered

2.4.1 The ECL systems considered include all forms of electronic reference by which flight crew are presented with a list of actions or checks to be carried out. Thus the resulting guidance should be applicable to actions/ instructions which appear on the various types of electronic flight information displays (e.g. Electronic Flight Information System – EFIS, Engine Indicating and Crew Alerting System – EICAS or Electronic Centralised Aircraft Monitoring – ECAM) as well as on dedicated ECL systems.

2.4.2 An ECL system requires a method of presenting information and choices to the pilot (output) and a method of allowing the pilot to select and indicate completion of items and checklists (input). This study assumed that the ECL interface makes use of a physical input device (e.g. cursor control device or touch screen), and a display screen for output, possibly with aural alerting or voice annunciation. Speech recognition systems for pilot input and the use of speech output for presenting options to pilots were not considered in detail.

2.4.3 The study covered systems which receive inputs from the aircraft system or from the state of switches in the cockpit (sensed systems), as well as those which respond only to inputs from the flight crew (stand-alone systems).

2.4.4 The study aimed to produce guidance which would be applicable to both existing and future systems, so far as these can practically be foreseen. The research included a survey of what types of ECL system were available at the time, in order to identify ECL types and features in generic terms.

2.5 Normal, Abnormal and Emergency Checklists

2.5.1 The original AAIB recommendation and SRG research invitation referred only to emergency and abnormal checklists. However, it was apparent that compatibility between these checklists and those for normal operations is a major requirement. In particular, pilots should not be faced with a different, and relatively unfamiliar, way of working under the high workload/ high stress conditions associated with abnormal and emergency conditions.

2.5.2 The issues associated with normal checklists are generally fewer, and simpler. For example, almost by definition, there should be no branching in a normal checklist. Hence it was agreed that the study would also cover normal checklists.

2.6 Organisational Issues

2.6.1 The study took into account the organisational context in which operators may use and modify ECLs and produced some general guidance. However, it was considered inappropriate to attempt any detailed guidance on these processes, since the best methods will be dependent on the structure and culture of any particular operator.

3 STUDY APPROACH

3.1 Rationale

3.1.1 ECL systems present wider and more complex research questions than those related to paper systems, both because of the increased flexibility of human-machine interaction which electronic systems offer and because there is not yet such extensive experience in their use.

3.1.2 It is unlikely that the potential safety benefits of ECL would be fully realised if systems were designed simply to mimic the paper equivalent. In the same way, it was evident that the guidance would not be comprehensive if it were derived merely from desk-based editing of the text of CAP 676. The approach was therefore designed to involve, and ask open-ended questions of, a wide range of pilots and other stakeholders. Emphasis was also placed on taking a positive approach – looking for opportunities to gain safety benefits from ECLs, as well as to minimise potential disbenefits.

3.1.3 Pilots should not have to switch between different ways of controlling the aircraft in the event of having to revert to paper, or when using a mixed system (i.e. one in which only the normal checklists or only the abnormal/emergency checklists are available electronically). Hence, there is a need to consider compatibility between paper and electronic systems. The text of CAP 676 was therefore an important input to the study, though not the only one.

3.1.4 The interaction issues which arise with ECLs are generally more complex than the presentation issues which they share with paper systems, and are not so easily tested. For example, while user trials can relatively easily compare the legibility of different typefaces, it is much more difficult to establish how best to allow users to return to and review an item or checklist. Optimal solutions to interaction problems depend on numerous factors, such as the overall flight deck display design and automation philosophy, stress and workload at the time, and the training and other personal preferences of the pilot.

3.1.5 In general, therefore, the guidance could not be as straightforward and definitive as that in CAP 676; the 'right answer' will often vary from one aircraft type and operator to another. Generic principles and requirements were therefore identified, and in cases of uncertainty the advantages and disadvantages of the various options were identified by testing against these principles and requirements. Factors which operators should take into account in making any particular decision requiring a trade-off between advantages and disadvantages were also pointed out.

3.2 Overview of Study Method

3.2.1 The study began with a 'context setting' phase (Chapter 4) in which the various types and uses of ECL were identified, to ensure completeness of the study, and categorised, to provide a structure for the subsequent work. The next stage (Chapter 5) comprised a comprehensive identification of the safety issues (potential benefits and disbenefits) associated with ECLs.

3.2.2 For each of these issues, human factors and risk management principles and requirements were applied to identify measures by which potential disbenefits could be minimised and potential benefits maximised (Chapter 6). These measures were then collated and translated into a set of recommendations and factors to considered, which formed the basis of the guidance document itself.

3.2.3 The study was informed by a literature review, by observations of the use of paper and electronic checklists in simulator sessions and commercial flights, and by discussions with line, training and management pilots.

3.3 Research Team

3.3.1 RMC managed the project and provided the overall understanding of aviation risk management and human factors, as well as drawing on experience from beyond the aviation domain in human-machine interaction and the drafting of emergency procedures and instructions.

3.3.2 The Human Factors Group at Cranfield College of Aeronautics provided specialist input in relation to human-machine interface issues (such as colour and symbology), in particular through a literature review.

3.3.3 The study was overseen and reviewed at regular intervals by a team of SRG specialists in aviation human factors, flight operations, design and production standards and a senior test pilot, under the general direction of the Research Management Department.

3.4 Industry Liaison

3.4.1 The CAA and RMC recognise the importance of industry liaison in developing guidance, both to obtain input from experienced users and to ensure that recommendations are practicable.

3.4.2 Numerous operators were contacted and provided information, especially in the initial context-setting phase. Extensive contributions came from British Midland Airways (BMA) and British Airways (BA), who made pilots available for meetings and arranged for observations of simulator training sessions on ECL-equipped aircraft (Boeing 777, Airbus 320 and Fokker 100).

3.4.3 Aircraft manufacturers and ECL equipment suppliers provided information on their products and related human factors research. In particular, Boeing provided much technical input and advice with regard to the ECL system on the Boeing 777, and the research and rationale behind its design.

4 CONTEXT SETTING

4.1 To ensure that the guidance would be as broadly applicable as possible, the study identified the types of ECL system in existence, or which might be anticipated in the foreseeable future. At the same time, by identifying and categorising the various aspects of these ECLs, it provided a structure for the subsequent identification of benefits and disbenefits, and for the guidance report itself. The aspects identified were grouped as follows:

- ECL system functionality (what the system does, for example whether it is sensed or stand-alone);
- the 'lifecycle' of an ECL system, from specification to disposal of the aircraft;
- a more detailed breakdown of the 'operational use' phase of the lifecycle, i.e. a task analysis, giving a step-by-step list of the actions taken by the pilots and the system;
- human machine interface and interaction attributes;
- the range of normal, abnormal and emergency scenarios for which checklists are available;
- conditions of use – e.g. lighting, smoke, vibration;
- the range of aircraft types, operators and crew competencies.

4.2 Details under each of these aspects were gathered from the literature and from contacts with airlines and suppliers, then collated and categorised to build up a picture of the problem domain.

5 IDENTIFICATION OF SAFETY ISSUES ASSOCIATED WITH ECLs

5.1 General

5.1.1 This phase of the work identified potential safety benefits and disbenefits associated with ECLs and gathered preliminary ideas on how the proposed guidance could help to minimise the disbenefits and maximise benefits.

5.2 Workshop Session

5.2.1 A major element in the identification process was a structured workshop, involving pilots and specialists in human factors and risk management. Use of a mixed group allows the interfaces between different subject areas to be covered. The structured approach ensures that it is as comprehensive as possible, while applying keyword prompts to the structure helps to promote imagination about what safety issues can arise, and recall of relevant errors and incidents.

5.2.2 The workshop comprised the following three main parts:

(i) Asking participants to note what they saw as the main distinguishing features of ECLs – how do they differ from paper checklists or other types of human-machine interface on the flight deck and elsewhere? This allowed broader consideration of high level issues surrounding ECLs and, by noting these distinguishing features, allowed subsequent discussions to be focused on ECL-specific issues rather than flight deck displays and automation issues in general.

(ii) For each ECL aspect as identified and categorised in the context setting task, benefits and disbenefits (ie safety issues) were identified. For example, participants were asked what safety issues arise at each stage of the lifecycle, and which of these might be associated with particular types of aircraft or operation.

(iii) The final part of the workshop looked in greater detail at the 'Operational Use' phase of the lifecycle, since it is only in this phase that benefits and disbenefits can be realised, i.e. that a dangerous situation can arise or be avoided. The meeting worked through a simplified and generalised version of the task analysis developed in the Context Setting stage. Keywords (such as NOT DONE, OTHER THAN, MISUNDERSTOOD or USED BEYOND INTENT) were applied to each step to prompt ideas about what might go wrong, or what errors might be avoided.

5.2.3 Wherever a safety issue was mentioned, participants were encouraged to suggest how presentation, design and usage – the topics within the remit of the guidance – could maximise the benefits and minimise the disbenefits. The meeting deliberately avoided analysis and evaluation of such ideas, however – the issues tend to be too complex and inter-related for unprepared group discussion. Rather, analysis and evaluation were conducted once all the disbenefits had been collated (see Chapter 6).

5.2.4 Further details of the conduct of the workshop are given in Appendix 1.

5.3 Other Sources

5.3.1 Safety issues were also identified from:

- the CAA's Mandatory Occurrence Reporting System (MORS), and the databases of the Confidential Human Factors Incident Reporting Programme (CHIRP) and Aviation Safety Reporting System (ASRS);
- observation and discussion of simulator training sessions (Boeing 777, Airbus 320, Fokker 100) which included substantial use of emergency and abnormal checklists;
- observation of the use of normal checklists (electronic and manual) during commercial flights;
- literature reviews (see Bibliography);
- a questionnaire to pilots.

5.4 Collation of Data

5.4.1 The safety issues identified from all the above sources were collated in a database. The database fields for each safety issue raised were:

- a unique identity number;
- cause (what leads to the disbenefit or benefit);
- effect (the potential safety-related consequences);
- risk reduction measure (what action could potentially be taken to minimise the disbenefit or maximise the benefit);
- source (how/ by whom the issue was raised – e.g. in the structured group workshop, during a simulator observation, reference in the literature).

5.4.2 Over 140 safety issues (benefits and disbenefits) were identified. Some examples are shown in Appendix 2.

6 IDENTIFICATION AND EVALUATION OF RISK MANAGEMENT MEASURES

6.1 General

6.1.1 Of the safety issues in the database (described in Chapter 5), over a third of them relate to disbenefits which could arise from inadequate design of the ECL system. For example, problems such as loosing awareness of how much of the checklist has been completed, indicating completion of an item or a whole checklist unintentionally, and repeating or omitting actions in a checklist.

6.1.2 The second largest category of safety issues are those where benefit and disbenefits can arise from the way the ECLs are written. For example, incorrect selection of a procedure because of inadequate titling, or errors arising from the layout or language used in the checklist.

6.1.3 The database included a significant number of safety issues relating to three further topics:

- choice of an ECL system;
- management of modification;
- training.

6.1.4 The safety issues in the database were reviewed as a whole, applying human factors and risk management principles to identify and evaluate risk reduction measures (within the intended remit of the guidance) by which disbenefits could be minimised and benefits maximised. In some cases, risk reduction had already been suggested in the original sources – the task now was to identify measures where none had yet been suggested, and to test all these suggestions against robust and consistent principles. These principles and the more specific requirements that flow from them are described in Sections 6.2 and 6.3.

6.2 Principles

6.2.1 Principles for testing the value of risk reduction measures can be derived by considering the purposes of checklists. At the highest level, a checklist is a device to reduce the potential for flight crew error in configuring the aircraft safely for the phase of flight, and for any failures that may have occurred. This very high level purpose applies across a broad spectrum of pilot tasks, and hence needs to be broken down into more specific human factors principles if it is to be useful as a test of particular risk management measures.

6.2.2 For both normal and abnormal/ emergency checklists, the potential for error is reduced principally by:

- **reducing reliance on long term memory;**

Normal checklists do this by providing the flight crew with a means of checking that all necessary routine actions have been carried out for each phase of flight. Emergency and abnormal checklists inform flight crew of the required actions (which are infrequently practised, and therefore tend not to be memorised).

6.2.3 The checklist (especially where it has a degree of sensing or internal intelligence) can also assist by:

- **trapping errors**

i.e. by detecting and alerting the flight crew to certain slips, lapses and mistakes or by preventing them occurring. For example, an ECL system with internal intelligence can prevent the pilot from removing a checklist before all the items have been completed.

6.2.4 Checklists, and especially abnormal and emergency checklists, have additional functions:

- **reducing workload**, by presenting the required actions in a readily accessible, concise and efficient form;
- **improving situational awareness**, by showing the crew where they are in a sequence of actions, and what they are trying to achieve.

6.2.5 Sensed ECL systems for abnormal and emergency cases have yet further purposes:

- **assisting in decision-making**, by presenting the most likely option(s);
- **reducing reliance on short term memory**. For example, to avoid the need for crew to recall which engine is on fire, a sensed ECL can present this information both in the ENGINE FIRE checklist title and by 'personalising' the action items. For example, it can show the item:

Fire bottle right.......................... Discharge

rather than:

Fire bottle (right or left)................. Discharge

as might appear in a paper checklist.

6.3 Requirements

6.3.1 The human factors principles noted above can be embodied in requirements which can be more directly implemented in the design, presentation and use of checklists. As in CAP 676, these requirements can be expressed as:

- accuracy,
- lack of ambiguity,
- clarity,
- succinctness (suppressing information not relevant to the task)
- consistency with other checklists, pilot expectations and airline culture and (for electronic checklists) consistency with other flight displays and the paper back-up.

6.3.2 Additional requirements can be stated for reducing mental workload. These are especially important for abnormal and emergency checklists:

(i) Provide unambiguous information and suppress information (or detail) that is not task relevant. This will remove the need for interpretation by providing adequate information (eg by displaying only the required branches of a checklist).

(ii) Avoid reliance on long-term memory (the main purpose of a checklist of any type). For example, do not refer to information on previous screens.

(iii) Reinforce task goals. Checklists are commonly titled with the name of the failure which has occurred (e.g. FUEL IMBALANCE), and where the desired recovery action is obvious and unique, this may be sufficient. In some cases, however, it may also be important to indicate clearly what the drill is trying to achieve – pilots may wish to review whether this is the most appropriate aim in the specific circumstances. Phrase checklist items to make clear the desired outcome.

(iv) Provide meaningful cues to the type of response expected. For example, a conditional statement could provide YES/NO response boxes, rather than leaving the form of response 'open'. For some failures it may be necessary to give more detailed instructions on what to do, rather than the 'Challenge-Response' format alone (in which the action to be taken is implicit).

(v) Avoid forcing absolute judgements by providing a reference where possible so relative judgements can be made instead (eg 'is there more smoke than before?' is better than 'is there a lot of smoke?').

(vi) Present information at appropriate rates, to avoid overloading short-term memory. Do this by:

- avoiding time delays that cause anticipation,
- avoiding rapid sequential presentation of similar information that needs to be recalled later,
- where possible provide information sequentially in discrete 'chunks' unless comparisons need to be made.

(vii) Minimise noise and redundancy.

(viii) Avoid the need for mental transformation and conversion (e.g. between flight level and altitude) by having the system calculate values rather than provide raw data (e.g. 'Vref + 10' can be avoided if Vref is known and entered).

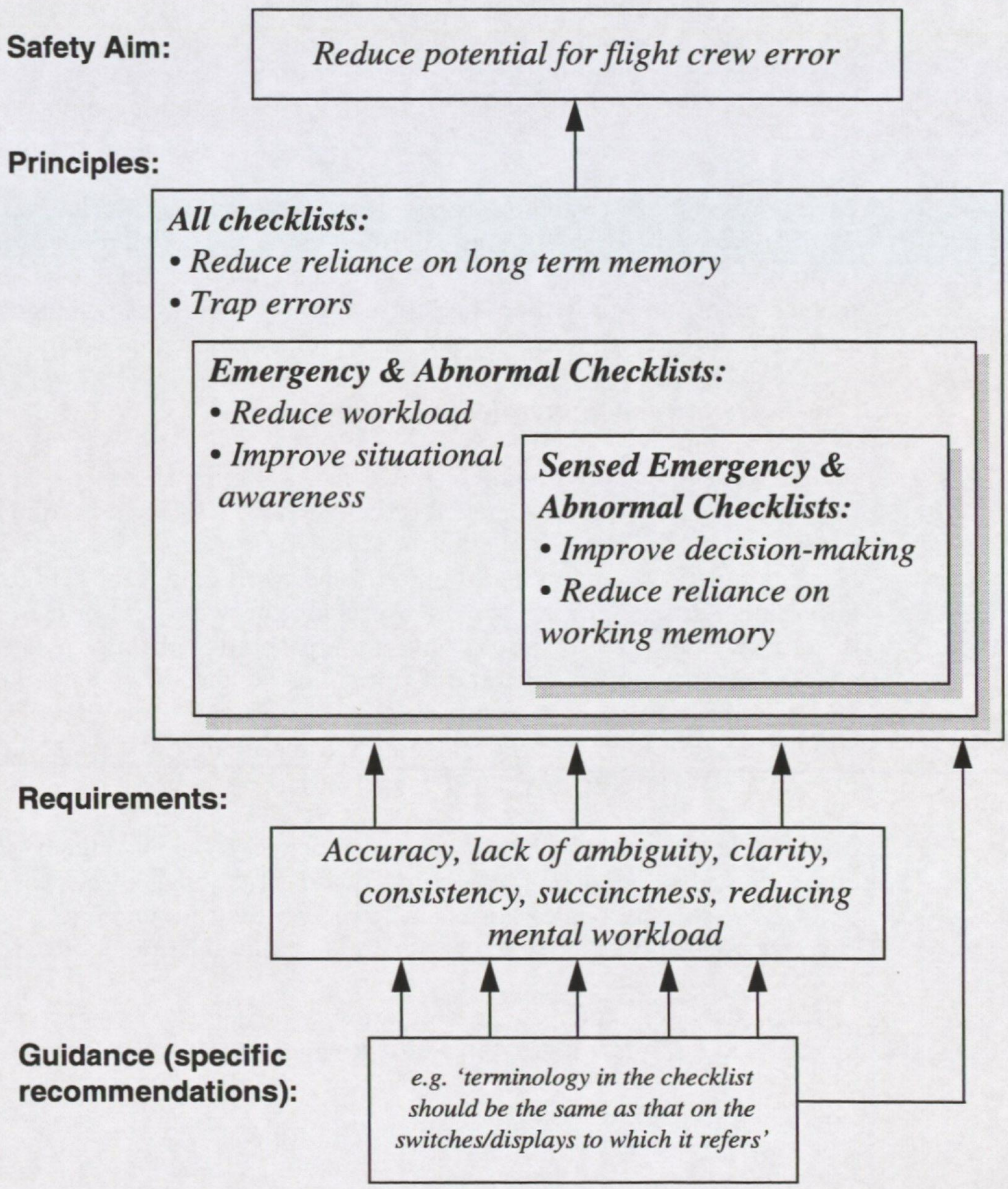
(ix) Maximise compatibility with user expectations and conceptual models (e.g. defining aircraft systems which accord with pilots mental models and experience, rather than those of system engineers).

(x) Maximise discriminability by reducing noise and redundancy. In particular, avoid screen clutter, unnecessary text and superfluous emphasis.

6.4 Relationship between Principles, Requirements and Guidance

6.4.1 Figure 6.1 summarises the relationships between principles, requirements and guidance recommendations (as described in Section 6.5 following). Each of the requirements may contribute in various ways to each of the principles in Section 6.2. The recommendations in the guidance document were tested for conformity with these requirements or more directly against the principles. Note that Figure 6.1 is not intended to be a universal model, merely a representation that was helpful in this study. As with any attempt at rationalising human factors issues, there are many other ways in which they can be categorised and related.

Figure 6.1: Principles, Requirements and Guidance



6.5 Applying the Principles and Requirements

6.5.1 Risk management measures for inclusion in the guidance were derived (where none had already been suggested) and tested by considering each safety issue against the principles and requirements.

Uncertainties in recommending risk management measures

6.5.2 For the human-machine interface issues, literature references support many of the recommendations made. As noted in Section 3.1, however, the human-machine interaction issues associated with ECLs are complex and experimental testing against principles is not generally practicable. The selection of risk management measures for the interaction issues was therefore largely based on subjective judgement against the principles and requirements. It necessarily relied to some extent on views expressed by pilots and others, but care was taken to look for justifiable reasons behind these views – testing them against the principles and requirements rather than merely accepting and combining them as in an opinion survey.

6.5.3 For many of the interaction issues, it was not possible to determine a universal 'right answer': the best solution will often vary from one aircraft type and operator to another, or there may be too much uncertainty to make a generic judgement. In such cases, the study identified the advantages and disadvantages of the various options and the factors to take into account in weighing these up.

Conflicts between principles/ requirements

6.5.4 There were inevitably many cases where a conflict arose between different principles, between requirements, or between principles and requirements.

6.5.5 For example, the principle of minimising workload can conflict with that of improving situational awareness. Applying the workload principle alone would dictate that flight crew should only be presented with information they actually need. The situational awareness principle, on the other hand, argues that the crew should be presented with all the options and allowed to make their own choice, since system designers cannot foresee all possible contexts or decide precisely what information may be relevant[1].

6.5.6 Another recurrent example is the balance between the advantage of displaying the entire checklist on one screen (improving situational awareness by letting the flight crew see the context of each item) and the requirement to use a minimum character size and line spacing to ensure legibility (clarity requirement).

6.5.7 In such cases the study could only identify the need to compromise and, where possible, identify factors that may affect where to set the balance in any particular case.

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[1] The contrast between different manufacturers' philosophies is very marked in this respect. At one pole, only immediately relevant items are displayed, and items are removed from the display once they have been completed, while at the other pole, detailed information and options are presented.

Benefits and Disbenefits of Automation

6.5.8 Many of the decisions that an operator may need to take are in essence about the optimum level of automation. For ECLs, the most relevant benefits and disbenefits of automation are summarised in Table 6.1.

Table 6.1 Advantages and Disadvantages of Automation

Advantages of a higher level of ECL automation	Disadvantages of a higher level of ECL automation
Error-trapping: reduced potential for leaving checklist items out or repeating items	Reduced need for flight crew to scan and check can result in errors due to reduced awareness of system state
Reduced workload – presenting only the information needed at the time	If higher perceived reliability results in fewer opportunities for practice in making decisions and dealing with errors during simulations, flight crew will be less prepared when an ECL error does occur.

6.5.9 The optimum balance cannot be determined by considering the ECL system in isolation. Aircraft manufacturers vary significantly in their approach to flight deck automation, and compatibility with this approach, and the resulting training and expectations of the crew, is an important consideration.

6.5.10 Operational and practical factors will also constrain the choices that an operator can make. Operators of aircraft in which the manufacturer provides the ECL will not normally have much control over the level of automation; the manufacturer will usually already have determined this in accordance with their overall philosophy. Nevertheless, it was considered important that operators' attention was drawn to this issue, which may be a factor in specifying, evaluating and selecting ECL systems, especially in the event of retrofitting a system.

6.6 Benefits and Disbenefits of ECLs

6.6.1 A large number of safety issues concerning potential benefits and disbenefits were identified for checklists and ECLs. The overall advantage of ECLs over traditional paper checklists can only be realised where the ECL system is designed according to principles that take account of these safety issues, in order to maximise the benefits and minimise the disbenefits of ECLs.

7 DRAFTING AND REFINING THE GUIDANCE DOCUMENT

7.1 As the safety issues database described in Section 5.4.1 was a working tool, rather than a final product, the selected risk reduction measures (see Section 6) were recorded in the database in varying degrees of detail. There was also much duplication and overlap. Producing the guidance material itself therefore required some translating and condensing of these records into clear and concise advice to users.

7.2 At the highest level, the structure of the guidance material is broadly in line with the model of the ECL lifecycle developed in the Context Setting part of the study. This follows the order in which operators will generally consider and use ECLs and, as a result, the chapter headings, as listed in Table 7.1, are broadly aligned with the main interests of readers having particular roles in operator organisations.

Table 7.1 Expected Readership of Chapters in the Guidance

	Chapter and Content	Roles of Main Expected Readership
1	Introduction	All
2	Choices (fundamental decisions about ECL type and what checklists are provided electronically)	High level flight safety and management decisions about whether to acquire ECLs, and what type Specification/ evaluation/selection of systems
3	Positioning of ECL on the flight deck	Specification/evaluation/selection of ECL systems (Retro)fitting of ECL systems
4	Physical display issues	Specification/ evaluation/selection of ECL systems
5	Interaction Issues	Specification/ evaluation/selection of ECL systems Human Factors departments
6	Language	Writing new or modified checklists
7	Education & Training	Training departments
8	Operational use	Design of Standard Operating Procedures Provision of paper back-ups
9	Evaluation and feedback	Line pilots and their representatives Modification of checklists
10	Management of Modifications	Modification of checklists

7.3 The extent to which operators have control over the design and presentation of electronic checklists is highly variable, depending on the type of system. The Boeing 777, for example, allows the user to modify or add checklists as required, whereas the checklists on the Airbus 320 are factory-fixed. It was therefore impossible to make any clear division between the guidance relevant to specifying and evaluating an ECL system and that for user modification once it has been installed in the aircraft.

7.4 As already noted, where it was not possible to offer definitive recommendation, the guidance indicates the advantages and disadvantages of the various options and the factors which operators should take into account in making a decision.

7.5 In order to keep the guidance concise, the reasoning behind each guideline is only explained in cases where this was not reasonably obvious in 'common-sense' terms. Similarly, illustrations of how or where the guidelines might be applied were only given in cases where it was considered that such examples might not easily come to mind.

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Acknowledgements

RMC would like to thank numerous individuals in the following organisations who provided valuable input to the study: Air New Zealand, British Aerospace, British Airways, British Midland Airways, Boeing Flight Technical Services, Brymon Airways, Bond Helicopters, CHIRP Charitable Trust, City Flyer Express, Debonair, Honeywell, Jersey European Airways, KLM UK, Maersk Air, Monarch, Royal Air Force, Rockwell Collins, Smith's Industries, Swissair, Virgin Atlantic

Appendix 1 Structured Group Workshop Identification of Safety Issues

A1.1 Format of Workshop

The overall format of the meeting is shown in outline below.

Session	Topic
1.	**Introductions** – project objectives – objectives and conduct of session
2.	**Distinguishing Features of Electronic Checklists**
3.	**Design, Presentation and Use Issues**
4.	**Operational Use (Task Analysis)**
5.	**Summary and Review** – actions/ information sources to follow up, next steps

A1.2 Attendees

The attendees and their roles within their respective organisations are given below.

- An SRG research project manager
- An SRG human factors specialist
- Pilot: Fleet Manager (F100)
- Pilot: B737 Captain and Company Medical Officer (also in the course of conversion training to A320)
- Pilot: Training Captain (A320)
- RMC's project manager
- RMC's human factors specialist

A1.3 **Method**

A1.3.1 *Distinguishing Features of ECL*

Participants were prompted to identify features of ECLs that distinguish them from paper checklists/ other electronic interfaces.

There is a danger that focusing on differences from paper checklists alone could constrain thinking to the paper metaphor. The session therefore also asked how ECLs differ from other electronic interfaces on the flight deck or in daily life.

The session was intended:

- to share high level issues which may be obvious to some participants but not to others;
- to indicate priority areas for more detailed discussion;
- to bring in issues from other domains, which might not be evident from considering ECLs in isolation.

The distinguishing features from this session were noted on a flipchart, and summarised and displayed in the following session, with the aim of focusing participants' attention on ECLs rather than flight deck displays or cockpit automation issues in general.

A1.3.2 *Design, Presentation and Use Issues*

In this session, each of the aspects of ECLs, as identified in the context setting phase was considered, asking what disbenefits these bring to mind. The session worked top-down, from general aspects such as the ECL lifecycle to the specific conditions which may apply in any particular situation.

As well as identifying disbenefits in their own right, this session was intended to get participants thinking about all the factors which surround and affect the operational tasks considered in the next session.

Key questions under each aspect were as follows:

- ECL lifecycle: where in the lifecycle (as shown in Table A1) can problems be created or benefits gained?
- Operator and aircraft types: what safety issues are related to particular types of operation (public versus private, two pilot versus single pilot operation)? The main focus of the study was on commercial public transport operations, but participants were also prompted to note any issues arising in the business aviation, GA and the PPL sector. Both rotary- and fixed-wing aircraft were considered.
- Checklist usage and scope: what disbenefits are raised by the use of electronic checklists alongside paper or instead of paper?

- Interface issues (how the pilot and system exchange information). Participants were reminded of the various modes of input and output (e.g. visual versus sound alert) and of parameters such as display characteristics, phraseology, layout, paging and scrolling, and asked to identify related safety issues.

- Interaction issues, e.g. methods of initiation, advance and completion. What disbenefits are raised if checklists are initiated, advanced or completed:

  - by pilot activation;

  - by sensing from switch positions;

  - by sensing aircraft system state?

- Conditions of use: what disbenefits are raised by consideration of different levels of visibility, smoke, noise, vibration, workload and stress?

- Types of checklist: are there any disbenefits specific to emergency procedures or abnormal procedures? Attention was drawn to some specific example checklists that illustrate a range of factors such as aircraft handling, branched or cascade procedures and impacts on other systems.

A1.3.3 *Operational Task Analysis*

This session looked more specifically at the operational phase within the lifecycle, since it is only here that benefits and disbenefits will be realised. The session structure followed the steps in a simplified, generic task analysis (derived from the more comprehensive version shown as Table A2), as follows:

(1) Determine need for checklist, select and initiate.

(2) Check or filter items already completed.

(3) Present and read challenge.

(4) Take action.

(5) Check action; Respond (check system state).

(6) IF BRANCHING: Determine which branch to follow.

(7) IF NOT COMPLETE: Advance to next item.

(8) Indicate completion; Check and confirm complete.

(9) Complete any deferred items later.

Keywords were applied to each step, to prompt thinking about what might go wrong with this intended process, and hence where disbenefits or benefits might arise. The keywords were as follows:

- NOT DONE/ NOT AVAILABLE,
- OTHER THAN (which includes the concepts misordered/ incorrect/ too late/ too early)
- MISUNDERSTOOD,
- USED BEYOND INTENT

A1.3.4 *ECL Lifecycle*

The most detailed focus of the meeting (session 3) was on the operational use of the ECL. However, this had to be set in the wider context of the ECL lifecycle to ensure that the study identified – at least at a high level – organisational and latent factors relevant to operators. The overall 'lifecycle' of the ECL, so far as the operator is concerned, can be described as in Table A1.1.

Table A1.1: ECL Lifecycle

1	Specify or select ECL system (acquire aircraft or retrofit ECL)
2	Fit ECL
3	Write/ adapt checklist
4	Authorisation, Implementation
5	Training
6	Operational Use (see Task Analysis in Table A2)
7	Review /Pilot feedback
8	Modifications (return to step 3)
9	Sell to another operator

A1.3.5 *Task analysis*

The steps involved in operational use phase of the lifecycle are given in more detail in the task analysis in Table A1.2. This is intended as a generalised account of the main tasks – there will be many variations between ECL types and operators' procedures. In addition, the columns for stand-alone and sensed ECL systems represent the end points of the wide range of possible system types, from a pure stand-alone system to fully sensed/ fully intelligent system at the most sophisticated level.

Table A1.2: Task Analysis for Operational Use of ECL

PAPER CL (for comparison)	ECL – stand-alone	ECL – sensed
PF determines need for and calls for CL	PF determines need for and calls for CL	System (or PF) determine need for CL
		System selects and presents checklist, and may alert pilots
PNF finds correct CL	PNF selects and initiates correct CL	PNF alerted to CL – calls CL title
		PF checks and confirms, requests call out of actions
PNF may mentally check off items already completed	PNF may indicate which items have already been completed	System may filter out items already completed
	➨ System: presents PNF challenge (and may also provide additional notes and warnings)	
➨ PNF: reads out challenge (and may note any references to, for example, QRH)	PNF reads out challenge (and may note any references to, for example, QRH)	
PNF takes action or requests execution	PNF takes action or requests execution	
PF (or PF and PNF) check actions and give verbal response	PF (or PF and PNF) check actions (and gives verbal response?)	
	PNF enters response	System checks switch position or system state and removes item or indicates complete
PNF assesses which branch to follow (where necessary)	System or PNF assesses which branch to follow (where necessary). System decision based on user's response to previous points only.	System or PNF assess which branch to follow (where necessary). System decision based on user's response or sensed information
PNF – move thumb or metal 'cursor' to next item	PNF – advances CL cursor (if provided) to next item	System advances CL cursor (if provided) to next item
Repeat from ➨ until complete	Repeat from ➨ until complete	
PNF calls complete	System indicates completion PNF informs PF	System indicates completion (or otherwise) PNF informs PF
PF checks complete	PF checks complete	
PF/PNF may review as required	PF/PNF may review as required System may re-present deferred items in later CL	

Appendix 2: Example Records From Safety Issues Database

A safety issues database was developed in order to collate, and enable traceability of, the numerous potential benefits and disbenefits identified and to record the risk reduction measures for each which could be included in the guidance. These are the entries as made at the time. Some may not be included in the guidance, for example if assessed as unrealistic or impractical, or of no overall benefit.

Id	Cause	Potential effect	Desired risk reduction measure	Source
8	Automatic removal of items already completed	Loss of system awareness	Consider balance of benefits and disbenefits of reducing workload and screen clutter	Observation of A320 simulator session
10	Unclear layout of text in branching checklist	Difficulty in knowing where the conditional steps end.	Avoid conditionals where possible. If used, system of indentation etc must be clear.	Discussion with BMA pilots
24	Interruption of checklist (ATC instruction & change of heading)	Distraction led to omission of item on resuming, (and subsequent engine flame-out)	Sensing of items or place holding	MORS
71	Action for clearing whole checklist is same as that for clearing an item	Inadvertent clearing of whole checklist	Require a different action to clear whole list	Workshop session
91	Flying pilot does not know current position in checklist	delays, confusion	Position display where visible to both pilots	Boeing paper (Boorman & Hartel, 1997)
125	Change to intended flap setting after 'Before Take-Off' completed	Pilot made calculations and set speed for new flap angle but did not actually reset the flap.	Sensed checklist could prompt crew to re-run checklist in the event of such changes.	CHIRP