Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2006/04

Minimum Colour Vision Requirements for Professional Flight Crew - Part 2

Task Analysis

www.caa.co.uk

Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2006/04

Minimum Colour Vision Requirements for Professional Flight Crew - Part 2

Task Analysis

14 August 2006

© Civil Aviation Authority 2006

All rights reserved. Copies of this publication may be reproduced for personal use, or for use within a company or organisation, but may not otherwise be reproduced for publication.

To use or reference CAA publications for any other purpose, for example within training material for students, please contact the CAA at the address below for formal agreement.

ISBN 0 11790 508 9

Enquiries regarding the content of this publication should be addressed to:
Research Management Department, Safety Regulation Group, Civil Aviation Authority, Aviation House, Gatwick Airport South, West Sussex, RH6 0YR.

The latest version of this document is available in electronic format at www.caa.co.uk, where you may also register for e-mail notification of amendments.

Published by TSO (The Stationery Office) on behalf of the UK Civil Aviation Authority.

Printed copy available from:
TSO, PO Box 29, Norwich NR3 1GN
Telephone orders/General enquiries: 0870 600 5522
Fax orders: 0870 600 5533
www.tso.co.uk/bookshop
E-mail: book.orders@tso.co.uk
Textphone: 0870 240 3701

List of Effective Pages

Part	Chapter	Page	Date
		iii	14 August 2006
		iv	14 August 2006
		v	14 August 2006
		vi	14 August 2006
		1	14 August 2006
		2	14 August 2006
		3	14 August 2006
		4	14 August 2006
		5	14 August 2006
		6	14 August 2006
		7	14 August 2006
		8	14 August 2006
		9	14 August 2006
		10	14 August 2006
		11	14 August 2006
		12	14 August 2006
		13	14 August 2006
		14	14 August 2006
		15	14 August 2006
		16	14 August 2006
		17	14 August 2006
		18	14 August 2006
		19	14 August 2006
		20	14 August 2006
		21	14 August 2006
		22	14 August 2006
		23	14 August 2006
		24	14 August 2006
		25	14 August 2006
		26	14 August 2006
		27	14 August 2006
		28	14 August 2006
		29	14 August 2006
		30	14 August 2006
		31	14 August 2006
		32	14 August 2006
		33	14 August 2006
		34	14 August 2006
	Appendix A	1	14 August 2006
	Appendix A	2	14 August 2006

INTENTIONALLY LEFT BLANK

Contents

INTENTIONALLY LEFT BLANK

Executive Summary

This report was prepared by QinetiQ on behalf of the City University under contract number CHSO/156 and reports the results of work undertaken to investigate the use and importance of colour by commercial flight crew.

The report summarises the methods and results of a task analysis undertaken to understand the importance of colour to the civilian pilot.

A task analysis was undertaken on two aircraft - an Airbus A321 and a Boeing 757. In addition the task analysis included lights and display exterior to the aircraft. The use of colour was placed into one of three categories:

1 Low importance for safety

2 Medium importance for safety

3 High importance for safety

It was concluded that the most colour critical elements in the pilots' environment were the PAPI lights and the parking lights.

The conclusions for the aircraft instrumentation were as follows.

Airbus A321

The following table summarises the safety classifications of the major functional components in the Airbus flight deck.

Table 1

Function	Classification
(a) Air-conditioning and 2 Pressurisation Controls	2
(b) Cabin Altitude Indication	3
(c) Communication	2
(d) Fire Protection	3
(e) Fuel	2
(f) Hydraulics	2
(g) Landing Gear	3
(h) Oxygen	3
(i) Pressurisation	2
(j) APU	2
(k) Power Plant	2
(l) Navigation	2 (3)
(m) Auto Flight	2
(n) Flight Controls	2
(o) Indicating Recording Systems	2(3)

Boeing 757

The following table summarises the safety classifications of the major functional components in the Boeing flight deck.

Table 2

Function	Classification
(a) Air-conditioning and Pressurisation Controls	2
(b) Automatic Flight	2
(c) Electrical	2
(d) Emergency Equipment	2
(e) Fire Protection	2
(f) Hydraulics	2
(g) Power Plant	2
(h) Warning Systems	2

1 Introduction

1.1 Background

1.1.1 This report was prepared by QinetiQ on behalf of the City University and the UK Civil Aviation Authority (CAA) under contract number CHSO/156 and reports the results of work undertaken to investigate the use and importance of colour by commercial flight crew.

1.1.2 Colour is used extensively in the aviation environment, both inside and outside the cockpit to code important information (1).

1.1.3 Some examples include:

- Anti-collision beacons and strobes are red or white.
- Navigation lights are red, green and white.
- Rotating/flashing beacons on ground emergency vehicles are red and/or blue.
- Airport ground support vehicles have amber rotating beacons in addition to the normal red. Vehicles also have the normal rear and brake lights as well as amber turn lights and white reversing lights.
- Red, amber, white green and blue lights are used on runways, taxiways and parking areas.
- Obstruction lights are usually red.
- Visual landing aids may include red, amber, yellow, green and white lights.
- Conventional panel instruments often carry coloured numerals, arcs and sectors, typically red, yellow, white, green or red.
- Attitude and directional indicators may have brown and blue hemisphere.
- Annunciator panels, i.e. panels conveying messages, may have red warnings and amber cautions.
- Electronic Flight Instrument Systems (EFIS) displays may use white, red, green, amber, blue, magenta colours as well as sometimes brown, yellow, blue-green, violet, purple, pink and mauve.
- Aviation maps are often printed in four or more colours chosen from brown, amber, yellow, green, blue, or purple.
- Visual Approach Slope Indicating Systems (VASISs) are typically colourcoded. An example is the Precision Approach Path Indicator (PAPI) which uses red and white lights to indicate the aircraft position relative to a defined glide-slope angle.

1.1.4 The traditional view (2) is that the use of colour enhances the performance (in both speed and accuracy) of tasks and object recognition for colour normal observers. Colour-defectives are assumed to be less able than colour-normals to use colour-coded information as reliably or as speedily (3). It is further assumed that restricting the benefits derived by colour normals in order to accommodate colour-defectives is not a practical proposition.

1.1.5 Therefore the current colour vision standards (4) for the UK Civil Aviation Authority (CAA) require the applicant to have good colour vision, and pass the colour vision tests currently used in the UK. This therefore instantly reduces the number of potential male pilots who might obtain a class one certificate. The CAA wanted to investigate if it would be safe for colour deficient pilots to fly commercial aircraft. It therefore initiated a research project, led by The City University, aimed at investigating

limitations of conventional colour screening tests, development of a new computer-based colour vision test, finding out how colour was used by commercial (JAA Class 1) flight crew and measuring colours in the flight deck.

1.1.6 As part of this project, QinetiQ Centre for Human Sciences undertook to carry out a task analysis of the pilot and the pilot working environment, including the interior and exterior environments of the aircraft as well as the airport surroundings. The task analysis aimed to highlight areas where the use of colour is thought to be important. The results of these investigations allowed the City University to undertake colorimetric analysis of those colours used by the pilot and to decide if the current colour vision standards could be relaxed.

1.2 Colour Coding

1.2.1 Before beginning an analysis of the use of colour by pilots it is important to understand exactly what is meant by colour coding.

1.2.2 A code is defined as "a system of symbols for meaningful communication" (5)

1.2.3 With respect to colour coding the symbol is light, either emitted or reflected, with meaning attached to the colour property of the light. In the case of real materials and lights it is almost always the case that a difference in the colour property is also accompanied by a difference in the brightness (lights) or lightness (surfaces) (6).

1.2.4 Colour codes can be classified broadly into three categories (7).

- CC1 The first category is the case where a single coloured light can simply either be on or off. Here there is only one "colour" - that is when the indicator is on. There is a clear change in intensity concurrent with the change in message of the indicator.
- CC2 The second category of colour code consists of a single display element, e.g. a single light, which changes colour to indicate a change in meaning. For example a single LED may be red to indicate one thing, and green to indicate another (with the additional situation of the LED being off when the device is not in use). In this situation there may be a change in intensity along with the change in state, but this needs to be determined for any particular situation.
- CC3 The third category effectively covers all other cases, where colour is used to delineate and differentiate between elements of a display, that is, it is used as a grouping cue. An example is maps and plans. The choice of colour may be arbitrary and it is likely there will be a number of colours used.

1.3 Colour Vision Tests for Airline Pilots.

1.3.1 The current colour vision standard requires all applicants to have good colour vision. This standard is the same for all of the Joint Aviation Authorities (JAA) member states.

1.3.2 A number of colour vision tests can be used by the JAA member states. These include Ishihara Plates (6) and Holmes-Wright Lantern (8, 9), which the UK CAA has adopted, and a number of other lantern tests including the Beyne lantern and the Spectrolux, which are used in other parts of Europe. Other lantern tests are available but not necessarily used as secondary tests by the JAA. Figure 2 shows photographs of four common lantern tests, two of which are used by JAA countries.

1.3.3 The colour vision test forms part of the medical examination for the class one certificate and follows two parts. Firstly the applicant carries out the Ishihara Plates. If they fail the Ishihara Plates they need to do a secondary test, for example the

Holmes Wright Lantern Test in the UK. If the applicant also fails the secondary test they are not classed as fit for the JAA Class One certificate.

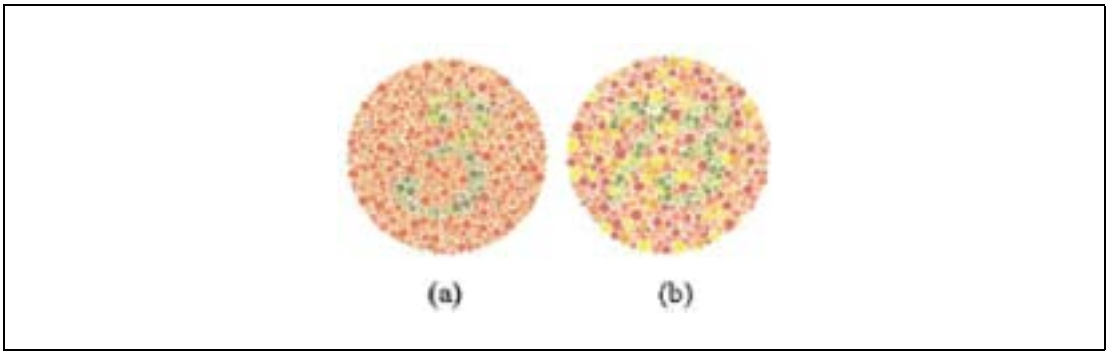

Figure 1 Two examples of an Ishihara plate. In (a) a colour normal would see a numeral 3, while an individual with defective colour vision woud see a 5. In (b) the normal sees the figure 73 whilst an individual with defective colour vision cannot read the plate.

Figure 2 Photographs of the four common lantern tests. Two of these (Holmes-Wright and Beyne) are used for testing in JAA countries.

1.3.4 The CAA perceives that these requirements may be too stringent. In order to assess whether this is the case it is essential to have an understanding of how colours are used by professional flight crew, what exactly these colours are and how important the colour component is. This report summarises the results of investigating the first aspect of this problem.

2 Data Gathering

2.1 General

2.1.1 Understanding how commercial pilots use colour is a challenging task. The flight deck is a complex environment and flight crews receive very high levels of training, such that many of the processes become semi-automatic. In addition, in many cases, colour is a redundant cue.

2.1.2 The approach undertaken was to carry out a task analysis. This required firstly, a detailed study of the many flight manuals (10, 11, 12) to achieve a detailed knowledge of the different operating procedures. This was followed by a number of interviews with operational pilots during scheduled flights. In addition some data gathering was undertaken in flight simulators.

2.2 Aircraft and Airport Selection

2.2.1 After discussions between CAA, City University and QinetiQ it was agreed that the task analysis would be restricted to two aircraft types in order to achieve a good level of understanding of the tasks, within the limited resources available.

2.2.2 The two aircraft selected for the analysis were the Airbus A321 and the Boeing 757. These two types of aircraft were selected in order that comparisons could be undertaken between two very different cockpit environments. The former is representative of a "glass cockpit" which incorporates computer systems to inform the pilot of the aircraft status. The latter is a hybrid cockpit, which comprises a combination of the traditional flight deck instrumentation and the glass cockpit philosophy.

2.2.3 A number of flights were carried out on a British Midland A321 and a British Airways 757 to gather data for the task analysis. The number of flights and the length of these flights depended on the availability of aircraft from British Midland and British Airways.

2.2.4 In addition to actual flights in aircraft, work was also undertaken using aircraft simulators. This was necessary in order to provide an assessment of emergency procedures, which could not be carried out on operational flight decks

2.2.5 The airport chosen for the assessment was London Heathrow Airport since this gave easy access to both the airlines and the aircraft.

2.3 Task Analysis

A Human Factors Consultant for QinetiQ, Centre for Human Sciences, collected the information required for the task analysis. The Human Factors Consultant spent time on flights, travelling on the flight deck of an Airbus A321 and a Boeing 757, observing and questioning the pilots from the two airlines. The nature of the many sequential actions that are carried out by pilots lends itself well to representation with flow diagrams and simple hierarchical task analysis. These methods are described briefly below:

- Flow Diagrams.

  The flow diagram is an analysis of task sequences. A graphical symbol is associated with each type of task together with the brief written description to indicate tasks, thoughts, actions and verbal communications.

  The flow diagrams were created from time spent in the aircraft simulators at Heathrow and Gatwick training centres. This enabled the Human Factors Consultant to gather data for the assessment of the emergency procedures. The

procedures for collecting this data carried the same format as those that were carried out on the aircraft, with the observation and questioning of the pilots and the tasks that they were carrying out.

- Hierarchical (Matrix) Analysis

  Hierarchical task analysis shows a simple and convenient form of representing tasks. A task can be broken down in to task components at a number of levels of description with more detail of the task being revealed at each level.

  There is no limit to the number of levels in the task analysis and it allows areas of the task to be highlighted in greater detail.

  A matrix of the controls and displays inside and outside of the aircraft that the pilot may use was also created.

2.4 Flights – British Midland (Airbus)

2.4.1 A return operation to Dublin was flown with time in between to analyse the data that had been gathered. The Human Factors Consultant and an assistant travelled on the flight deck to gather data for the task analysis. The flights involved observation and questions to the pilots on the tasks of a pilot.

2.4.2 An outline of the schedule is provided in Table 3.

2.4.3 The flights were recorded by video to allow QinetiQ staff to review the flights for the task analysis. Observations of emergency procedures were carried out in simulators.

2.5 Flights – British Airways (Boeing).

2.5.1 The procedure for the flights was similar to British Midland. There was a difference in the flight availability therefore one daytime flight and one night-time flight was studied.

2.5.2 These consisted of one 8-hour return flight to Athens and one 3-hour return flight to Frankfurt. Again the emergency procedures were assessed on the flight simulators. In this case the flights were not video recorded due to security restrictions by the airline.

2.5.3 The task analysis was used to document the tasks carried out by a pilot during the normal flight.

Table 3 Data gathering schedule for Tuesday 5th March and Wednesday 6th March 2002

Time	Activity
05.00	Arrive at London Heathrow. Collect tickets. Check in.
05.45	Meet Dr Graham Cresswell at the departure lounge. Set up camera equipment on the aircraft. Start the task analysis.
06.30	Flight departure for Dublin.
07.45	Arrive in Dublin.
08.35	Flight departure for Heathrow.
09.55	Arrive at Heathrow.
10.45	Flight departure for Dublin.
12.05	Arrive in Dublin.
	Night stop in Dublin
06.30	Flight departure for Heathrow.
08.00	Arrive at Heathrow.
08.55	Flight departure for Dublin.
10.10	Arrive in Dublin.
10.55	Fight departure for Heathrow.
12.15	Arrive at Heathrow.

3 Analysis Methods

3.1 General

3.1.1 The data gathered were collated to provide a detailed picture of how exactly colour information is used by Class one flight crew from the start to the end of a flight. The data were used to generate a Hierarchical Task Analysis (HTA) representation. For this particular study the process produced a very large and complex diagram. Although this captures all of the information gathered during the data gathering stage it is impractical to include it all in this report. The approach we have taken therefore is to abstract the most important features from it. Some aspects are illustrated using small sections of the HTA within the report however.

3.1.2 The role of the pilot on the Airbus A321 and the Boeing 757 have been described in detail in this report. These include the tasks that are carried out on a normal flight and also some emergency procedures. These task analyses required a combination of different recognised techniques that are based on the hierarchical task analysis and flow charts and matrix.

3.1.3 The flight of an airliner from its start to its destination is a sequence of events. Consequently, considering the stages along the flight best represents the understanding of the use of colour. At the top-most level therefore the task is considered to be "fly the aircraft from A to B".

3.1.4 This was then divided up in to a number of top-level tasks, which were:

- Pre Flight.
- Taxi.
- Take Off.
- During Flight.
- Landing.
- Taxi.

3.1.5 All of these flight phases require tasks to be carried out by both pilots on the flight deck, either independently or together. Each of these tasks, together with which member of the flight crew is carrying it out, has been identified on the task analysis.

3.1.6 Normal flight was assessed using a combination of the task analysis and the matrix and the emergency procedures were assessed using a combination of the flow diagrams and the matrix.

3.1.7 The perceived importance of colour in any particular task was, after discussions with pilots, placed into three categories:

1) Low importance for safety;
2) Medium importance for safety;
3) High importance for safety.

3.1.8 The task analysis was used to classify the importance of colour using one of the three categories. Only tasks involving colours in importance category 2 or 3 are discussed within the remainder of the report since these were most critical.

3.1.9 These categories relate, in the pilot's perception, to the safety critical nature of the task. However, in almost all situations there were **additional** sources of information to aid the taking of a particular decision. Very few instances were found in which colour was the sole source of information and therefore likely to be safety critical in its own right. Because the task analysis was a very large undertaking, the scope was of necessity restricted to colour information.

4 Results - Airbus A321

4.1 Introduction

4.1.1 This section of the report details the areas inside the flight deck where colour is used and considered to be important. The sections have been divided up to discuss the controls as they appear in the flight manuals for the aircraft. This is cross-referenced with the task analysis to highlight where the particular controls and displays are used in flight.

4.1.2 The Airbus A321 presented a variety of different colours on the flight deck. The use of colour in the representation of graphical and textual information is intended to aid the pilot in distinguishing between different information; this includes technical aircraft or flight information, actions, warnings and emergencies. If written instructions appear, the pilot will follow the instructions on the screen and then react as necessary. It may be necessary for them to recognise that the button is lit but many of the buttons are backlit text so therefore the colour may be redundant as the requirement is to read the text. In addition to the visual warnings on the buttons and displays there are audible warnings to alert the pilot to various situations. It was commented by a number of pilots that they would recognise the audible warnings first before referring to the displays to assess the situation. If an emergency situation is identified the pilots will then follow the procedures that they have been trained to do which includes taking instructions from the displays and following procedure sheets.

4.1.3 Figure 3 shows a view of the A321 flight deck with annotation of some of the instruments in order to provide an orientation when reading the text. Some of these displays present information on different "pages", thus have a multifunction element to them. In the context of colour use therefore different "pages" may use different colour combinations.

4.1.4 In addition Appendix A provides a diagrammatic view of portions of the flight of the Airbus.

Figure 3 View of the Airbus flight deck showing some of the key instruments discussed in the report. See main text for a more detailed description.

4.1.5 Several of the displays are complex in that information is stored in "pages". Flight crew can chose which of these pages is displayed at any one time. Directly ahead of the captain is the Electronic Flight Instrument System (EFIS). The Primary Flight Display (PFD) shows information such as aircraft speed, attitude and heading and the status of the Flight Management System. The Navigation Display (ND) screens show aircraft positional and course data. In Figure 3 the EFIS, PFD display and Navigation display are labelled on the captain's side of the cockpit. The same instruments are duplicated on the first officer's (F/O) side.

4.1.6 The ECAM is the Electronic Centralised Aircraft Monitor and provides much of the information about the aircraft. Figure 4 shows an example page from the system.

Figure 4 An example page from the ECAM system

4.1.7 The central panel between the captain and the first officer contains the Multifunction Control Display Unit (MCDU). This is also duplicated on the F/O side. In addition this central panel contains audio control panels, radio control, and various engine and aircraft control panels.

4.1.8 The overhead panel on the captain's side, moving from back to front, consists of the Air Data and Inertial Reference (ADIRS) Control display panel, the Flight Controls, Emergency Evacuation System and Emergency Electrical Power Controls, Ground Proximity Warning (GPWS) and Cockpit Voice Recorder and the Oxygen panel.

Table 4 Summary of the importance classification of the major functional components. Numbers in brackets indicate a component may be a higher classification than the overall area.

Function	Classification
(a) Air-conditioning and Pressurisation Controls	2
(b) Cabin Altitude Indication	3
(c) Communication	2
(d) Fire Protection	3
(e) Fuel	2
(f) Hydraulics	2
(g) Landing Gear	3
(h) Oxygen	3
(i) Pressurisation	2
(j) APU	2
(k) Power Plant	2
(l) Navigation	2 (3)
(m) Auto Flight	2 (3)
(n) Flight Controls	2 (3)
(o) Indicating Recording Systems	2 (3)

4.1.9 The central overhead panel contains the hydraulic control and fuel panel, the electrical control panel, the air conditioning and pneumatic panel and the anti-ice control window heat and cabin pressure panel. The overhead panel on the first officer's side contains a radio management panel; flight controls and cargo heat controls; cargos smoke panel and a ventilation panel; engine start panel and wiper controls.

4.1.10 Table 4 presents a summary of the main chapters within the flight manuals and their overall importance classification. The components with an importance classification of 2 or 3 within these functions are discussed in turn in the following sections. The table provides a focus for further analysis of display characteristics. Appendix A contains diagrams of the flight deck with the relevant areas highlighted with the relevant letter labels, for those functions identified as importance classification 3. Within the table, some chapters have an overall rating of 2 but certain elements had a higher classification of 3. These are indicated in the table as 2 (3).

4.2 Description of Controls

a) Air-conditioning and Pressurisation Controls - Safety Classification 2

A number of buttons and switches used colour. Buttons will generally fall in to the CC1 coding category in terms of how the colour is used. Colour was also used for computer screen text and diagrams. This would also correspond to CC1. The relevant buttons and screen information was as follows:

- Buttons and Switches.
    - Ram Air pushbutton – white.
    - Pack pushbutton – white, amber.
    - Mode selector - white, amber.
    - Ditching guarded pushbutton – blue.
- Computer Screen Text and Diagrams.
    - RAM AIR inlet – green, amber.
    - Pack compressor outlet temperature – green, amber.
    - Pack flow control valve – green, amber.
    - Pack indication – green, amber.
    - Cabin vertical speed – green, amber.
    - Cabin differential pressure – green, amber.
    - Cabin vertical speed – green, amber.

Although the pilots consider these items to be important there are other factors, which can be taken in to consideration when assessing the information they convey. It is important to determine if pilots solely rely on the colour presented to them in order to recognise the information. In all of these cases, as in many others, there are other indicators to alert the pilot that the status of the aircraft may be changing therefore colour does not represent the sole cue.

All of the above controls and displays are associated with additional indicators, an audible single chime, the illuminated master caution light in front of the pilots and the bleed page is called up on the ECAM system.

In addition to the standard additional indicators of audible signals and warning lights other indicators specific to the situation may be present. For example, if there is a problem indicated by the diagram of the pack flow control valve, this is also indicated by the illuminated pack fault light. In the case of pushbuttons the lights are illuminated in a number of different colours, white, amber and blue.

White indicates that a system is operating, amber indicates a fault in a system and blue, in the case of the ditching guarded switch, is used to indicate that it is on. Although colour is used in these cases it is not thought to add to the safety critical aspect of the control or display because the information presented on the buttons is in the form of backlit text.

The text and diagrams on the computer displays are also displayed in a range of different colours including white, green and amber. In all of these cases the colour has become a redundant feature. The colour may help in the recognition time but not necessarily in the recognition of the information. For example the RAM AIR inlet indicates the status of the RAM AIR inlet valve. A circle indicates the status of the valve with a line going through the centre in either a horizontal or vertical orientation. The colour change from amber to green depends on the status of the valve, and therefore the orientation of the line will change.

b) Cabin Altitude Indication – green, red – Safety Classification 3

The cabin altitude indication is the only display in this section to have been given an importance classification of 3. It is represented on the ECAM screen in green numerical format. This colour changes to red if the cabin altitude goes above 9550 feet. The master warning light accompanies this and the presentation of the cabin

pressure page comes up. The location of the screen within the flight deck is shown in Appendix A.

Table 5 Portion of the control matrix (with colour importance column removed) showing the cabin altitude light and the information associated with it.

Name.	Function.	Normal colours.	Colour change.	What The Colour Indicates In The Control.	Type Of Control. Switch Indicator, Light.	Other Indicators
CAB ALT FT (cabin altitude)	Shows the cabin altitude.	Analogue and digital green.	To Red.	Red if cabin altitude goes above 9550 feet. Digital presentation pulse if cabin altitude above 8800 feet. Resets at 8600 feet.	C.S.T. Number.	Chime. Master Warning Light. Cabin Pressure Page Comes Up.

c) Communication – Safety classification 2

The only display that was considered to have an importance classification of 2 in this section was the **radio navigation selection key**. The key is illuminated green when selected to indicate that it has been selected. There are no other indicators to show the pilot that this has been selected although it is not necessary to see the colour of the light, simply that the light is lit. This function therefore uses an intensity cue rather than an explicit colour cue and is a colour code CC1.

d) Fire Protection – Safety classification 3

This section provides information to the pilot about fire and smoke. It is therefore an important section for aircraft safety.

The following buttons have been classified at level 3 in terms of the importance of colour: -

- Engine 1 and 2 pushbutton guarded - red
- Agent 1 and 2 pushbutton – white, amber
- APU fire pushbutton- red
- Agent pushbutton– white, amber
- Fire light- red
- Gen. 1 line smoke light– amber
- Blower and extract pushbutton– white, amber
- Smoke light- red
- Disch. light– white, amber

Figure 5 Photograph of the engine 1 fire indicator and agent 1 and 2 lights. This panel is in the overhead panel.

Figure 6 Photograph of the two engine fire indicators and APU fire button (overhead panel)

The fire protection chapter presents a number of controls and displays with a safety classification of three. The pushbuttons have backlit text and therefore correspond to a code type of CC1. The backlight is either off or red or off or amber depending on the situation of the corresponding display. However, as with many cockpit warnings, the displays and indicators are all accompanied by an audible warning in the form of a bell, the master warning light illuminated in front of the pilots and the ECAM warning page also comes up. The ECAM warning page lists the faults with the system and the actions that need to be taken.

The faults and warnings are written in red and actions are in blue on a black background. It is necessary for the pilot to be able to recognise all of the controls and displays and read the actions that need to be carried out. One particularly important control that needs to be recognised is the smoke light on the overhead panel. The light indicates the compartment that contains smoke. This is the only indication to the pilot that there is smoke, for example, in the cargo compartment.

e) Fuel – Safety classification 2

There are a number of controls and displays that have been given an importance classification of 2 in the fuel chapter of the flight manuals and during the flights:

- L (R) TK PUMPS 1 (2) pushbutton– white, amber.
- X FEED pushbutton – white, green.
- Wing pump indications– green, amber.
- X FEED indications– green, amber.
- Fuel quantity indicator– green, amber.
- Fuel on board FOB indication– green, amber.
- Total fuel indication– green, amber.

The format of the controls and displays follows that of the controls and displays already discussed, with the master warning light and the ECAM screen. None of the controls and displays in this section relies on colour as a primary indicator to alert the pilot.

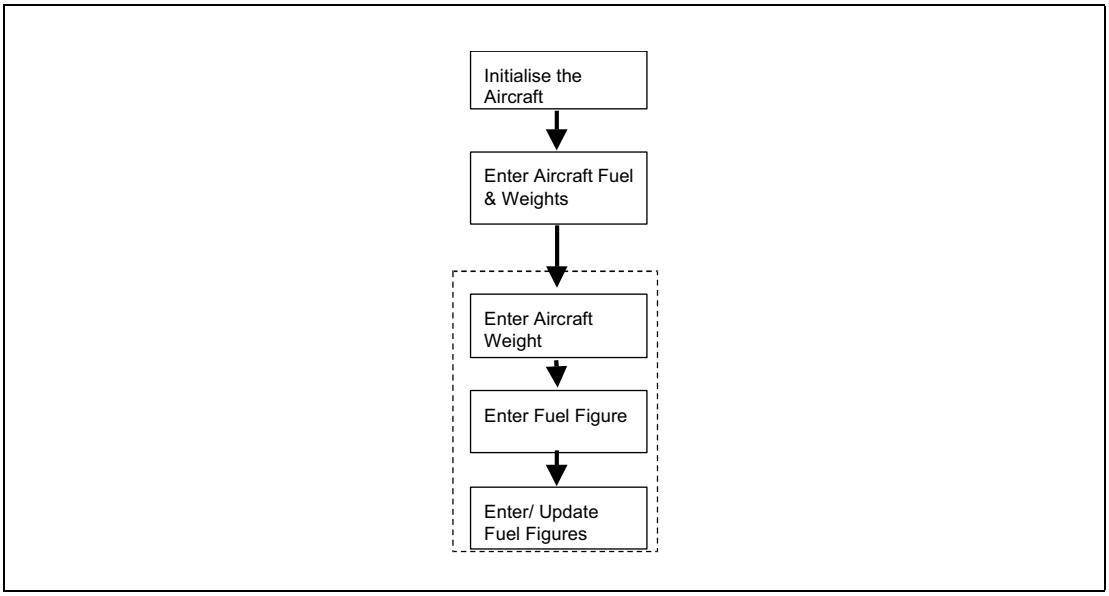

Figure 7 A section taken from the task analysis, showing where the pilot uses the fuel indications.

f) Hydraulics – Safety Classification 2.

The following buttons were identified as using colour within the hydraulics chapter of the flight manuals and during the flights:

- Eng. 1 (2) Pushbutton – white, amber.
- Blue elec. pump pushbutton– amber.
- PTU pushbutton– white, amber.

In addition the following indicators provide hydraulics information on the ECAM hydraulics page:

- Reservoir quantity indicator system label – green, amber.
- System pressure – green, amber.

- Pump indicators all follow the same format as before with other indicators – white, amber.

Reservoir LO AIR PRESS, Reservoir OVHT and OVHT messages appear on the ECAM screen and are amber if there is a problem in that system, although once activated to amber they follow the same other indicator format as before with audible warnings, master caution and warning lights.

Figure 8 Photograph of the ECAM hydraulic page.

g) Landing Gear – Safety Classification 3

There are a number of controls and displays classified as very important in this part of the flight manuals, although, once again as with all of the other systems described so far, none appear as a display or indicator in isolation.

They are the following:

- Landing gear position indicator – green, red.
- Landing gear door position indication – green, amber.
- Landing gear selector lever– red.
- Landing gear indicator panel – red.

All are important and highly safety critical but all have other indicators including audible warnings, caution and warning lights and a fault in that particular area would not occur in isolation to the pilot.

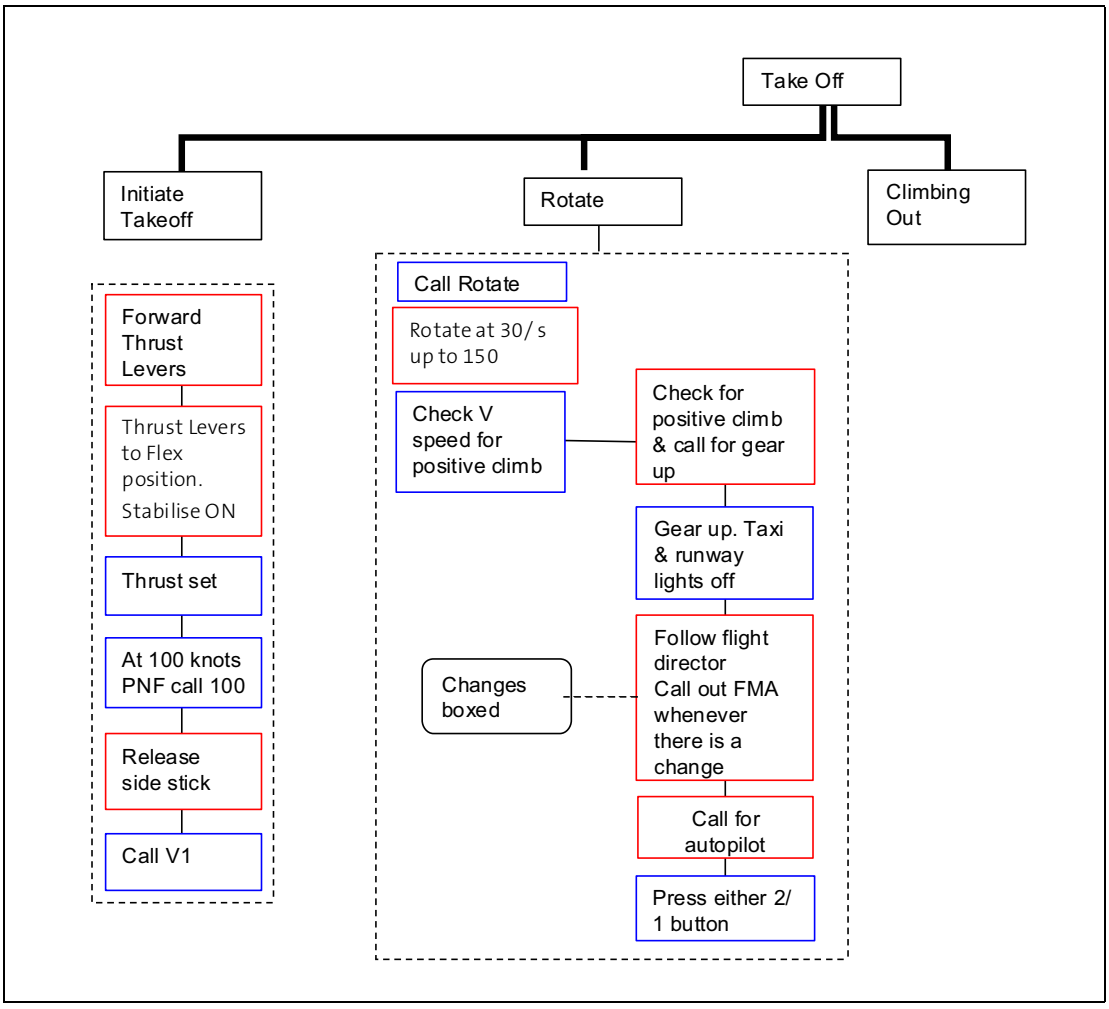

Figure 9 Part of the task analysis showing where the pilot uses landing gear indicators (boxes marked red).

h) Oxygen – Safety Classification 3

There are a number of controls and indicators in this chapter that have no other indications associated with them.

- OXY high pressure indication– green, amber.
- REGUL LO PR indication– amber.
- OXY indication– green, amber.

The OXY indication (text on ECAM door page) changes from green to amber (CC1 coding message) when low oxygen pressure is detected. This indicates to the pilot that the crew supply pushbutton is off.

Figure 10 APU Pushbutton (overhead panel), showing the blue backlit text.

i) Pressurisation - Safety Classification 2

The pushbutton (APU BLEED), illustrated in Figure 10 reads ON with blue back lit text on the button to indicate the valve is open, although when a fault is associated with the system the same additional indicators of audible warnings and warning lights are operated.

j) APU (auxiliary power unit) – Safety Classification 2

The APU chapter contains 2 controls and displays that have been given an importance classification of 2. These are displayed on the ECAM "DOOR" page. The door symbol changes from green to amber to indicate if the door is locked or unlocked. These both have the same indicators that accompany other controls and displays when there is a fault (master caution or warning light and audible signal).

- Door symbol– green, amber.
- Power plant fault light– amber.

The ECAM "DOOR" page is illustrated in figure 4-9.

k) Power Plant - Safety Classification 2

The following information is indicated by colour changes:

- LP Rotor speed (N1) – green, amber.
- HP Rotor speed (N2) – green, red.
- EGT indicator – green, amber, red.
- Oil pressure – green, red.
- Oil temperature – green, amber.

The control and displays in this chapter follow the same format as previous chapters with the addition that once the parameter limit has been reached it will change colour from green to amber; the introduction of this change also causes the number displayed to pulse. It is necessary to assess whether a person with a colour deficiency would notice the change of colour in the number if it were pulsing.

Figure 11 Photograph of the ECAM door and oxygen page

l) Navigation - Safety Classification 2

Other indicators to alert the pilot accompany all the controls and displays listed below.

- Navigation IR 1 (2) (3) Lt. – white, amber.
- ADR 1 (2) (3) Pushbutton – white, amber.
- TA Intruder –amber.
- PFD Indications Red Area.
- Green Area.
- Approach Procedures – white, amber, red.
- Procedures – blue.

However two items have a safety classification of 3:

- GPWS – G / S pushbutton – amber, red.
- RA intruder alert – red.

This pushbutton with backlit text was considered to be highly safety critical by the pilot questioned. The other indicator that accompanies this display and control is a voice alert. RA intruder alert, which is indicated by a red-square on the ECAM screen, was also considered highly safety critical. This however is accompanied by other information displayed on the ECAM screen in a text and a single audible chime. The master warning light that has occurred in many of the chapters as a warning would never appear in isolation to indicate that one problem has occurred but encourages the pilot to check the ECAM screen.

m)Auto Flight - Safety Classification 2

These displays all comprise of green or amber on a black background and are accompanied by other indicators (audible warnings, warning lights) as stated before.

- Effects of thrust lever movement A /THR – amber.
- Thrust lock function– amber.

- A / THR pushbutton– amber.
- Alpha floor FMA display – amber, green.

However, the following two items were classed as Importance Classification 3:

- Autoland warning light – red.
- Windshear detection function – red.

The red backlit text flashes for the autoland warning light and is the only indication to alert the pilot to a number of different situations, which may be occurring below 200 feet relative altitude (RA), with the AIRCRAFT IN LAND MODE. This was considered therefore to be a highly safety critical control that the pilot may need to rely on for information. When a problem is detected with the windshear detection function red windshear appears in red on the ECAM screen and is accompanied by aural windshear repeated 3 times. Table 6 provides an extract from the task analysis for Autoland Warning light.

n) Flight Controls - Safety Classification 2

Within this part of the flight manual the following indicator was given an importance classification of 2:

- PFD flight director bars – white.

Although the white colour of these bars does not change the pilots still need to be able to recognise them. It is not necessary that they are specifically able to recognise the actual colour as long as they can see the difference between the bars and other indications on the screen.

Table 6 Extract from the task analysis for Autoland Warning light

Name	Function	Normal colours	Colour change	What The Colour Indicates In The Control	Type Of Control-Switch/ Indicator/ light	Other Indicators
Autoland Warning Light	A number of situations, when occurring below 200 feet RA, with the Aircraft in LAND mode, trigger the warning light.	Black Background .	Flashing Autoland In Red.	A number of situations, when occurring below 200 feet RA, with the aircraft in LAND mode, trigger the warning light.	Light.	No other specific indications. Triple click only heard if you have a landing capability downgrade.

The following information was also classed as safety classification 2:

- Spoilers / speed brakes indication – amber, green.

This refers to a diagram on the ECAM page and represents the status of the spoilers. The diagram changes as well as the colour to indicate to the pilot the status of the spoilers. This is also accompanied by the usual other lights and audible warning indicators.

Three other colour changes were identified in this group:

- Aileron and elevator actuator indication - amber, green.

- Elevator positions indication – white, green, and amber.
- Slat and flap position indications – green amber.

Although the above controls and displays have been classified as importance 2, other warning indicators, master warning and caution lights and audible warnings also accompany them.

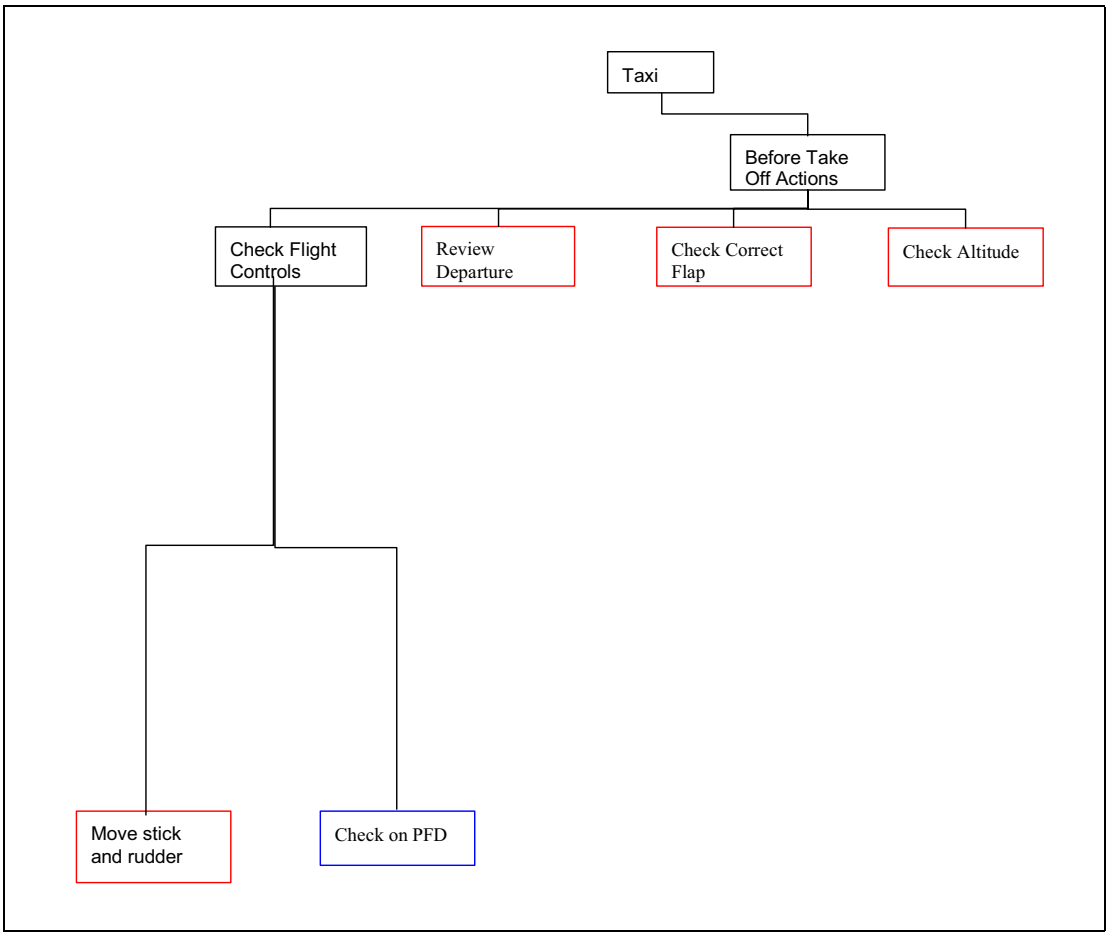

Figure 12 Part of the task analysis to indicate where the pilot uses the flight director bars (See Figures 13 and 24 for layout of the primary flight display).

Figure 13 Diagram of the Primary Flight Display. Red and black symbology provides information on low and high speeds.

Within the flight control area the Primary Flight Display (PFD) Speed Scale was given a safety classification of 3.

- PFD Speed Scale – black, red.

This black and red stripe symbol indicates the low speed stability of the aircraft and can be seen on the left of the PFD. When this gets dangerously low an audible warning is made and a synthetic voice message alerts the pilots to the possibility of a stall.

Figure 14 Photograph of the Primary Flight Display

o) Indicating Recording Systems - Safety Classification 2

There are a large number of colours related to these displays on the PFD, white, green, magenta, blue, amber, red, and yellow. In a few instances, there are other warnings or information to alert the pilot to the current situation including altitude alert, Check ATT, SPD LIM Flag, CHECK ALT Flag, LOC and G / S Flags, RA Flag, CHECK HDG Flag Localiser Deviation Bar, Glide Deviation, TERR: CHANGE MODE indication, Terrain Caution Alert, CHECK HDG Flag, LOC Flag and G / S Flag.

In all the remaining controls and displays it is necessary for the pilot to be able to read the text or diagram that is presented on the screen in the various different colours.

The following is a list of the relevant flags, alerts and other sources of information that involve colour:

- Flight Mode Enunciator – white, green, blue, magenta.
- Altitude Alert – yellow, amber.
- ATT Flag – red.
- Check ATT – yellow.
- SI Flag – red.
- FPV Flag – red.
- FD Flag – red.
- SPD LIM Flag – red.
- V1 INOP Flag – red.
- ALT Flag – red.
- CHECK ALT Flag – amber.
- ALT SEL Flag – red.
- LOC and G / S Flags – red.
- RA Flag – red.
- Check HDG Flag – amber.
- ILS 1 Flag – red.
- Localiser Deviation Bar – magenta.
- Glide Deviation – magenta.
- Lateral Deviation Bar – blue.
- Weather Radar Picture – black, green, yellow, red, magenta.
- TERR: CHANGE MODE indication – amber, red.
- Terrain Caution Alert – yellow.
- CHECK HDG Flag – red.
- LOC Flag – red.
- G / S Flag – red.
- VOR Flag – red.
- VOR Course Flag – blue, red.
- Barometer reference Display Window - white.

Figure 15 Photographs of the weather radar display

The majority of these colour displays are safety classification 2 but the following have been given a Safety Classification 3 although as with all the highly safety critical displays these have additional warnings, therefore the pilot does not rely solely on the colour of the display for information:

- Windshear Warning – red.
- PFD Warning and Caution messages – amber, red.
- Terrain Warning Alert – red.

5 Results - Boeing 757

5.1 Introduction

5.1.1 The main part of the 757 flight deck is illustrated in Figure 16. The controls and displays are more traditional. It was found during the task analysis that there are not so many controls and displays that have a safety classification of two or three as in the Airbus A321. This is because the majority of the information displayed on the computer screens is of one colour and does not change. Most of the switches and lights are all backlit text and there are very few instances where colour has not been made a redundant feature of the aircraft interface.

Figure 16 Photograph of the main controls in the Boeing 757 flight deck

5.1.2 The categorisation of the different systems is exactly the same as that used to analyse the Airbus.

a) Air Conditioning and Pressurisation - Safety Classification 2

Colour critical indicator:

- Cabin Altitude Light – red.

The cabin altitude light in this section is not considered a highly safety critical control or display, but if it is not actioned does become a highly safety critical control. As well as the cabin altitude light being illuminated, the same light is also repeated in front of the pilots, an EICAS (Engine Indicating and Crew Alert System) message appears on the screen and the master warning light also appears in front of the pilot.

b) Automatic Flight - Safety Classification 2

A number of switches use colour in the automatic flight functions as follows:

- EPOR Switch – white.
- Flight Level Change Switch – white.
- Heading Hold Switch – white.
- Altitude Hold Switch – white.
- Vertical Speed Switch – white.
- Vertical Navigation Switch – white.
- Lateral Navigation Switch – white.
- Approach Switch – white.
- Barometric Select Switch – white.
- Localiser Switch – white.

The list of controls and displays above are all part of the automatic flight chapter. These all function in the same way in terms of the use of colour. If not selected there is no colour associated with them however if they are selected the pushbutton associated with the control will light up with a white bar. The relevant information for each control will also be repeated in textual format on the ECAM screens.

Figure 17 Photograph of the glareshield showing the above controls and displays (see Figure 16)

- Autoland Status Enunciator – amber.

The autoland status annunciator indicates to the pilot if all three of the autopilot systems with their input are operating normal. The combinations of colours used in this display are green, white and amber backlit text. There are no other indicators to identify the status of this. It is therefore important that the pilot can see this although again not necessarily the colour, just the text.

Two amber lights with backlit text were given a safety classification of 3.

- Autopilot Light – amber.
- Auto throttle Disconnect Light – amber.

Also within this is the disengage switch. Although this switch is not colour coded, the result of pressing this switch, which disengages the autopilot, needs to be apparent to the pilot. Other indicators are associated with the activation of this switch and include the audible warning of a wailer, red warning light, autopilot disconnect light and an EICAS warning message in red. It was commented by the pilot that the attention to the situation would firstly be from the audible signal, before reading the messages on the computer screens.

Table 7 Part of the matrix showing the autopilot (A/P) disengage switch and the information associated with it

Name	Function	Normal colours	Colour change	What The Colour Indicates In The Control	Type Of Control. Switch Indicator, Light	Other Indicators
Autopilot disengage switch.	Disengages all the autopilots	No Colour	Black Button. No colour change	When pressed it disengages all A/Ps. A/P disconnect and master warning lights illuminate, EICAS message displayed and aural warnings sounds on disengagement. Second push extinguishes A/P disconnects light and silences aural warning.	Pushbutton	Wailer. Red Warning Light. A/P Disc Light. EICAS Warning – Red.

c) Electrical. - Safety Classification 2

The controls and displays listed below, although having no other specific indicators other than the backlit text on the pushbuttons, would not appear as a problem in isolation; - other faults would also be indicated to the pilot.

- AC BUS TIE Switch– amber.
- AC BUS Off Light – amber.
- APU Generator Off Light – amber.
- Generator Control Switch – amber.

The two controls below all have a message associated with them as well as a caution light and an audible beep.

- Generator Drive Light – amber.
- Standby Power BUS Off Light – amber.

d) Emergency Equipment - Safety Classification 2

All controls and displays in the emergency equipment chapter have an EICAS message associated with them. The switch below lights up with amber backlit text:

- Emergency Lights unarmed light – amber.

Within this group there is a single light with an importance classification of 3:

- Evacuation Light – red.

The whole button on the evacuation light lights up red as well as an audible sound of a horn.

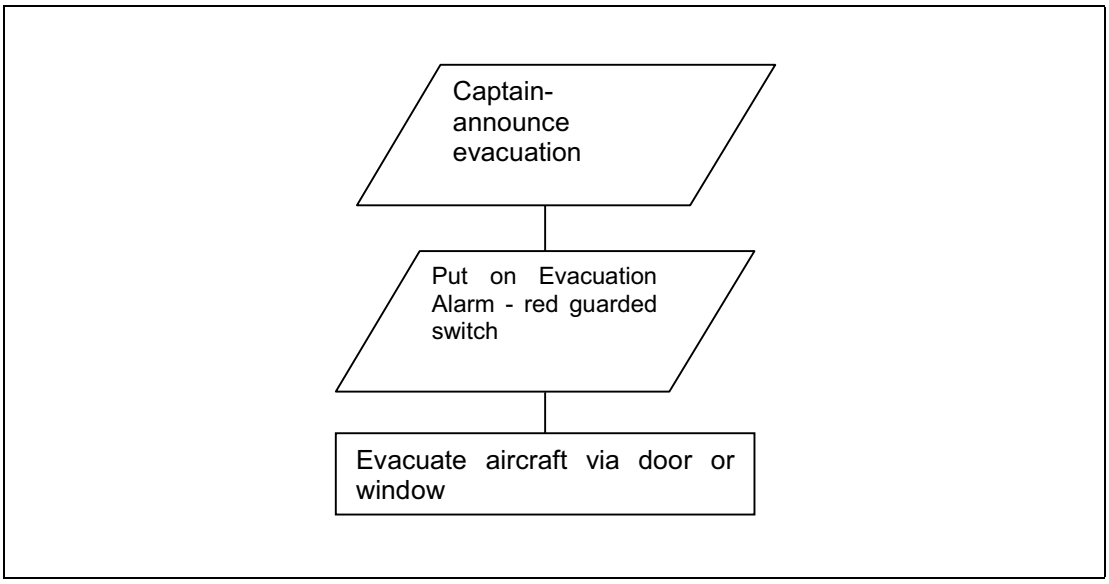

Figure 18 Part of the emergency evacuation flow diagram

e) Fire Protection - Safety Classification 2

The following indicator has a safety classification of 2:

- Engine Overheat Light – amber.

This is an amber backlit text and an EICAS message.

Within this area there are a number of indicators that were rated as being safety classification 3:

- Engine fire Warning Light – red.
- APU Fire Warning Light – red.
- Cargo Compartment Armed Switch – red.
- Fuel Control Switch Fire Light – red.
- Discreet Fire Warning Light – red.
- Wheel Well Fire Light – red.

All of the above are also associated with an EICAS message and an audible bell.

The two flow diagrams in Figure 19 illustrate where some of the controls and displays appear in the full flow diagrams of the emergency procedures.

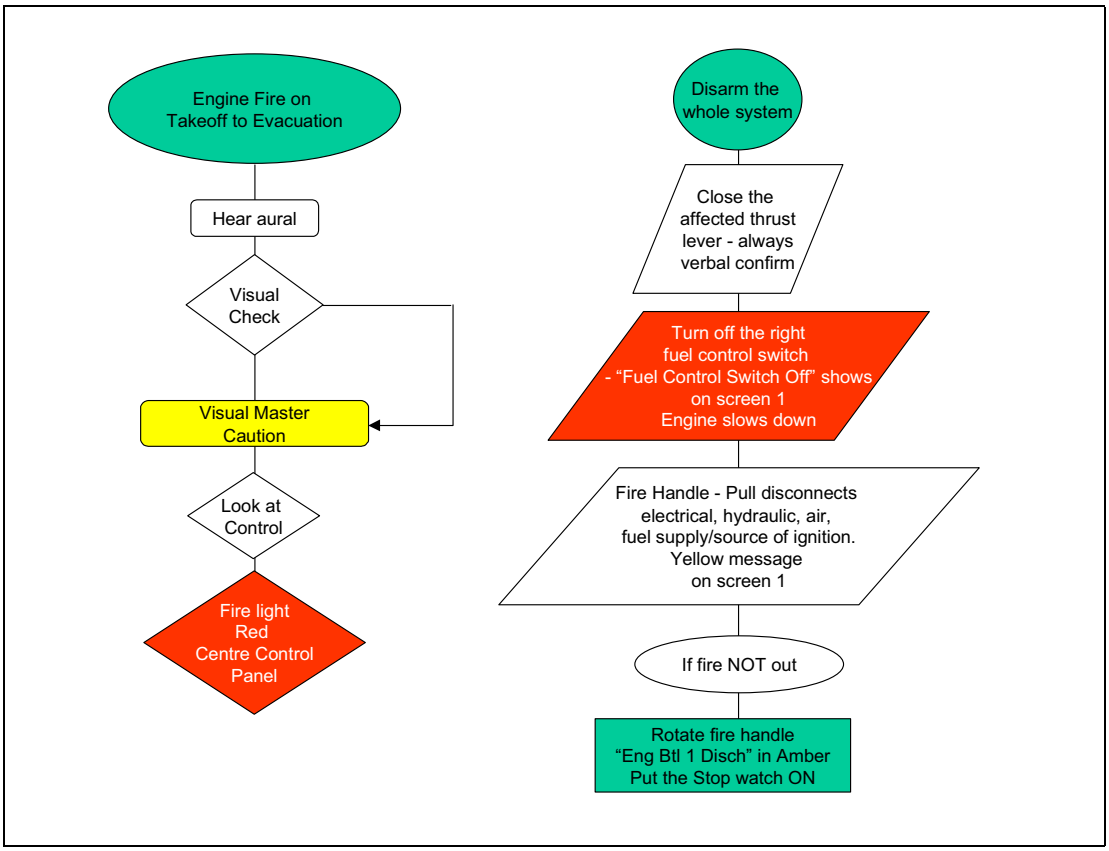

Figure 19 Some of the controls and displays that appear in the full flow diagrams of the emergency procedures

f) Hydraulic Power - Safety Classification 2

- Engine Pump Switch – white, amber.
- Engine Pump Overheat Light – amber.
- Electric Pump Switch – white, amber.
- Electric Pump Overheat Light – amber.
- Reserve Brakes Switch – white, amber.

All of the above are associated with a yellow message.

g) Power Plant - Safety Classification 2

- Secondary Engine Indications – blue.
- Red Line Limit – red.

All of the above are diagrams and indications in the EICAS displays.

h) Warning Systems - Safety Classification 2

- Master Warning Switch – red.
- Master Caution Switch – amber.
- Warning Messages – red.
- Caution Messages – amber.
- Pull Up Light – red.

- Windshear – red.
- Ground Proximity Light – amber.

All of the controls and displays are part of various different warning systems. However within this category one control is safety classification 3.

- TCAS – green, red.

i) Summary

As can be seen from the above examples, linked in with the task analysis and the flow diagrams of the emergency procedures, it is possible to assess where some of the more safety critical aspects of the flight are. Although the emergency procedures are considered in these areas the procedures that the pilots carry out are in a very systematic approach.

6 Exterior Displays

6.1 General

Lights are used extensively in the environment external to the cockpit. These are invariably colour coded. These have been divided into three categories – Precision Approach Path Indicator (PAPI) lights, Runway lighting and Parking lights.

a) PAPI Lights

These lights change from white to red or red to white to indicate to the pilot the angle of descent on the flight path. The optimum angle of descent will be represented by two white and two red PAPI lights. However, should the angle of approach deviate from this the pilot will need to recognise the difference in colour on the lights and the different colour combinations, for example two reds and two whites or if the angle of approach is not optimum this may change to three reds and one white.

Figure 20 PAPI lights on the runway viewed from the cockpit (within red box)

b) Runway Lighting

The runway lighting can be a number of different colours for various different indicators, this includes green and blue lights. Different aspects marked by lights include taxiways, edge of the runway, the runway centre line and end of runway markings. It is not necessarily essential for the pilot to be able to see the colour of the lights, just that the lights are present or the ability to see the lights change may be enough.

Figure 21 Photograph of the runway lighting as seen from the cockpit during landing

c) Parking Lights

The parking lights are an important display to the pilot when it comes to parking the aircraft at the stand. The parking indicator uses green and red lights to indicate to the pilot that they are on the right line for parking the aircraft at the stand. The colour of the lights changes to indicate the correct path and although not essential to see the colour of the lights the pilot needs to be able to recognise a difference in the lights.

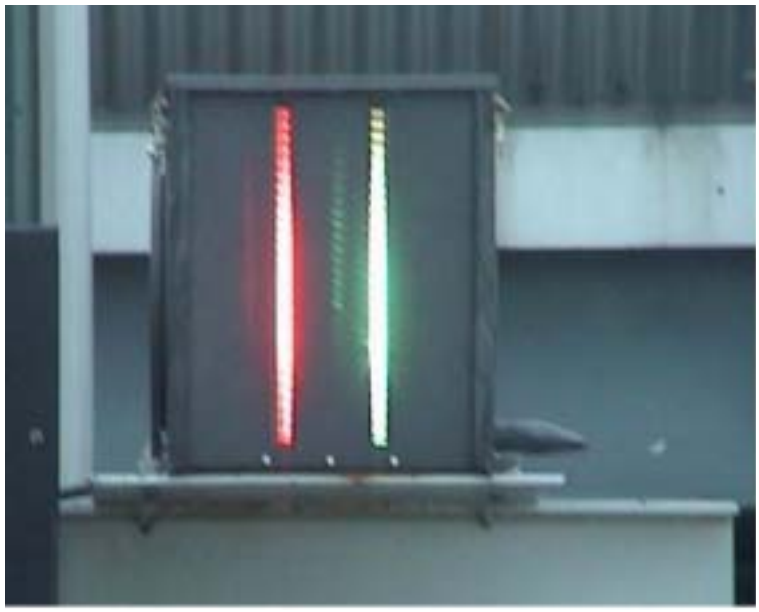

Figure 22 Photograph of the parking lights

7 Conclusions and Recommendations

The analysis identified a number of areas where colour is critical to the operations of the flight crew. These were more common on the Airbus than the Boeing.

It was concluded that the most colour critical elements in the pilots' environment were the PAPI light lights and the parking lights.

The conclusions for the aircraft instrumentation were as follows:

Airbus A321

The following table summarises the safety classifications of the major functional components in the Airbus flightdeck.

Function	Classification
(a) Air-conditioning and Pressurisation Controls	2
(b) Cabin Altitude Indication	3
(c) Communication	2
(d) Fire Protection	3
(e) Fuel	2
(f) Hydraulics	2
(g) Landing Gear	3
(h) Oxygen	3
(i) Pressurisation	2
(j) APU	2
(k) Power Plant	2
(l) Navigation	2 (3)
(m) Auto Flight	2
(n) Flight Controls	2
(o) Indicating Recording Systems	2 (3)

Boeing 757

The following table summarises the safety classifications of the major functional components in the Boeing flight deck.

Function	Classification
(a) Air-conditioning and Pressurisation Controls	2
(b) Automatic Flight	2
(c) Electrical	2
(d) Emergency Equipment	2
(e) Fire Protection	2
(f) Hydraulics	2
(g) Power Plant	2
(h) Warning Systems	2

The recommendation is that an assessment be made of the colorimetric characteristics of all the controls, displays and lights identified as colour safety critical (i.e. category 3) and that these measurements be related to the colour discrimination capabilities of different types of colour defectives.

8 References

1 Menu J. P., Ivan D., Daumann F-J., Diamantopoulos I., Firth J. L., Heikens M-F., LeBail B., Leger A., Walraven J., Alferdinck J., Yates J. T., Operational Colour Vision in the Modern Aviation Environment, NATO Report RTO-TR-016, (2001)

2 Kaiser, P., Boynton, R. M., Human Color Vision. Optical Society of America (1996)

3 Cole B.L., The handicap of abnormal colour vision. Aust J Optom 55:304-310, (1972)

4 JAR Class 1 Initial Examination Visual Standards, CAA

5 Merrian Webseter Online Dictionary. http://www.merriam-webster.com/cgibin/dictionary

6 Fletcher R., Voke J., Defective Colour Vision: fundamentals, diagnosis and Management, Adam Hilger, (1985)

7 ERGO/GERO Human Factors Science www.ergogero.com/FAQ

8 Cole B. L., Vingrys A.J., A survey and evaluation of lantern tests of color vision Amer J Optom & Physiol Optics 59:346-374. (1982)

9 Cole B.L., Vingrys A. J., Who fails lantern tests? Doc Ophthalmol 55:157-173, (1983).

10 British Midland Airbus Technical Manuals

11 British Airways 757 Technical Manual ATP 2352

12 British Airways 757 Flying Manual 2325

Appendix A Instrument Locations, Airbus

This appendix provides diagrams to help with the location of some of the instruments described in the main text.

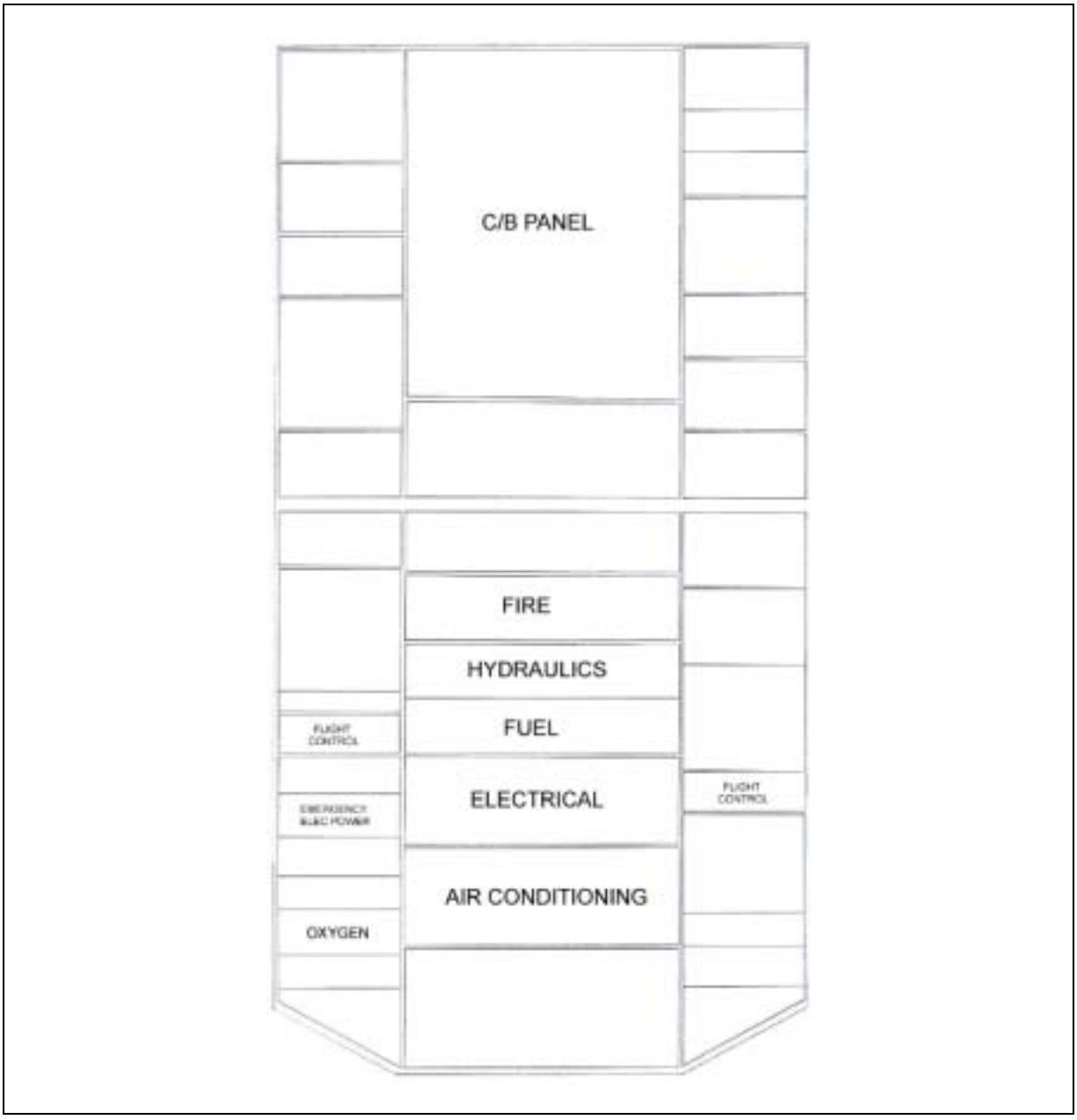

Figure 23 Diagram of the flight deck overhead panel showing the main functions of the different areas

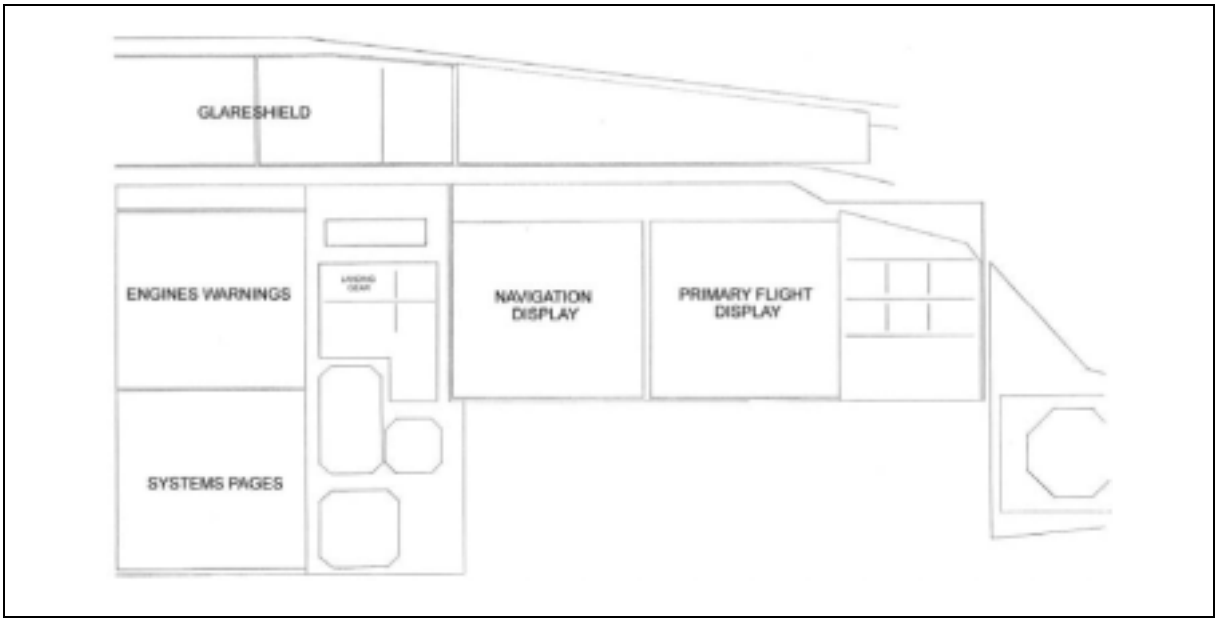

Figure 24 Diagram of forward view of flight deck, right seat showing the main functions of the different instrument groups

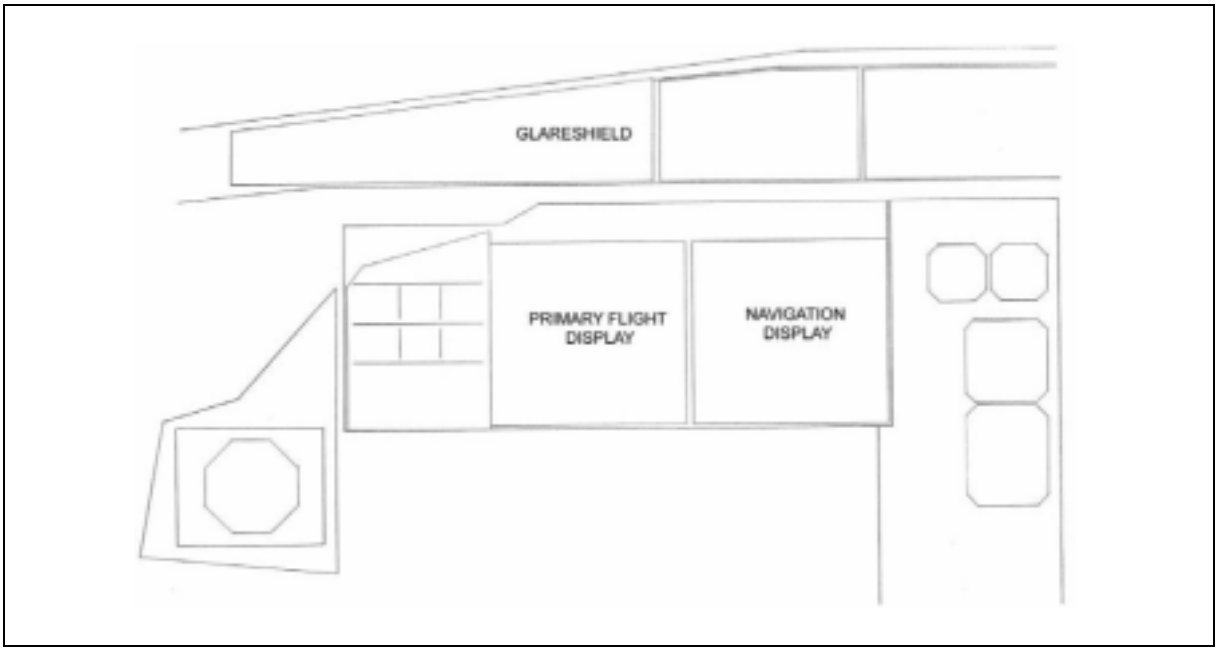

Figure 25 Diagram of forward view of flight deck, left seat showing the main functions of the different instrument groups