EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

This document is issued as an EATMP Guideline. The contents are not mandatory. They provide information and explanation or may indicate best practice.

Font Requirements for Next Generation Air Traffic Management Systems

HRS/HSP-006-REP-01

Edition	:	1.0
Edition Date	:	31.08.2000
Status	:	Released Issue
Class	:	EATMP

EUROPEAN AIR TRAFFIC MANAGEMENT PROGRAMME

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title		
Font Requirements for Next Generation Air Traffic Management Systems		
WORK PACKAGE REFERENCE NUMBER: HRS/HSP-006		
DELIVERABLE REFERENCE NUMBER	**EDITION:**	1.0
HRS/HSP-006-REP-01	**EDITION DATE:**	31.08.2000

Abstract

This document reports work carried out as part of the CORE Requirements for Air Traffic Management (ATM) Working Positions Project, conducted by the EUROCONTROL Experimental Centre (EEC) on behalf of the EUROCONTROL Human Factors and Manpower Unit* (DIS/HUM) within the EATMP** Human Resources Domain (HUM).

It addresses the issues involved in selecting and evaluating screen fonts suitable for use with the technologies to be employed in the emerging generation of ATM working positions. It provides reviews of display technologies, text processing in Air Traffic Control (ATC) applications and typography before presenting recommendations and guidelines for typography in ATC.

* Formerly known as the ‘ATM Human Resources Unit’
** European Air Traffic Management Programme

Keywords

Human Factors	Air Traffic Control (ATC)	Display Technology	Font Selection
Typography	Text Processing	Reading	Visual Search
Human-Machine Interface (HMI)	Graphical Interaction	Controller Working Position (CWP)	Design

CONTACT PERSON: A. JACKSON	**TEL:** +33-1-6988.7544	**UNIT:** EEC / ATM R&D CoE

AUTHOR: Stefana BROADBENT for CARA, BROADBENT & JEGHER

DOCUMENT STATUS AND TYPE

STATUS		CLASSIFICATION	
Working Draft	☐	General Public	☐
Draft	☐	EATMP	☑
Proposed Issue	☐	Restricted	☐
Released Issue	☑		

ELECTRONIC BACKUP

INTERNAL REFERENCE NAME: G\Own_use\Delvrabl\Released\HFs\Fonts_main.doc		
HOST SYSTEM	**MEDIA**	**SOFTWARE**
Microsoft Windows	Type:	**MicroSoft Office 97 (MS97)**
	Media Identification:	

DOCUMENT APPROVAL

The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
Manager CORE Project ATM Research and Development Centre of Expertise (ATM R&D CoE)	A. JACKSON	28.08.2000
Manager Human Factors Sub-Programme (HSP) Human Factors and Manpower Unit (DIS/HUM)	V.S.M. WOLDRING	28.08.2000
Manager Human Resources Programme (HRS) Human Factors and Manpower Unit (DIS/HUM)	M. BARBARINO	30.08.2000
Chairman Human Resources Team (HRT)	A. SKONIEZKI	31.08.2000
Senior Director Principal EATMP Directorate (SDE)	W. PHILIPP	31.08.2000

DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.1	30.05.1999	Draft	All
0.2	03.03.2000	Proposed Issue	All
1.0	31.08.2000	Released Issue	All (document configuration)

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This document reports work carried out under contract by CARA, BROADBENT AND JEGHER as part of the CORE Requirements for Air Traffic Management (ATM) Working Positions Project. This Human Resources Domain (HUM) activity is conducted within Work Package 6 of the Human Factors Sub-Programme (HSP) – part of the larger EATMP Human Resources Programme (HRS) - by the EUROCONTROL Experimental Centre (EEC) on behalf of the EUROCONTROL Human Factors and Manpower Unit[1] (DIS/HUM).

The report addresses the issues involved in selecting and evaluating screen fonts suitable for use with the technologies to be employed in the emerging generation of ATM working positions.

Chapter 1 provides the context of the study, introduces the role of text and text processing in ATM, and explains the structure of the document.

SECTION A provides a review of the technical environment.

Chapter 2 describes the different display technologies applicable to ATM, mainly based on Cathode Ray Tube (CTR) and liquid crystal technologies.

Chapter 3 explains the application of typographical technology to computer displays and introduces the concepts of hinting and anti-aliasing to improve font presentation.

SECTION B reviews the nature of text processing in ATM.

Chapter 4 provides a classification of text applications in ATM, in labels, menus, etc., and identifies important characteristics of text processing in these contexts.

Chapter 5 explores the differences in visual processing between searching and reading activities.

SECTION C reviews typography and introduces and explains the terminology employed in that specialist area.

Chapter 6 explains legibility and describes the associated variables. It discusses the important differences between emissive displays and text as presented on paper.

The report is completed by Recommendations for typography in ATC and by Conclusions.

Chapter 7 provides guidelines for the application of typography within ATM applications.

Chapter 8 concludes by identifying the need for a richer definition of legibility for ATC, making a distinction between **analytical legibility** (reflecting the normal definition of legibility based on reading) and **global legibility** in which familiar text is recognised holistically in a way comparable to iconic recognition.

[1] Formerly known as the 'ATM Human Resources Unit'

The Annexes include a short explanation of techniques for enhancing type fonts through anti-aliasing, an extensive Bibliography, a Glossary of typographical terms, which will be useful for reading this document but also for understanding some of the literature on fonts and readability we have referenced in the Bibliography, a list of the Abbreviations and Acronyms used in this document and a list of the Contributors to this document.

A Technical Annex ‘An Experimental Methodology for Selecting Fonts for Next Generation Air Traffic Management Systems’ (EATMP, 2000) describes a detailed methodology for the selection and evaluation of fonts based on the material in the current report.

1. INTRODUCTION

The CORE Requirements for ATM Working Positions Project is managed at the EUROCONTROL Experimental Centre (EEC) as part of the Human Factors Sub-Programme (HSP) of the EATMP Human Resources Programme (HRS). The main objectives of this project are concerned with supporting the development of ATM in ECAC[2] States through providing methods and material to assist the requirements capture, design, specification, development and evaluation of Controller Working Positions (CWPs) for European ATM.

In the domain of Human-Machine Interaction (HMI) the homogeneity of solutions and methods can greatly reduce the time of development and integration of new tools and can ensure that common human factors concepts are developed for all of Europe. In order to provide guidance on recurring problems, CORE wants to establish a reliable, stable and up-to-date set of reference studies on various aspects of the CWP.

In 1997, following an initial synthesis of HMI material for en-route working positions (Jackson & Pichancourt, 1995), a workshop was held at the EEC to identify issues and recurrent problems in the area.

One of the issues identified was that of **font selection** for the new generation of raster scan displays. In particular, the substitution of the current generation of stroke written displays which provide a high-definition cursive character set, opens up a number of questions regarding the best font candidates for the new generation of ATC equipment.

As a result a study contract was launched to:

- study the requirements for fonts for the next generation of ATM systems;

- establish a methodology for the identification and evaluation of suitable fonts against such requirements.

The contract was awarded to CARA, BROADBENT AND JEGHER Associates at the end of 1998 and resulted in the two following major deliverables:

- the current EATMP report, ‘Font Requirements for Next Generation Air Traffic Management Systems’, which reviews and explains the issues and requirements for fonts in ATM working positions;

- a technical annex, ‘An Experimental Methodology for Selecting Fonts for Next Generation Air Traffic Management Systems’ (EATMP, 2000), which describes a detailed procedure for the selection and evaluation of fonts for ATM applications.

---

[2] European Civil Aviation Conference

1.1 The Role of Text in Visual Displays for Air Traffic Control

The nature of air traffic controller activities puts very complex and stringent requirements on the selection of visual display elements for the screen. The lack of redundancy of the information available, the quantity of information displayed, the essentially visual nature of the information available, all contribute in making the visual interface extremely critical. This is even the more so in the future ATM system in which verbal communication between controllers and between controller and pilot will diminish as the relay of information is automated through the datalink system. This will imply that controller activities will be more and more oriented towards the monitoring of incoming information. Although the controller brings an enormous amount of experience, knowledge and inferring capacity to the task, the quality of information transmission has a direct impact on safety and performance.

Furthermore, given the range of information that can now be displayed on the radar (reduced versions of the strip information, menus, and control bars, etc.), there will be a significant increase in the quantity of **textual** information that will be displayed compared with the older generation of radar and screens. In future ATC windows-based interfaces, text will be used to designate at least the following:

- the function of buttons and controls,
- the functions or values in menus,
- the call sign and extended label information on the radar screens,
- aircraft data on tabular lists or electronic strips.

1.2 Requirements for Font Selection in Air Traffic Control

Introducing text as a fundamental source of information raises the issue of typography and font selection. All screen fonts used in ATC must meet high standards of legibility and readability, as alphanumerics that are not legible can lead to visual fatigue, errors and delays in the processing of information. However, as we will analyse further, **legibility is not an absolute characteristic of a font** but is dependent on the type of activities that are carried out by the observer, the existence of other elements within the visual display, the nature of the text and of the background support. Fonts, in other words, have to be selected for a specific context of use.

There are three essential contextual features to take into account the:

- type of text,
- background support,
- type of text processing that is involved in the activity.

Each factor introduces its own constraints and requirements. Furthermore, the interaction between these factors determines the unique characteristics of the ATC context which must be taken into account when selecting the appropriate set of screen fonts.

1.3 Structure of the Document

To address the various factors that affect the selection of screen fonts, we have divided the document in the following three main sections:

A. Technical Environment.
B. Text Processing.
C. Typography.

In the first section we will review the characteristics of the display technology - Cathode Ray Tube (CRT), Trinitron and Liquid Crystal Display (LCD) - and the available techniques for font design and improvement. This provides us with the technological constraints against which all choices must be made.

In the second section we will analyse the characteristics of the text that is being displayed on ATC screens and the type of text processing that this entails for controllers. We will also dedicate a chapter on the psycho-physiological explanations of the type of mental activities that controllers' are carrying out on the textual displays.

In the third section we will review the existing literature on the effects of different font features on reading. The review will be presented both for paper fonts and for screen fonts as there exists a vast literature on both.

The report is completed by recommendations for font requirements, by conclusions that provide an alternative definition of legibility for text processing in ATC, by a short annex on techniques for enhancing type fonts though anti-aliasing, and finally by a bibliography and a glossary of typographical terms.

Page intentionally left blank

SECTION A: THE TECHNICAL ENVIRONMENT

In this section we analyse the characteristics of the display technology for the new generation of ATM systems. We will review the constraints that such displays introduce for display of text. The available technology for font design and improvement will also be discussed to examine what are the possibilities offered to administrations who would want to enhance available types or fonts provided by the manufacturers of the screens.

Page intentionally left blank

2. THE CHARACTERISTICS OF NEW VISUAL DISPLAYS IN AIR TRAFFIC CONTROL

The new generation of visual displays in ATC will be raster-scan, Cathode Ray Tubes (CRTs). Although the use of colour capable displays has been tested frequently at the EEC and considered in Europe for the last twenty years, most air traffic controllers are still using monochromatic displays. EEC has been using 20" by 20" SONY Trinitron monitors, shadow mask, CRT, with 2048 addressable pixels in both horizontal and vertical dimensions.

We will briefly analyse the technical characteristics of this type of displays and examine their implications for font display.

2.1 Cathode Ray Tube Displays

All Cathode Ray Tube (CRT) displays used in television, computer and video monitors function basically in the same way: electron beams emitted by the CRT are directed towards a phosphor coated screen, thus exciting phosphor dots and displaying an image. Colour displays utilise three different electron guns, one for each Red, Green and Blue (RGB) signal. These emit electron beams from slightly different positions, thus the beams arrive on the phosphor screen at slightly different angles. A shadow mask or aperture grill is positioned a fraction of an inch (typically ½ inch) behind the phosphor screen to direct the beams onto the proper phosphor dots.

The phosphor dots have one of two arrangements: either in triangular formations called triads where each dot is at a corner of the triangle, or as vertical slots where the three colour phosphors are next to one another. The former configuration is most common in monitors, while the latter is common in televisions.

Three different approaches can be used to ensure that only the proper electron beam strikes each colour phosphor. All perform the same function:

- Dot mask - the phosphor screen is configured as RGB triads, the electron guns are also arranged in a triangular configuration, the shadow mask positioned just before the phosphor screen is a steel or InVar sheet filled with holes, one for each triad.

- Slot mask - the phosphor screen is configured as a succession of red green and blue vertical stripes (usually full vertical stripes interrupted by narrow gaps). The electron guns are also in line, which makes their adjustment simpler compared to the dot mask CRT. The shadow mask is a steel or InVar sheet filled with slots - one for each triple. To maintain the structural stability of the slot mask sheet, the vertical distance between each slot is kept as small as possible.

- Aperture grille - the phosphor screen is configured as triples of vertical RGB stripes, running the full height of the screen. The aperture grille is a series of tensioned steel wires running vertically behind the phosphor stripes - one for each triple. The electron guns are also in line. This CRT configuration, until recently available only in the Trinitron from Sony, is found both in television screens and monitors.

The clarity and resolution of a monitor depends on many factors such as the resolution of the video source, the sharpness of the electron beams, and the dot/slot/line pitch of the CRT. The focus or sharpness of the spot or spots that scan across the screen depends on the design of the electron guns in the CRT and the values of the various voltages that drive them. It is generally not possible to achieve an evenly distributed sharp focus over the whole screen: there are inherent limitations such as the fact that the negatively charged electrons repel each other and provide an inherent defocusing action. In any case, there is a clear limit beyond which increasing the sharpness of the focus of the electron guns would cease to be of any benefit: the spacing of the phosphor elements is the ultimate resolution of a colour CRT.

The pitch of a colour CRT refers to this spacing of phosphor triads or triples. For dot mask CRTs, this parameter is relevant in both the horizontal and vertical direction. For slot mask and aperture grille CRTs, the pitch is only relevant in the horizontal direction. Dot pitches typically range from 0.22 mm to 0.28 mm.

2.2 Cathode Ray Tube Resolution

Apart from dot pitch the true resolution capabilities of a CRT are also limited by the spot size, which depends directly on the dot or slot mask or aperture grill. For practically all CRTs the spot size is significantly larger than the dot pitch - up to twice the size or so at the corners. This does not necessarily cause a problem with the image quality, however, since the screen is not really resolving individual ‘pixels’ - what has to be resolved are the differences between adjacent pixels or pixel/line pairs. Oddly enough, it does not take a dot pitch of equal or greater size than a logical pixel to do this to most people's satisfaction.

If a CRT can actually illuminate less than a full phosphor triad its luminance resolution can exceed the dot pitch. There will be some colour fringing, but it may not be noticeable. In fact, human vision does not generally have the same spatial acuity for colour, we do not really see small details based on differences in colour alone, there has to be a difference in brightness. The human eye will be able to see such variations acceptably even when the size of the logical pixel is somewhat under the dot pitch size. When this occurs the observer will not perceive constant colour pixels - it is not possible even to get constant luminance pixels - but acceptable levels of detail to call the image 'sharp'.

2.3 Trinitron Technology

Trinitron is a CRT technology developed by Sony. The patent has recently expired and, therefore, other manufacturers are free to offer similar CRTs. The CRT uses a set of fine vertical wires called an aperture grill instead of a steel shadow mask to separate the R, G, and B electron beams and force them to strike only the appropriate coloured phosphors. This ‘aperture grill’ is made of around a thousand vertical wires under tension a fraction of an inch behind the glass faceplate with its phosphor stripes. The electron guns are consequently arranged in an in-line configuration.

This grill arrangement is supposed to provide a brighter image with simpler convergence and purity adjustments. The higher brightness is because there is more open space in the aperture grill than in a shadow mask. In addition, since there is no imposed structure in the vertical direction, undesirable moiré patterns caused by scan line pitch compared with the shadow mask dot pitch are eliminated. It is possible to recognise a Trinitron tube by the fact that the picture is made up of fine vertical stripes of red, green, and blue rather than dots or slots.

Since the aperture grill wires run the full height of the tube, stabilising wires are required to minimise vibration and distortion of the grill. These may be seen by looking closely one third and two third of the way down the screen. Without these the display would be very sensitive to any shock or vibration, which would result in visible shimmering or rippling. All Trinitron monitors thus use one, two or three stabilising wires (generally two, except for small monitors and screens larger than 21 inches which may use three wires) across the screen. These can be seen as very fine darker lines on bright images: these are the shadows cast by the wires.

Another noticeable characteristic of Trinitrons is the nearly cylindrical shape of the screen. Vertically, the screen is almost flat; there is a slight curvature but significantly less than horizontally. This is a feature born out of a requirement: the aperture grill wires are under tension and thus cannot follow the curve of the glass as in a normal shadow mask. Therefore, the glass must be flat or nearly flat in the vertical direction.

2.4 Flat Panel Technology

Flat Panel technology is evolving rapidly and there are a number of technologies that are starting to reach a maturity that puts them in direct competition with Liquid Crystal Displays (LCDs), until the present by far the most widespread flat panel technology. Gas plasma displays field emission displays and numerous advanced variations of traditional LCDs are some of these. For the present, however, LCDs are indisputably the leading technology, one that is improving all the time and has clear advantages over CRTs: they occupy a great deal less space and are much lighter, and they consume much less power and have no geometry problem.

Unfortunately, there are still serious flaws and problems yet to be resolved. The range of colours and grey scales that they can display is limited compared to CRTs; brightness is not as good as with CRT displays (CRTs are inherently a light emitting technology while LCDs have to rely on backlighting). Contrast has not yet reached the levels attainable on CRTs. The viewing angle at which LCDs can be viewed without colour inversion or worse is still quite limited. These limitations are being addressed, and the improvements to the technology are proceeding at a remarkable rate, yet CRTs are not likely to be displaced for the foreseeable future.

A final alternative technology to CRTs worth considering stems from a novel development in integrated micro-machining - the Texas Instruments Inc. Digital Micromirror Device (DMD). This is basically an integrated circuit with a tiltable micromirror for each pixel fabricated on top of a RAM cell. Projection displays using this technology could be built at nearly any size and would therefore be applicable to high-resolution computer monitors as well as High-Definition Television (HDTV). Since a reflective medium is used in this device, the light source can be as bright as needed. Commercial products based on the DMD are beginning to appear.

3. TYPOGRAPHICAL TECHNOLOGY FOR THE COMPUTER SCREEN

As we have seen in the previous paragraphs, most computer displays typically contain dot-matrix characters and lines, which give the appearance of stair casing or jagged edges. This is caused by the under-sampling the signal needed to produce continuous characters. The individual characters are formed by square dots (pixels). The human eye has limited ability to discern grey levels and spatial resolution. Such limitations have long been the subject of multidisciplinary studies by physicists, physiologists and psychologists.

It has been experimentally determined that the minimum discernible difference in grey level, called contrast sensitivity, is about 2% of full. Hence, a grey scale image needs only have about fifty levels of grey to meet the needs of apparent continuous grey scale representation. However, if a small section of that image were to be cut out and brightly illuminated, we might again see edges between the pixels because the definition of full scale for the new image has been changed by the fact of removing a portion of the image.

In bright illumination the adult and visually unimpaired human can resolve approximately sixty lines per degree of visual arc. By visual arc we mean the angle subtended by the area being viewed at the apparent focal point of the eye. Thus, if more than sixty lines are crowded side-by-side (with white space between them of the same width as the lines themselves) into a single subtended degree of viewed space, they will appear to merge into a single grey mass to the human viewer.

Another way of saying this is that the human eye can individually discern 120 pixels per subtended degree of visual arc. This spatial resolution limit of human visual acuity derives from the fact that the colour sensing **cone cells** that are concentrated at the centre of the retina are packed approximately 120 across a distance of 290 micrometers of the retina. But one degree of a scene is played across 290 micrometers of the retina by the eye's lens, hence the pixel-like sampling of the image that takes place in the eye.

As a consequence, at conventional resolutions of computer displays (72-75 pixels to the inch), fonts are generally less legible online than on a printed page. High-resolution screens simply decrease the size of the pixel, which visually shrinks the image to fit more pixels into a small space, rather than increases the resolution of the image itself. This is why some subtleties of font design such as thick or thin lines are lost in font sizes smaller than 12 points. Hence a series of adjustments must be made to ensure a good level of legibility: fonts are bigger than on paper, italic and serif fonts are avoided. These are often hard to read especially at low resolutions. Jagged edges cause eyestrain; smoothness and clarity are easier on the eye and permit faster recognition.

For instance, Times is an excellent typeface for printing newspapers, but it is difficult for reading on-screen. Its original version was designed to squeeze as many letters as possible on a printed page and still remain legible. Therefore, its print version has a medium x height while being fairly narrow, with sharp and small serifs. Its small ascenders and descenders make it very economical, because they reduce the need for leading, enabling the typesetter to set more lines per page. The major problem with the bitmapped version of Times (the one that appears on the screen) is that it does not translate those subtleties. A pixel is a pixel - the smallest possible unit - there is no such thing as half a pixel and even anti-aliasing does not help at copy sizes. So a formerly tiny serif is now as big as a stem and adds a lot of unnecessary visual noise, especially within 'small' and narrow fonts like Times.

3.1 What makes a typeface appropriate for the screen?

Although most standard typefaces have been adapted for use in computer desktop publishing systems, these faces are still primarily designed for relatively high-resolution (300 dots per inch or more) use on paper. Typefaces used on the screen should always be judged solely by their appearance on the computer screen, and not by the aesthetics of a particular font as printed on paper. The low resolution of screen displays often severely compromises the legibility of condensed, light, extended or Decorative typefaces.

In general, typefaces designed for maximum legibility in low-resolution displays have relatively large x heights and simple character shapes, and the characters at each of the smaller font sizes (9, 10, 12 points) are optimised for legibility on the screen by providing bitmap files.

Proportionally spaced typefaces such as the standard Macintosh screen face Geneva or New York (Apple computer 1993), MS Sans Serif or MS Serif (Microsoft 1993) or Adobe's Stone and Lucida PostScript typeface families (Adobe 1993b) were specifically designed the be legible in a wide variety of low-resolution media.

What most of the new optimised typefaces have in common is that they have a more open face, wider letters, increased x height and a wider letter spacing. They fit nicely into the square pixel grid without looking distorted and do not have the letter-spacing problems that standard screen fonts have. In fact, it is now understood that in order to keep characters distinct, tightly set characters must be avoided because the limited number of pixels available at low resolutions can squash characters together turning an ‘r n’ into an ‘m’ or creating distracting black patches in a word.

Other features that are carefully designed are the relationship between straight and curved strokes to avoid the confusion between similar characters that can easily be confused such as the lowercase ‘i j l’, the uppercase ‘I J L’ and the numeral ‘1’.

3.2 Techniques to design or improve fonts for the screen

Although the selection of fonts is considerable, as there are at least 10.000 existing bitmapped fonts, for many specific uses it is necessary to improve the quality of the display of a font on the screen. There are in fact techniques to improve the resolution of screen fonts either automatically or by hand.

With the relatively coarse resolution of computer screens individual pixels become quite apparent. Horizontal and vertical pixel lines or lines at 45 degrees fit the grid of the computer screen perfectly and cause no problem. However, lines drawn at any other angle have to be approximated because they conflict with the natural grid and look stepped. Any edge that is does not fall on the natural grid produces steps. By introducing pixels of a colour somewhere between the foreground and background colours, the edges of the lines are effectively smoothed. To smooth the edge of a simple black on white character on the screen, a program like Photoshop will create sixteen to twenty intermediate tones of grey to fill in the steps and, from normal viewing distances, the type will look smooth. Clearly, this assumes that the display can handle these colour gradations; on an eight-bit display with only 256 colours, all these subtleties of tone are going to get lost.

As the type gets smaller, the conflict with the natural pixel grid becomes increasingly more severe. The main horizontal and vertical strokes of a typeface should, ideally, align perfectly with the pixel grid. When they do not, there are two possible solutions:

- Move the strokes so that they align with the grid - at the expense of the proportion of the characters. This is called hinting.
- Simulate the true position of the strokes using tonal illusion to smooth edges. To get the impression of a line that should strictly be between two pixels, one can use lighter tones of the colour in adjacent rows of pixels. This technique is called anti-aliaising.

3.2.1 Hinting

Hinting is a technique that allows detailed specification of how a font will be transformed from an outline into a bitmap. Most fonts are created by designing the outline of each character, irrespective of the point size and the resolution of the target output device that the font will be used in. In the specific case of a screen being the target output device, this entails transforming the outline into a low-resolution bitmap. Getting a satisfactory result is especially difficult at smaller point sizes in which the number of pixels to work with is very limited. Hinting is so called because it instructs the rasterizer (that transforms outlines into bitmaps) in handling effectively this transformation.

The rasterizer uses the instructions embedded within the font file to adapt the outline of the characters to the bitmap grid defined by the target point size. Thus, the hinting instructions are used to adjust the outline of each character for every desired point size.

The rasterizer needs the additional hinting instructions outlined above for a fairly simple reason: the character outline will rarely coincide exactly with the pixel grid, thus the edges of the outlines will most likely not coincide with the pixel edges. In that case the crucial decision must be taken of whether to switch on or off a partially covered pixel. This is especially true in the case of monochrome text, where the decision is a binary one; it is a great deal simpler in the case of greyscale rasterizers where the pixel can be shaded proportionally to the amount the outline overlaps the pixel. The problem with unhinted outline fonts with monochrome text, is that the binary choice between switching a pixel on or off will depend on rounding either up or down the co-ordinates (within pixel grid) of the outline edge. The resulting solution is much too simple to ensure good quality in the rendition of the font, especially at small point sizes.

The font features that are most affected by the rasterising process are: serif details, stem weights and crossbar widths. Irregularities with these features at small point sizes can reduce the legibility of the individual characters. Clearly, this leads to greatly reduced legibility of the font as a whole.

Hinting an outline font provides a solution to the problems inherent with the rasterisation process: poor performance at low resolutions, where selecting the right pixels to turn on is as much an art as a science. The great advantage of hinting is that it overcomes these problems while maintaining the resolution independence of outline fonts with which one font file can be used to display fonts on screen, print on high-resolution printers and all of this, at any point size.

3.2.2 Anti-aliasing

Aliasing is a term used to describe the undesirable effects produced when visual information is presented at a lower than optimal resolution. Most current computer display screens offer resolutions of 72 pixels per inch, or about 5,184 pixels per square inch of screen. Line artwork and typography in magazines printed on coated paper typically have resolutions of at least 1,440,000 dots per square inch (1200 dpi), or about 278 times the resolution of a typical computer screen. Using the technique of graphic anti-aliasing the apparent resolution of type and graphics may be increased on the computer screen. Reading tests have consistently shown that low-resolution text on the computer screen is less legible than high-resolution text on the printed page (Wright, 1983). When reading anti-aliased text readers' scores could be brought up to almost 98% of scores from paper documents (Brand 1987 & Schmandt, 1987).

Type sizes of fourteen pixels up can usually be anti-aliased quite successfully. At around twelve pixels high, the success of anti-aliasing depends on the weight and design of the typeface.

Times set at 16 points not anti-aliased

Aliasing is a term used to describe the undesirable effects produced when visual information is presented at a lower than optimal resolution.

Anti-aliased Times at 16 points

Aliasing is a term used to describe the undesirable effects produced when visual information is presented at a lower than optimal resolution.

3.2.3 Automatic anti-aliasing

The anti-aliasing of text on screen is functionality often provided by the text engine whether embedded in the Operating System (OS) Windows 95, Mac OS 8.5, etc., or as an extension to the OS (such as Adobe Type Manager). There are several ways in which anti-aliasing can be implemented. Probably, the most common and straightforward is to take a bitmap larger than the one needed and then sub-sampling (i.e. dithering) it down to the target size, thus yielding glyphs made up of shades of grey, including black and white.

In the case of outline fonts this means generating internally a bitmap which is generally either two or four times larger than the target point size. Clearly, given the nature of outline fonts, any size bitmap can be generated and the choice of sub-sampling factor will depend on desired result (generally, dithering down a larger pixel grid will produce a greater range of shades of grey). In the case of bitmap fonts, where the range of point sizes is limited, a bitmap double the size of the target is generally used. For example, to produce an anti-aliased version of Times Roman 12 point, Times Roman 24 point is used.

3.2.4 Anti-aliasing by hand

The techniques outlined above for anti-aliasing text are effective notwithstanding the simple algorithm involved. However, as was the case with hinting, better results can be achieved by applying some 'art' to the science of typography: anti-aliasing by hand can be surprisingly effective. An odd result of anti-aliasing done properly is that the resulting text can look blacker than plain text, even though only grey has been added, and in some rare cases black pixels have been lightened to grey.

Anti-aliasing by hand by designing fonts at specific point sizes using a grey scale palette is a painstaking technique that yields the ultimate level of control over the final appearance of the characters and in the hands of the right font designer would give the best possible results.

It is not necessarily, though, the only way to anti-alias text 'by hand'. This can alternatively mean designing bitmap fonts that have been explicitly tailored to provide good results when anti-aliased by a text engine. In the case of the algorithm outlined above (dither-copying or sub-sampling), this means designing bitmap fonts at double the size of the target point size, such that the algorithm will produce the desired results.

A detailed presentation of three basic techniques for anti-aliasing and constructing double-sized bitmaps to yield the desired result is provided as an Annex.

3.3 Solutions for Liquid Crystal Display Screens

Recently an innovative approach to anti-aliasing that applies exclusively to Liquid Crystal Display (LCD) panels has emerged based on a fundamental characteristic of LCDs that differentiates them from CRTs: each pixel of an LCD screen is actually composed of three sub-pixels: one Red, one Green, and one Blue (RGB). The sub-pixels are interleaved in sequence (RGBRGBRGB) thus effectively yielding rows of sub-pixels that are three times as dense as the nominal pixel resolution. In other words, 100 pixels on a LCD are actually made up of 100 red, 100 blue and 100 green sub-pixels; i.e. 300 sub-pixels. If one could address the sub-pixels individually one would triple the horizontal resolution of any LCD screen. Unfortunately, though, the individual colour sub-pixels are not addressable individually; anti-aliasing using colour can virtually achieve the same results.

If colour patches are spaced close enough, the human vision system is incapable of distinguishing the individual colours and perceives instead an intermediate hue. This is particularly true with primary colours.

Since the ordering of the sub-pixels in an LCD is known (there are only two possibilities: RGB or BGR) and in any case each sub-pixel is adjacent to another primary colour, we can exploit the basic nature of human eyes above, into perceiving smooth edges by borrowing sub-pixels from adjacent whole pixels by slightly changing the colour of 'whole' pixels and thus switching on or off the sub-pixels. In other words, we can obtain access to the individual sub-pixels by carefully controlling the colour of pixels on the edges; typeface features can be displayed with three times more horizontal accuracy, our eyes co-operating by seeing only black and white.

Sub-pixel anti-aliasing is in essence a superset of standard anti-aliasing, the latter being basically grey scale anti-aliasing, while the former is full colour anti-aliasing. A severe limitation of this technique is that it is not applicable to CRTs. Even the best CRTs (even Trinitrons) will not resolve the sub-pixel positional information contained within sub-pixel anti-aliasing.

3.4 Conclusions

To enhance the legibility of fonts on the screen it is crucial to select fonts that have been explicitly designed with the screen in mind. Furthermore, if the screen is going to be the sole output device and the selection of point sizes used on screen is going to be limited, there is no need for fonts to be able to support a variety of resolutions. In this case it is advisable to use bitmap fonts directly, as opposed to outline fonts that have been hinted. This ensures that the fonts have been designed with the limitations of the pixel grid in mind. The fonts should be designed for each point size at which they will be used, so as to maximise the legibility of each character.

As far as anti-aliasing is concerned, it is highly recommended to use it for the display of point sizes above 12 points. A good anti-aliasing engine will increase the apparent sharpness and legibility of the characters. For smaller point sizes an unaided anti-aliasing engine will produce results that are probably fuzzy and less clear than the simple unaltered bitmap. This problem can be circumvented by aiding the anti-aliasing algorithm by specifying by hand the anti-aliasing to be performed. Clearly, a further option is to avoid the use of any automatic anti-aliasing and simply use fonts that are not monochrome but include the aliasing in the font bitmap itself. Thus, control on the final aspect of the font is completely in the hands of the font designer, the only proviso being that this can presumably only be achieved if the colour of the background that the font will be set against is known beforehand and fixed.

In summary, the simplest solution is probably the best for the task at hand: select or design fixed point bitmap fonts for a high degree of screen legibility and that can be effectively anti-aliased on screen.

Page intentionally left blank

SECTION B: TEXT PROCESSING

The first question we will try to address in this section is what are the characteristics of the text and text processing in various phases of ATC activity:

- the type of text that is being displayed,
- the type of activities that the text is supporting.

This should allow us to identify the numerous constraints and requirements that this very specific environment imposes on the criteria of legibility that a set of fonts for the ATC environment must satisfy. Having identified the characteristics of ATC text and the text processing done by the controllers, it will be easier to examine what typographical features are most appropriate for the ATC environment.

Text processing is essentially a mental process in the sense that the controllers translate the codes and text represented on the screen into an internal mental representation that they must process at various levels. To describe how controllers do text processing we will have to refer to these internal mental processes. The sections on reading and visual search will attempt to provide some understanding on how the mental processes that we invoke in ATC have been described in the literature on cognitive psychology.

<u>Note</u>: *For convenience please note that in this section and those following the masculine gender (he, him, his) has systematically been used to refer to professional categories (as opposed to individuals) such as air traffic controllers, pilots, students, learners and instructors, even though these categories obviously also include females and should be considered as such by the readers.*

Page intentionally left blank

4. TEXT PROCESSING IN AIR TRAFFIC CONTROL

4.1 Characteristics of the text on Air Traffic Control Displays

If we look at the text on the type of screens that are emerging in the new generation of Controller Work Positions (CWPs), there are mainly four categories of texts:

- alphanumeric codes as present on the call signs and labels,
- the menus,
- tabular lists,
- labels on buttons.

Most of the text is therefore single word, numerals or alphanumeric codes. When there are more units, the combination of units is by juxtaposition of alphanumeric elements. There are absolutely no paragraphs in which a discourse structure is couched. There are no sentences in the sense of traditional continuous text although there are clear syntactic rules governing the combination of units. There can be multiple references to the same aircraft on different sections of the screen and there are multiple descriptors for each aircraft: namely the flight plan information presented in tabular format, or the extended versions of the radar label on the radar screen. This information presents a syntax in the sense that there is a precise accepted order of elements and any permutation can modify the meaning.

By taking the various text elements one by one we can analyse how each type of text is being processed by the controllers.

4.2 Call Signs and Labels

Call signs are displayed as alphanumeric codes on the radar screen. They are composed of up to nine alphanumerics and have a well-defined morphology, as they are composed systematically of the company code and flight number. The flight label, which includes the call sign, can be in various states standard, selected or extended for instance. For each state the amount of information regarding the flight plan displayed is different (ranging from two lines to four if all the details are provided such as the requested flight level, exit flight level, etc.) Call signs and labels are the object of constant monitoring. They are read and re-read many times in the course of the monitoring activity.

4.2.1 Searching for a call sign never seen before

In the process of assuming a flight there are instances in which the air traffic controller is searching for a call sign he has not seen before; e.g. following a call from a pilot entering his sector. In this case the controller has an auditory trace of the call sign and some knowledge of the position which the aircraft is coming from and thus can restrict his search on the screen.

Very often the controller must mentally create a new entry for the new call sign (what in cognitive psychology is called a lexical entry), as he has not encountered the code before (or at least not in the current conditions). A new call sign or code will then be semantically enriched by associating a number of other information elements with it (about its route, its current flight level, aircraft type, etc.). The code, therefore, will become both a recognisable configuration and a rich representation.

There are obviously many cases in which a call sign is already known (the BA going every day from London to Johannesburg) and, therefore, the controllers will have prior knowledge of that flight and will already possess a partial entry for the code.

4.2.2 Searching for a call sign already seen

After a controller has assumed a flight he may not need to consider it for some time. At a certain point he may either want to verify the position of the aircraft or carry out some operation on the menus. This implies scanning the display to identify the new position of the call sign.

In this instance the controller knows what he is looking for, has a mental representation of the call sign and is looking at the display to identify a configuration that matches his mental representation. In this type of search the controller is probably looking for a global configuration resembling his mental representation and is not looking at the single letters. He may look at single letters or numbers when there are possible ambiguities between similar call signs.

4.2.3 Recognising a call sign already seen

In many cases the air traffic controller will be monitoring the screen and regularly check or encounter a call sign he has already seen and to which he has already attended. While not actively searching for this item, the controller recognizes the call sign when he sees it which means that recognizing the configuration triggers a set of associated information about that code (its route, destination, aircraft type, etc.).

As before, the controller is recognizing the call sign on the basis of a global configuration and only looks at individual letters and numerals if there are similar configurations. This type of search is probably based on minimum discriminable differences.

4.3 Menus

Most menu items are in fixed positions on the screen, but in the case of radar labels the menus follow the movement of the aircraft, although they are retrievable always from the same position within the label. Examples of label menus are the flight level menus or the waypoint menus, which are accessed from the label.

The content of the menus is either a list of numerals (as in the case of flight level menus), a list of codes (as in the case of waypoint menu) or a list of single words. The critical issue in reading menu text is discriminating between items in the list.

4.3.1 Searching and recognising a known menu item

In many cases the controller will be opening a menu and scrolling within it to search a numeral or a word before selecting it.

In this instance the controller knows what he is looking for, has a mental representation of the text or code and is looking at the display to identify a configuration that matches his mental representation. The items within a menu are generally well known, the user has seen them many times before. Furthermore, the label on the menu provides a first categorization of the items and therefore restricts the number of expected words or codes. As he opens a menu, the controller already makes a hypothesis of what the items in the menu list will be because he knows what are the set of potential items that are contained in the menu he has selected.

Because of the fixed vertical structure of menus, the navigation within a menu can be directed both by semantic and motor processes. In fact, the recognition and reading of a text item in the menu can orient the search process. For instance, in a menu containing flight levels the controller uses his knowledge of the sequence of flight levels and of the sequential structure of the menu to calibrate his movement when he perceives the numerals 230 and he is trying to reach flight level 310. The processing of text in this context, therefore, is not just pattern matching between a target numeral and the numerals that scroll by, the text becomes a sort of waypoint for the controller's trajectory in the menu, guiding the direction of his movement.

4.3.2 Discriminating between items in a menu

The items in a menu often belong to a same category or family (e.g. a list of possible flight levels), a list of waypoints, or of numerals indicating headings or speed. The discrimination between items of the same category or between numerals that are on a continuum can be very difficult. There are many studies showing that similar categories are more difficult to discriminate than similar words of totally different categories.

4.4 Labels

Labels (not to be confused with the radar label of the aircraft) or titles on buttons are mostly single words. They are usually composed only of letters and the words are common lexical items and not acronyms or codes.

These are practically the only units of text that always maintain the same position within a given window (although the consistency of similar controls between different windows is not always assured). Therefore, air traffic controllers should in principle know where the items are thus reducing the search time.

The type of reading that these items imply is:

- searching for a known item,
- recognizing an item.

Once the controller has identified the region of the screen where he expects to encounter the button or command, he must then discriminate between the available text items in that region to recognise the target item. He then must keep the item in focus until he has reached the label with the pointing device and has selected it.

Evidently, the more the text items are discriminable from each other, the faster is the recognition. Categorical grouping of items even by colour may help this process.

4.5 Lists

Tabular lists can contain multiple items and are organised according to a fixed order. In the case of electronic strips, for instance, a line on the list contains a set of codes, abbreviations, numerals, words, that all normally pertain to the same aircraft. It provides an organised set of information on the aircraft.

There are other tools in which a list may contain relational information regarding two or more aircraft.

4.5.1 First reading

At a first reading the air traffic controllers may read the whole line from left to right, progressively obtaining more information about the aircraft and flight plan. Most of the codes and abbreviations will be rapidly recognized as they are well known and predictable. For instance, the flight plan will indicate the desired route by displaying a set of waypoints. The waypoint codes are obviously extremely familiar and the controller will recognise them very rapidly as a global visual configuration. The same process will also be applied to the aircraft type, which will trigger a set of associated data on the aircraft performance stored in long-term memory. Similarly, entry and exit levels will also be associated to a known configuration of the traffic.

Controllers may however read sections only of the line concentrating on destination and flight levels, ignoring other sections or leaving them for further scrutiny. Skimming the line implies focusing only on sections of it. They are helped in this process by the familiarity with the organisation of the text in which items always are displayed in the same order and position (e.g. the call sign on the left followed by the expected time over the entry waypoint, etc.) Although it is envisaged that controllers may in the future reconfigure lists to their needs and liking, we can make the hypothesis that they will always create a stable environment where the order of the items is known and can be predicted.

This type of acquisition of information corresponds more closely to the type of reading process described for continuous text. Controllers have a series of words and codes in sequence, which enrich the description of the aircraft. They deal with the sequential nature of the presentation by trying to interpret each successive word or code as soon as they encounter it, integrating the new information they have obtained with what they already know about the aircraft.

4.5.2 Searching and further reading of a list

The lines on the list change position as new flights are added to the list and older items disappear from the list. It will often be the case that the controllers will want to go back to an item on the list to check an information to which they did not previously attend or they may want to check whether the system has taken some input modification into account. This means, firstly, identifying the correct line by skimming the list until the desired element is found.

4.6 Conclusions

There are two features of the text displayed on ATC screens that have major implications on how it is processed by air traffic controllers:

- text is dynamic and therefore needs to be found before being read;

- text is short and over-learnt and, therefore, is treated as an icon and recognised rather than read.

Finally, a third property is that some of the text is interactive and the locus of a control action.

4.6.1 Text is dynamic

One of the most significant and unique features of the text used in ATC is that the text can be dynamic; it changes position all the time. Some text processing is therefore done a first time triggered by a novel presentation. Some text processing consists in the processing of elements that have changed position but have been seen before. Most text processing is preceded by an active prior search of the unit.

The mobility of the text implies that there are at least four types of text processing activities that are carried out by the controllers:

- processing text for the first time,
- recognizing text that has been previously processed,
- searching and identifying text previously processed,
- searching and identifying text that has never been processed.

Each of these activities corresponds to a different perceptual and cognitive process in which the activation of memory structures are considerably different and in which the perceptual processes are different. To put it simply:

- the first time a text or code is read the reader must match the processed pattern with a lexical entry stored in long-term memory;

- when the controller searches for an item he must on the contrary identify the visual configuration in front of him as the element he is currently mentally representing;

- when the controller has already seen a word or code and **encounters** it again (perhaps in another position) the process will correspond to recognition and will be faster than when the unit is read for the first time.

4.6.2 Text as icons

Reading is not the only processing activity that text items support. Text responds also to a storage function: the information is available outside and can be easily recovered. In this case, the basic process is pattern recognition - recognition of letters and words. The text, in this case, functions as an icon and prompts particular responses. The Coca-Cola logo, for instance, is a form of text that is not read, in the sense of reading a continuous text, but rather processed as a unique pictorial or iconic entity.

This view goes against the traditional distinction between:

- iconographic, which is also referred to as pictorial, the figurative or the eidetic as, for example, when a picture of a horse stands for a horse;

- arbitrary, the non-pictorial or abstract, which is generally defined as purely conventional, since there is no systematic link between sign and sound until we reach true writing systems using word signs (logograms), where the shorthand disappears in favour of an exact transcription of a linguistic statement; for example, three cows are represented by two word signs, one for three, one for cow (that is, linguistically), rather that by three similar signs (whether pictorial or abstract) for cow (that is, non-linguistically, representing sight rather than sound). Designing Visual Interfaces (Mullet & Sano, 1995).

Most of the textual items on the controllers' screens have this iconic property. The menus and the labels for instance are over-learnt and identified as a cluster. Controllers process text both analytically (reading new text) and holistically recognising the script as a whole in particular within the context of monitoring.

Since recognition is based on the shape of the text as a whole, typography plays a major role. However, at the moment we have no direct evidence to help us specify what the critical parameters are. Instead, we have a good understanding of how the process of visual search works and of what the critical features of this process are.

4.6.3 Text is both interactive and descriptive

Another significant property of text items in ATC is that most of the text is interactive. Menus, call signs and button labels are usually interactive: clicking on the text produces a change of state, both at the level of the interface and the system. A menu supports action by recalling the range of available actions and by identifying the commands to modify the data and the user interface. Text on the radar gives detailed descriptions of the aircraft identity and route, gives access to commands and specifies the values that variables can take. It supports the actual control: modification of the route, of the aircraft status, etc.

This is a significant difference with descriptive text that provides read-only items that cannot be selected or modified on the screen. These two textual forms, in fact, presuppose activities that are radically different. Interactive texts require a hand-eye coordination as controllers will have to move the cursor to the text to activate the command. Once the controller has identified the item among the others he will therefore focus on the text for a longer time than that required to read it, as he will have to maintain the text as a visual target to reach with his mouse or pointing device.

Descriptive text provides information on the status of the parameters controlled. This information is obviously critical to the elaboration of a sound representation of traffic. For instance, the quality of memorisation, monitoring, or conflict detection depends on how the aircraft identity and route are coded.

Page intentionally left blank

5. READING AND SEARCHING

As we have seen above there are multiple processes involved in using text, which are both perceptual and cognitive. In this chapter we will look more closely at what is known about text processing in order to understand the mental activity that we have identified in the controllers' use of textual information. Based on a distinction between processing continuous text and processing text items that are short and iconic, we will make the distinction between reading and recognition, and briefly present an account of these processes.

5.1 Reading

Reading is a complex cognitive task, which includes a number of processes: feature analysis, word recognition, sentence perception and attribution of meaning. Even the control and guidance of eye movement is a part of the reading process. Processing is carried out simultaneously at all different levels of the cognitive system. Although a particular portion of the text may be subjected to a series of analyses (feature analysis, word recognition, sentence perception) the readers' attention passes seamlessly between these different levels of processing.

At a very low molecular level reading involves discriminating between meaningful marks on a background. Just & al. (1972) have called the process of converting the lines that represent characters into the characters themselves 'automaticity'. They hypothesise that, while beginning readers may spend up to 90% of their brain's available processing time on this process, more experienced readers will spend in this process less than 10% of their time only. This frees mental resources to deal with the conversion of letters into words and the processing of those words into concepts or information (comprehension).

Most cognitive theories of the reading process like Rumelhart (1977) or Mitchell (1982) propose that, in the first stage, information is picked out by the eye and registered in a visual information store or short-term visual memory. It is then ready to be used by an operation that attempts to identify the word represented by each cluster of features.

At the level of word recognition, a central cognitive device that co-ordinates pattern recognition with information about the letter shape, information in the mental lexicon and information about the contextual information works out the most probable interpretation of the text. Information from these different sources is brought together and contributes to elaborating a set of hypotheses about the entities that might be present in the stimuli and stored in the visual information store. The word level also involves accessing its meaning from a mental dictionary or lexicon, a process often described as lexical access. Lexical access provides the conventional meaning of the word including its common interpretation.

Most cognitive models such as Mitchell's consider that context and reader's expectations and knowledge influence the reading process especially when the legibility is degraded. When the print is clear the lexical hypothesis derived from featural information may reach an acceptable strength before the reader has the time to generate a higher level hypothesis on the word. However, when the legibility is reduced the process of word recognition is guided by hypotheses led by prior knowledge or the present context.

The word level is however not sufficient for comprehension. Individual words must be put together to form a larger structure that indicates the relation among concepts in phrases or clauses. The reading of continuous text includes the process of constructing meaning at the level of the sentence and then of the paragraph or the whole text. Readers deal with the sequential nature of language by trying to interpret each successive word of a text as soon as they encounter it, integrating the new information they have obtained with what they already know about the text and its context and subject matter. This is called the immediacy of interpretation (Just & Carpenter, 1987). The immediacy of interpretation theories presume that readers do not wait until they have read all the text to construct an interpretation, but rather build a meaning as they go along, revising their previous interpretations as they obtain new information.

The immediacy of interpretation entails all levels of comprehension: encoding the word, accessing its meaning, associating it with a referent, determining its semantic and syntactic status in the sentence or discourse. The cognitive system attempts the multiple levels of interpretation as soon as it gets access to the word and does not carry out the different levels of processing.

Finally there are numerous theories about how comprehension is constructed at the level of discourse. This part of the reading process is typically analysed as a top-down process. It is in fact generally assumed that in his identification and construction of discourse, the reader is driven by hypotheses and prior knowledge. There is typically a lot of predictive work being done as the text is read and comprehension proceeds by progressive stages of revision of hypotheses.

5.2 Recognition and Visual Search

Chapter 4 has led us to consider that the cognitive activities involved in the reading and recognition of text in ATC are nearly systematically preceded by a phase of visual search.

The very short and isolated text items and the fact that controllers go back and forwards between over-learnt items make us think that they are most often looking for an item that they have already seen. This is much closer to the mental activity of visual search.

There is a vast literature on visual search, mostly experimental. Most theories nowadays agree in considering that it is a two-step process: a pre-attentive process and an attentive process. The pre-attentive process does a sort of first filtering of the items and directs the attentive process to the most probable items on the basis of some simple features such as big, small, tilted straight. Subsequent attentional processes use this information to find and/or identify those poorly described objects.

Pre-attentive information exists to be used, not as an end in itself. Pre-attentive processing of any feature can be used to guide the subsequent deployment of attention. Pre-attentive processes exist to direct attention to the locations of interesting objects in the visual field. There are two ways in which a pre-attentive process can be used to direct attention: bottom-up (stimulus-driven) and top-down (user-driven).

Bottom-up

Bottom-up pre-attentive processes alert us to the presence of stimuli in the world that might be worthy of our attention. If a target is sufficiently different from the distractors, efficient search is possible even if the subject does not know the target's identity in advance. This summoning of attention to an unusual item is what is usually meant when the term ‘pop out’ is used.

Top-down Processing

Top-down pre-attentive processes are needed to deploy our attention to stimuli that we have decided are worthy of attention. That is, we need top-down, user-driven control of our pre-attentive processes. In searches for a target defined by a single feature the clearest evidence for top-down control comes from colour search tasks with very heterogeneous distractors. Even when each distractor is of a different colour it is possible to search efficiently for a target of a specified colour.

5.3 Basic Features in Visual Search

Wolfe (1996) does a very extensive review of the basic features in visual search and concludes that there appear to be about eight to ten basic features: colour, orientation, motion, size, curvature, depth, vernier offset, gloss and, perhaps, intersection and spatial position/phase. This section will quote extensively Wolfe’s review. Although we will concentrate only on the features that seem to be most relevant for the selection of typographical characters.

The experimental paradigm most often employed in this domain is that of asking subjects to identify as quickly as possible an item (with a certain set of features) displayed within a set of distractors. In 50% of the trials the target is present while it is absent in the other 50%. Measures are taken of the reaction time and accuracy of response. Often the object of study is both the feature of the target object and the features of the distractors. In fact, it is widely agreed that the difficulty of a search task can be explained by the similarity relationships between targets and distractors and between different types of distractors.

5.3.1 Orientation

Orientation is a widely studied basic feature in visual search. It is generally accepted that subjects can discriminate between lines that differ by one or two degrees in orientation but a difference of about fifteen degrees is required to support efficient (in the sense of fast and accurate) visual search. Foster and his colleagues argue that performance on simple orientation tasks can be accounted for by two broadly-tuned channels, one near vertical and one near horizontal (Foster & Ward, 1991b; Foster & Westland, 1995) Wolfe (1992) argues for channels roughly corresponding to the categorical terms ‘steep’, ‘shallow’, ‘left’ and ‘right’:

> *The notion of four (or even of two) broadly-tuned channels for the pre-attentive processing of orientation can go a long way toward explaining search asymmetries in orientation search tasks. For example, it is harder to find a vertical target among distractors tilted 20 degrees off vertical than it is to find a 20 degree target among vertical distractors (Treisman & Souther, 1985; Wolfe et al., 1992). In terms of four categorical orientation filters, the tilted target is easy to find because it is uniquely ‘tilted right’ while the vertical target is merely the ‘steepest’ item and is not categorically unique.*
>
> Wolfe (1994)

Wolfe suggests that the effects of orientation on pre-attentive search are also a function of the background distractors:

> *In addition to the complexities of pre-attentive orientation processing already mentioned, one needs to consider the relationship between orientations. Symmetry between target and distractors makes it harder to find a 50 degrees target among -50 degrees distractors than to find the same target among -10 degrees distractors even though angular difference between target and distractors is greater in the former case than in the latter (Wolfe & Friedman-Hill, 1992a). Moreover, the angles formed by neighbouring items in a display can be a clue to the presence of a target of unique orientation. That is, if there are two distractor types separated by 90 degrees in orientation, a target of a third orientation can be found by the acute angle it will form with neighbouring distractors. This works even if the orientations involved change from trial to trial (Wolfe & Friedman-Hill, 1992c). Meigen and Lagreze (1994) report that the overall structure of the visual field modulates search performance. In their experiments, search for a tilted item was easier if the background, distractor items were colinear with each other.*
>
> Wolfe (1994)

5.3.2 Curvature

Curvature is another basic features used by subjects to search and discriminate objects. Treisman and Gormican (1988) found that curved lines could be found among straight distractors. Moreover, there is what is called a search asymmetry: when the target is straight and the distractors are curved, search is less efficient, than when the target is curved and the distractors straight. This makes researchers suggest that it is easier to detect the presence than the absence of curvature. Wolfe discusses the nature of this feature:

> *The alternative to curvature as a feature is that a curve might just be a point of high variation in orientation - a place where orientation is changing rapidly. Earlier research about the featural status of curvature (having nothing to do with visual attention) could not find evidence for this objection (Blakemore & Over, 1974; Riggs, 1973; Stromeyer & Riggs, 1974). Wolfe, Yee and Friedman-Hill (1992) tested this hypothesis by having subjects search for curved targets among uncurved distractors that were similar for local change in orientation. Efficient search for curvature remained possible.*
>
> Wolfe (1996)

5.3.3 Vernier offset

Human observers are very good at detecting small departures from the colinearity of two line segments - a so-called vernier stimulus. Fahle finds that, while the presence or absence of a vernier break can be found efficiently, determining if a line is broken to the right or to the left requires attention. Subjects could learn to do a left-vernier among right-vernier search, but only on the basis of an orientation cue. The ability went away when Fahle disrupted the orientation cue inherent in a stimulus composed of vernier breaks in vertical lines. As with other features discussed in this section it seems that the efficiency of vernier search increases as the difference between the target and the distractors is increased (Fahle, 1990).

5.3.4 Size, spatial frequency and scale

There are two aspects of size studied in visual search experiments that seem to be relevant for font recognition:

1) Size difference.
2) Scale difference.

The results show that, if the **size difference** is sufficient, a target of one size will be found efficiently among distractors of another size.

In Treisman's work on search asymmetries, she found that it was harder to find small among big than big among small (Treisman & Gormican, 1988). However, given one size of distractors, it was no easier to find a bigger target than a smaller one. Looking for the medium sized item among larger and smaller items is inefficient unless the size differences are very large (Treisman & Gelade, 1980; Wolfe & Bose - unpublished data; see also Alkhateeb et al., 1990). Like orientation, search for stimuli of different sizes can be very efficient even if the contours of the stimuli are defined by chromatic change, texture, motion, illusory contours, etc. (Cavanagh et al., 1990).

Wolfe (1996)

Scale is a property of the stimuli in relation to its environment. In daily perception it is possible to examine a scene at several scales without any difference in the visual stimulus. If I am looking at a room I can search for the biggest person in the room, for a book in the shelf or for a pen. While the visual stimulus remains the same, the scale of the search changes. There are some classical experiments regarding the search of small letters forming a set of bigger letters:

ff
ff
ff
ffffffffff

Navon (1977) argued that stimuli are processed first at a coarse, global scale and, somewhat later, at a finer local scale (subjects first see the big ‘L’ and then the small ‘f’). Verghese & Pelli (1994) show that subjects can select a scale at which to examine a visual search display (subjects see the ‘f’ before the ‘L’).

5.3.5 Shape

As Wolfe suggests in her review one of the most problematical basic features in visual search literature is shape or form. There are many experiments that point toward shape features that are not reducible to orientation and curvature (e.g. Cohen & Ivry, 1991). The main problem seems to be a lack of a widely agreed upon understanding of the layout of ‘shape space’ which would help determine the primitives of pre-attentive shape perception. While it is possible to define colour space or orientation and size it is much less obvious what the ‘axes’ of shape space might be.

Several shape attributes have been suggested as candidate basic features. Perhaps the best supported is line termination (Julesz, 1984; Julesz & Bergen, 1983). Wolfe (1996) reports that in their paper on search asymmetries, Treisman & Gormican (1988) had subjects search for a ‘C’ among ‘O’s or vice versa. Search was more efficient when the ‘C’ was the target, suggesting that the gap or line terminators were the feature being detected. Julesz, using an 'E' vs. 'S' task, argued that a target with more terminators could be found amongst distractors with fewer terminators. However there if there are too many terminators in a figure the search process is slowed down significantly.

There is also evidence that closure is important in the pre-attentive processing of form. Chen (1982) suggests that some topological features such as the presence of holes in targets is also detected pre-attentively, while Julesz (1984) proposes intersections are basic features. Some gestalt notions of good form seem to underlie these findings, as subjects seem to be detecting deviation from a 'good figure'.

5.3.6 Motion

Motion seems to be a relatively uncontroversial basic feature. Subjects find it very easy to find a moving stimulus among stationary distractors. However, it is more difficult to find a stationary target among moving distractors (Dick, 1989). On the other hand, in the case of moving stimuli, it is easier to find the fast target among slow distractors than vice versa (Ivry, 1992).

> *Short-range apparent motion stimuli support efficient search but long-range stimuli do not. The apparent motion results suggest that motion differs from orientation. While a vertical stimulus will pop-out amongst horizontal distractors no matter how that stimulus is made (contours derived from colour, motion, luminance, etc.) (Cavanagh et al., 1990), only certain motion stimuli work (short-range - yes, long-range-no). This distinction is bolstered by the finding that isoluminant motion stimuli are not available pre-attentively (Luschow & Nothdurft, 1993).*
>
> Wolfe (1996)

5.3.7 Colour

A long history of basic and applied research points to colour as one of the best ways to make a stimulus 'pop out' from its surroundings (Van Orden, 1993).

When there is more than one distractor colour efficient search is still possible even if there are constraints. A number of experiments have shown efficient search for targets of unique colour among at least nine distractor colours (Wolfe et al., 1990). These searches with heterogeneous distractors are efficient only if the colours are widely separated in colour space. When more similar colours are used search is inefficient if the distractor colours flank the target colour in colour space (D'Zmura, 1991).

5.4 Conclusions

The general picture resulting from the studies of reading is that fluent readers have efficient strategies to predict what they will be seeing. Reading is as much about picking up patterns and configurations from the paper or the screen, as it is about being able to make good guesses on what is being displayed. However, the theories on reading processes briefly presented above have been derived from the study of reading continuous text. The overall process clearly does not apply to ATC, although there are a number of sub-process or components of the process that are common to all forms of reading (eye fixation, pattern recognition, word recognition, lexical access, etc.).

It is important to realise that text processing in ATC can only partially be described as reading, because the nature of the text being processed is different from the continuous text that is the object of what is typically described as reading. There is no sentence or discourse construction, there is no syntactical processing and there is no morphological analysis. The implications of this fact are that in ATC the presentation of text or typography is not there to sustain the process of sentence construction or comprehension, but word and letter recognition.

As we will see in Chapter 6 most of the studies on the effects of typography on text processing have in fact measured how different typographical features affect speed of reading, comprehension or memorisation of continuous text. Both the available literature on reading from paper and from the screen use experimental paradigms in which different typographical solutions are compared on the basis of the time employed to read a document. There is very little knowledge on how typography can support effective letter and word recognition.

The literature on visual search is highly relevant to ATC because, as we have seen in Chapter 4, it is very often the case that text must be found before being read or processed. The theories of visual search have pointed out a pre-attentive process that guides the focusing of attention on specific items. The vast literature on the features of objects that are used to guide the identification and discrimination of objects reveals that there is a set of basic features that we use effectively at a pre-attentive level. These are motion, orientation, colour, shape, curvature, vernier offset and size. It appears that human beings are very good at picking out elements that possess these features from a background of similar items that however differ in terms of the target feature. It is important to note that this literature stresses the relation between the target and the background. All the reported results in fact show that a target is more or less rapidly identified according to what distractors are set in the background.

Although letters have occasionally been used as visual stimuli for these tasks, we could not find any direct evidence on searching for words. We can however make the hypothesis that the basic features such as curvature, shape and orientation are being used in the search and identification of letters and words. When a reader searches for a text item in a list he has a mental representation of the target word or code; we can easily imagine that the representation comprises some of the basic features such as orientation or shape.

We will discuss the implications of these findings for the selection of fonts, in Chapter 7. However, it is immediately clear that, if humans are particularly efficient in identifying and discriminating objects that differ in terms of curvature, closure or orientation, typographical solutions that reinforce these features will be particularly effective to support the visual search of items on the radar screen.

Page intentionally left blank

SECTION C: TYPOGRAPHY

Writing systems serve representational purposes, that is, they represent oral language. However, being representations and not copies of the spoken word, writing systems operate a selection and a formatting of the oral information. They highlight certain features, reflect underlying structure and underscore other characteristics. In the course of this process, the written system - the text - becomes a visible artefact, a device for visual communication. The designers of text render it with some intention, i.e. that of conveying the name of a button, encoding it in a specific textual format selected for that purpose. The users of text recover that intention by decoding and interpreting the text.

Olson (1994) says, for instance, that *reading is a matter of rendering visible marks into a linguistic form, of recovering or inferring authorial intentions by means of recognition of graphic symbols*.

Because of this interpretative dimension, reading is not neutral, but purposive in nature. Depending on the activity text is designed to support specific interpretations, highlight particular aspects of the information or favour particular kinds of information processing.

Therefore, we can say with no doubt that **text shapes cognitive processes**. Typographical choices have an impact on what draws the reader's attention, on the inferences readers make about the relative importance of the elements, on what is left to memory and what to the external supports.

The following literature review analyses the experimental data that has been collected to examine the impact of variations in the characteristics of text presentation on the cognitive processes involved in reading and text processing. In particular, a vast experimental literature exists on the impact of text characteristics on the legibility of text, measured as the effectiveness with which a reader processes a text.

Page intentionally left blank

6. STUDIES OF THE LEGIBILITY OF FONTS

The design of a new typeface is a lengthy process requiring very specific expertise and techniques. Criteria that enter in the design process can be stylistic, cultural or technical. However, one primary concern that is in the forefront of all font design for the screen is **legibility**. Legibility was first studied in the late nineteenth century by Jean Anisson and has been an issue for most typographers since. Studies of legibility investigate how the shapes of letters help people read a text effectively, rapidly and with understanding.

There are two sets of studies that are relevant for the issue of font selection in ATC:

1. results from studies of legibility of text on **paper**.
2. results from studies relating to the legibility of text on the **screen**.

6.1 Results from Studies of Fonts for Paper

Most of the research on the effects of typographical features on reading has been carried out in the first half of this century on paper support. Although the **results** of these studies bear little relevance on the process of reading from the screen, they do point in the direction of what are the **features** that seem to have an effect on legibility and readability. It is therefore these features that have to be examined and considered when selecting fonts.

There have been extensive studies on type to determine which factors influence different aspects of reading, such as reading speed, retention of information, recognition of letter forms, etc. The main typographical features examined are:

- size of fonts,
- type form,
- character spacing,
- word spacing,
- spacing between the lines (leading),
- reverse type,
- colour.

6.1.1 Size of fonts

All the literature agrees that there exists no optimum size of type for reading, as this is a function of the visual distance and visual angle. The measurement of displayed information cannot in fact take into account the physical size of the character only, but also the distance of the character from the eye. Character size is measured by the height of the character in terms of its visual angle. The visual angle is used as a unit of measurement and is specified in terms of minutes of arc or degrees (one degree is equal to sixty minutes of arc).

Character legibility approaches 100% as the visual angle exceeds ten minutes of arc.

6.1.2 Type form

The form of fonts such as capital, lowercase and italic all affect reading speed. There are some very classical results of the studies by Tinker and Paterson (1963) showing that lowercase is read 13.4% faster than all capitals. Brown (1998) has confirmed these results. Reading speed is optimal when uppercase and lowercase are used together.

Text in all uppercase is more difficult to read than text in mixed case. Tullis (1988) reviews literature, suggesting that people read mixed case text about 13% faster than uppercase. This is because lowercase letters look more different from one another than do uppercase letters, making it easier to determine a word in part by its overall shape. Uppercase letters should be reserved for captions, labels, titles or other things that need to stand out in a display, because searching for a single uppercase item is about 13% faster than searching for one in many mixed case items. Thus, ease of reading is gained by mixed case, while ease of finding is gained by uppercase when it is embedded in otherwise mixed-case text. There is some evidence (Williams, 1998) that uppercase is better for menu items, but it is not clear under what range of conditions this finding might hold up.

Text printed in italics is slightly less legible than material in lowercase letters and decreases speed of reading somewhat. Text in lowercase is read 2.8% faster than italics (Tinker & Paterson, 1963).

Serif and Sans Serif typefaces are equally preferred by readers (Tinker, 1963) and are read equally fast (Gould et al., 1987; Hartley & Rooum, 1983). Serif faces are easier to read in continuous text than Sans Serif faces (Burt, 1959; Robinson et al., 1971; Wheildon, 1995).

6.1.3 Proportional vs. monospaced fonts

It is very important to consider the differences between monospaced and proportional fonts, since this is possibly the parameter providing the greatest contrast between fonts. It is also a factor that affects the global legibility of words.

Lines below set in Times New Roman 12 point.

The quick brown fox jumps over the lazy dog.

The dirty green dog walks past the blue fox.

www iii

iii www

Lines below set in Courier New 12 point.

```
The quick brown fox jumps over the lazy dog.
The dirty green dog walks past the blue fox.
```

```
www iii
iii www
```

Monospaced fonts are designed so that each character occupies the same amount horizontal space. Thus, ‘thin’ characters like ‘I’ and ‘l’ are the same width as ‘fat’ characters like ‘w’ and ‘m’. In the example lines above you can see how Courier aligns precisely the characters irrespective of their shape; the sequence ‘www’ aligns with ‘iii’. This replicates the spacing of letters from mechanical typewriters.

Proportional fonts like Times New Roman in the example above, give each character a different width according to its shape. In the example you can see how there is no alignment between the pairs of lines even though they consist of the same number of characters.

Proportional spacing has been shown to improve the speed of reading of lists of isolated words (Beldie, Pastoor & Schwartz, 1983). The lack of horizontal alignment is also in most cases very important as it avoids a ‘grid’ effect. Monospaced fonts cause a visual grid formed by the intercharacter spaces to be formed in multi-line text; this makes the separation of one line from the next more difficult and also impedes the whole word recognition process.

6.1.4 Character spacing

Character spacing is the horizontal space between characters. When letter spacing is too tight, letters are hard to distinguish from each other, making them less legible. Tight letter spacing, for instance, can make it difficult to distinguish between ‘rn’ (‘r’ & ‘n’) and ‘m’. The appropriate amount of space between characters varies according to letter combination.

6.1.5 Word spacing

Word spacing is the horizontal space between characters at a word boundary. Our cognitive and visual system uses this cue to identify letter groups as words. When letter spacing is too tight letters are hard to distinguish from each other, making them less legible. When word spacing is too tight the boundaries are more difficult to identify, making word recognition slower. Most software, for rendering type on the screen, adjusts lines to one margin and places a uniform space between words.

6.1.6 Spacing between the lines (leading)

Line spacing that is too tight decreases readability, because it makes it difficult for the reader to separate the individual words and phrases and for his eyes to find the beginning of the next line. Reading is faster when text is set with 1 to 4 points leading than when the text is set solid. As the effects of type size line length and interline spacing interact, a general the following leading guidelines should be followed:

- 9, 10, 11-point type needs between 1 and 3 points of leading;

- 12-point type needs between 2 and 4 points of leading;
- 14-point type need between 3 and 6 points of leading;
- 16-point type needs between 4 and 6 points of leading.

6.1.7 Colour

Guidelines about font size have to be corrected when colour is introduced. In fact, it is a known principle that, if the letters are in colour, the font size has to be bigger to obtain the same level of legibility than black text. This is because the receptors in the eye vary with their ability to detect colour. The minimum size for characters displayed in colour depends on the colour of the text and background.

The combination of black characters on a white background produces faster reading than the reverse and most readers prefer it.

6.1.8 Conclusions of research on fonts for paper supports

In conclusion, the research results presented above indicate the following:

- the best results in terms of legibility of fonts on paper are obtained:
  - ⇨ when it is easy to distinguish one character from another;
  - ⇨ when features are moderated, that is whenever the typeface has no extreme feature (thick strokes, very thin strokes, strong contrasts, tall and narrow forms, short and squatty forms, slanted characters, fancy Serif).
- On the contrary, legibility decreases:
  - ⇨ when text is set in all capital letters, since words all acquire a very similar shape, losing one of the significant facilitators for word recognition, namely the shape of the word. A word written in capital letters in fact has a global rectangular shape that demands that reader process one letter at the time.
  - ⇨ when letter and word spacing is uneven, because it requires constant adjustments between words.
  - ⇨ when spacing is consistently too close or too far apart.
- Serif typefaces are easier to read when there is a lot of text, the Serifs contributing to guiding the reader along the lines.
- Sans Serif letter forms instead are more instantly recognisable when there is a small amount of text.

6.2 Studies on the Legibility of Screen Fonts

Most ergonomic work on reading from screens has concentrated on the differences between screen and paper. Muter, Latremouille, Treurniet and Beam (1982), for instance, compared speed and comprehension in reading from a terminal and a book. Results over two hours of reading indicated that, though extended reading from a screen was feasible, it was 28% slower than reading from paper. There was no significant difference in comprehension.

In general, text on screen has been found to be less legible than text on paper. The most extensive studies have been carried out by J. Gould at IBM (from 1982 to 1987). Gould concluded that the reported differences between paper and screen are mainly perceptual and lie in the fact that reading requires discrimination of characters and words from a background. The better the image quality, the more reading from the screen resembles reading from paper and, hence, the performance differences disappear. Reading speed equivalent to that on paper may be obtained through the use of high-quality anti-aliased fonts displayed with dark characters on a light background on a high-resolution screen.

Other reported results provide some additional and more specific data on some of the features that are particularly critical for screen fonts. These features are:

- the size of the screen font,
- the contrast between background and text.

6.2.1 Size of fonts

As we have discussed in Section A, there is, on a screen, a physical limit to the minimum size of type, because the individual characters are formed by square dots (pixels). It is not possible to form a capital character set less than seven pixels high. In lowercase too nine pixels top to bottom are needed.

At conventional resolutions of computer displays, therefore, fonts are generally less legible online than on a printed page. Hence, a series of adjustments must be made to ensure a good level of legibility: fonts are bigger than on paper, italic and serif fonts are avoided.

Various ergonomic sources provide different standards for font size on the screen:

The Federal Aviation Administration (FAA) (Cardosi, 1995) suggests that legible characters should have character heights of at least sixteen minutes of arc with a preferred height of twenty to twenty-two minutes of arc (ANSI, 1988). A simple formula indicates that the minimum height of the characters should be 1/200 of the viewing distance (Avery & Bowers, 1992). At a viewing distance of 53 cm this translates into 8, 11, 12 points.

The font size is obviously a function of the distance of the viewer. As the distance between the observer and the screen increases, the retinal image size decreases linearly, but this effect is counterbalanced by the fact that retinal eccentricity also decreases (distance of the image from the fovea). Visual acuity is not dependent on the size of the retinal image but is a decreasing linear function of eccentricity.

Hopkin (1994) suggests that, for viewing distances around 450 mm, the minimum character height should be about 3 mm, minimum width about 2 mm, minimum horizontal separation between characters about 1mm and minimum vertical separation between rows of characters about 50% of character height.

Commercially successful products having high-resolution, black on white characters, and a Sans Serif font use character heights of 0.12, 0.09, 0.06, 0.04 inches, depending on the task. At standard screen reading distances text blocks should be set at a minimum of 9 points, with relatively generous leading (9/13, or 9/14) to improve the legibility of small print. The default font used for interface elements in Windows is MS Sans Serif for 8-point. Menu bar titles, menu items, control labels, and other interface text all use 8-point MS Sans Serif.

On the other hand, there are other significant measures to take into account, such as the relative ratio between x height and width. The ratio between character height and width should be between 1:1 and 1:0.6 (NUREG, 1981). Slightly expanding the horizontal dimensions of a suitable screen typeface is a good trick for making thicker or boldface fonts more legible and can sometimes make very small type sizes a little easier to read.

Another effective solution to improve the legibility of small fonts is to increase leading between lines. A good rule of thumb in smaller text sizes is to use a 'line height' or leading three to 4 points greater than the size of the type. For example, for 12-point type choose 15 ou 16 points of leading. The extra line spacing makes scanning across the lines of type easier on the eye, and can actually make the type appear larger than it really is.

Finally, character spacing can also play a role in balancing effects of size. The possible range of character spacing of type for the computer screen is limited by the coarseness of the display, from zero to two pixels in most cases. This spacing varies from font to font, with fonts designed especially for the screen providing more uniform spacing. However, it is recommended to introduce a minimum spacing between characters of one stroke width (NUREG, 1981).

6.2.2 Contrast

The legibility of alphanumeric characters is affected by the colour and the luminance of the characters and the colour and luminance of the background. Coloured text should differ from their coloured backgrounds by a minimum of 100 colour distance units as measured by an international lighting and colour standard, CIE method.

The contrast of foreground text and symbols against the background luminance is referred to as contrast ratio, which is measured by dividing the luminance of the foreground by the luminance of the background. ICAO (1993) recommends that on ATC displays the luminance of dynamic text and symbols must be eight times that of the static background symbology.

Good, high-contrast text/background combinations include white, yellow or cyan on a black background, and blue or black on a white background. Literature on the topic suggests avoiding low-contrast combinations such as blue on black or yellow on mint green. Pale and muted background avoids interfering with text. Background patterns and colour should contrast well with the lettering to maintain legibility (background refers to both backgrounds of pages and backgrounds of images).

Reverse (or inverse) video affects the relation between text and background. Reverse video is a reverse of normal video presentation. If the screen displays light objects on a dark background, then using reverse video means surrounding a dark object with a light background. On the other hand, if objects are displayed as dark on a light background, then light objects on a dark background would be reverse video. To be effective reverse video works as a contrastive element with respect to all other objects on the screen. A reverse video text is more swiftly identified if all other objects are in normal state, obviously if all the text items are displayed in reverse the target text does not stand out. Reverse video is another effective way to make something in a display stand out and draw the user's attention. There is some evidence to suggests that reverse video is a more powerful search cue than bold but that it slows down the reading process by 15%.

Another feature that affects colour contrast is 'bold'. Bold text is text constructed of letters that are heavier than normal intensity text. It can be an effective way to make something, such as caption or title, stand out. Most systems have one level of bold. That is, there is a standard intensity to objects or text on the screen, and one option for making things high intensity or bold. Some systems have more than one alternative level of bold, such as normal, medium and bold. Any more than three different levels of bold should be avoided, as people may have difficulty in perceiving and remembering the differences.

6.2.3 Polarity

Regarding positive and negative polarity of text,

> *Evidence suggests (Radl, 1983) that a large majority of users prefer positive polarity (dark characters on a light background). In theory, positive polarity reduces optical distortion, and increases visual acuity, contrast sensitivity, speed of accommodation, and depth of field. It also decreases the problem of interfering reflections of external light (Bauer, 1987). However, a disadvantage of positive polarity is an increase in the risk of perceived flicker, though this problem can be overcome with a sufficiently high refresh rate*.
>
> Muter (1996)

6.2.4 Variables affecting perception of flicker

Flicker is one of the identified causes for explaining why reading from the screen is less efficient than reading from paper. Muter (1996) suggests that the probability of perceiving flicker increases:

- with increasing luminance (e.g. dark characters on a light background);
- as phosphor persistence time decreases;
- if the screen is seen peripherally;
- if the user is talking (vibrations are transmitted from the vocal cords to the eye);
- with line jitter;
- with the size of the screen;
- with temporal contrast.

6.2.5 Dynamic text presentation

A method of dynamic text presentation that has been tested is ‘Rapid Serial Visual Presentation (RSVP)’.

With RSVP text is presented at a fixed location on the screen, one word at a time or a few words at a time. Several researchers have demonstrated that readers can perform approximately as efficiently with RSVP as with normal page-format reading (e.g. Juola, Ward & McNamara, 1982).

6.3 Conclusions

The results and recommendations presented above provide a series of indications on some of the basic parameters to follow when selecting fonts for paper and screen. However, as has been pointed out by Dillon (1994), when assessing reading it is necessary to draw a distinction between outcome and process. Outcome measures are taken on the results of reading: information retrieved, accuracy of recall, time taken. Process measures are concerned with what happens during reading: where the reader looks and fixates, how comprehension is constructed during the reading process. Most literature on reading from a screen has focused on outcome measures.

In the case of ATC the issue of finding the most adequate set of fonts for the type of text processing that is specific to controllers' activity, requires that we take the nature of the reading process into consideration. In particular, the fact that the text is visually searched before being read entails that solutions must be found to satisfy the need for rapid identification of whole words or codes.

While the proposed criteria for contrast and colour seem to be appropriate for radar screens, recommendations regarding typefaces or sizes must be evaluated against the requirements unique to the ATC environment.

Page intentionally left blank

RECOMMENDATIONS

Providing a set of guidelines for designing the most appropriate set of fonts for the ATC display environment is particularly difficult as it is not possible to rely completely on the existing literature on the effects of typographical parameters on reading. The lack of specific literature on the effects of fonts on the type of text processing that is involved in monitoring tasks of dynamic objects implies that empirical evidence must be collected to fully confirm the choices made.

The recommendations that we will provide in this section must be seen as a first orientation in the decision process. Ultimately, empirical validation must be carried out to verify the appropriateness of the choices made regarding the textual displays.

Page intentionally left blank

7. GUIDELINES FOR TYPOGRAPHY IN AIR TRAFFIC CONTROL

The recommendations provided in this chapter will make a distinction between the different parameters that characterise typographical solutions for text in ATC displays:

There is a set of parameters that pertain to the **font type**:

- character shape,
- intercharacter spacing,
- stroke width of characters,
- size of characters.

A set of parameters that are a function of the **layout** of the text:

- interline spacing,
- use of colour and highlighting,
- characters per line.

A set of parameters that are linked to the **display medium**:

- resolution,
- edge sharpness,
- polarity (light characters on a dark background vs. the reverse),
- contrast ratio between characters and background,
- stability (potential flicker or jitter),
- interference from reflections.

7.1 Font Type

7.1.1 Size

There is a major requirement with regard to the size of characters in ATC as air traffic controllers request very small type sizes to avoid overlap of labels. On the other hand, as we have seen above, even with a high-resolution screen smaller types inherit problems of jaggedness. While, from a purely perceptual point of view, fonts smaller than the recommended 8 points (or 20 to 22 minutes of arc as recommended by the FAA and EUROCONTROL) could be read by the controllers with no real reduction of visual acuity, the problem of small characters is to be found in the bitmap display.

Techniques of anti-aliasing or hinting can improve character display below 12 points if it is done by hand. However, if the background colour changes in different regions of the screen or if it changes over time, anti-aliasing cannot be used as the technique consists in introducing coloured pixels around the pixels of the characters and the colour of the added pixels is chosen with respect to the background.

Anti-aliasing is therefore possible for static elements such as buttons or for elements that have a constant background. On the contrary, it is not recommended for labels and any dynamic element on the radar screen, given the background and contour effects.

It is therefore recommended to rely on the standards (twenty to twenty-two minutes of arc) that have been defined by the FAA and EUROCONTROL.

7.1.2 Typefaces

Recommendations regarding font type are possibly the most difficult to provide given the variety of parameters that make up a type and the variety of typefaces that are available. We will provide a set of broad guidelines for the following parameters:

– style,
– x height,
– character shape,
– openness,
– character width and intercharacter spacing.

Style

In typography there are identified five or six major styles:

– Modern: Avantgard,
– Oldstyle: Garamond, Times,
– Serif: Serifa,
– Sans Serif: Arial, Futurist,
– Decorative: Braggadocio.

There are styles that are obviously not adapted for the context such as all the Decorative types.

Serif and Oldstyle fonts are the most recommended for long texts.

For short texts Sans Serif styles seem to be more effective in supporting word recognition.

x height

A second important criteria to follow in the selection of fonts is to avoid extreme ‘**x’ heights**.

A very high x height such as (n h) reduces legibility because it reduces the differences between characters that have the same lower section (e.g. ‘n’ and ‘h’).

A low x height such as (k h) is also less legible because it reduces the lower part of the character and puts in evidence the straight ascenders which again reduces the distinctiveness of each character.

Shape

In consideration of the legibility requirements for ATC discussed in Chapter 6, typeface must support both analytic and global legibility.

At a first level there are some obvious principles to follow to increase the perceptual discrimination of the letters: it is best to use regular weight (not **bold**) and not to use condensed or *oblique* fonts. Extrapolating from the results on visual search effective fonts are those which possess most distinctive features in terms of closure, openness and orientation. These types of basic pre-attentive features can explain why condensed (condensed) characters that tend to reduce the space between characters and within the characters, make the recognition of letters and words much more difficult.

To follow the features proposed by the research on pre-attentive visual search, characters are well distinguished when the shapes and orientations of the strokes and character components are clearly marked and stressed. When the orientation of the oblique sections of the character are sufficiently distinguished from the vertical or horizontal lines and when the closed characters (such as ‘O’) are different from the characters with line terminators (such as ’C’), distinction between ‘C’ and ‘O’ will be facilitated.

This is the case, for instance, of Verdana, which is a font designed for the screen.

Verdana 8 point

Verdana 9 point

BA8763

Letter spacing

One of the main features to support word recognition is a correct width and spacing of characters. The width of the characters and the intercharacter distance must be kept rather wide to keep the characters distinct from each other.

Verdana, for instance, has a wide intercharacter space and a wide character dimension. This makes for a more readable font than

Futurist Condensed which reduces both the intercharacter distance and the character width.

7.1.3 Proportional vs. monospaced fonts

The differences between monospaced and proportional fonts introduce one of the parameters providing the greatest contrast between fonts.

As discussed in Chapter 6 monospaced fonts are designed so that each character occupies the same amount horizontal space while proportional fonts give each character a different width according to its shape.

Proportional fonts are significantly more legible and they facilitate whole word recognition, as opposed to letter by letter parsing. Therefore, monospaced fonts should be used vary sparingly: only when strict alignment is necessary, such as in tables of numbers, should they be chosen over a proportional font. A special case concerns input fields in interfaces, where it is recommended to use monospaced fonts for clarity.

7.1.4 Case

The general recommendation is to mix cases and not use all uppercase because it reduces reading speed and renders all words indistinguishable. Lowercase enhances reading efficiency because word shape is helpful in word recognition (Rudnicky & Kolers, 1984). We would therefore recommend lowercase to support fast word recognition.

Further investigation should however be done on a very relevant result reported by Muter (1996) indicating that searching for words is faster with uppercase characters. It may therefore be interesting to keep in mind this result when experimenting on the legibility of a set of fonts in ATC.

7.2 Text Layout

While text layout is very important for the legibility of continuous text, the devices that can be applied to short text items such as those discussed here for ATC are very limited.

Two parameters are relevant:

- highlighting techniques,
- interline spacing.

7.2.1 Colour and highlighting

New ATM displays are making a considerable use of colour coding, reverse video and other techniques for highlighting and displaying change of status by visual coding. The report by Metcalfe and Reynolds (1996) for NATS provides an extensive review and set of proposals for the use of colour on ATC screens.

Our recommendations regard the use of colour in fonts:

- if the letters are in colour, the font size has to be bigger to obtain the same level of legibility than black text;
- the legibility of coloured letters depends on the text vs. background contrast ratio;
- negative polarity is to be preferred (dark text on a clear background).

Techniques for highlighting such as underlining, enclosing in a box, reversing polarity, flashing on-off; fluctuating brightness or varying size, font or brightness must be used sparingly.

The evidence on highlighting suggests that it does not systematically help recognition and processing but that it can have a negative effect on the speed of recognition (Fisher & Tan, 1989). A key variable seems to be highlighting validity: the percentage of time that a target, as opposed to a distractor, is highlighted. This result is extremely significant in the context of ATC where status is signalled by changes in colour coding and reverse video effects.

7.2.2 Interline spacing

This is relevant for tabular lists and for menus. A larger line spacing has the effect of compensating for a small type size. As previously noted single spacing or, in general, reduced interline spacing has been found to be less legible and reduce reading time. Evidence by Wilkins (1986) suggests that increasing spacing between lines and proportionately decreasing horizontal spacing between letters may improve the clarity and comfort of text without affecting the density of the text. Close interline spacing impairs reading because of vertical masking and because return sweeps are more difficult.

In small text sizes we suggest to use a ‘line height’ or leading of 3 to 4 points greater than the size of the type. For example, for 8-point type choose 11 or 12 interline spacing.

In particular, interline spacing must be increased if the typeface has a large x height, as in Sans Serif fonts, and if reverse video is being used.

7.3 Screen Characteristics

All the literature agrees that the quality of the screen as a support for text explains why reading from the screen is less effective than reading from paper. Screen resolution, flicker, interference from reflections, aspect ratio, curvature of screen, distortion in corners, all contribute in making the perceptual process more difficult and more tiring.

In ATC the selection of screens follows the most stringent quality criteria and there is therefore nothing more to do than keeping up-to-date with the evolution of technology. From the point of view of the font types themselves there seems to be little to be done in terms of compensating the effects of the screen. However, there are a set of minimum requirements to consider when discussing solutions to improve screen displays. These regard techniques for reducing flicker, reflection and increasing contrast.

7.3.1 Flicker

On a bitmapped display characters are constantly fading and being regenerated giving the impression of flickering. The amount of perceived flicker depends on the phosphors' persistence Bauer and al (1983) have suggested that a refresh rate of 93 Hz is necessary in order for 99% of the users to perceive a display of dark characters on a light background without flicker.

As an example 20'' Trinitron screens currently advertise 30-86 Hz Horizontal, and 48-150 Hz Vertical. The display screens should therefore offer a refresh rate higher that 100 Hz to avoid flicker.

7.3.2 Resolution

One measure of resolution is the resolution/addressability ratio, which is the width of pixels divided by the peak-to-peak distance between pixels. A high ratio results in better visual search performance.

7.3.3 Reflections

While screen reflection is reduced in ATC environments given the ambient lighting that is commonly employed there are some technical solutions proposed by the manufacturers to reduce reflection.

IBM (on www.ibm.com), for instance, discusses the following techniques:

- **Diffusing surface**: A technique whereby the display surface is roughened to make it optically irregular and break the reflected image. This technique can however blur the display image because it diffuses not only the reflection but also the light rays of the phosphors.

- **Screen orientation:** A simple method of positioning the screen to avoid reflection.

- **Anti-reflective coating:** A special thin film optical coating can be deposited on glass to modify the interface between air and glass, to increase the quantity of light transmitted through the glass and reduce the reflection from the surface. On computer displays this technique can reduce reflections by 90%.

7.3.4 Contrast

A contrast ratio of 3:1 is a minimum for character sizes of 16 minutes of arc in standard activities. Coloured text should differ from their coloured backgrounds by a minimum of hundred colour distance units as measured by an international lighting and colour standard, CIE method.

The contrast of foreground text and symbols against the background luminance is referred to as contrast ratio which is measured by dividing the luminance of the foreground by the luminance of the background. ICAO (1993) recommends that on ATC displays the luminance of dynamic text and symbols must be eight times that of the static background.

Given the nature of ATC activities that requires fast recognition we would recommend a contrast ratio of 20:1. This requires, however, that the screen can display a sharp image. In consideration of the fact that ATC control rooms are darkened or have low illumination it is not necessary to add contrast enhancement filters, hoods or mesh which increase contrast by reducing reflected room lights.

Page intentionally left blank

CONCLUSIONS

Page intentionally left blank

8. REDEFINING LEGIBILITY FOR AIR TRAFFIC CONTROL

In the literature reviewed in the previous chapters the terms of readability and legibility are used to refer to two different aspects of typography. Hopkin (1995) for instance refers legibility primarily to perceptual clarity. Failures of legibility are attributed to the inability to perceive information correctly because of psycho-physical deficiencies, such as inadequate size or contrast, or because of specific design deficiencies whereby items or characters are too similar and confused perceptually with each other. Readability instead refers to comprehension and understanding. While legibility can vary greatly between characters on the same display, readability refers to the display of information in general.

Contrary to this view, which takes legibility to involve mainly perceptual processes and reserves the term readability to account for cognitive processes, we suggest using both legibility and readability to express the property of texts to facilitate the recovery of meaning. However, we distinguish between the readability of an extended amount of text, such as an article or a book, and the legibility of short texts.

Legibility of short texts is function of internal, structural properties of text and of its elements, for instance character brightness, contrast between the letter and the background, font size, inter-word spacing, line spacing, paragraph spacing and line length. However, legibility can also depend on more global properties of text that can stand out as a whole block. Take, for instance, the Coca-Cola brand label. It has low internal legibility - the font is idiosyncratic, the letters are not well spaced and clearly distinguished - but high **iconic legibility**. It is recognised as a whole, swiftly from a dense background of items.

The two kinds of legibility (analytical and global) are equally important. However, their relative importance can vary depending on the phase of the text processing. During familiarisation with a new user-interface, in the initial treatment of a new aircraft entering the sector, reading may be more of an analytic process. In that case the readability of the elements and of the internal structure may be more critical. Once the user interface has become familiar and the activity is essentially monitoring, the legibility of the text as a whole may become more critical.

8.1 Two Types of Legibility: Analytical and Global

If legibility in ATC has to be defined both in analytical terms and global holistic terms, the requirements for fonts in ATC cannot only refer to analytical properties.

From the point of view of ensuring an analytical legibility the important issues are:

- enabling the discrimination between characters;
- enabling the identification of single characters.

From the point of view of a holistic legibility the important issues are:

- ensuring immediate recognition of the text item as a whole;
- enabling discrimination between words or codes.

Guidelines and recommendations for typographical solutions in ATC must therefore take these two levels into account and ensure that the selected fonts support both analytical and global legibility.

Selecting fonts that meet the criteria of **analytic legibility** means, for instance, ensuring that a the font allows to discriminate between the following set of problematic characters:

X and K T and Y I and L N M and W I and l 0 and, 0 and Q S and 5 U and V

Selecting fonts that meet the criteria of **global legibility** instead means finding solutions for word or code discrimination and differentiating typefaces between different categories of text items.

8.2 General Conclusions

The overview of the issues and literature reviewed in the previous chapters leads us towards two important conclusions which have an impact on how to determine the requirements for fonts on ATC displays:

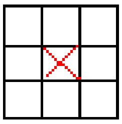
1. A new definition of legibility is required for ATC. Legibility and readability of text for ATC cannot be defined simply in terms of a good ratio between speed and understanding as is the case in the literature on reading continuous text. There are other factors that make a text item legible for an air traffic controller such as allowing a swift recognition or standing out from the background of similar items.

2. Given the perceptual and cognitive mechanisms that characterise controllers' processing of the textual information present on their screens, it is not possible to take the results of the literature on reading continuous text as guidelines to the selection of typographical solutions. New guidelines must be defined, which take into consideration the fact that text processing in ATC involves visual search, pattern recognition and frequent rereading of the same items.

ANNEX: TECHNIQUES FOR ANTI-ALIASING BY HAND

The following anti-aliasing guidelines present an example of the kind of techniques that can be used to modify 'by hand' font bitmaps, so as to aid the dithercopy (sub-sampling) algorithm to high-quality anti-aliased fonts. In practice, one modifies the bitmap of a font double the size of the target font if the sub-sampling ratio is 2x.

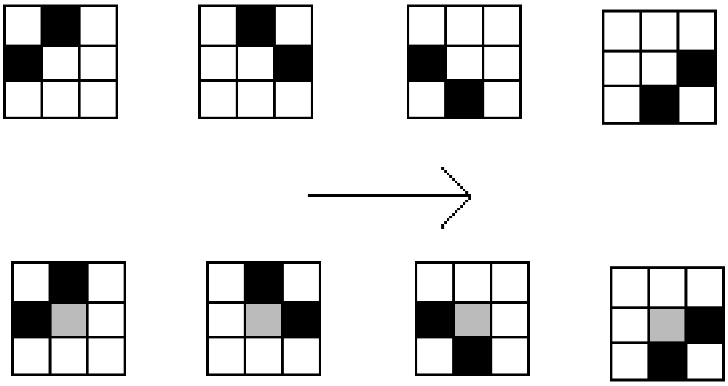
Consider a 3 by 3 pixel block where the target pixel is the centre one:



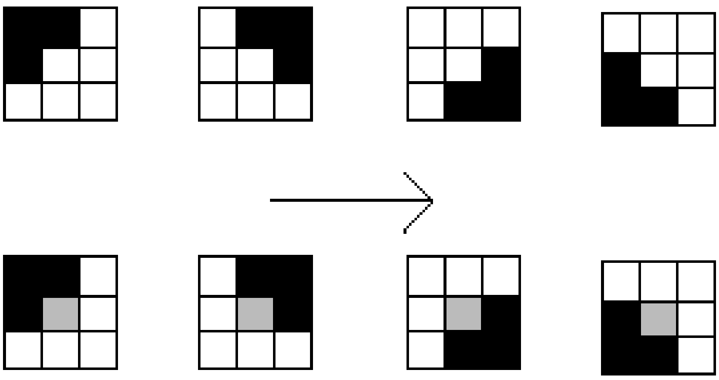
We will illustrate how to modify the centre pixel according to the status of the surrounding pixel grid.

Darkening

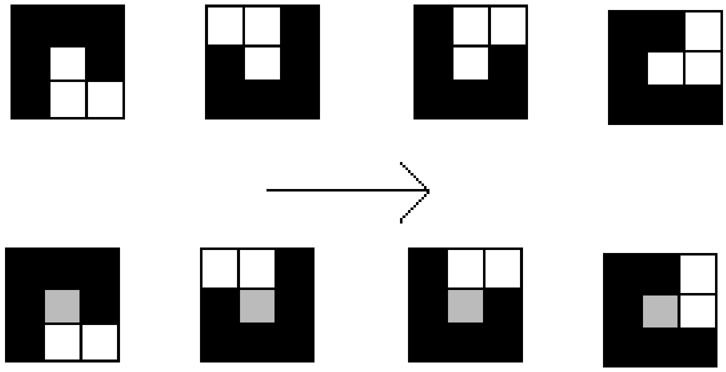
- If the center pixel is black it is left unchanged.



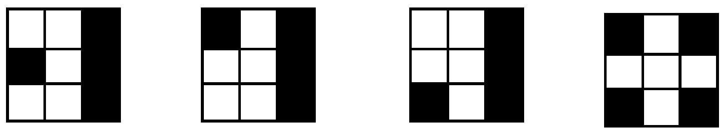
- Corner pixels are darkened by using a light shade of grey (e.g. 1/4).



- Corner pixels in the above configuration can also be darkened but this darkens the character significantly.

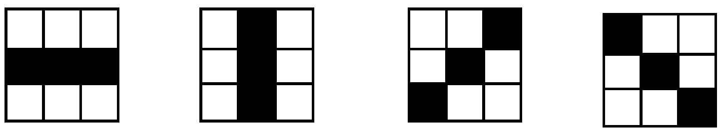


- Heavily surrounded corners are also similarly darkened.

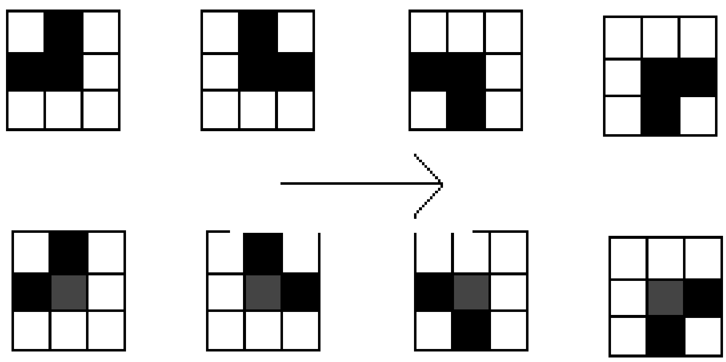


- In general, when the pixel grid configuration is enough to give the optical illusion of a grey pixel (as above), the centre pixel should be left as is. Orientation is always important.

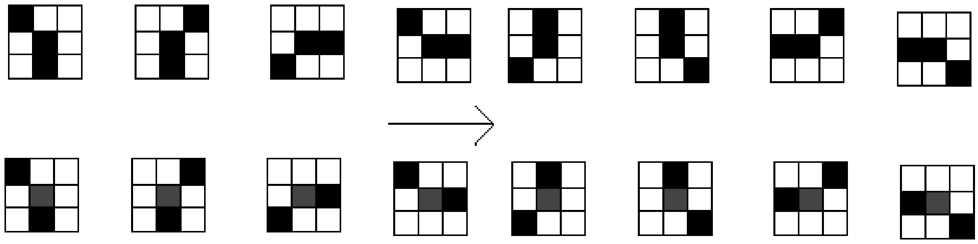
Lightening



- Line segments should not be lightened.



- Black corner pixels can be lightened by using 3/4 grey thus softening the edges.



- Black pixels within can be softened also with 3/4 grey, though with the risk to wash out the font somewhat.

As a general practice, rules such as those above should be applied consistently: if a rule is used to modify a few letters it should be used throughout the whole character set.

There are many possible rule sets, the above being an illustration rather than strict guidelines. Clearly, these rules could also be automated into the anti-aliasing engine itself.

Finally, let us not forget that rules such as the above could be used to modify the font bitmap at the target point size directly, thus obviating the need for an anti-aliasing engine altogether. The ultimate control would come from designing the bitmaps as greyscale fonts in the first place.

Page intentionally left blank

REFERENCES

Alkhateeb, W. F., Morris, R. J. & Ruddock, K. H. (1990). *Effects of stimulus complexity on simple spatial discriminations*. Spatial Vision, 5, 129-141.

ANSI/HFS (1988). *American national standards for human factors engineering in visual display terminals.* (ANSI/HFS 100 1988) Santa Monica, CA: Human factors Society.

Avery, L.W. & Bowers, S.E. (Eds.) (1992). *Department of defense human-computer interface style guide.* Fort Lewis, WA: Pacific Northwest Laboratory.

Bauer, D. (1987). *Improving the VDU workplace by introducing a physiologically optimized bright-background screen with dark characters: advantages and requirements.* In: B. Knave & P.G. Wideback (Eds.), *Work with display units 86*. Amsterdam: North Holland.

Beldie, I.P., Pastoor, S. & Schwarz, E. (1983). *Fixed versus variable letter width for televised text.* Human Factors, 25, 273-277.

Brown, P. (1988). Hypertext the way forward, in: J.C. Van Vliet (Ed.). *Document manipulation and typography*, pp. 183-9. Cambridge, UK: Cambridge University Press.

Burt, C.L. (1959). *A psychological study of typography*. Cambridge, UK: Cambridge University Press.

Cardosi, K. & Murphy, M. (Ed.) (1995). *Human factors in the design and evaluation of ATC systems*. FAA/RD-95/3 DOT VTNSC-FAA-95-3.

Cavanagh, P., Arguin, M. & Treisman, A. (1990). *Effect of surface medium on visual search for orientation and size features.* Journal of Experimental Psychology - Human Perception and Performance, 16, 479-492.

Chen, L. (1982). *Toplogical structure in visual perception*. Science, 218, 699-700.

Cohen, A. & Ivry, R.B. (1991). *Density effects in conjunction search: Evidence for coarse location mechanism of feature integration*. Journal of Experimental Psychology Human Perception and Performance, 17(4), 891-901.

Dehaene, S. (1989). *Discriminability and dimensionality effects in visual search for featural conjunctions: a functional pop-out.* Perception & Psychophysics, 46(1), 72-80.

Dillon, A. (1994). *Designing usable electronic text*. London: Taylor & Francis.

D'Zmura, M. (1991). *Color in visual search. Vision Research*, 31(6), 951-966.

EATMP Human Resources Team (2000). *Technical Annex: An Experimental Methodology for Selecting Fonts for Next Generation Air Traffic Management Systems.* HRS/HSP-006-REP-02. Released Issue. Ed. 1.0. Brussels: EUROCONTROL.

Fahle, M. (1991a). *A new elementary feature of vision.* Investigations in Ophthalmological. Visual. Science, 32(7), 2151-2155.

Fahle, M. (1991b). *Parallel perception of vernier offests, curvature, and chevrons in humans.* Vision Research, 31(12), 2149-2184.

Fisher, D.L. (1976). *Spatial Factors in Reading and Search: The Case for Space*, in: R.A. Monty & J.W. Senders (Eds.) *Eye Movements and Psychological Processes.* NJ: Lawrence Erlbaum Associates.

Fisher, D.L. & Tan, K.C. (1989). *Visual displays: The highlighting paradox.* Human Factors, 31, 17-30.

Foster, D.H., Westland, S. (1996). *Orientation fine-structure in line-target detection.* In: A. Gale, K. Carr (Ed.). Visual Search III: Taylor & Francis.

Foster, D.H. & Ward, P.A. (1991). *Asymmetries in oriented-line detection indicate two orthogonal filters in early vision.* Proceedings of the Royal Society (London UK), 243, 75-81.

Goody, J. (1987). *The interface between the oral and the written*. Cambridge, UK: Cambridge University Press.

Gould, J.D. & Grischkowsky, N. (1984). *Doing the same work with hard copy and CRT computer terminals.* Human Factors 26(3), 323-337.

Gould, J.D., Alfaro, L., Finn, R., Grischkowsky, N. & Minuto, A. (1987). *Why reading from CRT is slower than from paper.* Human Factors 29, 3, 269-299.

Gould, J.D., Alfaro, L., Finn, R., Haupt, N. & Minuto, A. (1987). *Reading from CRT display can be as fast as reading from paper.* Human Factors 29, 5, 497-517.

Hartley, J. & Rooum, D. (1983). *Sir Cyril Burt and Typography.* British Journal of Psychology 74, 2, 202-212.

Huey, Edmund Burke (1968). *The Psychology and Pedagogy of Reading.* The M.I.T. Press.

Hopkin, V.D. (1995). *Human factors in Air Traffic Control*. London: Taylor & Francis.

Ivry, R.B. (1992). *Asymmetry in visual search for targets defined by differences in movement speed.* Journal of Experimental Psychology: Human Perception & Performance, 18, 1045-1057.

Jackson, A. & Pichancourt, I. (1995). *A human machine interface reference system for en route air traffic control.* EEC Report No. 292. France: EUROCONTROL.

Julesz, B. (1984). *A brief outline of the texton theory of human vision.* Trends in Neuroscience, 7, 41-45.

Julesz, B. & Bergen, J. R. (1983). *Textons, the fundamental elements in pre-attentive vision and perceptions of textures.* Bell Systems Technologies Journal, 62, 1619- 1646.

Juola, J.F., Ward, N.J. & McNamara, T. (1982). *Visual search and reading of rapid serial presentations of letter strings, words, and text*. Journal of Experimental Psychology: General, 111, 208-227.

Just, M.A., Carpenter, P.A. (1987). *The psychology of reading and language comprehension*. Boston: Mass. Allyn & Bacon.

Just, M.A., Carpenter, P.A., Keller, T.A., Eddy, W.F., Thulborn, K.R. (1996). *Brain Activation Modulated by Sentence Comprehension, Science.* 274 (5284).

LaBerge, D. & Samuels, S.J. (1974). *Toward a theory of automatic information processing in reading.* Cognitive Psychology. 6, 293-323.

Luschow, A. & Nothdurft, H.C. (1993). *Pop-out of orientation but not pop-out of motion at isoluminance.* Vision Research, 33(1), 91-104.

Mansfield, S. (1996). *Font effects in normal and low vision,* Psychophysics of Reading, vol. XV.

McConkie, G.W. (1976). *The Use of Eye-Movement Data in Determining the Perceptual Span in Reading*. In: R.A. Monty & J.W. Senders, (Eds.*). Eye Movements and Psychological Processes.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Metcalfe, C. & Reynolds, L. (1996). Report 9834. NATS standards for the use of colour on air traffic control displays.

Mullet, K. & Sano, D. (1995*). Designing visual interfaces: communication-oriented techniques*. Mountain View, CA: Sunsoft Press.

Murch, G.M. & Beaton, R.J. (1987). *Matching display characteristics to human visual capacity.* In: B. Knave, & P.G. Wideback (Eds.). *Work with display units 86*. Amsterdam: North Holland.

Muter, P. (1996). *Interface Design and Optimization of Reading of Continuous Text.* In: H. van Oostendorp & S. de Mul (Eds*.). Cognitive aspects of electronic text processing*. Norwood, NJ: Ablex.

Muter, P., Latremouille, S.A., Treurniet, W.C. & Beam, P. (1982). *Extended reading of continuous text on television screens.* Human Factors, 24, 501-508.

Myer, B.J.F. (1981). *Basic Research on Prose Comprehension: A Critical Review.* In: D.F. Fisher & C.W. Peters (Eds.). *Comprehension and the Competent Reader: Inter-Speciality Perspectives*. New York: Praeger Publishers.

Navon, D. (1977). *Forest before the trees: The precedence of global features in visual perception.* Cognitive Psychology, 9, 353-383.

NUREG (1981). *Guidelines for control room design reviews* (NUREG 1981 007), US Nuclear Regulatory Commission.

Olson, D.R. (1994). *The world on paper*. Cambridge: Cambridge University Press.

Ong, W.J. (1982). *Orality and Literacy* . London, UK: Routledge.

Radl, G.W. (1983). *Experimental investigations for optimal presentation mode and colours of symbols on the CRT screen.* In: E. Grandjean & E. Vigliani (Eds.). *Ergonomic aspects of visual display terminals*. London, UK: Taylor & Francis.

Robinson, D., Abbamonte, M. & Evans, S.H. (1971). *Why serifs are important: the perception of small print.* Visible Language, 4, 353-359.

Rudnicky, A.L. & Kolers, P.A. (1984). *Size and case of type as stimuli in reading.* Journal of Experimental Psychology: Human Perception and Performance, 10, 231-249.

Schriver, K. (1997). *Dynamics in document design*. New York: John Wiley & sons.

Tinker, M.A. (1963). *Legibility of print.* Ames IA: Iowa State University Press.

Tinker, M.A. & Paterson, D. (1963). *Studies of Typographical factors influencing speed of reading.* The Journal of applied psychology, Vol. 13 nº2 (205-219).

Treisman, A. & Gelade, G. (1980). *A feature integration theory of attention.* Cognitive Psychology, 12, 97-136.

Treisman, A. & Gormican, S. (1988). *Feature analysis in early vision: Evidence from search asymmetries*. Psychological Review, 95, 15-48.

Van Orden, K.F. (1993). *Redundant use of luminance and flashing with shape and color as highlighting codes in symbolic displays.* Human Factors, 35(2), 195-204.

Van Nes, F.L. (1984)*. Limits of Visual Perception in the Technology of Visual Display Terminals.* Behavior and Information Technology, Vol. 3, n°4, pp *371-277.*

Verghese, P. & Pelli, D.G. (1994). *The scale bandwidth of visual search.* Vision Research, 34(7), 955-962.

Wheildon, C. (1995). *Type and layout: how typography and design can get your message across, or get in the way*. Berkley, CA: Strathmoor Press.

Wilkins, A. (1986). *Intermittent illumination from visual display units and fluorescent lighting affects movements of the eyes across text.* Human Factors, 28, 75-81.

Williams, R. (1998).*The non-designer's type book.* Berkley, CA: Peachpit Press.

Wolfe, J.M. (1992). *'Effortless' texture segmentation and 'parallel' visual search are not the same thing.* Vision Research, 32(4), 757-763.

Wolfe, J.M. (1996). *Visual search.* In: H. Pashler (Ed.), *Attention.* London, UK: University College London Press.

Wolfe, J.M., Yu, K.P., Stewart, M.I., Shorter, A.D., Friedman-Hill, S.R. & Cave, K.R. (1990). *Limitations on the parallel guidance of visual search: Color X color and orientation X orientation conjunctions.* Journal of Experimental Psychology; Human Perception and Performance*,* 16(4), 879-892.

Page intentionally left blank

GLOSSARY OF TYPOGRAPHY TERMS

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

Aliasing / Anti-aliasing: Aliasing is a term used to describe the undesirable effects produced when visual information is presented at a lower than optimal resolution. Anti-aliasing is a technique to improve the legibility of screen types by introducing pixels of a colour somewhere between the foreground and background colours, to smooth the edges of the lines that seem jagged and 'staired'.

Ascender: The part of certain lowercase letters that extends above the x height of a font.

Base Line: The line along which the bases of all capital letters (and most lowercase letters) are positioned.

Boldface Type: A thick, heavy variety of type, often used for highlighting**.**

Cap Height: The height of the uppercase letters within a font.

Cap Line: A line marking the height of uppercase letters within a font.

Condensed Type: Type that is narrow in width proportional to its height (less than 1:3 ratio).

Descender: The part of certain lowercase letters that extends below the base line of the letter.

Descender Line: A line marking the lowest point of the descenders within a font.

Display Type: Type intended to catch the eye, usually of a large size and distinctive typeface.

Em: A unit of measurement equal to the current type size e.g., an em in 12-point type is equal to 12 points. Originally derived from the width of the uppercase *M.*

Expanded Type: Type that is elongated in width proportional to its height (usually greater than 1:2).

Flush: Aligned to the margin, i.e. with no indention. 'Flush Left' means aligned to the left; 'Flush Right' means aligned to the right.

Font and Typeface: Traditionally, a complete set of characters for one typeface at one particular type size. Often used more loosely as a synonym for 'typeface'.

A font is a source of a typeface. There are two types of fonts: screen and printer fonts.

The typeface refers to the complete set of characters, punctuation and symbols that share a common design.

In other words, one must install the appropriate fonts on the computer to produce documents that are set in certain typeface. In the context of user interfaces a type style such as Courier, Helvetica or Times Roman is used to display alphanumeric information on the computer screen.

Hinting: A technique to reduce the effects of pixel resolution. At low resolution, with few pixels describing character shape, features such as Serif details or crossbar width can become blurred or disappear. 'True Type' allows the designer to move any point on a glyph's outline as much as is necessary to turn off or on any pixel on the bitmap grid. This type of application provides more control than a bitmap editor.

Justification: Horizontal adjustments made to the space bands within a line of type so that it fully extends to a particular line length.

Line Spacing or Leading: The vertical space between lines of text.

Line spacing is an important attribute of font size. It is the space between the ascenders of one line and the descenders of the other line above. A reduced line spacing causes the descenders to make contact with the ascenders. This can create patterns that are visually confusing.

Leading is expressed as two numbers: the typeface point size and the baseline to baseline measurement. Like type size leading is also expressed in points. A document set in 10-point type with a 12-point leading is written 10/12 which means twice 2 points of leading between every two lines of 10-point type.

Setting a text solid means leaving zero space between the lines. Typographers generally design types that maintain legibility even if the text is set solid. However, lack of leading tends to reduce readability.

Some processors automatically adjust leading incrementally, depending on the size of the type. Most are set to a default with 2 points of leading. Which means that, if the type is 12, the leading will be 12/14.

Letter spacing: The space inserted between letters in a word.

Monospaced fonts: Designed with every character, both upper- and lowercase having exactly the same width, thus ‘thin’ characters like ‘I’ and ‘l’ are the same width as ‘fat’ characters like ‘w’ and ‘m’.

Pica: A unit of measurement traditionally equal to about 1/6 inch. (In some Modern type-setting systems, a pica is treated as exactly 1/6 inch.) There are 12 points to a pica.

Point: A unit of measurement, often used to measure type size, equal to 0.013837 inch. Some Modern type-setting systems consider the point to be 1/72 of an inch, or 0.013888 ... inch.

Proportional fonts: Proportional fonts like Times New Roman are designed so that each character has a different width according to its shape; as opposed to monospaced fonts in which all characters have the same width.

Serif and Sans Serif: Two of the major styles of typography.

A Serif is a small cross stroke accentuating the end of the main stroke of a letter in some typefaces. Serif typefaces, also called Roman, are the more traditional style found in books and magazines. They all present a finishing line at the end of the letter form.

Sans Serif as the name suggests is a face without serifs. Text using typefaces that have no serifs, such as Helvetica, Optima or Futura.

Stress: The angle of the thickest part of the curved strokes in a letter form is the stress of a typeface. Stress can be either vertical or oblique, slightly angled to the left. The variation of stroke thickness in letter forms. Some letters have little to no stress, where others have a great deal.

Type families: Groups of related typefaces unified by a set of similar design features. Most type families have a range of styles, bold, extra bold, light, regular.

Type Size: Is measured in points between the bottom of the descender and the top of the ascender. The standard measuring unit for type size is the point (there are 72 points to an inch) Typefaces can have sizes from 4 to 144 points but are generally used in 6 to 72. Type size, also called the point size, is measured from the top of the highest ascenders to the bottom of the lowest descender. To this is added a little extra vertical space above the ascenders and below the descenders. This measure is inherited from the days of metal handset type where the metal blocks had a frame that was not printed.

Typography: In the sense of digital typography the available selection of fonts (type sizes and type styles) and their use in organizing the contents of visual displays.

Word Spacing: The horizontal distance between two words in a line.

x height: The x height of a typeface is the size of the body of the characters represented by the letter x, since x is the only letter that reaches out to all four corners of space. The x height is the height of a lowercase x in any font. Variations of this height can make a font appear large or small in contrast to other fonts, independent of size.

This is a complementary measure to the type size. When a typeface is defined as being a certain size, for instance 24 points, this is only the approximation of the actual number of points from the top of the characters' ascenders to the bottom of the descenders. Within that size the ascenders or descenders can be any size. The x height therefore provides a supplementary measure and constraint.

Words written in uppercase letters do not share this contrast having only baseline and cap height.

ABBREVIATIONS AND ACRONYMS

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

ATC	Air Traffic Control
ATM	Air Traffic Management
ATM R&D CoE	ATM R&D Centre of Expertise *(EEC)*
CRT	Cathode Ray Tube
CWP	Controller Working Position
DIS	Director(ate) Infrastructure, ATC Systems & Support *(EUROCONTROL Headquarters, SDE)*
DIS/HUM	*See HUM Unit*
DMD	Digital Micromirror Device
Doc	Document
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme *(now EATMP)*
EATMP	European Air Traffic Management Programme *(formerly EATCHIP*)
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre *(France)*
EWP	EATMP Work Programme
HDTV	High-Definition TeleVision
HFSG	Human Factors Sub-Group *(EATCHIP/EATMP, HRT)*
HMI	Human-Machine Interface/Interaction
HRS	Human Resources Programme *(EATMP, HUM)*
HRT	Human Resources Team *(EATCHIP/EATMP)*
HSP	Human Factors Sub-Programme *(EATMP, HUM, HRS)*
HUM	Human Resources (Domain)*(EATCHIP/EATMP)*

HUM (Unit)	Human Factors and Manpower Unit *(EUROCONTROL Headquarters, SDE, DIS; also known as ‘DIS/HUM’; formerly stood for ‘ATM Human Resources Unit’)*
ICAO	International Civil Aviation Organisation
InVar	*A material not subject to thermal expansion and contraction*
LCD	Liquid Crystal Display
OS	Operating System
R&D	Research and Development
REP	Report *(EATCHIP/EATMP)*
RGB	Red, Green, Blue *(the three phosphor colours on a CRT)*
RSVP	Rapid Serial Visual Presentation
SDE	Senior Director, Principal EATMP Directorate *or, in short,* Senior Director(ate) EATMP*(EUROCONTROL Headquarters)*
WP	Work Package

CONTRIBUTORS

Reviewers

Alexandra DORBES	EUROCONTROL Experimental Centre, ATM R&D Centre of Expertise
Alistair JACKSON	EUROCONTROL Experimental Centre, ATM R&D Centre of Expertise

The Members of the HRT Human Factors Sub-Group (HFSG)

Document Configuration

Carine HELLINCKX	EUROCONTROL Headquarters, DIS/HUM

Page intentionally left blank