AN EXAMINATION OF THE DESIGN AND APPROPRIATE DEPICTION OF TOPOGRAPHIC INFORMATION ON INSTRUMENT APPROACH CHARTS

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An Examination of the Design and Appropriate Depiction of Topographic Information on Instrument Approach Charts

by

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ABSTRACT

Cartographers create maps to represent the spatial relationships of real world phenomena at a much reduced scale and in a limited amount of space. This restricts the amount of information that the cartographer can portray. One of the main objectives of the cartographer is to present the data in a way that maximizes the communicative properties of the map.

The cockpit of a modern aircraft is a very complex place. The pilot has to contend with information from many different sources. This volume of information requires a high level of concentration in order to operate the aircraft safely. The same holds true for the navigational charts that are used on a routine basis. The pilot must be able to make quick decisions based on the information presented on the charts. If there is too much, or not enough information, the pilot's ability to make effective decisions may be hindered. Maps must be designed to make the task of extracting navigational information as simple and effective as possible.

This research investigates the effects of cartographic generalization on the pilot's ability to extract information effectively from instrument approach charts. Although the International Civil Aviation Organization (ICAO) sets standards for the construction of aeronautical charts, the standard for topography on an instrument approach chart is vague about the amount of information to be included. Twenty pilots were asked to perform two specific map-use tasks. While performing these tasks, subject's eye movements were recorded using the Stoelting Eyetracker/Pupilometer system. The dependent variables of number of fixations and duration of fixations were examined as well as subjective and objective measures of chart complexity.

Data obtained through eye movement recording showed that topographic representation should be kept to a minimum. Certain tasks, however, utilize both aero-navigational and topographic information, hence, some topographic data is essential. A subjective evaluation of topographic information content also revealed that subjects derived some benefit from the presence of topographic data. These results corroborated the eye movement data by indicating that charts displaying a high level of topographic information contributed to inefficient data extraction and difficulty of use.

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1.0 Introduction

Studies show that 59% of all air accidents occur during approach and landing. Of these accidents, 75% are a result of human error (Nagel, 1988). While pilot error is often listed as a probable cause, it usually refers to an all-inclusive term used to describe some breakdown in the human component of the system. It is important to remember, though, that there are usually underlying causes for the error. Increasing aircraft speed and traffic are placing extraordinary demands on the pilot, resulting in much more information to process when making critical decisions. In many cases, no one factor can be singled out as a direct cause. It is possible, however, that one of the contributing factors is a less than efficient design of the instrument approach chart[1].

The purpose of the instrument approach chart is to provide the pilot with the information necessary for an instrument approach to a given runway. Among the information shown on the chart is the instrument approach procedure, missed approach procedures, holding patterns and other aero-navigational information[2]. The aero-navigational information is

1 In the course of this thesis, the terms chart and map will be used interchangeably. Unless otherwise noted, chart or map will refer to instrument approach charts.

2 Examples of aero-navigational information include: minimum safe altitude messages; procedural tracks; navigational beacon locations and radio frequency messages.

essential to the purpose of the chart and must be shown. The instrument approach chart also contains topographic information[3] which aids the transition from instrument to visual flight and provides a geographic reference for the aero-navigational data. There is, however, a little more flexibility in the volume of topographic information that is depicted. An examination of current instrument approach charts reflects that there is no consensus on the appropriate amount of information that should be included. Since the majority of flight takes place either at night or above the clouds, many people have argued that topography is not necessary on such charts. Conversely, there are many, such as D. Lewtas (1992) of the ICAO[4], who argue for its presence. The topographic information may also provide some psychological benefits to the user in that it provides a geographic frame of reference, anchoring the aero-navigational data.

Each instrument approach chart is used for an approach to a given runway along a single path[5], showing a different area while employing what should be a common symbology. Many charts do not. The principal benefit of a common symbolic approach to mapping for this application lies in allowing the user to switch freely between charts with little difficulty. Pilots would not only benefit from a common set of symbols, but also from a common level of information depicted on approach charts. A standardized presentation should provide the user with a similar volume of information

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3 Topographic information may include: height of land, symbolized by spot heights and contours; obstacles; coastlines and other hydrographic features.

4 International Civil Aviation Organization headquartered in Montreal.

5 Each approach to a runway is unique. A single runway has two approaches, one from each direction. Consequently, a single runway requires two instrument approach charts to cover both directions.

to process, making the charts easier to use and resulting in greater comprehension.

In order to standardize the amount of information to be represented, the cartographer must first identify the data relevant to the purpose of the map. Cartographers create maps to represent geographic relationships at a much reduced scale and in a limited amount of space. The real world contains far too much information to show on a single map sheet. As a result, the cartographer must implement the processes of generalization. Monmonier (1991: 25) pointed out that "Reality is three-dimensional, rich in detail, and far too factual to allow a complete, yet uncluttered two-dimensional graphic scale model. Indeed a map that did not generalize would be useless." Although the limitations of scale and space restrict the amount of information that can be shown, the cartographer must still provide enough to allow for effective map use. Essential data must be retained and simplified so that the map is meaningful and correctly represents the geographic relationships.

1.1 Problem Statement

The flight deck of a modern aircraft is a very complex place. The pilot must contend with information coming from many different sources, such as: information from the surroundings; feedback from the aircraft (how the aircraft 'feels' and 'sounds'); data from the aircraft's instrumentation; and navigational information from charts. This richness of information requires a high level of concentration in order to operate the aircraft safely. This point was reinforced by Nagel (1988: 275) who stated that:

> Aircraft pilots must continually maintain an awareness of their situation if they are to conduct a safe flight; breakdowns in this situational awareness caused by faulty acquisition and processing of information represent one of the most serious human factors problems in aviation operations.

Instrument approach charts are included as one of the sources of information for the pilot (see Figure 1.1). The pilot must be able to make quick decisions based on the information presented in the charts. For example, the decision time frame for landing in marginal weather conditions is approximately five seconds, not a great deal of time when the consequences are considered (Bressey, 1976). In normal pre-flight preparation, the pilot has time to study the charts for the intended destination. But, in spite of this, there are still problems associated with chart use.

Specific incidents resulting from problems with chart use have been recorded. On 29 October, 1990, an aircraft on an instrument approach to Watson Lake Airport, Yukon, touched down 75 feet to the left of the runway. Although there were no injuries, the situation could have been much worse. One of the findings of the investigators was that "The crew was not aware of the offset localizer, despite the fact that this information was depicted on the approach chart." (Transportation Safety Board, 1993a: 29). Other examples, while not directly traced to incorrect chart use, may indicate that problems exist with instrument approach charts.

Pilots have to deal with far too much information to memorize the charts and usually, therefore, must refer to the approach chart during flight, and sometimes just prior to the approach. On occasion, the aircraft must be diverted to an airport or approach for which the pilot has not prepared. In these situations, the pilot may be viewing the chart for the first time.

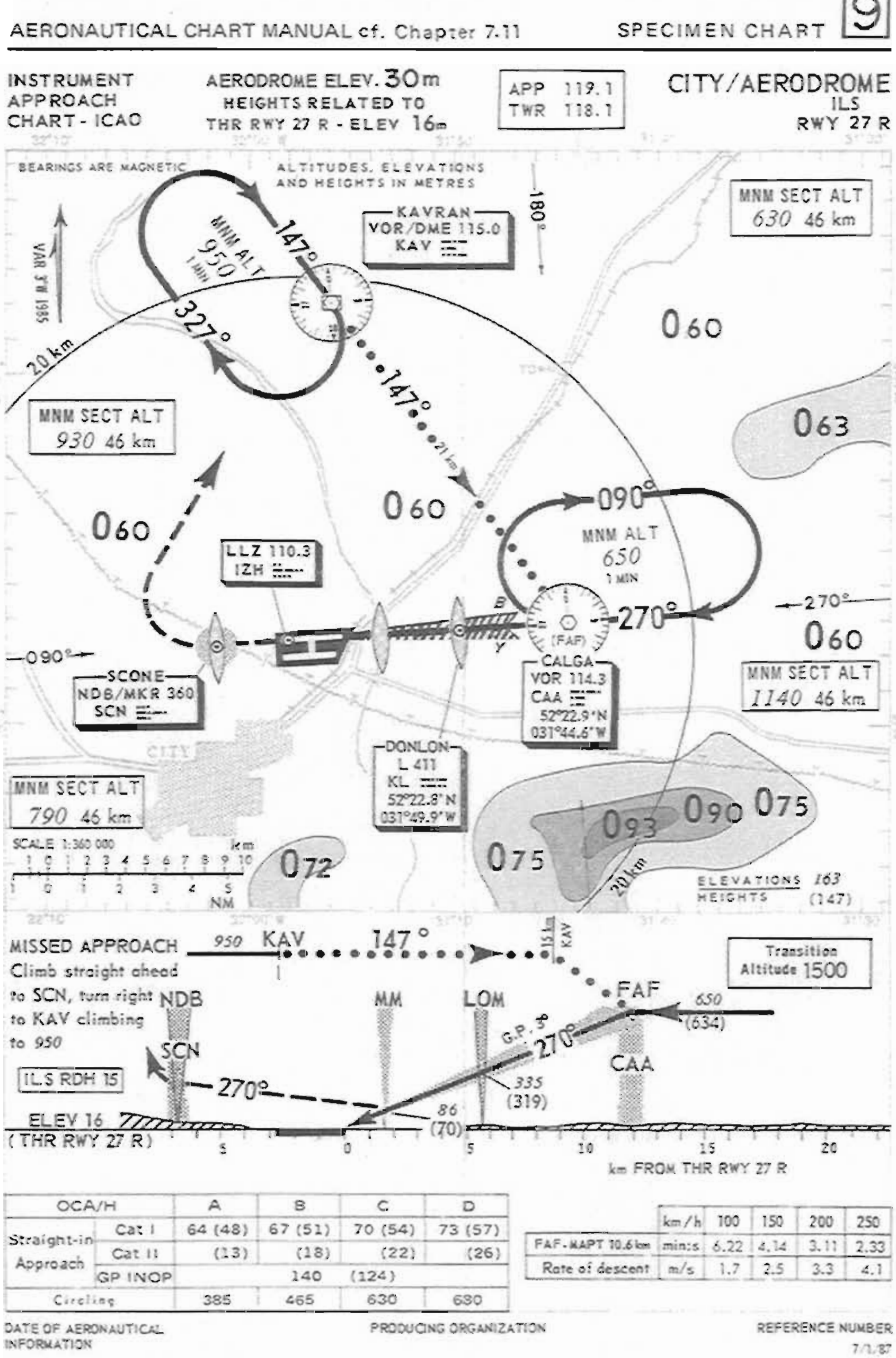

Figure 1.1 Specimen instrument approach chart provided with the *Aeronautical Chart Manual* (ICAO, 1987)

On approach to an airport, whether or not it is the intended destination, the pilot must have charts of the highest accuracy and quality to ensure a safe flight.

On 19 April, 1993, an aircraft crashed while on instrument approach to Brampton, Ontario, fatally injuring the pilot and seriously injuring two passengers. Investigators determined that the pilot descended below the final approach fix altitude before reaching the final approach fix and continued to descend until the aircraft struck the ground. A direct cause for the accident could not be determined, but it was speculated that fatigue was a significant factor. The pilot had experienced a 16-hour day and had to make a sudden and unexpected transition to instrument flight and an unfamiliar instrument approach (Transportation Safety Board, 1994b). The fatigue experienced by the pilot may have contributed to a navigation error that may have been avoided had the pilot known what to expect on the chart. Fatigue has an adverse affect on how a pilot deals with the volume of information on the flight deck. The fact that this pilot was unfamiliar with this instrument approach is also quite significant. With a standardized chart design, the pilot would have a consistent level of information to process, similar symbology, and vital information would be placed in common locations on the chart. As a result of this standardization, the pilot could know what to expect in terms of information and would know where to find vital information. Switching from chart to chart would hold few surprises and the effects of unexpectedly shifting to an unfamiliar chart would be significantly reduced.

The amount of information displayed on the approach chart should conform to established norms. It is crucial that the pilot has the appropriate amount of information on instrument approach charts. If the chart contains too much information, the clutter potentially interferes with data extraction. If there is not enough information, the pilot may not have the proper data to complete the task. In either case, the effectiveness of the chart is diminished and the pilot's ability to make rapid decisions is hindered, which could spell disaster.

With the increasing velocity of modern aircraft, and the increased volume of air traffic, the speed at which a pilot is able to make decisions is very important. Therefore, the problem arises: **"With the wealth of information that can be presented on a single chart, what effect does the volume of chart information have on a pilot's ability to quickly and accurately extract the necessary information?"** Given the potentially tragic consequences of an erroneous decision, or difficulty in making a quick decision, it is very important to understand the implications of design decisions made by the cartographer when constructing these charts. This is especially important now that several agencies are currently converting conventional paper charts to a digital format. The variability in information content and the quantity of included data is a problem that needs to be resolved in order to provide the pilot with the most useful and effective charts possible.

1.2 The Role of ICAO in Standardization

The International Civil Aviation Organization (ICAO) has established a set of standards that are to be used when constructing aeronautical charts. The standards defined by the ICAO have been published in the *Aeronautical*

Chart Manual (ICAO, 1987). This was done in an attempt to reduce the problems that existed due to varying designs of aeronautical charts. In spite of this, there is still enough variation in existing charts to cause concern.

For aeronautical charts in general, ICAO addresses several operational requirements governing the presentation of information that is essential to the charts:

1) Each chart should present data relevant to the function of the chart.

2) Each chart should present data relevant to the phase of flight.

3) The data must be presented in a form that is accurate, free from distortion and clutter, unambiguous, and readable under all normal operating conditions.

4) The selection of colour tints and type sizes must enable the chart to be easily read and interpreted by the pilot in varying conditions.

5) The information must be in a form which enables the pilot to acquire it in a reasonable time consistent with workload and operating conditions.

6) The data presentation must permit smooth transition from chart to chart according to the phase of flight.

7) Each chart must be true north oriented.

8) The sheet size of the chart should be 8.27" x 5.82" (International A5).

(ICAO, 1987: 7-2-1)

These requirements are general descriptions of the information that should be presented on each chart. They are not very specific, however, and are left open to a variety of interpretations. Simply stated, the present guidelines are ambiguous. There are no guidelines governing how much information should be shown, or even how it is to be represented. To further illustrate this problem, the section of the chart manual pertaining to instrument approach charts simply suggests that flight crews should be provided with information to enable them to perform the necessary task:

> The primary function to be satisfied by this chart is to provide flight crews with information which will enable them to perform an approved instrument approach procedure and, where applicable, the associated holding patterns. (ICAO, 1987: 7-11-1)

This guideline, as stated, does not describe how much information is enough. As a result, most charts contain differing levels of topographic information. Similarly, with reference to the topographic information that should be presented, the chart manual recommends that the topographical information pertinent to the safe execution of the instrument approach procedure be included, such as major land masses, significant lakes and rivers (ICAO, 1987). The approach chart manual also states that the scale selected must ensure optimum legibility consistent with the procedure indicated and with the sheet size. Again, this is left open to interpretation and may significantly vary from chart to chart. There is one point that does provide for standardization; the centre point of the chart. The chart should be centred on the radio aid for which the specific procedure is based. This ensures that the positioning of the aerodrome on the chart is standardized. A quick inspection of a variety of charts reveals that this is indeed the case. As a result, a pilot would expect that the aerodrome would always be found at the centre of the chart.

In general, ICAO standards for cultural symbols and topography on aeronautical charts provide only a suggestion as to what should be shown.

This provides little guidance for exactly what should be shown. The standards, for example, state that:

> Relief must be portrayed in a manner that will satisfy the chart user's need for:
>
> a) orientation and identification
>
> b) safe terrain clearance
>
> c) clarity of aeronautical information when shown
>
> d) planning
>
> (ICAO, 1987: 7-2-8)

The ICAO chart manual contains suggestions for line symbolization; specifically, how procedure tracks and other features are to be symbolized, but is lacking in specifics. Standard 2.10.1, for example, states that "International boundaries must be shown but may be interrupted if data more important to the use of the chart would be obscured."(ICAO, 1987: 7-2-7) There are no specific written design specifications for representing symbols, but sample drawings are provided as draughting illustrations. There is, however, no mention in the manual of line weights, dimensions, or specifications on spacing of dashes or length of dash. Apart from specifications for depiction of lines, the chart manual is equally vague when describing other design elements, for example, contour envelopes. The use of spot heights are discouraged in favour of contour envelopes, which are smoothed contour lines that surround or encircle areas of a given height. Even though these contour envelopes are discussed in the chart manual, they are not widely used. Many countries, when producing charts, continue to use conventional contours, spot heights and combinations of both elements.

It appears, then, that ICAO is not fully accomplishing its goal. Standardization of aeronautical charts is not being achieved. This problem seems to be rooted in ambiguities that exist in the ICAO *Aeronautical Chart Manual*. The inconsistencies on aeronautical charts are a result of different interpretations of standards, or in some cases, a disregard of the ICAO chart manual. The *Aeronautical Chart Manual*, as it is written, is not a collection of standards and specifications, but a list of recommendations, none of which is mandatory. The manual should be revised to be more specific, should state what must be done, what must be shown, and then give detailed instructions on exactly how to incorporate the information to receive ICAO approval.

These standards, in some cases, have been changed to accommodate countries that are less technically advanced and unable to produce charts comparable to those of developed nations. There are also cases where countries have decided to act independently, disregard ICAO recommendations and produce charts based on their own design. It would be in the best interest of all nations to provide standardized charts of the highest quality. ICAO should precisely define and maintain standards of the highest degree. Compromising standardized chart production can only diminish the safety of the flight by placing undue pressure on the pilot to read and interpret inadequate charts.

1.3 Comparison of Chart Designs

Charts currently in use world-wide are variously constructed and have different design properties. To illustrate the problem of non-standardized chart design, a comparison of two charts (Figs. 1.2 and 1.3) shows

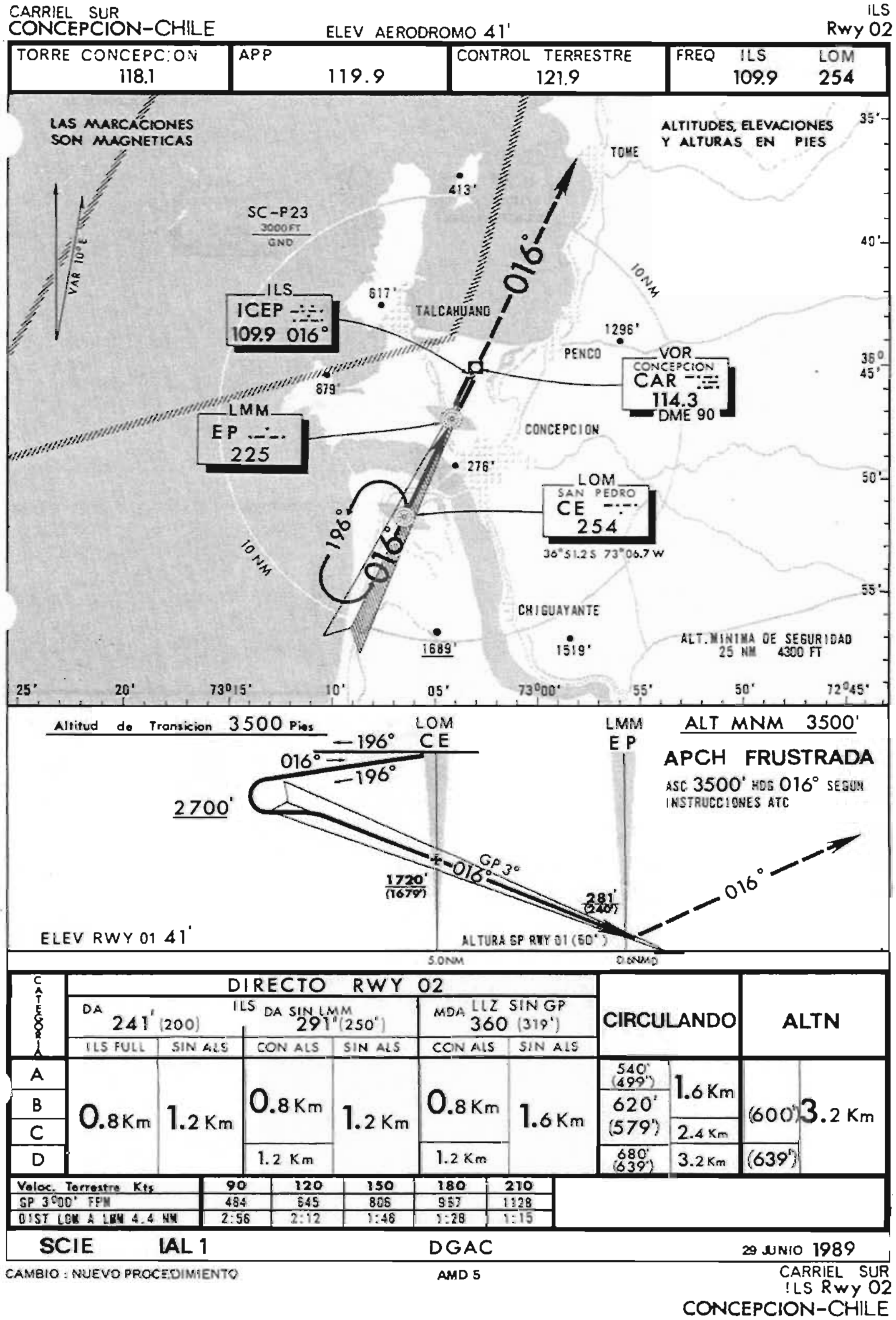

Figure 1.2. Instrument approach chart for an ILS approach to runway 02, Conception, Chile

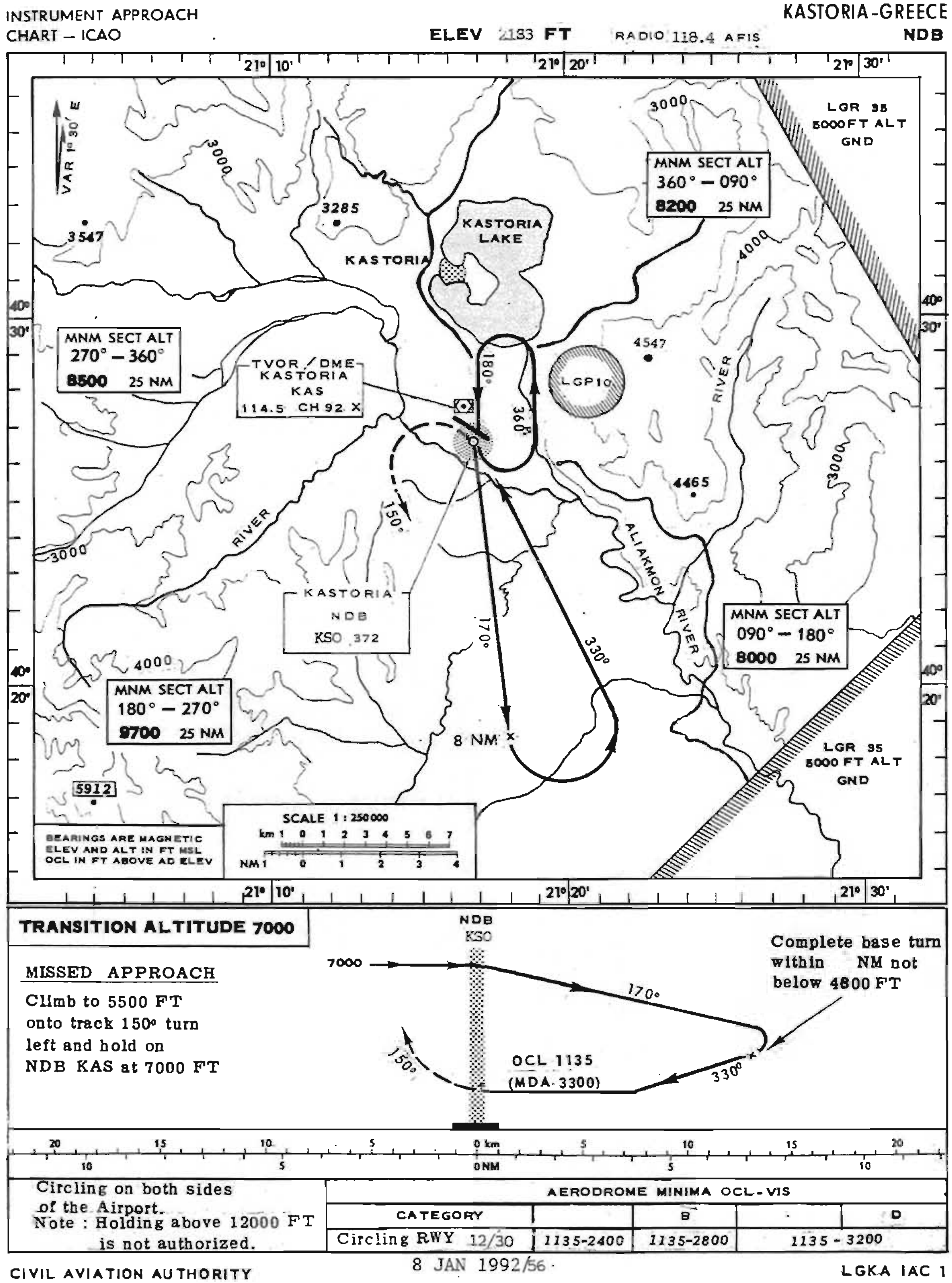

Figure 1.3. Instrument approach chart for an NDB approach to Kastoria, Greece

that there are few similarities. Figure 1.2 is a chart depicting an approach to Conception, Chile and Figure 1.3 shows an approach to Kastoria, Greece.

The variations present in all aspects of chart design include line weights, symbol representation, amounts of information displayed, and the lay-out of the chart. A discrepancy in line weights may not be a problem provided that a visual hierarchy of chart information is maintained. First of all, the pilot must be able to differentiate between aero-navigational and topographic information. Secondly, the pilot must be able to identify the different symbols used to represent topographic features. There must be no uncertainty as to what feature each symbol represents. One serious problem is that the visual hierarchy of information is not always maintained. By circumventing this structure, the cartographer is contributing to confusion in symbology used to represent aero-navigational and topographic information. Line weights, lengths of lines, spacing between dashes, and design of other symbols used to represent aero-navigational data all vary greatly on these charts. These technical differences are summarized in Table 1.1.

Table 1.1. Summary of measurements and descriptions of design elements used to represent aero-navigational data on instrument approach charts.

CHART	Approach Procedure Track			Missed Approach Procedure Track			MSA* Message	Leader Lines	Approach Zone**			Navigation Beacon Id	
	Line Weight	Arrow Head Length	Arrow Head Width	Line Weight	Dash Length	Dash Spacing	Line Weight	Line Weight	Contain. Line Width	Diagonals Line Width	Diagonals Spacing	Shadow	Line Weight
CHILE Fig. 1.2	.18"	.225"	.070"	.022"	.135"	.025"	N/A	.004"	.005"	.004"	.012"	Y	.007"
GREECE Fig. 1.3	.027"	.2"	.066"	.025"	Varying	Varying	.013"	.012"	N/A	N/A	N/A	N	.007"

* Minimum Safe Altitude

** Area represented by triangular shape surrounding the vectored approach procedure track

There are many differences in the chart designs that are quite obvious. Initially, the size difference of the charts is most evident. The image area of Figure 1.2 is 11.8 cm x 18.5 cm as compared with the 18.0 cm x 25.5 cm of Figure 1.3. The difference of scale (if any) is not immediately evident since Figure 1.2 does not contain an expression of scale. The scale of Figure 1.3, however, is expressed as 1:250,000, also symbolized by linear scales portraying both kilometres and nautical miles. One item that may provide some clue of scale is the ten nautical mile circle on Figure 1.2, which is not shown on Figure 1.3. The ten nautical mile circle of Figure 1.2 may be compared with a point indicated on the approach track of Figure 1.3, eight nautical miles from the locator beacon. Comparing these two items shows that the scales of the charts do not match. Apart from variations of size and scale, another major difference is that Figure 1.3 is annotated in English, the international language of flight, whereas Figure 1.2 is in Spanish.

With respect to topographic information on the two charts being compared, both show major water features, but there is a difference in how this information is symbolized. Figure 1.2 depicts rivers and bodies of water in a grey tone (approximately 30% black) with no coastline. Figure 1.3 also represents water bodies with a grey tone similar to that of Figure 1.2, but uses a solid black line to represent coastline and rivers. The rivers shown on Figure 1.3 could be easily confused with the roads which are symbolized in a very similar manner. The same problem exists for Figure 1.2 on which the roads are represented by a grey, linear symbol very similar in character to the river symbol. Both charts show spot heights, but Figure 1.3 also shows contours at an interval of 1000 metres. The contours add a great deal of visual information to the chart, but further analysis is required to determine whether or not their contribution to understanding the terrain outweighs the clutter they add to the map.

Urban areas on Figure 1.3 are symbolized as a dot pattern contained with a solid black line. This symbolization is very different from that used on Figure 1.2. Urban areas on Figure 1.2 are represented in a pattern consisting of 'L-shaped' characters with no containing line. One additional comment pertaining to topographic information is that all information on Figure 1.3 (Kastoria) is shown in solid black. The topographic information on Figure 1.2 (Conception), however, is shown in a grey tone, but labeled in black. The latter technique provides a greater separation in the two layers of information (topographic and aero-navigational) making the chart easier to read. The information on the Kastoria chart, however, does not provide the same visual hierarchy of chart information, forcing the reader to struggle with identification and interpretation of the aero-navigational data.

The differences in chart information are not limited to the topographic information. Both charts also differ in how the aero-navigational information is presented. Since this information is intended to be in the foreground of the charts, that is, the information to be read first, it is printed in a solid black. The topographic information supporting the aero-navigational data should be of a lower visual priority and printed so that it does not immediately attract the reader's eye. This effect is achieved quite easily on Figure 1.2, but it is less evident on Figure 1.3. There is a very poor visual hierarchy of information on Figure 1.3 (Kastoria). The aero-navigational information is not as prominent as it should be on this type of map. In fact, there are some roads symbolized with lines almost as thick as the one used to represent the procedural track for the aircraft. Instrument approach charts usually contain small blocks of text which contain messages such as radio frequencies, minimum safe altitudes and other notices crucial to the approach. Both charts present the necessary radio frequencies directly on the chart in message blocks. Figure 1.2 also has a shadow effect added to the message blocks to give them a little more visual prominence. As well as presenting the frequencies on the map, Figure 1.2 also lists them in the margin. Figure 1.3 does not repeat the frequencies in the margin, but does show minimum safe altitudes on the chart, a vital piece of information not given on Figure 1.2.

Aeronautical charts have highly specific purposes and designs to suit the phase of flight for which they are intended. A standard set of symbols is normally used when designing a chart, leaving the amount of information presented as the remaining variable. As demonstrated, there are many differences in the design of aeronautical charts. While the depiction of geographic and aero-navigational features may be relatively standard, there are many differences in the technical execution of the symbols which make them easily confused with other symbols. The problems presented by inconsistent symbolism are further compounded by differing volumes of information. The changing symbolism and amounts of information must be problematic, since the user can never be sure of what information there is to work with. In order for pilots to use charts efficiently and effectively, an appropriate level of information for depiction on the chart must be determined. The standards contained in the ICAO chart manual need to be refined and restated to give a more specific set of guidelines for chart production. Revising the guidelines will clarify for the cartographer exactly what is to be shown. Cartographers need precise guidelines to achieve a consistent level of generalization. Eliminating the 'guesswork' from the generalization routine will result in a more consistent level of chart information for the pilot to process. To ensure that the charts are produced with the most efficient level of information, the perceptual implications of generalization must be fully understood. Otherwise, how can cartographers effectively produce a chart that provides the greatest benefit to the pilot in terms of information content and ease of use?

1.4 Objectives

There are several questions that the cartographer should ask when constructing a chart: How much topography is enough? How much is too much? To answer such questions, the following problems must be addressed:

1. What effect does not showing topography have on the pilot's ability to perform a task?

2. What amount of topographic information should be displayed to enable the pilot to effectively perform the task?

3. If there is a lack of physical topographic information, would prominent cultural landmarks, buildings, and other man-made landmarks be useful to the pilot?

To gain an understanding of these design problems, it is necessary to know the impact they have on how a subject reads a map. To accomplish this effectively, the reader must use the map in a way that replicates common use situations while monitoring the effects of the design decisions. By recording subjects' eye movements, the experimenter can examine precisely how a subject views the chart, rather than relying on a subjective response or evaluation. In addition to the eye movement record, an interview of the subjects should uncover cognitive aspects not revealed by the system, such as perceived complexity. How a chart is perceived by the user must be considered along with the objective measures obtained through the eye movement recordings. If the user is not 'comfortable' with the map, even it has been designed adequately, it may be as difficult to use as a poorly designed map. What this study aims to investigate is whether too much information, and likewise, not enough information depicted on instrument approach charts present a hindrance to their effective use. The eye movement recordings should help to identify the amount of displayed information necessary for effective, efficient use by the pilot.

If presented with a standardized, common level of information, the pilot may more readily extract the information needed during the approach phase of flight. Standardizing the amount of information portrayed should reduce the time needed to become familiar with the chart, therefore making more efficient use of time on the flight deck. Before standardizing the amount of information, efforts must be taken to determine the most effective amount of information to portray. This research will help to identify two principal areas of concern:

1. Problem areas in the graphic design and presentation of information on the charts.

2. The most effective amount of topographic information for portrayal on the chart. This will be accomplished by comparing patterns of subjects' eye movement while reading a series of instrument approach charts chosen for the variety of amounts of topographic information they display.

The eye movement data collected in this experiment will help to reveal some of the problems surrounding chart design. Some design-deficient charts that may create frustration, but which are currently used by pilots, will be examined to identify both the favorable points and the troublesome areas of the charts. In addition to the identification of the problem areas of chart design, the most efficient level of chart information portrayal will be determined. By standardizing the charts at the most efficient level of data, the quality of the instrument approach chart can be improved, thereby increasing the safety of flight.

In Chapter 1 some of the problems associated with instrument approach charts have been introduced along with a brief discussion of where improvements might be made. The remainder of this thesis is organized as follows: Chapter 2 reviews the literature on the benefits and disadvantages of the concept of standardization in cartography and also briefly outlines the principles of generalization. Chapter 3 focuses on background research in the area of eye movement recordings, particularly as it has been applied to cartography, and how eye movement studies have been adapted to study problems facing the pilot on the flight deck. The testing procedure, facilities and equipment are outlined and described in Chapter 4. Experimental results are presented in Chapter 5 with a brief discussion of the experimental findings. Chapter 6 contains an in-depth discussion of the results with conclusions and recommendations for further research and suggested improvements to instrument approach charts and aeronautical charts in general. The thesis concludes with a bibliography and appendices of supportive information for the research.

Chapter 2
Standardization and Generalization of Maps and Applications to Aeronautical Charts.

2.0 Standardization in Cartography

The symbols used in cartography have been referred to as components of a natural language (Head, 1984). Each map tells a story. In maps, the symbols are the words. Map symbols used in different contexts can have different meanings, just as some words can have more than a single meaning. A red dot on one map, for example, may not represent the same feature on a second or subsequent maps. In order to understand the meaning of the symbols and the message contained in the map, the reader must refer to a legend, or an explanatory list that would act as a dictionary (Raisz, 1962). Different types of maps will necessarily use different sets of symbols. Thus, maps usually have a unique set of symbols in their legend.

It has been suggested by Nikishov and Preobrazhensky (1971) that forcing the map reader to learn a different method of symbolization for each map discourages use of the map. Similarly, Monmonier (1991) stated that standardization promotes efficiency in both map production and use. Therefore, by standardizing the symbolization used in mapping, the reader would know what each symbol represented. Thus, the ease of map use may be facilitated, thereby making the map user more comfortable reading maps.

Learning what a different set of symbols represents requires additional time in the map reading process, time that some users may not have. There may also be cases where a map legend is not available. If the reader, therefore, is unable to interpret the symbols, the map may be less than useful. An analogy can be drawn to literature. If the language in which a book is written must be learned before it can be read, there may be very few books read.

There are several conventions of map design that already exist that could be adopted as standards for most, if not all, maps. On colour maps, for example, blue is usually selected to represent water and other hydrographic features. Board (1973) points out that existing conventions may be so well established that they can provide the basis of standardization without experimental research. Different symbolization options should be investigated, however, to determine if there is a better method of representation. The best symbolization technique, once determined, could then be adopted as a standard. The resulting map design standards could make use of a common symbol and colour set for all maps that are produced, thereby establishing a common lexicon for maps. Standardizing symbolization schemes, for example, works well in the topographic map series of many nations where standardization and habituation of use has led to the adoption of map symbol conventions. Thus, in certain circumstances, standardization of map symbols is preferred, and perhaps, even necessary.

2.1 Advantages and Disadvantages of Standardization

Standardization of maps is a proposition that has been debated for many years. Many cartographers, such as Robinson (1973), Board (1973) and

Meine (1978) have debated the advantages and disadvantages of standardization in cartography. Both Robinson and Board agreed that there was merit in each argument; however, Board seemed to indicate that there were more problems than benefits associated with standardization.

The **disadvantages** of standardization as indicated by Board (1973) and Robinson (1973) include:

1. <u>Problems with language - Standards written in English may not translate into other languages</u>.

   Board (1973) wrote of problems with language. He stated that design principles described in English may not necessarily have equivalents in other languages, a problem also pointed out by Meynen (1969). In his attempts to establish a dictionary of technical terms in cartography, Meynen encountered several expressions that had varying meanings when translated into different languages. One such term that takes on different meanings when translated, for example, is the German term 'navigationskarte', the English term 'navigation chart', and the French term 'carte marine'. Although each term is a translation from the other language, the English and German terms refer to navigation charts in general, (both nautical and aeronautical) whereas the French term refers to nautical charts only.

2. <u>Cultural differences with respect to symbol and colour selection</u>.

   Board (1973) points out, as does Robinson (1973), that there appear to be many cultural conflicts with respect to the selection of colours and the choice of symbols. There are many differences, such as those that exist between languages and alphabets, that would have to be eliminated before map symbols could be standardized. Robinson (1973) stated that different alphabets used in some languages, for example, Roman and Cyrillic, present problems in the approach to a common map design. This would result in different symbolization of place names and labels found on maps which would impact the entire map design.

3. Reduced communicability.

Robinson (1973:20) warned that:

> A standardized treatment might, in many instances, result in less effective communication than a design more carefully fitted to the objective. A thematic map attempts to evoke in the minds of viewers the same image that the cartographer had. To realize that objective most efficiently may require special treatment because of the complications of geography, perception and objective.

4. A standardized system does not allow for varying abilities of map users.

Robinson (1973) also stated that all map readers are not alike and that each has individual preferences. The level of experience of the map user is quite variable. Differences in abilities among members of a user group would tend to make the standardization of maps difficult.

On the other hand, Robinson (1973) pointed out that there are several **advantages** to a standardized approach to cartography:

1. The same symbolism would always mean the same thing to anyone, regardless of nationality.

Robinson (1973) stated that by using a standardized system of symbolization, the symbols would mean the same to all map users, regardless of nationality or language. Such a system would be agreed on internationally. People could be taught that a certain symbol would have a specific meaning. There are several symbols that have universal meaning: The stop sign, for example. The red octagonal shape of the stop sign virtually has the same meaning worldwide. Once people learn what the symbols mean, they could understand what each represents. Less reliance on legends to explain what the symbols mean would be the end result.

2. <u>Once established, the system would not vary and there would be less dependence on map legends</u>.

Meine (1978) stated that cartographic communication could be improved through the development of standardized symbols and cartographic representations by developing an alphabet of graphics. Applied to cartography, map users would eventually have little need for map legends.

3. <u>Assuming the standardization to be systematic, it would be easier to teach</u>.

Robinson (1973) assumed that this system would be systematic in its approach which would make it easier to teach than current methods of symbolization.

4. <u>Presumably, a standard set of symbols would reduce the work of cartographers because there may be less concern with map design</u>.

Finally, Robinson (1973) stated that standardization would benefit the cartographer by reducing the amount of design decision-making. The cartographer would be given the data to insert into a set methodology which would result in a map designed by convention. With design templates established for a series of maps, cartographers would likely have to worry less about map design and the consequences of their decisions for individual charts. This point holds immense implications given the current computerized production environment; the cartographer need only select the appropriate symbol and apply it to the data.

2.2 Application of Standardization to Thematic Cartography

Standardization in thematic cartography has been attempted on several occasions for both tourist and economic maps in Eastern Europe (Ratajski, 1971; Pustkowski, 1978). Pustkowski (1978) examined the state of tourist maps in the former German Democratic Republic (GDR). He noted that standardization of these maps should not be difficult, as their focus was relatively narrow. Moreover, he stated that standardization was important to the development of maps and would also enhance their value to the user. Clarke (1989) conducted a study to investigate the efficiency of point symbols used on tourist maps in Britain. It was noted that symbols which have a wide spread use were found to be more efficient because of their familiarity. Clarke (1989:110) concluded that "If a standardized symbol set could be used in all tourist publications and signposting this would increase user familiarity and assist in comprehension." As users learned the graphic 'language' the map's message could be more readily interpreted resulting in more efficient use.

Although cartographic standardization appears to be of great benefit, it is not without its problems. Robinson (1973) pointed out that it would be difficult to get people to agree on the need for standardization. Furthermore, Robinson was not completely convinced that standardization was a good thing. He felt that while forcing the map to conform to a pre-determined design may in some ways improve its level of communication, it would in others, diminish the overall quality of the thematic map. Yet another point to be considered is that the system of symbolization must be open ended to allow for technological changes and advances. In other words, there is a constant need to develop symbols to describe and portray new phenomena as they are developed.

While some success has been experienced with tourist maps, it appears that the development of one system of symbolization applied to thematic mapping as a whole would be an extremely difficult task. This point was also expressed by Arnberger (1974) who stated that the application of standardization to thematic cartography and the field of cartography in general, was virtually impossible. He claimed that the discipline and the topics mapped was too diverse to make standardization feasible. If a common symbolism was developed to be applied to all maps, the number of symbols required would be immense. Cartographers could not take advantage of the versatility of some symbols in that each one could only have a single meaning. There are, however, areas within the discipline of cartography in which standardization could be applied. One such area is aeronautical charting where the focus of the product and the variety of phenomena to be represented is much narrower.

2.3 Standardization of Aeronautical Charts

A degree of standardization appears to have been achieved for certain types of maps with specific purposes. Examples include geological maps, topographic maps, and nautical and aeronautical charts, all of which employ map symbols that are relatively though not uniformly standard for each category of map. The application of standardization to these maps has not been that difficult since their purposes are very specific. Furthermore, in the case of nautical and aeronautical charts, both the user group, and the training of its members to use the charts are very specific. As a result of the specialized training of the user group, several of the obstacles facing standardization have been reduced or eliminated. Consequently, navigational charts can be distributed to users in several different nations without regard to differences in language or culture.

Other attempts at standardization result from international acceptance. The language of flight, for example, has been established as English and this is reflected on most aeronautical charts. Ormeling (1978) reported that many of the successes of standardization resulted from similar international agreements. International organizations, Ormeling (1978) suggested, would provide the mechanism to monitor the development of standardized symbolization schemes.

As instrument approach charts are intended for an extremely specific user group and task, it would thus appear that standardization of aeronautical charts is both desirable and feasible. Contrary to Robinson's (1973) assertions that standardization would result in reduced communicability, in this instance, standardized designs could improve the quality, useability, and readability of instrument approach charts. On a standardized chart, the pilot would know exactly what each symbol meant, where to look to find the necessary data, and would encounter approximately the same level of information. It appears that aeronautical charting could only benefit from standardization. This point is underscored by Guelke:

> Aviation charts . . . need to be used and understood by peoples of many nationalities. It is important in this case that a standard set of symbols be devised and learned by those who will be using such charts.
>
> (Guelke, 1979:67)

Standardization of aeronautical charts has become progressively more important. Flights have become much longer, and the number of countries that now may be over-flown during a given flight have dramatically increased. But, inconsistencies are not a new problem in aeronautical charting, as documented by Sebert (1986). He wrote of the importance of the British Commonwealth Air Training Plan and the war effort on the development of the first aeronautical charts in Canada. The Second World War created a need to achieve significant chart coverage of Canada for allied air crews training there. The charts being constructed in Canada, however, were vastly different than those being used in Britain and Europe. For the last few months of their training, air crews used charts of Canadian terrain that were constructed using British chart standards. This was a duplication of effort that could have been avoided had some international agreement governing the design and symbolization of the charts been in place.

As a result of chart incompatibility, the air crews had to break their training schedule in order to learn how to read a different set of charts. Later, when the United States entered the war, a co-operative effort was reached between Canada and the U.S. in the preparation of aeronautical charts. The Canadian pilots, however, were trained on charts at scales different from those the Americans were using. As a result, there was considerable disagreement over what scale should be used on the new charts.

In the formative days of commercial aviation, there was no organization to monitor or regulate the construction of aeronautical charts. Each country, therefore, developed its own charts to individual standards and with unique symbolization. In the early days of air travel, this would not present a great problem since flights generally were rather short. But when international flight was involved it became a serious problem and remains so, even on what may be considered a domestic flight. Flights between Halifax, Nova Scotia and St. John's, Newfoundland routinely overfly the islands of St. Pierre and Miquelon, both possessions of France. Canadian flight publications, however, do not contain charts for the airport on St. Pierre, as was discovered by a pilot wanting to land there after declaring an in-flight emergency (Transportation Safety Board, 1993b). The charts for this airport are produced by France with differing designs than Canadian charts, despite the fact that these islands are surrounded by what is primarily Canadian airspace.

The greater distances involved in international flights mean that air crews can expect to encounter charts from many different countries. Air crews may encounter different symbolization schemes from chart to chart, with the potential for confusion among the cartographic symbols used. An example of this problem was recently reported by the Confidential Aviation Safety Reporting Program (CASRP). Class "F" airspace on Canadian charts is considered to be an "Advisory" or "Restricted" zone. On American charts, however, Class "F" airspace is considered to be a prohibited area, "Military Operations" or "Restricted" area. Similar symbology with different meaning such as this can result in serious confusion with extreme consequences. To alleviate this problem and remind pilots to use the proper charts, Canadian charts contain the disclaimer "Warning: Refer to current U.S. charts and Flight Information Publications for information within U.S. airspace." (Transportation Safety Board, 1994a) With standardization, such warnings would be unnecessary and a great deal of confusion and extra data on the chart could be eliminated.

In addition to concern about standardizing symbols for geographic features, the style and size of text used on aeronautical charts is important. Any labels for features or denotative information, such as spot elevations, compass directions, frequencies of radio beacons, and the like, must be legible under a variety of lighting conditions. Considerable work has been done with typefaces used on charts. It is stressed that cartographers take great care when indicating digits on charts so that there is little chance of confusion (Lewtas, 1992). Similar care should be taken when portraying topographic features. It is just as important to correctly identify all chart symbols as it is for text or digits. If the pilot must struggle to determine whether or not a line represents a road or a river, valuable time is lost.

Within cartography in general, there have been other pressures for standardization. These initiatives, for the most part, were a result of the increase in computer technology used in cartographic production. Greater reliance on digital cartographic methods has resulted in greater demand for the transfer and interchange of digital spatial data. In order to facilitate this interchange, the definitions of various cartographic objects and the format of data require standardization. Several committees were formed, starting in

1982, under the umbrella of Working Group IV of ACSM[6]. These committees were to formulate digital cartographic data standards covering topics that included:

1. The identification and definition of cartographic objects;
2. Specifications for spatial data transfer;
3. Quality of digital cartographic data;
4. Descriptions and models of cartographic features.

The standardization initiatives discussed by the ACSM Working Group pertain mostly to communication between computer systems, computer software, and the interchange of data among cartographers. But the initiatives also reflect the importance of data communication from the cartographer to the map user. Map data must be conveyed to the user in the most efficient manner possible. The user in many instances is presented with maps displaying similar subject matter while representing different areas. When maps have common purposes, cartographic communication may be improved by standardizing the symbols and levels of generalization. A standardized visual presentation should reduce the effects of some of the variables in the map reading process, thereby eliminating problems of inefficient extraction of information from the map. Most cartographers agree with Monmonier (1991:35) who states that "standard symbols, designed for ready, unambiguous recognition and proportioned for a particular scale, are

[6] The committees formed under the auspices of the American Congress on Surveying and Mapping (ACSM) and the United States Geological Survey (USGS) were: The National Committee for Digital Cartographic Data Standards (NCDCDS) formed in 1982; The Standards working Group of the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC-SWG) formed in 1983; and The Digital Cartographic Data Standards Task Force (DCDSTF) formed in 1987.

common in cartography and promote efficiency in both map production and map use."

Although topographic maps, nautical charts, and aeronautical charts, for the most part, have each been standardized with respect to the symbols used, there has been little discussion about standardization of the amount of data that should be presented. This is an issue that becomes increasingly important when the maps must be used under constraints of time and less than ideal conditions. When dealing with aeronautical charts, for example, the ICAO chart production manual does not specify how much data is enough, or how much is too much. As a result, it is difficult to obtain a consistent level of information. The 'human' factors surrounding generalization of the data must be reduced in the decision making process. The standards should be expressed in the most specific manner possible and followed precisely as stated. Giving the cartographer precise instructions will reduce the variability in the generalization process. Standardization can be achieved if the principles of cartographic generalization are applied in a consistent manner on all charts.

2.4 Cartographic Generalization

Cartographic generalization, for the most part, has been performed by cartographers as they proceed through the design and production of a map. Brassel and Weibel (1988) stated that generalization is a human activity involving intellectual functions. The cartographer must make decisions during this process regarding which features to retain and which to discard. Muller (1991) discussed attempts to establish a series of rules for generalization. He commented on the individuality of generalization and the difficulty of the process to get cartographers to explain this function. He stated "This process has the advantage of promoting a formalization of the generalization process which, in the minds of many cartographers, remains somewhat of a mystical operation whose essence cannot be easily shared" (Muller, 1991:139). Although cartographers have had great difficulty defining the generalization process, it must be clearly understood to obtain maps of consistent design and information content.

Generalization of approach chart data should also be carried out to a level that will make the charts more readable and more useful to the people using them. Cuff and Mattson (1982), point out that complex map features are generalized to an extent that is consistent with the map's purpose. Cartographers must not forget, as Dent (1985) reminds, that poorly performed generalization can cause the whole map effort to fail. DeLucia (1976) also makes the point:

> The most useful and meaningful standard against which all maps should be designed and subsequently evaluated is function. From the beginning we must design our maps to enable some human user to perform some functional act or operation. To properly evaluate our maps once created we must conduct objective experiments the results of which must enable the designer to rank his map specifically in terms of how efficiently it permitted its users to execute the functions specified in the original design problem (DeLucia, 1976:143).

The cartographic representation of spatial relationships poses several problems. Since maps are, almost by definition, at a scale reduced from the reality they portray, not only must the dimensions of the selected features to be mapped be made smaller, the distances separating these features are also reduced. This is true not only for point symbols used on maps, but also for the detail contained in the representation of a line. As the representation of map data becomes closer in detail to reality, the map becomes more crowded and visually complex. Cartographic information overload, therefore, hinders effective communication of the map and makes data extraction very difficult. To enhance the communicative properties of the map, the cartographer must select the points that must be represented in order to maintain a reasonable shape and representation of the feature. On a small scale map, a river or a section of coastline could be shown as a curving line to reflect its character, but if all the smaller twists and turns were included, it may only serve to clutter and make the line less readable.

One of the main objectives of the cartographer is to present geographic data in a way that maximizes the communicative properties of the map. This may be accomplished by eliminating data that is not pertinent to the purpose of the map, or by eliminating data that while pertinent to the map, reduces the effectiveness of communication. Cartographic generalization can be summarized as the process that cartographers use to reduce the amount of data portrayed, thereby converting the data to something meaningful, and ultimately achieving the necessary objective of clarity in communication.

2.5 Elements of Generalization

Robinson *et al.* (1984:150) have identified four categories of processes that make up cartographic generalization. They are:

1. **Simplification** - the determination of the important characteristics of the data, the retention and possible exaggeration of the important characteristics and the elimination of unwanted detail.

2. **Classification** - The ordering or scaling and grouping of data.

3. **Symbolization** - The graphic coding of the scaled and/or grouped essential characteristics, comparative significances, and relative positions.

4. **Induction** - The application in cartography of the logical process of inference.

Cartographic generalization in itself is too broad a topic to be covered in a single study. The aspect of generalization of greatest interest in the present study is the process of simplification. Simplification will be examined with respect to the selection of topographic features for display and the representation of cartographic lines.

The process of simplification includes: the elimination of unnecessary topographic features; smoothing lines; and the reduction of the number of data points used to represent a line. Simplification enables the cartographer to fulfill the goal of producing maps that are effective in their communicative properties. When applied to the topographic information for instrument approach charts, the data that will make the chart most effective will be retained while excess data that clutters the chart will be eliminated. The techniques of simplification can be applied to all charts to a similar extent. This will ensure that all charts are symbolized in a consistent manner with the same volume of information. The major problems encountered with current charts may well be a result of generalization that is not applied in a consistent manner from chart to chart. Muehrcke (1986: 75-76) stated that "the aim of generalization is to produce clear and legible representations at different map scales. Problems in map use arise because the degree of generalization tends to vary from place to place and from one phenomenon to another." This inconsistency may cause many different problems for the map user, such as overloading maps with data that clutters the map, with the result that accurate, efficient map use is inhibited.

Monmonier (1991) pointed out that the value of a map is judged by how well the generalized image reflects the features it symbolizes. The map must present a concise message that enables the map reader to extract the most from it. Intelligent decisions must be made to retain certain vital geographic features for use by the reader. The cartographer must selectively reduce the amount of data. Some unnecessary areal features may require elimination. At the same time, care must be exercised to maintain critical points and the caricature of original lines (Douglas and Peucker, 1973). Since the function of aeronautical charts can be so precisely defined, so to we should be able to define an appropriate level of generalization. As any other type of map, aeronautical charts should be generalized to a standardized level of geographic and navigational information, contain a standardized set of symbols, and be designed to conform with a standardized set of specifications.

This chapter has outlined the advantages and disadvantages of cartographic standardization. The conclusion is that aviation can only benefit from chart standardization. To benefit the air crews and for greater public safety, every effort should be taken to ensure the standardization of charts. This action would minimize, or even eliminate any possible confusion arising from using a number of charts covering aerodromes in different countries. In order to standardize, however, the most appropriate amount of data to be shown must be identified. The aeronautical charts could then be generalized to reflect the most appropriate amount of data. The various processes of generalization can be employed by the cartographer far more effectively if the goal has been determined. In order to accurately determine what is effective, a technique to evaluate the map readers' performance while using the maps must be used. Eye-movement studies have long been used to evaluate the design of graphics and in recent years, to evaluate the design of maps. Chapter 3 will provide a summary of eye-movement research and its implications for the current research.

Chapter 3
Related Research

3.0 Early Eye Movement Research

Early studies in eye movements were conducted primarily outside of the field of cartography. Among the earlier applications of eye movement recordings was the work of Buswell (1935). Using works of art as stimuli, Buswell conducted studies examining subjects' eye movements to identify areas of greatest interest. In the experiment, subjects performed both task-specific and free scans of the stimuli. Buswell discovered that the pattern of subjects' eye movements were different when performing a specific task than when performing a simple free scan of the stimulus. When subjects conducted free scans of the stimulus, the resulting pattern of eye movements was more random than for task specific scans.

Many years later, Yarbus (1967) found that as subjects scanned a picture, they searched for elements important to understanding the purpose of the graphic. He also found that subjects' eye fixations were concentrated on the areas which contained information potentially important to completing the task. This discovery was later confirmed by Tversky (1974) and also by Antes (1974). Antes found that initially, subjects made many fixations of short durations on the more informative areas of the map. As viewing progressed, subjects made longer fixations on less informative areas. The information potential of parts of a graphic were also investigated by Noton and Stark

(1971). They found that subjects concentrated their fixations around the angular, directional changes in the lines, which as Attneave (1954) had indicated, were the most informative parts of a line. In a review of eye movement studies during scene perception, Rayner and Pollatsek (1992) discussed several aspects of information extraction from vision. Rayner and Pollatsek asserted that the "gist" of a particular scene can be extracted from a single fixation, which they termed the perceptual window. They found that as visual complexity increased or comprehension became difficult, the perceptual window got smaller. Based on this argument, it follows that as a graphic becomes more complex the number of fixations that a subject makes will increase. The perceptual process presented by Rayner and Pollatsek (1992) suggests that a subject makes an initial fixation on the graphic. During the fixation, the subject is able to extract some information to process, not all of which can be accurately resolved. Although fine detail cannot be resolved in the visual periphery, it serves an important function in visual perception. The information obtained from peripheral vision directs the eye to the next location of fixation. The eye is attracted toward areas which may be potentially informative, characterized by differences of brightness, contours and changes of line direction. Thus, from a single fixation, information can be resolved and interpreted, and vital information used to direct the eye to the next location is obtained.

Much work has been done to identify what determines the pattern of eye movement. Gould (1967) and Gould and Schaffer (1965, 1967) have performed several experiments in which subjects' eye movements were monitored during a pattern matching task. The results of the Gould (1967) experiment indicated a correlation among several of the stimuli's attributes and eye movement parameters. His results showed that both the mean duration and mean number of fixations increased on both target and non-target patterns. Gould (1967: 399) stated that, "As a perceptual task becomes more difficult, by definition the time to perceive increases. In a perceptual task that involves visual scanning, this change is correlated with a change in one or more eye movement parameters." In related research, Gould and Schaffer (1965, 1967) examined how subjects performed while scanning stimuli for a specific target pattern. They found that subjects fixated longer on patterns that exactly matched those they were looking for. This, they concluded, indicated that the subject was making definite analytical comparisons of details and differences in the pattern matching task. Longer fixations, therefore, indicated an increased amount of cognitive processing on the part of the subject.

Similar to the work of Gould and Schaffer (1965,1967), Mocharnuk (1978) conducted a series of experiments in which he examined the eye movements and scanning performance of subjects while searching for a target pattern in a visual stimulus. In his experiments, Mocharnuk imposed a series of different conditions for observation which included processing of information available from a single fixation, when there were a constant number of fixations and when there were no limits placed on observation. The stimuli that were used for these experiments were groups of letters arranged in circular clusters that varied in number and position in the visual field. Among his findings, Mocharnuk (1978) found that subjects' accuracy increased as the exposure duration increased. He also discovered that subjects' performances decreased as the peripheral vision requirements increased; this decrease in subject performance was also marked by a decrease in the accuracy level recorded as the number of items in each stimulus cluster increased. These findings led Mocharnuk (1978: 626) to the conclusion " ...the number of items in the display and the total information are the most important factors in visual search performance."

3.1 Eye Movement Studies in Cartography

Although most of the early eye movement research did not deal directly with maps, many of the principles have cartographic applications (DeLucia, 1974). Jenks (1973) and others, most notably Dobson (1977) and Steinke (1979), also saw the potential of eye movement studies as a means to evaluate map design. Jenks found, as Buswell had earlier, that in non-task-specific applications, scan paths were highly redundant and unorganized. However, he saw great utility for these studies in the field of cartography as a way to gain an understanding of design decisions being made by cartographers on a routine basis. Jenks (1973) found that many of the design principles taken for granted could be researched with this relatively new technique. He felt that cartographers needed to fully understand the implications of their design decisions and how those decisions affected the ability of the map reader to effectively use the map. He did stress, however, that such research would not provide all the answers:

> ...I would remind you of the mythical woman, Pandora. When we started on this search we thought that pieces of the map reading puzzle might fall into place quite readily. Instead the ills, woes, and troubles of all thematic cartography have been turned loose to haunt us.
>
> (Jenks, 1973:33)

Eye movements have long been considered a reflection of how a subject deals with information from a map or graphic (Castner and Eastman, 1984, 1985; Gould, 1967; Gould and Schaffer, 1965, 1967; Chang, Lenzen, and Antes, 1985; Phillips, DeLucia, and Skelton, 1975). In a comprehensive review of eye movement studies, Castner and Eastman (1984, 1985) revealed that experiments which examined only where the eyes moved could be misleading. Based on their findings, they stated that a study showing how the eyes moved rather than where the eyes moved would be more informative. Their review of eye movement studies also revealed a link between the behaviour of subjects' eyes and subjects' cognitive processing. Castner and Eastman (1984:115) stated that "... eye movements are an outward manifestation of visual/cognitive processing." This was demonstrated by the results of two specific variables, fixation duration and interfixation distance[7]. Fixation duration, they found, seemed to correlate with depth of processing, or in other words, the degree of interpretation being undertaken at that point in the viewing sequence. Interfixation distances correlated with the complexity of the map, but depended more on how much information was being processed from peripheral vision. From these results, Castner and Eastman (1984) suggested that fixation duration may be used as an indicator of comparative map complexity. They further suggested that an analysis of the interfixation distances might serve as an indicator of the quality of the design of the map, in terms of map noise (unnecessary map data) or the level of organization or fragmentation of the design.

[7] The variable interfixation distance used by Castner and Eastman (1984), represents the distance between two points of fixation on a stimulus.

In a follow-up study, Castner and Eastman (1985) performed an experiment to confirm the assertions presented in their earlier work. They concluded that perceived complexity is directly related to the readers difficulty of generating a mental image of the map area (imageability). In particular, they found that maps perceived as being more complex required considerable cognitive processing. This was reflected in the increased duration of the eye fixations and shorter interfixation distances. It appeared that by adding more data, the map became more informative, but it may have also become less readable. In other words, presenting an increased amount of data may create a map so complex that it's utility actually decreases.

In addition to affecting eye movements and visual scanning behaviour, map design can influence the message the map presents. Antes, Chang, and Mullis (1985) found that good cartographic design directs the eye to more informative areas of the map. They performed an experiment in which subjects viewed maps with balanced and unbalanced designs[8]. Their results showed that not only did subjects exhibit greater concentration with balanced maps, but also produced longer fixations on the more informative areas of the map. Antes and Chang (1990), in a similar type of experiment, examined a subject's cognitive difficulty with area symbols of varying designs. They measured duration of fixations which they used as an indicator of processing difficulty. The results Antes and Chang (1990) obtained showed that the greater the difficulty in visual processing, the longer the fixation durations.

[8] Antes, Chang, and Mullis (1985:144) state that balance in cartographic design concerns "... the arrangement and organization of map components within a map frame."

In his eye movement studies, Dobson (1977) developed a schematic representation of the visual search procedure (Figure 3.1). His model, in part,

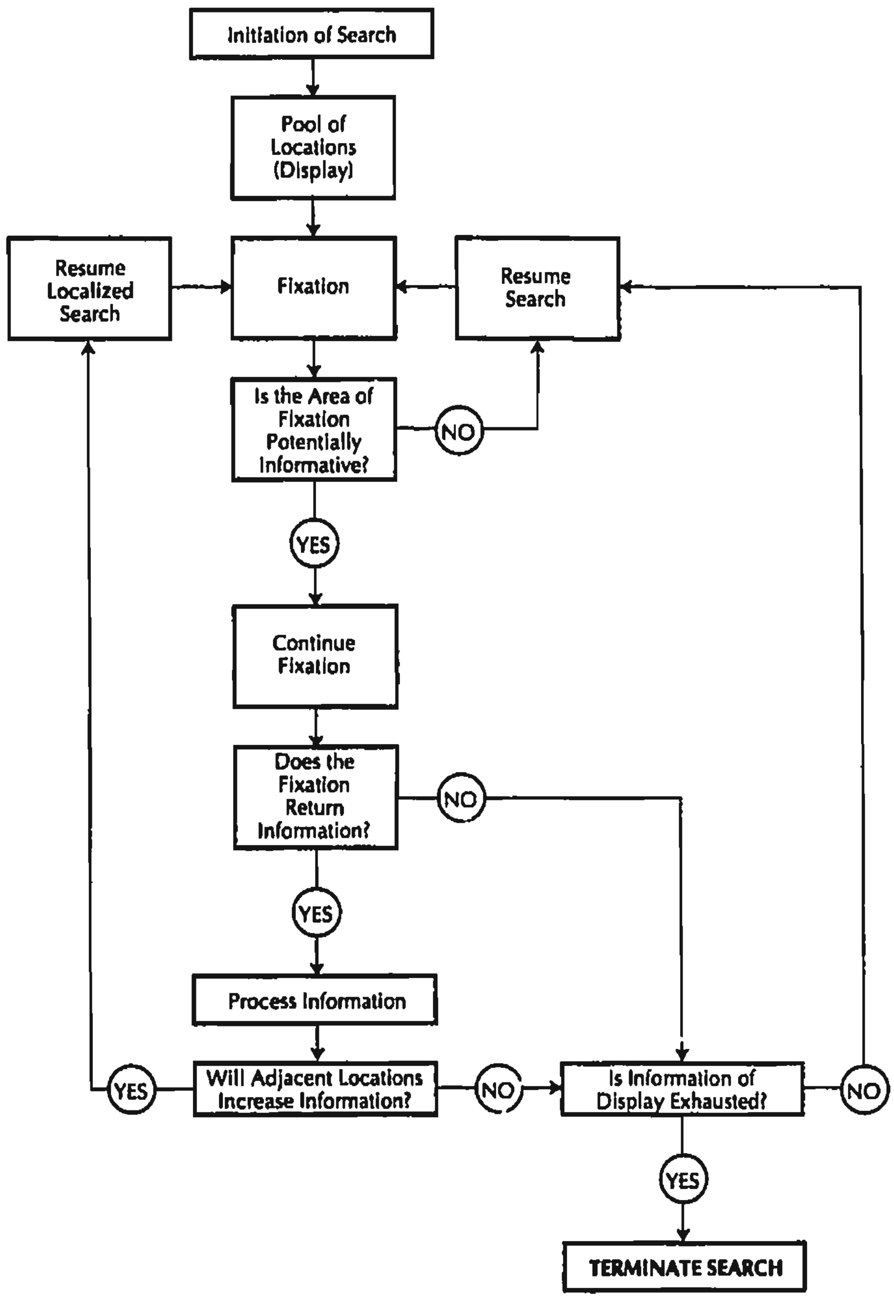

Figure 3.1. Schematic representation of the visual search procedure (after Dobson, 1977)

serves to explain why subjects experiencing difficulty with certain graphic representations require more time and fixate more often in order to extract the message contained in the map. Simply stated, if one area of a map contains more information than another, there is more on which to fixate and process. The greater the information load, the longer the time necessary to extract the information. Thus, a subject experiencing difficulty understanding the cartographic message will likely continue to fixate on various elements of the map until the data can be interpreted. Dobson (1977, 1980) also investigated the effects of information volume in a cartographic context. In these studies, subjects viewed a series of maps of the United States, with and without the state boundaries, and each containing increasing amounts of information. Dobson was primarily interested in how the presence of the boundary lines would influence subjects' eye movements. He concluded from the viewing record, that subjects may be attempting to interpret the overall pattern of the data present on the map rather than trying to assign a specific numerical value to the individual symbols. Dobson discovered that the presence of the boundary lines had no effect on the way subjects scanned the map. He had thought that adding the boundary lines would provide additional figure-ground structure by providing the fundamental geographic relationship for the data. Adding this information should provide greater comprehension, Dobson felt, when he asked the rhetorical question, "Is it not a more serious problem to assign a location on a map that has no internal boundaries than when the boundaries are present?" (Dobson, 1977:47) In a similar study, Dobson (1980) investigated the effects of adding more symbols on a subject's ability to perform some perceptual task.

Subjects were asked to compare a target symbol with a group of symbols combined with varying degrees of additional data. The results provided evidence that increasing the quantity of information on the maps decreased subjects' ability to process the map information correctly. Dobson (1980:31) stated that:

> The decrease in the accuracy of matching in respect to the increases of information, then, must be viewed as evidence of the inability to totally ignore information deemed irrelevant or unnecessary for the solution of the momentary task. In this sense, increasing graphic information must generate increased processing demands.

The studies conducted by Dobson (1977, 1980) show that increasing the volume of information presented causes problems for the map user. The results shown by Dobson (1977) indicate that, in general, map users try to interpret map symbols initially in terms of the larger geographic relationship. Given more time to evaluate these relationships, Dobson (1980) showed that the presence of information not relevant to the immediate task proves to be problematic to the map user.

As one of the parameters of cartographic design, the figure-ground relationship is a fundamental component. This subject has been investigated by Wood (1992) who evaluated the effects of the figure-ground relationship in a cartographic context. Using three eye movement variables, namely, 1) number of fixations, 2) duration of fixations, and 3) duration per fixation, Wood evaluated maps with varying designs. Test maps were constructed that used three different design parameters, specifically, 1) different brightness levels between figure and ground, 2) varying degrees of generalization, and 3) differing visual angles (size of image). Subjects' eye movements were recorded while they performed three map analysis tasks that simulated general map use.

In one of the map analysis tasks, Wood's (1992) results indicated that subjects required fewer fixations and shorter durations to complete the assigned task when the amount of cartographic detail was reduced. Maps that lacked figure-ground structure generally required more fixations of greater duration, and the mean duration per fixation decreased steadily as map stimuli increased in size. He showed that subjects who experienced difficulty in processing the information generated a greater mean number of fixations and longer fixation durations. Predictably, processing difficulty was also manifested in certain test maps that produced an increased number of subject errors.

Wood (1992), confirming what Jenks (1973) had expressed concerning the importance and utility of eye movement studies pertaining to cartographic design stated: "The facilitation of accurate, efficient cartographic information processing can be enhanced through further investigations of this fundamental map design element" (Wood, 1992:279). Although Wood's comment referred to figure-ground relationships, there are many map design elements currently accepted as 'rules of thumb' that need further investigation in order to be fully understood. The use of eye movement research has proved to be quite beneficial to understanding cartographic design. Although studies pertinent to this current research have been highlighted and discussed, several authors, most notably DeLucia (1974), Steinke (1979), and Wood (1992), have conducted extensive reviews of eye movement studies in cartography. Their work provides an exhaustive record of eye movement studies and their application to cartographic design. Eye movement studies have also been used quite effectively to examine human performance in many other fields of research. Human factors in aviation, for example, is one of them.

3.2 Eye Movement Studies in Aviation

Eye movement research has a number of aviation applications. The most prominent are those that deal with the pilot's eye movements while performing some specific in-flight task (Milton, 1952; Thomas, 1963; Byford, 1963; Sanders *et al.*, 1977; Papin, Naureils, and Santucci, 1980). The purpose of Milton's (1952) study was to examine how pilots look at the aircraft's instrumentation. The results of this study enabled him to determine if the layout of the instrument panel contributed to efficiency of use. Milton examined frequency of fixation and length of fixation as variables indicative of design. Frequency of fixation was used as an indicator of the relative importance of the instrument, while length of fixation indicates the relative difficulty of checking and interpreting the instrument. Using eye movement recordings, Milton found that subjects fixated directly on each instrument for an appreciable amount of time before quickly shifting their eyes to the next instrument.

Sanders *et al.* (1977) used eye movements to evaluate the visual workload of aircrews in UH-1H helicopters. In this experiment, it was asserted that subjects required significant amounts of time to perform navigational tasks within the cockpit. In order to evaluate what the workload was and how it might be reduced, the current workload of the aircrew was measured and evaluated. Subjects were given time to familiarize themselves with the maps and the in-flight procedures prior to the testing session. Then, subjects' eye movements were recorded during flight. The amount of time the subject spent referencing the various areas within the visual reference frame was recorded and analyzed. The data showed that the navigator's workload was more onerous than had previously been thought: too much time was spent referencing the navigational charts. The conclusions reached by the researchers were that newly designed charts should be developed that would result in a reduction of the navigator's visual search and information processing time. Sanders *et al.* (1977) recommended that new navigational aids be developed that would provide information to reduce the time spent on navigation tasks. It is interesting to note that although the crew was given sufficient time to study the maps in advance, it was still deemed necessary to reduce the amount of time the navigator spent referencing information on the charts. In an emergency situation where the crew was relatively unfamiliar with the charts, the pressure placed on them to correctly interpret and extract the required chart information would be magnified.

When pilots are placed in more demanding situations, they may be able to restrict their attentions to more informative data sources as suggested by the findings of Beach (1984). Beach examined the eye movements of Sea King helicopter pilots when landing on a ship's deck to determine the effectiveness of the visual aids on the flight deck. The pattern of eye movements recorded showed a marked difference in the pilot's scanning behaviour between day and night landings. Beach found that night landings were more demanding for the pilots, possibly due to a lack of a natural horizon. When pilots experienced an increase in difficulty, their eye movements were more restricted and confined primarily to the visual aids that were considered most useful.

Eye movement studies have also found great utility in examining how pilots move their eyes, in order to aid in the instruction of new pilots. Papin (1984) used eye movements to study fighter pilots while they performed a routine task in a flight simulator. Papin discussed the value of understanding eye movements in light of the volume of information pilots have to process in flight. Studying the information presented to the pilots raised two questions described by Papin (1984:367), "An ergonomic question: how to provide the crew with only that information needed at a given moment of the flight and in the best possible form" and secondly; "A pedagogical question: how to teach users efficient information pickup and processing". Through the use of eye movement recording technology, flight instructors gained a valuable tool to instruct new pilots. Instructors were able to use the eye movement recordings of experienced pilots to show students how they might direct their observations. More importantly, the eye movements could be used to identify problem areas for student pilots. By examining the eye movement data, the instructor would be able to understand how the pilots performed the task and then suggest ways to correct any noticeable problem.

3.3 Evaluation of Workload

The use of these eye movement studies is one method to evaluate what the cognitive workload of the pilot may be during flight. Several other techniques have been used to determine what may be problematic to the pilot. One such technique is to investigate any incident involving actual or possible damage, or casualties after the fact to determine the probable cause. There are several advantages and disadvantages to this approach. In the case of a fatal accident, the investigators are sometimes left to speculate on the cause. Stone, Babcock, and Edmunds (1984) related that the causes of many accidents are classed as pilot error, but there is no way to determine, and commonly little effort expended, to identify the initial cause for the error. Every effort must be taken to determine the problems that cause human errors. Clearly, the best technique is to identify potential problems before they occur. While objective measures are most appropriate, in many cases investigators often rely on interviews with the air crew involved in similar incidents. In cases where the pilot or crew has been interviewed a different set of problems are introduced. Nagel (1988) discussed several methods to study pilot error, they included:

1. Direct observation- Observers may make errors of observation and the presence of the observer may change the behavior of the observed. There are many variables that cannot be controlled.

2. Accident data and post accident analysis - Information record may be incomplete. Humans many times are implicated but the cause of the error cannot be determined

3. Self report - Voluntary system, some incidents may not be reported.

4. Simulator or laboratory conditions - Elements can be controlled to get to the root of the problem. Many errors, however, only become apparent in the complex high pressure situation of actual use.

The amount of information that pilots must deal with has dramatically increased over time. Several authors have expressed concern over the increasing volume of information that pilots are required to process (Bergeron and Hinton, 1985; Huntoon, 1985). There have been many changes in the cockpit, more and more controls have been automated, and attempts have been made at simplification. Huntoon (1985) argued that advances in technology have increased the workload so dramatically that they have actually contributed to a decrease in pilot effectiveness. He reported that research into the human factors considering the development of displays, the overall impact of the total avionics suite, and the simplification of related data would reduce workload and improve overall pilot performance. Huntoon encouraged research into the human factors, stating that:

> Improvements in technology are not commensurate with improvements in human performance. Indeed, if human capabilities and limitations are not continually re-evaluated with the requirements of the system mission, total system performance may be degraded rather than enhanced by technological advancements.
>
> (Huntoon, 1985:131)

Bergeron and Hinton (1985) also warned of the dangers of failing to consider the volume of information that pilots must process. Contrary to Huntoon's assertion, though, they argued that automation can reduce cockpit complexity and enhance the safety and utility of the aircraft provided certain guidelines are followed. Bergeron and Hinton (1985) proposed several guidelines for the presentation of data to the pilot:

1. Present aircraft status information in as simple and precise a manner as possible.

2. Present all flight-critical information to the pilot in a simple format and in a continuous manner (visual, audio, and/or tactile).

3. Design the control console to minimize the number of pilot inputs (combine and integrate control console operations where possible)

4. All routine, noncritical operations should be automated.
5. Eliminate irrelevant and redundant control console operations.
6. Relate control console operations and information feedback in a simple and natural manner (example: co-locate control inputs and feedback whenever possible).

(Bergeron and Hinton, 1985:148)

Bergeron and Hinton (1985), based on these guidelines, described a digital advanced avionics system (DAAS) that would incorporate autopilot, navigation, and display systems. This system would integrate all information that the pilot would need into a single display. It must be remembered, as Huntoon (1985) pointed out, that overloading the pilot with information can be much more dangerous than advancing the technology. Both Bergeron and Hinton (1985) and Huntoon (1985) stressed the need for simplification of the data presented to the pilots and the tasks they are expected to perform, but the extent of the simplification must be determined.

Video monitors to display a variety of in-flight information, including maps, are now used routinely on the flight decks of many aircraft. Stokes and Wickens (1988) point out that this type of display has many advantages over conventional paper maps. Two advantages reported by Stokes and Wickens (1988:393) are that, "They are less cumbersome to manipulate physically, and they have the potential to augment information in a novel format, taking advantage of the computer's flexible graphic capabilities." Stokes and Wickens (1988) also expressed concern that this new system of presenting in-flight information to the pilot may in fact <u>increase</u> the cognitive workload of the pilot. They indicated that some research had been done on 'decluttering' the map by removing items not necessary at that point in time. This process, however, actually increases the pilot's cognitive workload since the pilot must remember what is displayed, and what additional information is available to be displayed.

Huntoon (1985), Bergeron and Hinton (1985), and Stokes and Wickens (1988) have all expressed concerns with respect to the cognitive workload of pilots. The technology of flight and method of presenting the pilot with valuable flight data are experiencing marked advancement. Research into how these technological advances are affecting the pilots using the equipment has been falling behind. One naturally assumes that automating a task makes it easier: This is not necessarily the case. Research into the human factors of aviation is vital to understand how technological advances are affecting the pilot and the safe operation of the aircraft.

There has been a great deal of interest in improving the technology and physical aspects of the aircraft but very little research into the maps and charts that pilots use. Taylor and Hopkins (1975: 196) stated that "Traditional attitudes to map making have tended to encourage design principles and procedures associated more with the graphic arts than with the display of technical information." Taylor and Hopkins (1984: 203) also related that "The literature on ergonomics and on principles for designing information displays contains surprisingly few references to maps." In the past, pilots mostly used topographic maps. As aviation became more complex, pilots requested maps with less and less topographic information, resulting in the creation of highly specialized aeronautical charts. In the course of their investigation, Taylor and Hopkins (1975) found that the most serious problem facing pilots was that maps contained much more information than other visual displays. They suggested that information on maps be restricted to a 'need to know' basis. In spite of this, Taylor and Hopkins (1975) conceded that even the basic information required for navigation and geographic orientation could cause problems. Although maps have to be designed to maximize the appearance and visual organization of the data, Taylor and Hopkins (1975) stated that research into the psychological principles associated with map use is equally important. The effects of the cartographic design decisions must be fully understood to ensure that aeronautical charts effectively communicate their data.

As discussed earlier, a number of different techniques have been used to evaluate the design of graphics. Many of these techniques rely on subjective evaluations to accomplish this goal. Depending exclusively on a subjective evaluation provides a review that may not be entirely accurate. Eye movement studies have been used quite extensively to provide an objective measure of the quality of a graphic design. A similar approach could be used to investigate aeronautical charts that the pilots routinely use. Understanding how a pilot searches an aeronautical chart could assist the cartographer in designing and producing a chart that more effectively and efficiently communicates the required navigational information. Studying the eye movements of subjects as they perform a navigational task is one way to determine the effective level of information to be displayed on the map. The knowledge gained from these experiments can be used to provide the pilot with the most effective chart and thereby reduce the cognitive workload.

Vision, is without question, the most important sense that the pilot will use in flight. Measurements of eye movements provide an accurate record which can be used to examine an important aspect of cognitive performance while executing a task typically associated with flight: The viewing of the chart. Whether the stimulus is cockpit instrumentation, as in the study conducted by Milton (1952), navigational charts (Sanders *et al.*, 1977), or a study of eye movements in general aviation (Beach, 1984; Papin, 1984), each study adds insight to understanding human performance. Maps are an important source of in-flight information for the pilot. Applying eye movement studies to these charts produces valuable data for the cartographer to incorporate into the design process, so that the profession can provide maps of the highest calibre. In this current study, eye movement recording equipment has been adapted for use in evaluation of the instrument approach chart. In the next chapter, the testing environment is outlined, together with a description of the facilities, equipment, subjects, and test stimuli.

Chapter 4
The Experimental Methodology

4.0 Introduction

Eye movement recordings have been demonstrated to be an effective method to evaluate the design of maps and graphics. The data obtained through such recordings provide an accurate, objective record of the subjects' observation and use of the chart. The analysis of these observations provides a method to study the cognitive processing undertaken by the subject while using the map (Castner and Eastman, 1984). The variables, number of fixations, duration of fixations[9], and duration per fixation[10] have been used in numerous studies, as cited earlier, to provide the experimenter with the information to evaluate the quality of the graphic design.

There are some concerns associated with evaluating the design of aeronautical charts in a static situation. First of all, many problems with charts do not arise until the pressure of the situation causes them. Secondly, there are no immediate consequences associated with an erroneous decision. On the other hand, there are many advantages to conducting this type of experiment under controlled laboratory conditions. There are many variables which may be introduced into the experiment that can be eliminated under

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[9] Duration of fixations refers to the sum of the duration of all fixations made during the observation of a single map in the testing session.

[10] Duration per fixation refers to the average duration of each fixation on the stimulus. The value of this variable is obtained by dividing the duration of fixation, by the number of fixations made during the observation of the map in the testing session.

controlled conditions. Controlled experimental conditions allow both subject and experimenter to concentrate more fully on the stimulus, providing an accurate evaluation of the chart's design.

Researchers using eye movement recording techniques can usually orient their experimental method either to fit the equipment, or to satisfy a specific experimental environment. In this case, the testing facilities were adapted to suit the eye movement recording equipment. Ideally, it would have been preferable to test the charts in the environment and under the conditions of normal use. Testing with this particular equipment in actual flight or in a flight simulator, however, is not possible. The nature of the equipment does not allow for testing under flight (or simulated flight) conditions. In flight, the pilot's head is constantly moving to maintain an awareness of the conditions of the aircraft. The equipment used in this experiment to record eye movements requires the subject to keep their head absolutely still.

Although the data were not collected in a situation that mimics the conditions of chart use in flight, the objectives of the experiment could still be realized. The purpose of this experiment was to examine how differing chart designs affect a pilot's ability to accurately extract the displayed information. The charts used as stimuli were designed for and used by a specialized audience. The tasks performed during the test session were specific to flight and simulated how instrument approach charts are normally used.

4.1 The Test Facilities

All test sessions were conducted in the Eye Movement Laboratory of the Department of Geography, located on the campus of Memorial University of Newfoundland. To optimize testing conditions, the windows in the room were covered to ensure constant lighting. The lighting in the room was slightly subdued, accomplished by suspending an opaque baffle approximately 12 inches below ceiling-mounted, fluorescent light fixtures. The subdued lighting caused subjects' pupils to open more and eliminated interference due to reflection from subjects' cheeks, thereby producing a better image for data recording.

The experiment used the Stoelting Wide-Angle Eye Tracker/TV Pupillometer system Model 12861 (Figure 4.1) to track a subject's eye movements while observing the stimulus. The Stoelting system, also used in the study conducted by Wood (1992), is capable of accurately tracking locations of fixations, monitoring the duration of fixations, and recording scan path sequences. Technical data and specifications pertaining to the Stoelting system are summarized in Table 4.1. Although the system also records subjects' pupil diameters, these data were not evaluated. The system's principal components are as follows:

1. An **IBM PC/XT** (not shown in Figure 4.1) fitted with an analogue-to-digital conversion card to interface with the processor of the eye track system. The PC is used to control the steps in the eye monitoring session. It also collects and stores the data obtained during the experimental session.

2. The **Illuminator** projects a beam of infrared light onto the cornea of the subject's left eye. Both the position of the light source and the level of illumination are adjustable to allow the experimenter to aim the light on the retina of the subject's eye.

3. The **Head Support Unit** consists of a forehead brace and chin rest. This unit provides the necessary support for the subject's head, and assists in maintaining the proper position of the subject relative to the target.

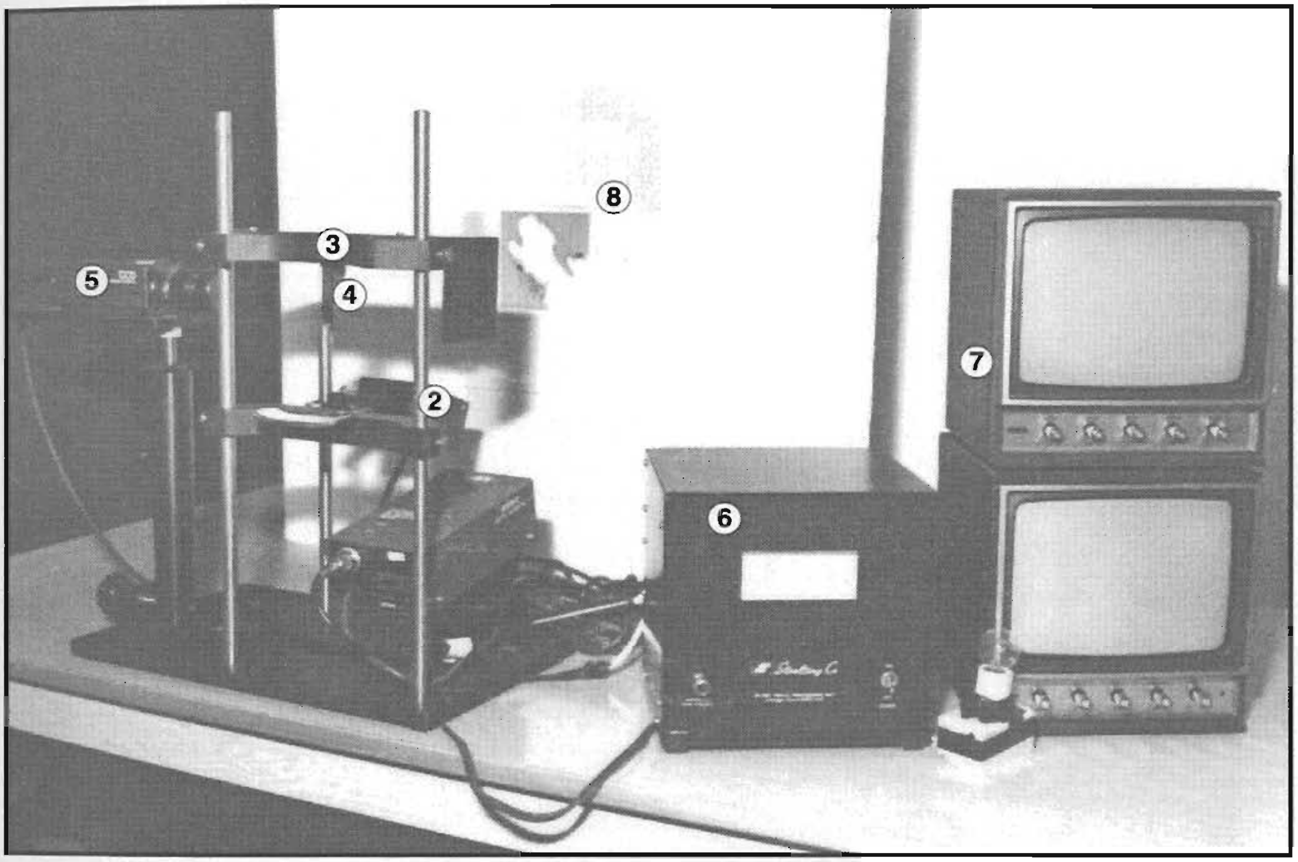

Figure 4.1. The Stoelting Wide-Angle Eye Tracker/TV Pupillometer system used in the experiment to record subject's eye movements.

4. The **Half-Silvered Mirror** is positioned in front of the subject's left eye at a 45^{0} angle to the optical axis. The mirror allows the subject to view the stimulus through it, with a minimum of interference, while at the same time reflecting the infrared light into the lens of the video camera.

5. The infrared light reflected from the subject's eye is captured by a **Video Camera** mounted at right angles to the visual axis and to the left of the head mount unit. The camera is fitted with a 50mm 1:1.8 lens and a 15mm extension tube. This configuration enables the experimenter to isolate and focus directly on the subject's left eye. The arrangement of half-silvered mirror and camera allows the subject to observe the stimulus with minimal interference. The

infrared light signal gathered by the camera is transmitted to the next component in the system, the processor unit.

6. The **Processor Unit** translates the signal from the camera, separating the various channels of information gathered from the observation of the stimulus. It then sends the information to the computer which converts the data from digital to analogue, and then collects and stores the data for subsequent analysis.

7. The images of the eye captured by the video camera are displayed on **Video Monitors**. These images enable the experimenter to visually monitor the position of the eye and watch for potential problems such as drooping eyelids. When such problems are noticed, the experimenter can ask the subject to open their eyes wider.

8. The calibration and test charts were held in the **Image Frame** which presented the stimuli at a distance of twenty inches from the subject's eye. All test stimuli were mounted on rigid card stock so that they could be placed in the image frame; ensuring that all stimuli were presented in the same position.

Table 4.1. Technical data and specifications of the Stoelting system (Wood, 1992).

Model Number	12861
Type of System	Chin Rest/Forehead Brace
Illumination	IR Filtered Lamp
Illumination Level	1.5 ft. Lamberts (Adjustable)
Tracking Range	$\pm$ 45° Vertical/Horizontal
Resolution	1° Vertical/Horizontal
Meter Accuracy	1%
Digital Outputs	3
Analogue Outputs	3

The Eye Tracker/Pupillometer system collects several types of data. As the data are collected, they are translated by the data reduction software[11] to provide, among other information: 1) the x and y location of fixations, 2) the duration of the fixations, 3) the change of direction and distance between points of fixation, and 4) the scan paths of the subjects. The data report lists the sequenced number of fixations by x-y location and the average duration of fixation which are of greatest interest in this experiment. The number and durations of fixations and the average duration per fixation are used as indicators of the design quality of the instrument approach charts tested.

4.2 The Charts

Five instrument approach charts (Figures 4.2-4.6) were used in the experimental sessions. The selected charts were black and white ICAO-approved instrument approach charts, modified slightly for the experiment by removing the elevation or profile views. The purpose of this modification was to focus the subject's attention entirely on the planimetric portion of the approach chart. Each chart represented a different approach and airport, and also contained different amounts of information. Increasing the amount of data presented on the chart, should increase its visual complexity. To verify this assumption, an overall measure of complexity was calculated for each test stimulus based on the total amount of information each chart contained. The methodology used to calculate the complexity of the charts and to choose those for use in testing is described in Appendix A. The instrument approach

[11] The data collection and reduction software used in the experiment was developed for the Stoelting system by McConkie *et al.*, (1988).

charts, their measured complexity, and the number assigned to each for testing purposes are listed in Table 4.2.

Table 4.2. The charts used in the testing procedure and level of complexity.

Chart Number	Airport	Level of Complexity
1	Ouarzazate, Morocco	0.008242
2	Mariehamn, Finland	0.022310
3	Narsarsuaq, Greenland	0.032968
4	Hannover, Germany	0.042212
5	Banak, Norway	0.054788

The stimuli used in the experiment were black and white photographic prints of the planimetric portion of the approach charts. The size of each chart was approximately the same, although there were minor differences. Since existing charts were used, it is virtually impossible to acquire charts with the necessary differences in design, printed at the same size. The size differences (see Table 4.3), in the context of the current experiment, were considered to be negligible.

Table 4.3. Sizes of stimuli used in the eye movement testing.

Chart Number	Airport	Size		Visual Angle*	
		Vertical	Horizontal	Vertical	Horizontal
1	Ouarzazate, Morocco	7.47"	7.65"	21.2°	21.7°
2	Mariehamn, Finland	7.2"	7.6"	20.4°	21.5°
3	Narsarsuaq, Greenland	7.07"	7.07"	20.1°	20.1°
4	Hannover, Germany	7.25"	6.75"	20.6°	19.2°
5	Banak, Norway	7.3"	8.05"	20.7°	22.8°

*All charts were viewed from a distance of 20 inches

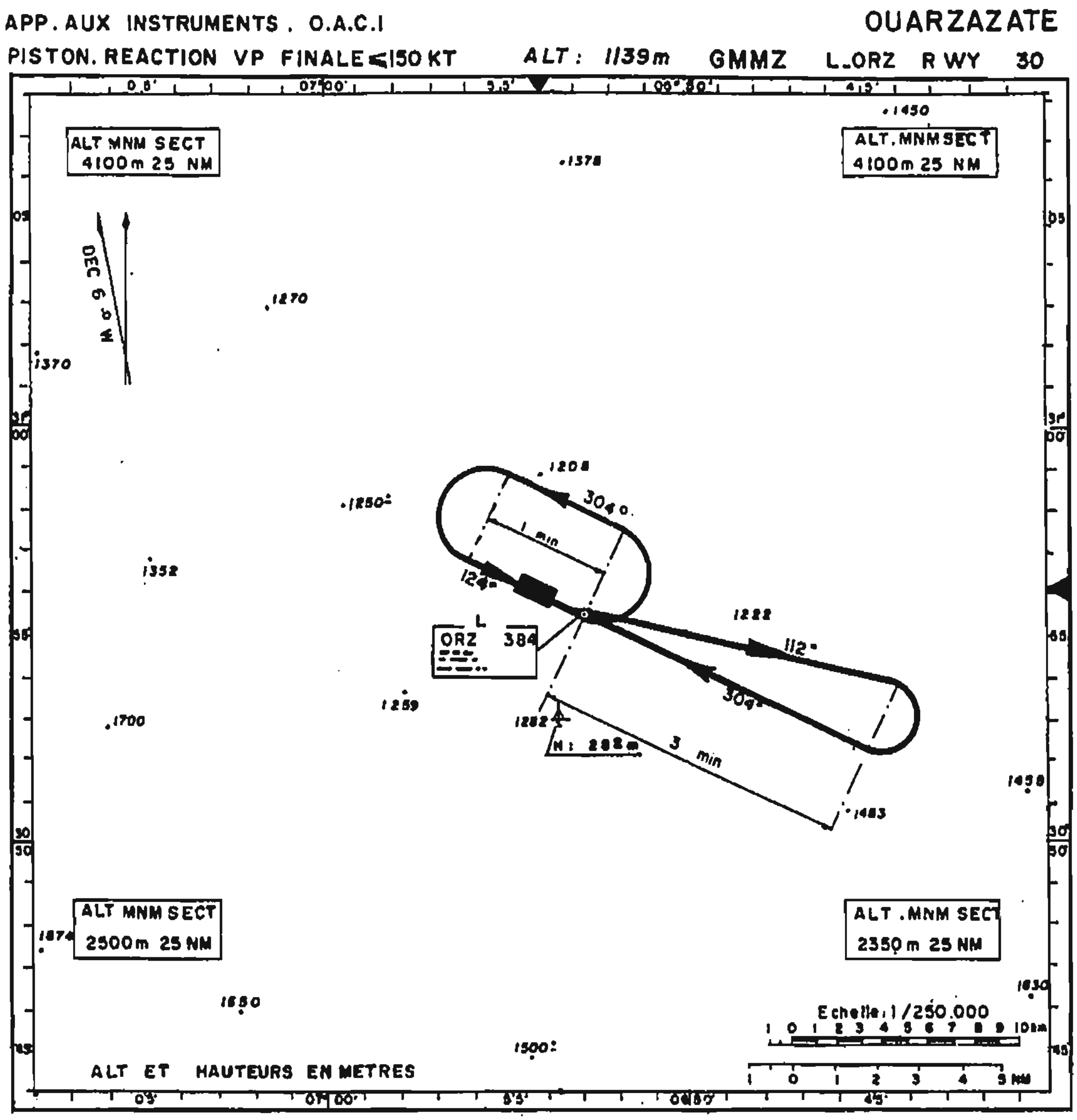

Figure 4.2. Test chart 1 - Ouarzazate, Morocco.

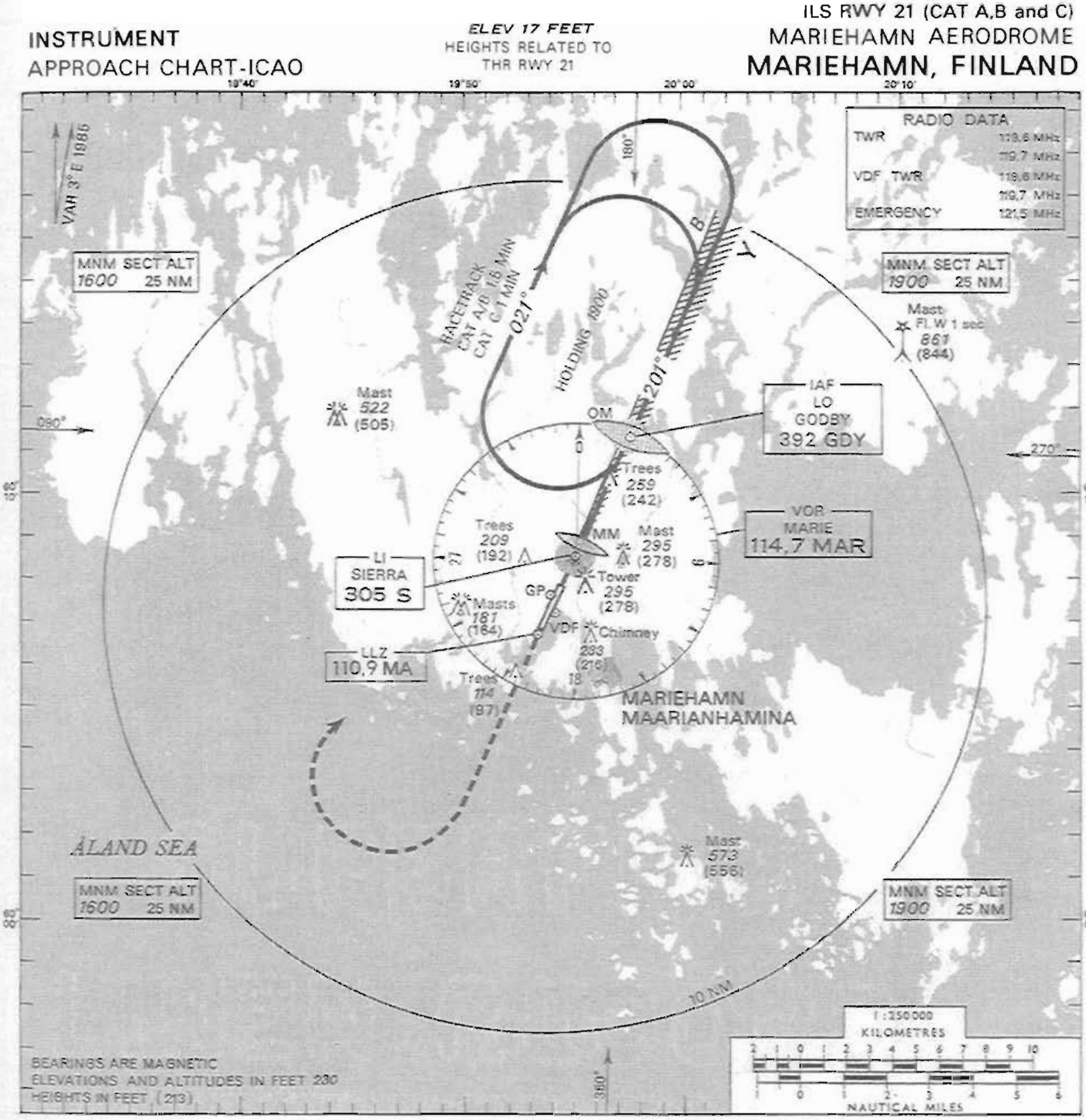

Figure 4.3. Test chart 2 - Mariehamn, Finland.

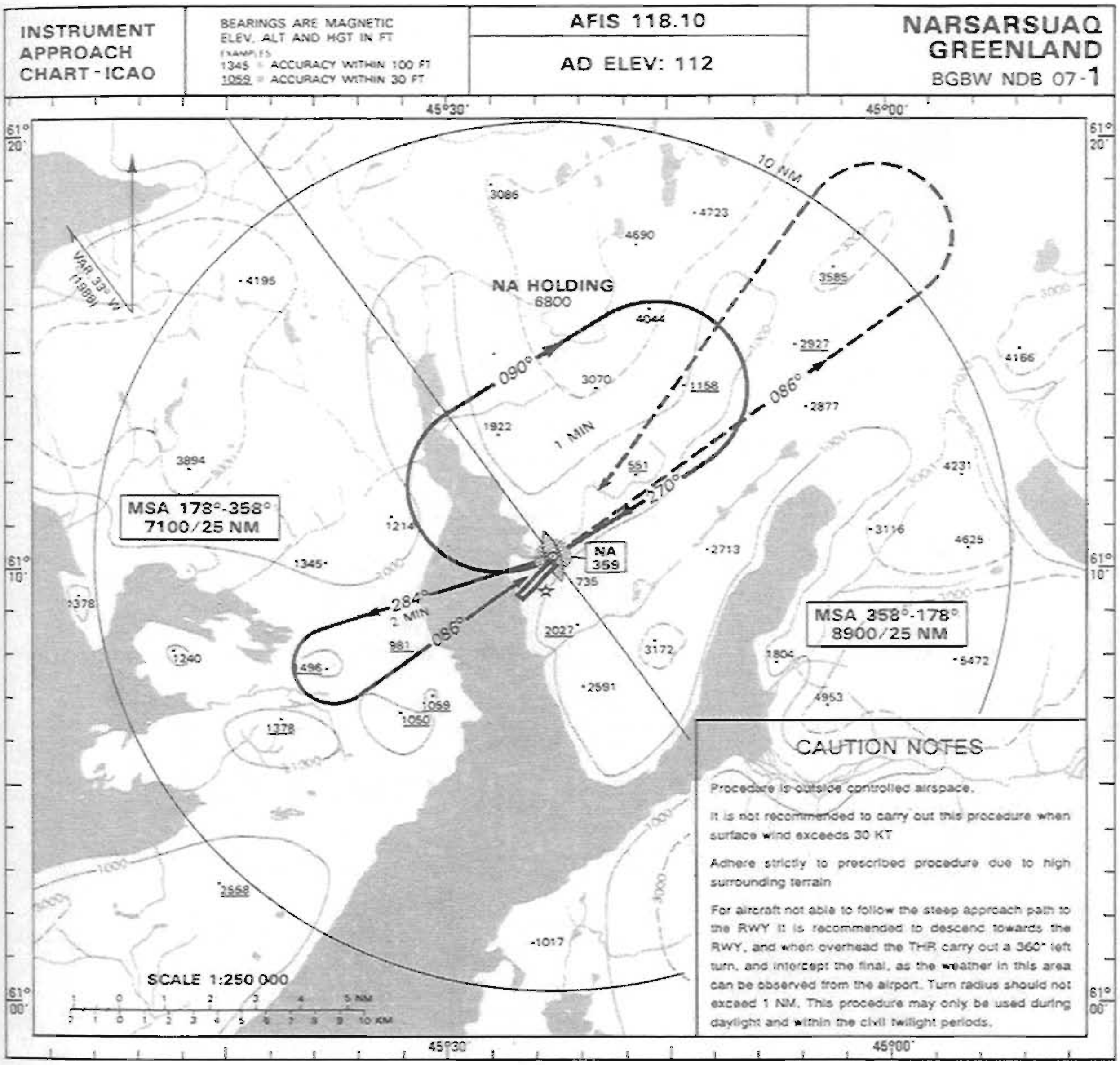

Figure 4.4. Test chart 3 - Narsarsuaq, Greenland.

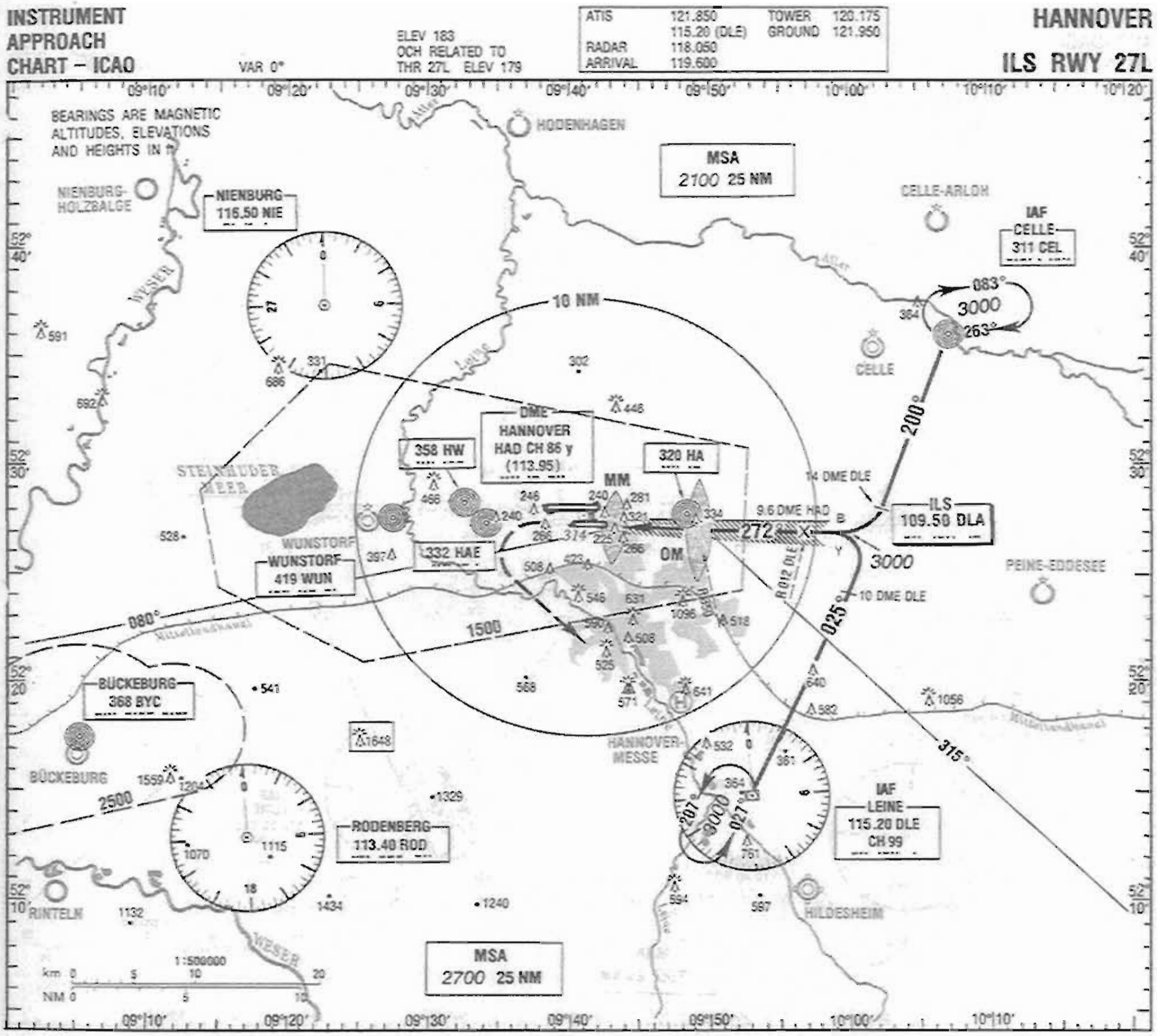

Figure 4.5. Test chart 4 - Hannover, Germany.

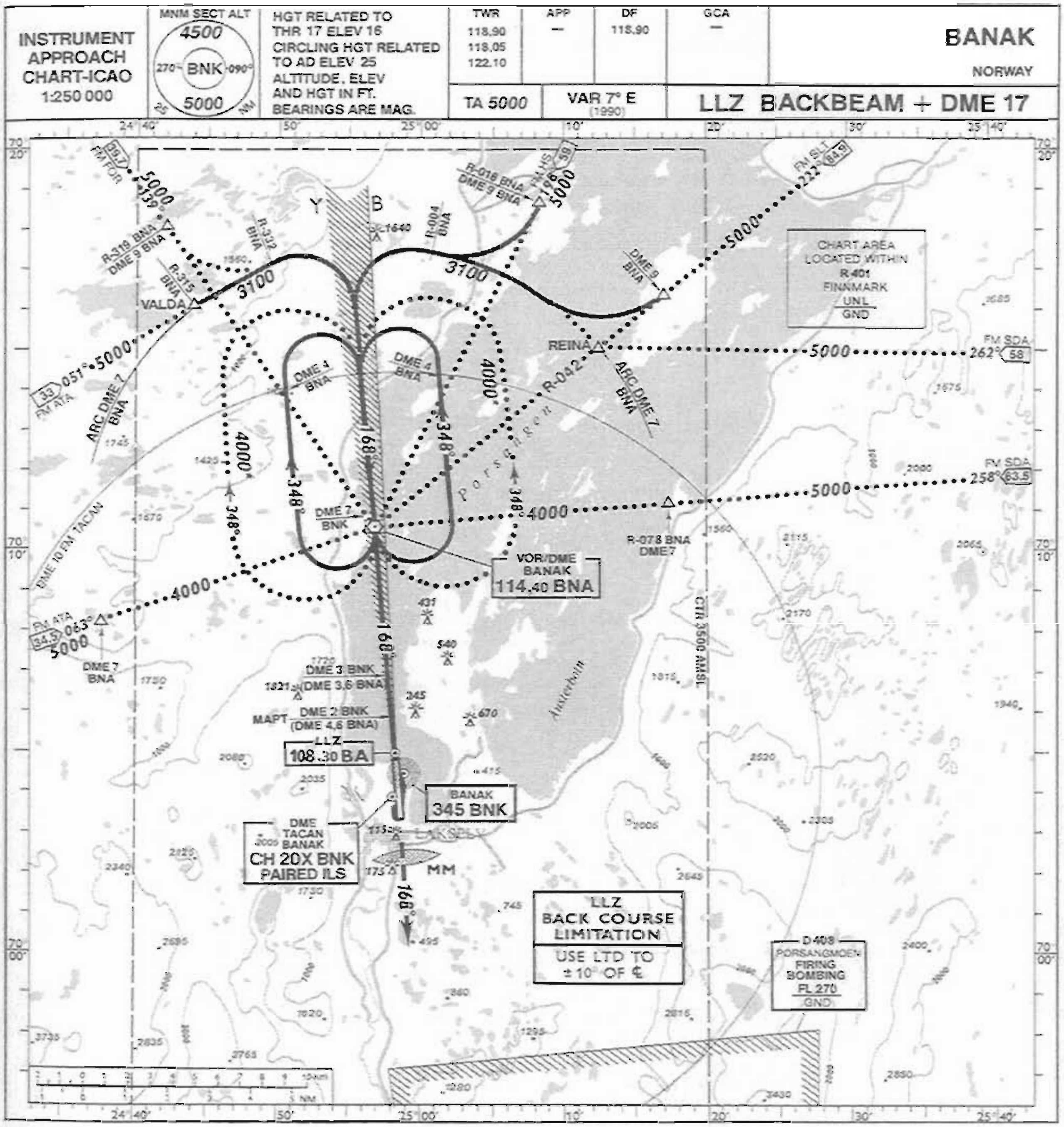

Figure 4.6. Test chart 5 - Banak, Norway.

Each chart was presented to the subjects in a balanced sequence (see Appendix B). The presentation order was designed so that no two subjects observed the charts in the same order. Each chart was presented in each position of the sequence an equal number of times. Thus, experimental bias and learning effects were distributed equally across all subjects in the experiment.

For each instrument approach chart used in the experiment there was a corresponding nine-point calibration chart (Figure 4.7). The calibration charts provided the Stoelting system with the chart dimensions used in testing and established anchor coordinates of the stimuli.

Each calibration chart consisted of nine dots arranged in three rows. numbered sequentially from the upper left corner.[12] The dots corresponded to the centre of the test chart, the four corners, and the midpoint of each side. The presentation of each test chart was preceded and followed by the display of a calibration chart. An example of the presentation sequence of the first stimulus in the experimental session is as follows:

1. Display of calibration chart for test chart 1 (Pre-calibration)
2. Presentation of test chart 1
3. Display of calibration chart for test chart 1 (Post-calibration)

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[12] The dots were solid black circles approximately 5mm in diameter with a 12 point Helvetica bold numeral printed in white in the centre of the black dot. Each dot was numbered 1 through 9. The numbering started in the upper left hand corner, numbered 1 through 3 on the top row, 4 through 6 on the second row and 7 through 9 on the bottom row.

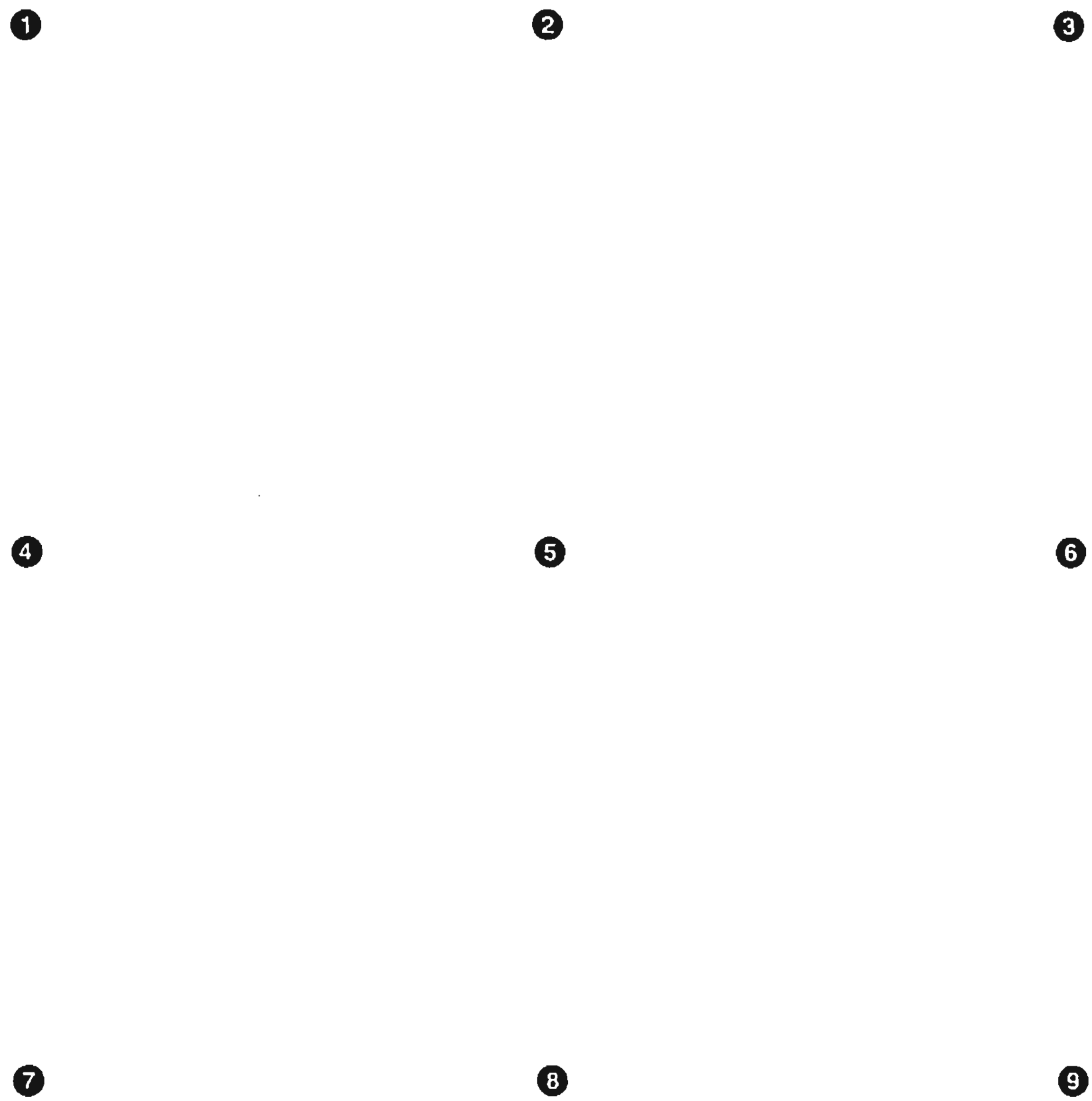

Figure 4.7. Sample calibration chart.

4.3 The Subjects

Twenty subjects participated in this experiment[13]. The subjects were all unpaid volunteers recruited from local airlines, government agencies, and flight schools. Nineteen of the twenty subjects were males. The subjects ranged in age from nineteen to forty-one years with a mean age of 28.9 years. All subjects were licensed pilots and qualified for instrument flight with experience on a wide variety of aircraft. The amount of flight experience ranged from one year to twenty-one years with a mean of 7.9 years.

Owing to the nature of the eye tracking system, subjects could not wear corrective lenses. In order to check subject suitability for this experiment, each potential subject was pre-screened (see section 4.5.1, page 75). The subject was asked to view a sample calibration chart and to fixate on a number specified by the experimenter. Three potential subjects proved unsuitable for testing purposes because their uncorrected visual acuity did not meet the requirements for participation in this study.

4.4 The Tasks

Subjects were asked to perform two tasks while observing the charts:

Task 1 - On these charts, there are messages that give the minimum safe altitude in a particular sector. **Determine the lowest minimum safe altitude from the messages.**

Task 2 - On these charts, there may be symbols that represent obstacles. Obstacles within a five kilometre radius of the aerodrome constitute a potential hazard to navigation. **Determine the distance from the flight path, IN KILOMETRES, of the highest obstacle.**

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13 Given the limitations of availability of suitable subjects, and the amount of time required for a complete testing session (including set up, calibration, and testing), a subject pool of twenty instrument flight qualified pilots was chosen. Wood (1992) set a precedent by achieving excellent results with a subject pool of sixteen subjects .

Both tasks were designed to simulate common usages of instrument approach charts. These tasks were devised after consultation with several pilots on the types of information extracted from instrument approach charts. Since the charts were designed for a specialized use and specific user group, it was extremely important that the tasks reflect how the charts are actually used.

Task 1 was intended as a visual search task. The purpose of this task was to study the effects of additional chart information on the ability of the subject to locate this crucial piece of information (minimum safe altitude) and return a correct answer. There are several pieces of aero-navigational information presented in a similar manner that are vital for the safe conduct of the flight. If the additional topographic data hinders the extraction of this information, the overall effectiveness of the chart is reduced.

The second task had a two-fold purpose. First, Task 2 was to determine if the amount of information contributed to, or detracted from the pilot's ability to locate the target symbols within the specified radius of the aerodrome. The second purpose was to determine whether or not the quantity of information on the chart would influence the subject's ability to estimate distances correctly. This task required subjects to identify a symbol and then determine its distance from the aerodrome. The distance was to be reported in kilometres, not in the more typically utilized nautical miles[14]. The reason for requesting distances in kilometres was to determine whether or not the pilot would use the linear scale given on the chart. If the kilometre

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[14] The kilometre was chosen as the unit of measure for Task 2 to force subjects to use the scale bar shown on the map. Each approach chart contains distance clues such as the 10NM distance circle, for example, which could have been used by the subject rather than the linear bar scale.

is not a unit commonly used in flight, its presence on the chart is adding clutter and is a potential source of confusion with more conventionally used units.

Many tasks that these charts are used for involve a combination of aero-navigational and topographic information. Since aero-navigational information is essential to the purpose of the chart, the correct balance of topographic data must be found. If the chart contains too little data, the pilot's job may be hindered because of a lack of important information. Likewise, if too much data is presented, the additional material may clutter the chart resulting in inefficient use. It is hypothesized that as chart complexity increases, the effectiveness of the map will increase until the optimum level of data has been reached. As the amount of data presented continues to increase, the effectiveness of the chart will diminish. The effectiveness of an instrument approach chart is reflected by number of fixations, duration of fixations, and average duration per fixation. An increase in the values obtained for these three variables is indicative of increased cognitive processing on the part of the subject and therefore increased difficulty with the charts.

4.5 The Testing Procedure

Each subject, upon reporting for the experiment, was given a copy of the "Subject Instructions" (see Appendix C) and asked to read it completely and carefully. The instructions explained the general purpose of the research, briefly described the eye monitoring equipment, and outlined the procedures the subject would be expected to follow during the testing session. Once subjects had carefully read the procedural sheet and had agreed to continue, they were introduced briefly to the eye movement equipment. The function of each component, how the system operated, and the experimental procedure were all explained fully to each subject. Wood (1992) had found that by acquainting subjects with the system prior to testing, subjects felt more at ease. By reducing the curiosity and anxiety, subjects were more likely to remain motionless during data collection, thereby providing higher quality results.

4.5.1 Subject Pre-Screening

Subjects were pre-screened before actually participating in the data collection session. To determine suitability for participation, subjects were asked a series of questions. Subjects were asked if they were qualified for instrument flight. If an accurate evaluation of the chart was to be obtained, subjects must be familiar with how the charts are used. Due to the nature of the Stoelting eye tracker system, subjects can not wear corrective lenses. Subjects were asked if they wore glasses or contact lenses. If they answered yes, they were asked if they could read at the distance charts were viewed in the test setup (20 inches). This fact was verified during the preliminary setup when subjects were asked to view a sample calibration chart and to fixate on a number specified by the experimenter. Subjects were judged unsuitable when they were observed experiencing difficulty in reading or locating the numbers on the calibration chart. Subjects searching for a number while squinting would render an inadequate image of the eye and a poor data set. Although no eye movement data could be collected from these subjects, they were asked for and did provide useful insight about typical, in-flight, instrument approach chart usage.

Subjects who were able to continue with the test session were provided with more detail on the operation of the Stoelting system and the testing procedure. Once subjects were familiar with the system, they were seated at the eye monitoring equipment and preliminary adjustments were made. These adjustments were necessary for each subject in order to ensure subject comfort. In addition to considering the comfort of the subject, fine-tuning the adjustments to the equipment were necessary to minimize or even eliminate any head movement to optimize the image of the eye during the test session. It was essential that all adjustments were correct at this time since the subject was exposed to the charts only once for each task. At no time during the preliminary adjustments were subjects allowed to see any of the test charts to prevent the extraction of information to complete the task prior to the eye movement recording session.

Following the adjustments, the subjects were told to sit back, relax, and then they were briefed on the specific task they were about to perform. Once the experimenter was assured that the subjects understood what the task was, the subjects were asked to take their position at the equipment. Any necessary final adjustment was made, and the test session began.

4.5.2 Pre-Calibration Procedure

The experimental session consisted of three events for each of the five charts: 1) looking at a pre-calibration chart; 2) reading the test stimulus; and 3) viewing a post-calibration chart. In the pre-calibration routine, each subject was asked to fixate on each of the nine numbers in a numerical sequence.

This operation established anchor x-y coordinates for the position of each calibration number which corresponded to a key location on the test chart. The nine calibration points corresponded to the centre, four corners, and mid-point of each side of the test chart. Subjects were asked to fixate on each number as requested and hold until requested to move to the next. This process was repeated until all nine points were sampled at least twice. If the two samples for a given point did not fall within the tolerances set for the calibration, that point was sampled again until the tolerances were met. Once the pre-calibration routine was complete, the subjects were asked to close their eyes while the experimenter replaced the calibration chart with one of the test instrument approach charts.

4.5.3 Map Observation

Each subject was reminded that information extracted from an aeronautical chart must be obtained quickly and accurately. Subjects were asked, therefore, to complete the task as quickly as possible, but to ensure that enough time had been taken to verify their answer. The experimenter signaled the start of the map observation by the verbal command BEGIN. The subjects opened their eyes and commenced the task. Once enough information to complete the task had been collected, the subject pressed the button on the light switch to signal the experimenter. On the command STOP, subjects closed their eyes. The subject was then prompted to respond to the correct answer from a group of four possible answers orally presented by the experimenter.[15] When subjects heard the one answer that matched

[15] Subjects were to refrain from talking or moving their lower jaw in any way since that would destroy the calibration and render the data unreliable. To communicate with the experimenter, therefore, subjects answered questions by flashing a light to signal responses to multiple choice questions.

theirs, they again pressed the light switch to signal their response to the experimenter who then recorded it. The observation of the map was followed by another calibration routine. The test chart was replaced with the post-calibration chart, the subjects were asked to open their eyes, and the calibration routine was repeated.

4.5.4 Post-Calibration Procedure

The post-calibration procedure was the same as that for the pre-calibration. Each subject was asked to "Fixate on number 1, number 2, number 3", and so on, concentrating on each point until asked to move to another. The calibration routines preceded and followed the viewing of each map. The pre- and post-calibration routines were used by the data reduction software to verify the stability of the head position. Had fixation locations changed by more than three values between pre- and post-calibrations, indicating a shift in head position, the reduction routine would have failed to reduce the data. All data collected in the experiment satisfied the calibration requirement.

The entire testing procedure was repeated for each of the five charts in the set. Once finished, the subject was asked to sit back, relax, and to rest before continuing on with the second task. After a suitable delay, the subject was briefed on the requirements of Task 2, and the entire procedure was repeated once more using the same five experimental charts for the second task. The requirements of Task 1 were very different from those of Task 2. In Task 1, subjects were looking for a specific piece of information on the chart. Also, subjects were asked to respond as quickly as possible which reduced the chance of subjects lingering on the chart to study the information they contained. Since subjects were not familiar with Task 2 while performing Task 1, there was no conflict with the information searched for in each task. Since both type of tasks are performed on these charts routinely, it was important to understand the implications of performing each task on the same chart. Test Chart 1, for example, may contain the most effective level of information for Task 1, but not for Task 2. The same set of five test charts, therefore, were used for each task.

4.5.5 Post-testing Questionnaire

Once the testing was complete, the subject was given a questionnaire to complete that gathered information about the subject's background, personal information and additional observations about the charts that were used in the test sessions. The data gathered with the questionnaire were used in conjunction with the eye movement recordings to help provide greater insight on the subjects' perceptions of each chart. The subjects were asked to give subjective ratings to the amount of information each chart contained. They were also asked whether or not they thought the charts contained too much, or not enough information. Subjects were encouraged to make comments on the charts they had viewed, charts in general, and on the testing procedure. Any additional candid comment that the subject made pertaining to the chart was noted. The questionnaire as it was presented to the subjects is contained in Appendix D. The entire formal testing session lasted approximately one hour, although most subjects were quite eager to stay and discuss problems encountered with aeronautical charts.

4.6 Analysis of the Data

The experiment was established as a single-factor repeated measures design. Twenty subjects were asked to complete a specific task while viewing a series of five test charts of increasing visual complexity. Three dependent variables, number of fixations, duration of fixation, and average duration per fixation were recorded for analysis. Analysis of variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) procedures of SPSS/PC+ were applied to the results. Additional testing was performed by applying ANOVA procedures to the results grouped by subject's age and experience. The data obtained in the experiment and results of the analysis are presented in Chapter 5.

Chapter 5
Results and Analysis

5.0 The Data

The data collected by the Stoelting eye tracking system during the testing session provide a complete record of the subject's viewing of the map. The data were reduced from their raw form to a more useful format using the data reduction algorithm developed by McConkie *et al.* (1988). The reduced data file produces a matrix of data that provides information about the subject's cognitive processing of the map. Each row of data in the matrix is a record of one 'gaze'[16] on the stimulus. From the data matrix, the experimenter can glean several pieces of information such as the x and y coordinates of a fixation location and the duration of fixation on a particular point. The experimenter can also extract the total number and the total duration of fixations from the viewing record of each subject. Using the dependent variables of number of fixations and duration of fixations, a third, average duration per fixation, can be calculated. These dependent variables,

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16 Vision is characterized by a brief pause or fixation, followed by a short saccade or jump of eye position that generally lasts from 30 to 120 msec (Wood, 1992). Due to limitations of the eye-tracking system, the duration of the saccade cannot be measured. It has been demonstrated, however, that vision is sufficiently impaired during a saccade so that any data collected during a saccade may provide little reliable fixation information. Because the eye-tracking system only samples every 16.67 msec, the researcher is left with an incomplete record of events that consists primarily of a subject's pauses during visual search. Under these conditions, eye fixation can be best considered as a gaze. A gaze is defined as the period of time from the beginning of one stable period in the data to the beginning of the next stable period and includes fixation time and a brief period of movement. It should be noted that fixation durations usually are not under 200-250 msec and may last upwards of a second (Wood, 1992)

also referred to by some researchers as eye-movement parameters, have been used in many eye-movement studies as indicators of cognitive processing on the part of the subject[17]. These three variables were extracted from the data sets for each subject and are of prime interest in this study. The results from the viewing record of each subject were then used to calculate mean values for each of the three variables. Examination and comparison of means, however, is not sufficient to determine the significance of the differences among values. A closer examination of the mean values using techniques of statistical analysis such as analysis of variance will provide a more meaningful comparison.

An analysis of variance routine (ANOVA) was performed on the data. Using the ANOVA procedure of SPSS/PC+, the mean values for the maps were examined for statistically significant differences. While this test could determine if the differences among the means were statistically significant, it could not identify which map differences were, or were not, significant. Once it was determined that there were significant differences, a multiple comparison test, Tukey's HSD (honestly significant difference), was applied to identify which map pairs among the group of five test maps were significantly different. Using the Tukey's HSD test, the significance level could be maintained at 95%, reducing the probability of a Type I error possible through conducting pair-wise comparisons such as *t*-tests.

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17 In experiments conducted by Gould & Schaffer (1965, 1967), Gould (1967), Dobson (1977, 1980), Antes & Chang (1990) and Wood (1992), the variables used as the prime indicators of cognitive difficulty were number of fixation and duration of fixation. Increased numbers of fixation and longer duration of fixation indicated that the subject was experiencing increased difficulty processing the information contained in the map.

5.1 Results from Task 1 - Visual Search

The first task that subjects performed was one of visual search. This task asked the subject to locate a specific symbol on the chart and report the information contained in the object. More specifically, the subject searched for minimum safe altitude message blocks to report the lowest minimum safe altitude from the symbol blocks found on the map. The test charts contained as few as one message block and as many as four. Subjects were required to search the chart completely to ensure that all the necessary information had been obtained. Once completed, subjects were asked to respond to one of four possible answers, of which only one was correct. The results of the subject's eye-movement recordings are given in Table 5.1.

Table 5.1. Mean scores and standard deviations of Task 1 for the dependent variables, number of fixations, duration of fixations and average duration per fixation.

	Map 1	Map 2	Map 3	Map 4	Map 5
Map Complexity	0.008242	0.022310	0.032968	0.042212	0.054788
NUMBER OF FIXATIONS					
Mean	19.050	27.500	28.900	33.750	52.500
Standard Deviation	10.714	35.963	13.902	15.210	41.849
Ranking	1	2	3	4	5
DURATION OF FIXATIONS					
Mean	375.750	551.350	551.850	577.900	1118.10
Standard Deviation	155.441	783.484	266.941	249.169	950.363
Ranking	1	2	3	4	5
DURATION PER FIXATION					
Mean	21.737	19.840	19.785	17.594	21.631
Standard Deviation	7.347	4.108	4.396	2.998	4.608
Ranking	5	3	2	1	4

5.1.1 Task 1. Number of Fixations

The results shown in Table 5.1 indicate several trends in the data. For Task 1, we see that the mean number of fixations increased as the complexity of the maps increased. Map 1, the least complex map, produced the fewest fixations while Map 5, the most complex, recorded the highest mean number of fixations. The ANOVA procedure was applied to the data for mean number of fixations in Task 1 and showed that the means were significantly different, $F(4,76)=4.39$, $p<.01$.

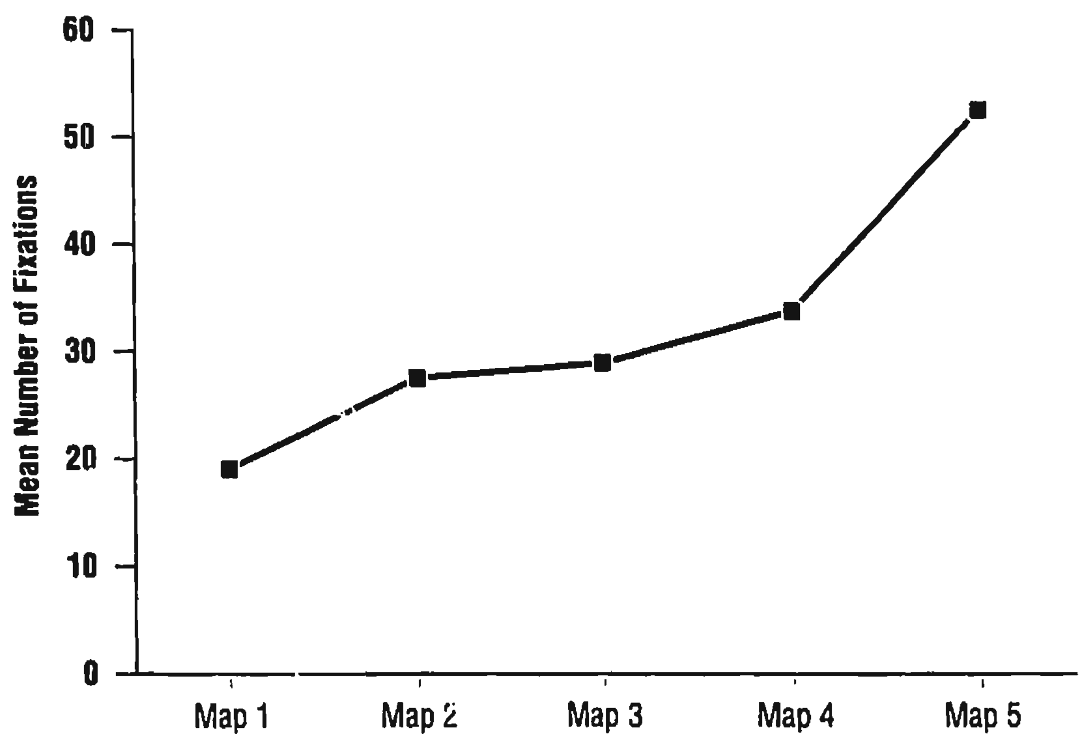

Figure 5.1. Mean number of fixations for Task 1.

For a closer look at the differences between the mean values for the each map, Tukey's HSD tests were performed on the mean number of fixations for Task 1. The test results indicate that the mean number of fixations on Maps 1, 2, 3, and 4 are not significantly different from each other. The mean number of fixations on Maps 1, 2, and 3, however, are significantly different from those on Map 5. The significant differences revealed by the results of the Tukey's tests for number of fixations in Task 1 are summarized in Table 5.2.

Table 5.2. Summary of significant differences among means for Task 1, number of fixations.

	1	2	3	4	5
1					
2	–				
3	–	–			
4	–	–	–		
5	X	X	X	–	

X Significant difference at .05 confidence interval

– No significant difference

5.1.2 Task 1, Duration of Fixations

The data contained in Table 5.1 also show that the mean duration of fixations increased as the complexity of the maps increased. Map 1, the least complex map, produced the shortest duration while Map 5, the most complex, accounted for the longest mean duration of fixation. Analysis of variance conducted on the data for duration of fixation showed that the differences were statistically significant, $F(4,76)=4.93$, $p<.01$.

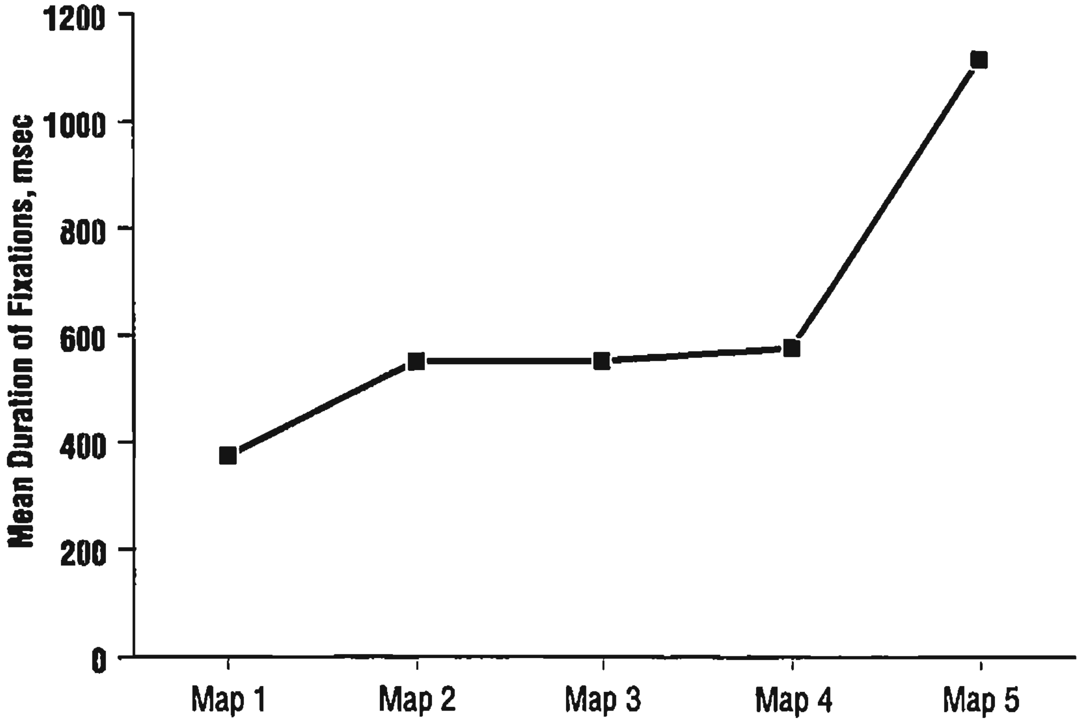

Figure 5.2. Mean duration of fixations for Task 1.

As a result of the significant *F* statistic for the duration of fixations, it was necessary to conduct Tukey's tests to identify significant differences among the test maps. Results obtained from the post-hoc testing indicate that the mean duration of fixations for Maps 1, 2, 3, and 4 are not significantly different from each other, but are significantly different from the mean duration of fixations for Map 5. Apart from the significant differences recorded between Maps 1, 2, 3, 4 and Map 5, there are no other differences among map pairs significant at the .05 confidence interval. The significant differences revealed by the results of the Tukey's tests for durations of fixations in Task 1 are summarized in Table 5.3.

Table 5.3. Summary of significant differences among means for Task 1, duration of fixations.

	1	2	3	4	5
1					
2	–				
3	–	–			
4	–	–	–		
5	X	X	X	X	

X Significant difference at .05 confidence interval

– No significant difference

5.1.3 Task 1, Duration per Fixation

The data for average duration per fixation presented in Table 5.1 do not show a clear relationship between the average duration per fixation and the level of map complexity. There is, however, a general trend toward a decreasing duration per fixation as the map complexity increases. The most and the least complex maps (Map 1 and Map 5, respectively) generated the longest durations, while Map 4 exhibited the shortest durations per fixation. The three maps in the mid-levels of complexity showed the shortest durations per fixation while exhibiting a general trend toward decreasing durations per fixation. Despite the apparent lack of definite trends in the data, analyses of variance conducted on the data did show that the differences in average duration per fixation were statistically significant, $F(4,76)=3.34$, $p<.02$. It is also interesting to note that while Map 1 exhibited the fewest number of fixations and the shortest duration of fixation, it had the longest average duration per fixation.

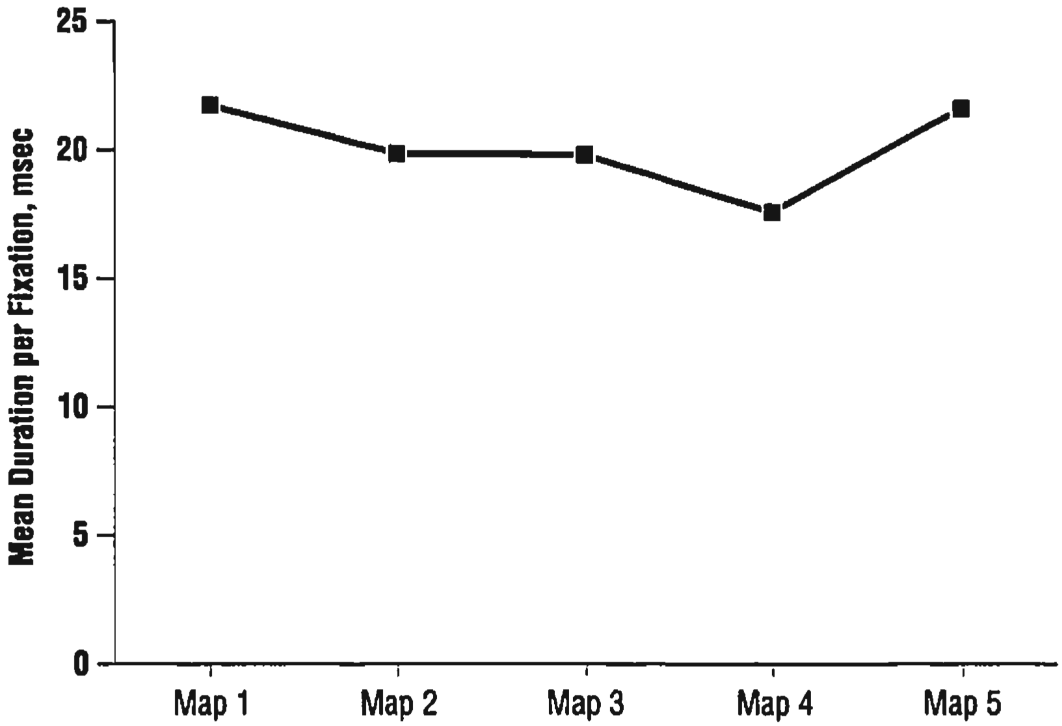

Figure 5.3. Mean duration per fixation for Task 1.

The ANOVA routine applied to the average duration of fixation for Task 1 produced a significant *F* statistic. Post-hoc testing of the mean values recorded for the maps was then conducted to further examine the differences among the maps. The results of Tukey's tests indicate that the average duration per fixation on Map 4, which has the lowest duration per fixation, is statistically different from Map 1 and Map 5. Map 4 did not record mean durations per fixation that were significantly different from those of Maps 2 and 3 at the .05 confidence interval. Significant differences among the mean for the pairs of maps revealed by Tukey's tests are summarized in Table 5.4 below.

Table 5.4. Summary of significant differences among means for Task 1, average duration per fixation.

	1	2	3	4	5
1	\				
2	–	\			
3	–	–	\		
4	**X**	–	–	\	
5	–	–	–	**X**	\

X Significant difference at .05 confidence interval

– No significant difference

5.1.4 Effects of subject age and level of experience, Task 1

The data were examined to determine if there were any differences in the results by subject age. Analysis of variance (ANOVA) routines were applied to the results obtained for the variables number of fixation, duration of fixation, and mean duration per fixation. Subject age was used as a covariate. One subject did not report their age; the investigation into the effects of subject age, therefore, was based on the results of nineteen subjects only. No obvious trends emerged from an inspection of the means for the dependent variables when grouped by age. ANOVA procedures applied to the data confirmed that for number and duration of fixations, there were no significant differences at the 95% confidence interval that could be attributed to subject age. There were, however, significant differences, $F(1,89)=4.053$, $p<.05$, for the average duration per fixation by age of subject.

The level of subjects' experience was also investigated to determine if there was a significant effect on the variables, mean number of fixation, mean duration of fixation, and mean duration per fixation. ANOVA procedures were applied to data from all twenty subjects for the variables number of fixations, duration of fixations, and mean duration per fixation with subject experience used as a covariate. Similar to the results obtained for subject age, no obvious trends emerged from an inspection of the means, and there were no significant differences at the .05 confidence interval.

5.2 Results from Task 2 - Distance Estimation

The second Task that the subjects performed was designed primarily to examine the effects of the differing levels of chart information on distance estimation. Subjects were asked to locate an obstacle within a given distance of the aerodrome and then estimate its distance from the flight path. The distance was estimated in kilometres as opposed to nautical miles, the unit of measurement more commonly used. This task, it is argued, would force subjects to use the scale bar so it's effectiveness could also be examined. Subjects were prompted for their answer to the nearest half kilometre by responding to one of four possible answers, only one of which was correct. The results of the testing are given below in Table 5.5. As with Task 1, the data were examined with the ANOVA routine. If the ANOVA revealed a significant difference in the mean values, Tukey's HSD tests were then employed to identify the significant differences among pairs of maps.

Table 5.5. Mean scores and standard deviations of Task 2 for the dependent variables, number of fixations, duration of fixations and average duration per fixation.

	Map 1	Map 2	Map 3	Map 4	Map 5
Map Complexity	0.008242	0.022310	0.032968	0.042212	0.054788
NUMBER OF FIXATIONS					
Mean	69.550	39.850	66.650	55.700	60.850
Standard Deviation	37.216	18.732	30.788	25.582	21.881
Ranking	5	1	4	2	3
DURATION OF FIXATIONS					
Mean	1511.80	1346.15	1738.55	1666.55	1638.05
Standard Deviation	726.109	608.546	784.636	634.554	659.853
Ranking	2	1	5	4	3
DURATION PER FIXATION					
Mean	22.738	37.054	26.647	32.121	27.479
Standard Deviation	3.758	15.174	6.712	9.272	6.901
Ranking	1	5	2	4	3

5.2.1 Task 2, Number of Fixations

The results presented in Table 5.5 are means and standard deviations for maps used in Task 2. The dependent variables, namely, number of fixations, duration of fixation, and duration per fixation, were used once again as indicators of cognitive processing. The number of fixations initially decreased, but then increased as the level of map complexity increased. Map 1, the least complex map, produced the highest mean number of fixations, while Map 2 the second least complex, yielded the lowest mean number of fixations. To generally describe the trend, a decrease in the number of fixations was noted as the complexity began to increase, but then tended toward an increasing mean number of fixations as the map complexity further increased. Analysis of variance conducted on the data showed that the differences were statistically significant, $F(4,76)=5.41$, $p<.01$.

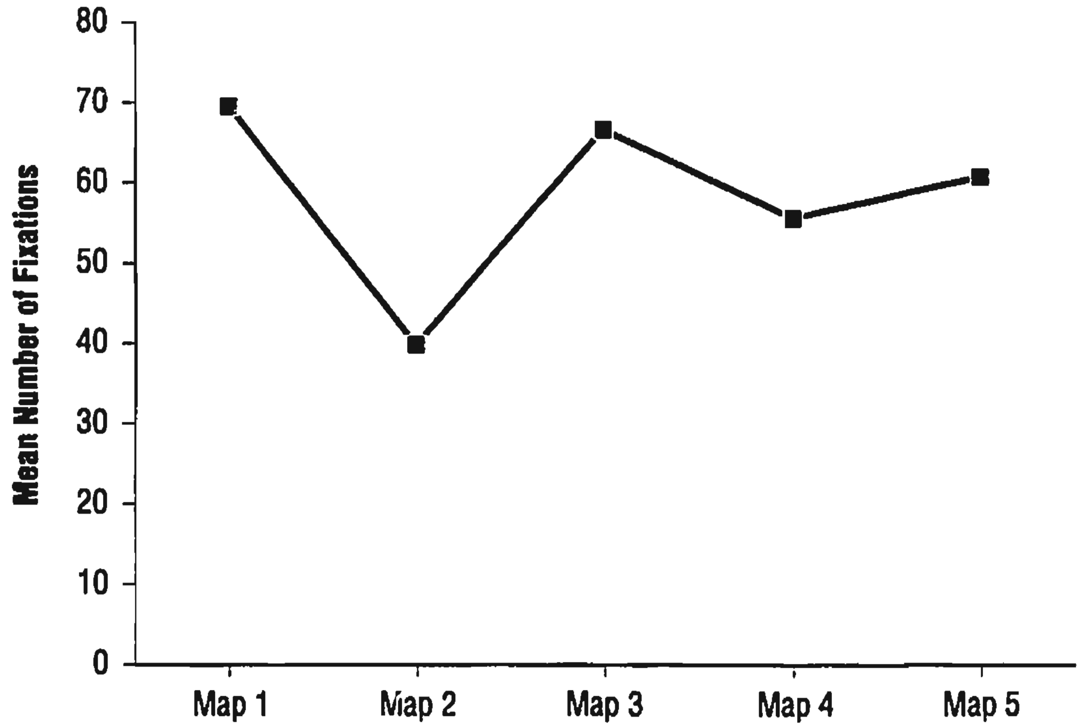

Figure 5.4. Mean number of fixations for Task 2.

The significant *F* score calculated for mean number of fixations in Task 2 indicated that further testing was necessary to determine which pairs of maps were statistically different. Tukey's HSD tests conducted on the mean number of fixations from Task 2 show that there are significant differences among some of the test maps at the 95% confidence level. The results for Map 2 were significantly different from the means for Map 1 and Map 3. Map 2 was not, however, significantly different from Maps 4 and 5 at the .05 confidence interval. The results obtained from the Tukey's HSD test are summarized in Table 5.6 below.

Table 5.6. Summary of significant differences among means for Task 2, number of fixations.

	1	2	3	4	5
1	\				
2	X	\			
3	–	X	\		
4	–	–	–	\	
5	–	–	–	–	\

X Significant difference at .05 confidence interval

– No significant difference

5.2.2 Task 2. Duration of Fixation

The results from Task 2 reveal that the average duration of fixations did not exhibit any obvious pattern as the complexity of the maps increased. Map 2, the second least complex map, generated the shortest mean duration of fixation, while the average duration of fixation was longest for Map 3. There was initially, a trend toward shorter mean durations of fixation as map complexity increased with Map 3 showing the longest mean duration of fixation. While the mean durations decreased consecutively for Maps 1 and 2, even though the levels of complexity were increasing, the duration means were still smaller than Maps 3, 4, and 5, which were progressively more complex. Analyses of variance conducted on the data showed that the differences were **not** statistically significant at the 95% confidence level.

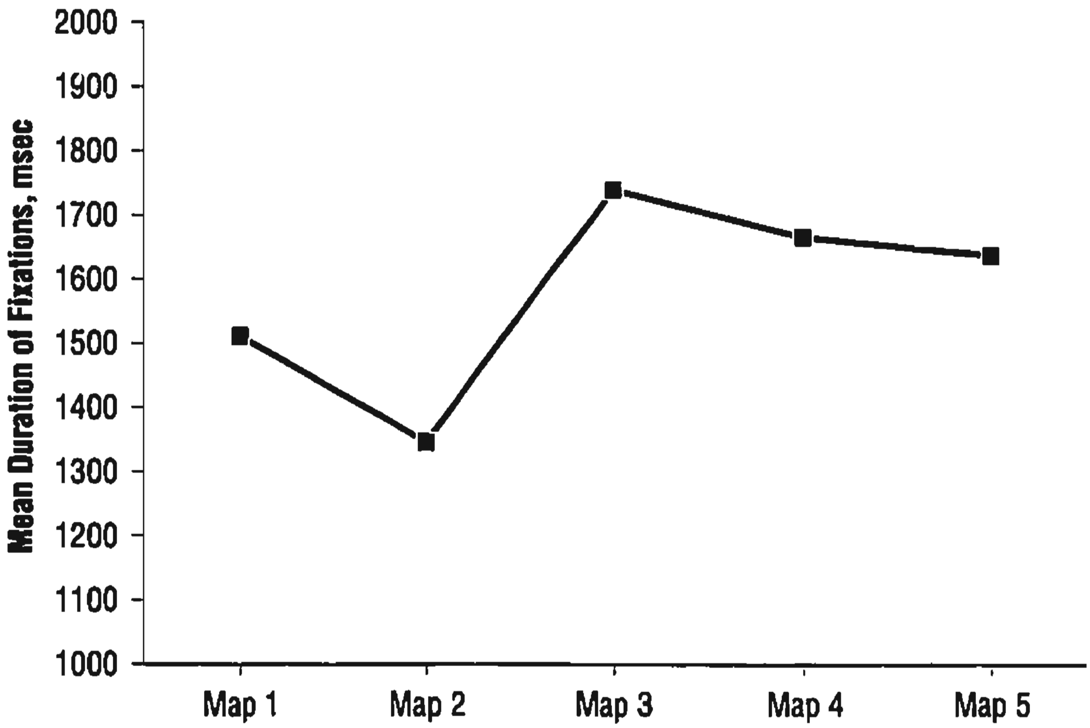

Figure 5.5. Mean duration of fixations for Task 2.

It had already been established by the ANOVA procedure that there were no significant differences. It was unnecessary, therefore, to conduct further post-hoc testing to establish which mean values were significantly different. Any additional testing would only contribute to a Type I error where the results had been judged falsely to be significant when there was in fact no significant difference.

5.2.3 Task 2. Duration per Fixation

The data presented in Table 5.5 for average duration per fixation indicate that there is no direct relationship between the average duration per fixation and the level of map complexity. Map 1 in this case exhibited the shortest mean duration per fixation while Map 2 showed the longest average duration per fixation. It is also interesting to note that while Map 2 exhibited the lowest mean number of fixations, and the shortest mean duration of fixations, it showed the longest mean duration per fixation. Analyses of variance conducted on the data showed that the differences among the mean durations per fixation were statistically significant, $F(4,76)=13.97$, $p<.01$.

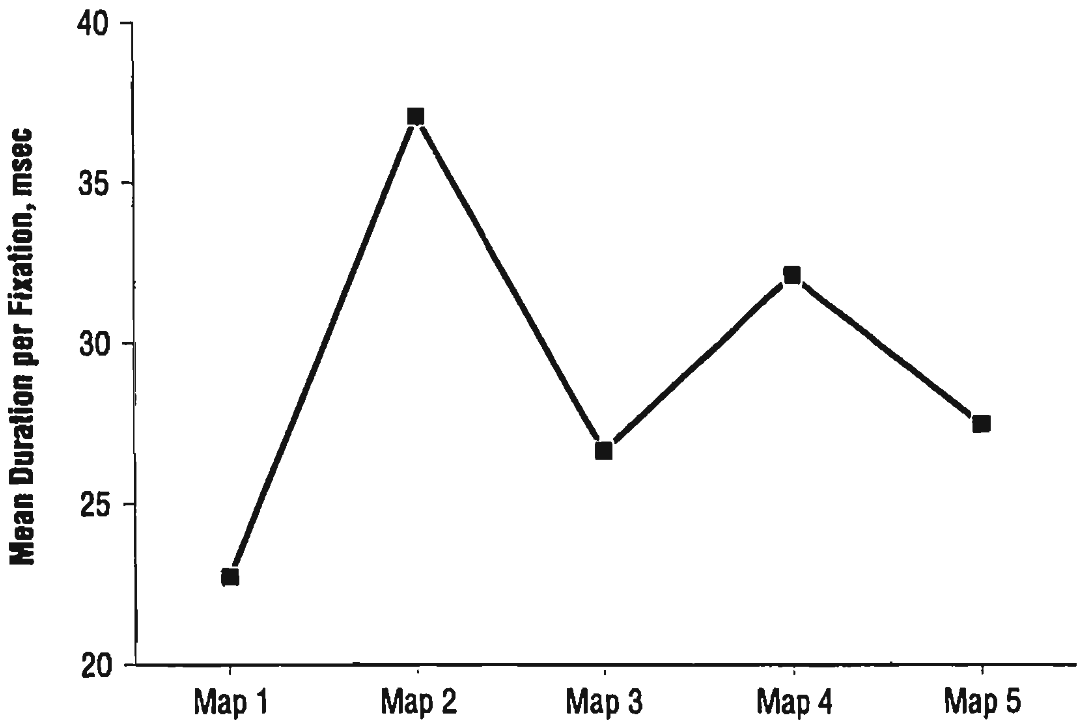

Figure 5.6. Mean duration per fixation for Task 2.

The ANOVA routine performed on the data for the duration per fixation in Task 2 returned a significant F score. Tukey's tests conducted on the mean durations per fixation of all maps show that there are significant differences between Maps 1 and 2, Maps 1 and 4, Maps 2 and 3, and Maps 2 and 5. The summary of statistically significant differences is presented in Table 5.7.

Table 5.7. Summary of significant differences among means for Task 2, average duration per fixation.

	1	2	3	4	5
1	\				
2	X	\			
3	–	X	\		
4	X	–	–	\	
5	–	X	–	–	\

X Significant difference at .05 confidence interval

-- No significant difference

5.2.4 Effects of Subject Age and Level of Experience, Task 2

The data obtained from Task 2 were examined to determine if there were any differences in the results by subject age. ANOVA routines were applied to the results obtained for the variables number of fixations, durations of fixation, and mean duration per fixation from nineteen subjects[18]. Subject age was used as a covariate. No obvious trends emerged from an inspection of the means for the dependent variables when grouped by age. ANOVA procedures applied to the data, however, revealed that there were significant differences for number of fixations [$F(1,89)=6.051$, $p<.05$] and also for duration of fixation [$F(1,89)=9.201$, $p<.01$] when investigated by subject age. An investigation of mean duration per fixation by age of subject showed that there were no significant differences at the .05 confidence interval.

The level of subject's experience was also investigated to determine if there was a significant effect on the variables, mean number of fixations, mean durations of fixation, and mean duration per fixation. Once again, no obvious trends emerged from an inspection of the means. ANOVA

[18] One subject did not report their age, so in actual fact, the analysis was based on the data of nineteen subjects instead of the full set of twenty

procedures were applied to data from all twenty subjects for the variables number of fixations, duration of fixations, and mean duration per fixation with subject experience used as a covariate. The investigation of number of fixations and duration of fixations by subject experience returned significant results, $F(1,94)=4.669$, $p<.05$ and $F(1,94)= 5.022$, $p<.05$ respectively. There was, however, no significant difference in the mean duration per fixation at the .05 confidence interval when examined by subject experience.

5.3 Responses to the Tasks

Upon completion of the task on each map, subjects were prompted for their answer. The responses were recorded and compared to the correct responses. The number of errors committed for each map are presented below in Table 5.8. The number of errors committed by subjects also serves as an indicator of the communication effectiveness of the map. If a subject committed a number of errors, it might signify that the map design was inadequate for the task, for whatever reason. An abnormal number of errors would indicate a communication lapse between map and map user.

Table 5.8. Number of erroneous responses to tasks by map.

Number of Errors	Map 1	Map 2	Map 3	Map 4	Map 5
Task 1	1	3	4	5	1
Task 2	13	15	17	16	18

The lowest number of errors in Task 1 was recorded for Map 1 and Map 5. Map 1 (Task 1) also recorded the lowest mean number of fixations and the shortest mean durations of fixation. The number of errors for Task 2 is significantly higher than for Task 1. Still, Map 1 in Task 2 had the fewest number of errors while Map 5 (Task 2), the most complex, had the highest incidence of errors. There is for both Task 1 and 2, a general trend toward increasing errors as map complexity increased.

5.4 Additional Information from Questionnaire:

In addition to the information gathered from the eye-movement recording, subjects were given questionnaires to complete. This provided background information on each subject and also examined perceptions and opinions on the maps that the subjects had just viewed. The questionnaire is presented in full in Appendix D and a complete subject profile is presented in Appendix E.

The first part of the questionnaire provided some background information on the subject and their experience with instrument approach charts. One topic addressed in the questionnaire was language[19]. Eighteen of twenty subjects reported that they were not familiar with other languages, one understood French, while another spoke and understood French. Subjects were asked whether or not they had used charts other than Canadian charts, or if they had used any of the charts presented in the test session. Twelve of the twenty subjects had only used Canadian charts, the remaining eight subjects reported using charts for American aerodromes, more specifically, charts produced by the Jeppesen Corporation. None of the subjects reported any prior exposure to the charts used in the testing session.

[19] The language of aviation is English. In spite of this, charts are produced in languages other than English.

Subjects were asked to rank the charts according to increasing complexity. This measure of perceived complexity actually closely reflected the measured complexity of the charts, ranking Map 1 - Ouarzazate as the least complex and Map 5 - Banak as the most complex. Ouarzazate was ranked as least complex by thirteen of twenty subjects (65% of the subjects), while Banak was ranked as most complex by eleven of twenty subjects, or 55% percent of the sample, as presented in Table 5.9.

Table 5.9. Charts ranked in order of increasing perceived complexity.

Map	Perceived Ranking by Subjects				
	1	2	3	4	5
1 Ouarzazate	**13 (65%)**	1 (5%)	4 (20%)	0	2 (10%)
2 Narsarsuaq	3 (15%)	**11 (55%)**	5 (25%)	2 (10%)	0
3 Mariehamn	3 (15%)	6 (30%)	**10 (50%)**	0	1 (5%)
4 Hannover	1 (5%)	1 (5%)	1 (5%)	**11 (55%)**	6 (30%)
5 Banak	0	1 (5%)	0	7 (35%)	**11(55%)**

-Numbers indicate how many times a map was ranked in that position.
-Numbers in brackets indicate the ranking as a percentage of the total.

The measured ranking of complexity was compared to the perceived ranking of chart complexity. The rankings of complexity matched almost exactly with one exception; subjects placed Map 2 above Map 3. Weighted averages[20] for each of the rankings were calculated for the charts and used as a value of perceived complexity. These results are presented in Table 5.10.

[20] The weighted averages were calculated using the equation $\Sigma(C^*V)/N$. Where C = number of times the map was chosen for that position; V = value of the position, one to five (least to most complex); and N = number of subjects.

Table 5.10. Complexity value derived from subjects' rankings.

Map	Perceived Complexity	Ranking of perceived complexity
1 Ouarzazate	1.85	1
2 Narsarsuaq	2.40	3
3 Mariehamn	2.50	2
4 Hannover	4.00	4
5 Banak	4.25	5

Subjects were also asked to rank each chart based on the amount of data that each chart contained. This exercise was carried out to determine how subjects viewed the quantity of information portrayed on the test charts, that is, whether they thought a chart had too much detail, too little, or the right amount. A chart, for example, may have been judged to be complex, but the subject may have been comfortable with the level of information presented on the chart. A weighted average was calculated using the same technique as for the values in Table 5.10. The weighted average, in this case, is used to determine an overall value for subjects' opinion on the amount of topographic information presented on the charts. The rankings determined from the subjects' observations are presented in Table 5.11. The results presented in Table 5.11 show that subjects thought there was not enough information presented on Chart 1 - Ouarzazate, Charts 2, 3, 4 had approximately the right amount of information, but Chart 5 - Banak, had too much topographic data.

Table 5.11. Ranking of subjects' opinion of the amount of topographic information.

Map	Not Enough 1	2	Just Right 3	4	Too Much 5	Weighted Average*
1 Ouarzazate	13	5	2	0	0	1.45
2 Narsarsuaq	0	3	10	6	1	3.25
3 Mariehamn	0	2	15	3	0	3.05
4 Hannover	0	4	4	4	8	3.8
5 Banak	0	0	2	9	9	4.35

(*Same ranking scheme applies to this column, 1= not enough, 5 = too much)

In this chapter, the results of the data collection and testing have been presented and analyzed. The following chapter discusses the results in the context of the designs of the charts and the amount of topographic information each contains. The discussion on chart design will naturally lead to a discussion of suggested improvements to the designs.

Chapter 6
Discussion and Conclusions

6.0 Experimental Hypothesis

In the previous chapter, results from the eye-movement experiment were presented. There were two tasks that subjects performed while viewing a series of instrument approach charts. Each task was designed to replicate common usage of the charts and required the subject to use various skills. Because the tasks were slightly different in nature, each was investigated separately. Task 1, was a visual search that required the subject to locate a specific piece of information (Minimum Safe Altitude). Task 2, required subjects to identify an obstacle and estimate its distance from the flight path.

The effectiveness of an instrument approach chart, reflected by number of fixations, duration of fixations, and average duration per fixation depends on the volume of topographic information presented. It is hypothesized that **as the volume of information presented on a chart increases, the effectiveness of the chart will increase until the optimum level of data has been reached. As the amount of chart data continues to increase, the effectiveness of the chart will diminish.** Too much and, likewise, not enough data can adversely affect the pilot's ability to quickly and accurately extract the requisite information necessary for safe aircraft operation, thereby rendering the chart less than effective in its use. There is a broad range in the amount of topographic information depicted on current instrument approach charts. At one extreme, there is a complete lack of topographic information. Chart 1-

Ouarzazate, for example, shows very little topographic information. With the exception of spot heights and a single obstacle shown on this chart, there is no other topographic information. On the other hand, charts can show so much information that they actually decrease the chart's effectiveness by adding to the visual complexity, thereby retarding information accessibility. It is possible that the additional chart data may be masking[21] what is actually of greatest interest on the chart, that is, data vital to the safety of the flight. Between these extremes, the topographic representation that provides the pilot with the appropriate amount of information must be identified. The relationship between the volume of information and effectiveness is displayed in graphic form in Figure 6.1 below.

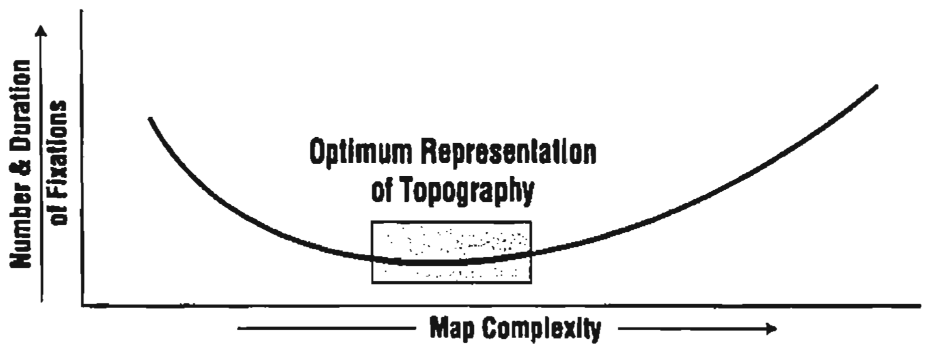

Figure 6.1. Optimum representation of chart information.

6.1 Discussion of Task 1

The eye movement experiment was expected to reveal that subjects would experience difficulty at both extremes of topographic representation, that is, instances where the charts contain either too little, or too much

[21] Masking can be described as the process where presenting additional data would decrease the readability of the chart. The additional data, therefore, would produce a mask that may hide some of the existing information displayed on the map.

information. The dependent variables, specifically number of fixations, durations of fixation, and average duration per fixation, were used to examine the effectiveness of the amount of data presented on each chart. It was thought that as chart complexity increased, the values of the dependent variables should decrease. At the optimum level of chart data, the variables should reach their lowest level. As chart complexity increased beyond the optimal representation, the number and duration of fixations along with average duration per fixation were expected to achieve their highest levels.

6.1.1 Number of Fixations, Task 1

Results from the examination of one dependent variable, number of fixations, presented in the previous chapter, indicate trends that differ from the hypothesis stated above in section 6.0. The average **number of fixations** recorded for Task 1 showed an increasing trend in direct relation to the increase in map complexity (Fig. 5.1, p. 84). An increased number of fixations associated with a higher quantity of information corresponds to the findings of Yarbus (1967), Tversky (1974) and Antes (1974). In their experiments, they found that subjects searched the stimulus to identify graphic elements that may contain information necessary to complete the task. It follows then, that as the amount of information presented on the charts increases, the subject would make more fixations while searching for data that would satisfy a particular need or task. In other words, with greater chart complexity, the increase in data and graphic detail provide the subject with more data to browse over, thereby making more fixations to extract useful information to arrive at an answer for the task.

Although statistical analysis revealed that there were significant differences in the mean number of fixations as map complexity increased, post-hoc testing (Tukey's HSD) revealed that not all changes in number of fixations between maps were significantly different. Tukey's HSD tests performed on the data show that the mean number of fixations for Maps 1, 2, and 3, while not significantly different from each other, are significantly different from the mean number of fixations for Map 5, but not Map 4. Also, there is no statistically significant difference between Maps 4 and 5. These results seems to indicate that while the differences in the level of topographic information are causing a slight increase in the number of fixations, the factor causing the greatest change seems to be the placement of the crucial information, namely, the minimum safe altitude (MSA) diagram. Minimum safe altitude is a piece of information normally presented directly on the chart, as shown by four out of five of the test charts. Subjects may have been influenced by the location of this information, in that it was expected to be found directly on the chart, that is, within the chart frame and not in the chart margins. The volume of topographic information may have also caused difficulty since it may have hidden the fact that the information was not on the map.

6.1.2 Duration of Fixations, Task 1

In a relationship similar to that shown by the number of fixations, the mean **duration of fixation** recorded for Task 1 increased as the complexity of the maps increased (Fig. 5.2, p. 86). It should be noted that the nature of Task 1 is a visual search that does not require the subject to perform a great deal of processing of the data extracted from the chart. The subject was briefed on what to look for. It was simply a matter of finding the object. Longer durations of fixation, therefore, indicate that the subject experienced greater difficulty locating the minimum safe altitude (MSA) data as the amount of information contained on the charts increased. This result agrees with the findings of Castner and Eastman (1985) who found that maps with increasing perceived complexity showed an increase in the duration of fixation.

Analysis of the data determined that increasing the amount of information on instrument approach charts produced changes in the mean duration of fixation for each map. Tukey's HSD test, however, revealed that increasing the amount of topographic information did not necessarily result in a significant increase in the duration of fixations. The increase in topographic information, while resulting in a slight increase in the durations of fixation, did not produce results that showed significant differences among all maps. Similar to the results demonstrated by the number of fixations, Maps 1, 2, 3, and 4, while not significantly different from each other, were significantly different from Map 5.

Even though durations of fixation are treated as a dependent variable, it is probable that they are partially related to the number of fixations. The increase in durations of fixation may be an artifact of the increasing number of fixations. In other words, if the duration of each fixation were held constant, a larger number of fixations would also enlarge the sum of fixation durations. As a result, both number and durations of fixations should be considered together as an indicator of cognitive difficulty on the part of the subject. In order to fully understand the relationship between the complexity of the chart and duration of fixation, the average duration per fixation must be examined.

6.1.3 Duration per Fixation, Task 1

In contrast to the relationships shown by both number and duration of fixation, there appears to be no direct relationship between the average **duration per fixation** and the level of map complexity (Fig. 5.3, p. 88). The most and the least complex maps produced the longest durations, while Map 4 generated the shortest durations per fixation. There is, however, a general trend toward a decrease in the average duration per fixation as map complexity increased. As the amount of information increased, subjects generally spent shorter periods of time on each fixation. Longer average durations per fixation have been shown by Antes, Chang & Mullis (1985) and Antes & Chang (1990) as an indicator of increased cognitive processing and difficulty on the part of the subject. It appears that as map complexity increases, subjects may not need to fixate on the individual elements for quite as long since each fixation is richer in potentially important information. The additional topographic information may, in fact, make the chart easier to use. The maps, although perceived as more complex due to the volume of data, may be less difficult to use because of the presence of additional information necessary to the successful completion of the task.

Results obtained from the post-hoc testing (Tukey's HSD) were used to compare the differences among the average durations per fixation. Map 4 recorded the lowest duration per fixation and is statistically different from Map 1 and Map 5. It is also interesting to note that while Map 1 showed the lowest number of fixations and the shortest durations of fixation, it had the longest durations per fixation. This examination of average durations per fixation with number of fixations indicates that while there were fewer fixations on Map 1, they were more informative and may have contributed more to the successful completion of the task.

The absence of a distinct trend in the data suggests that the volume of topographic information is not the only factor influencing the durations per fixation. The results obtained from the number of fixations and duration of fixations for Task 1 demonstrated that the placement of important information has a significant role. While volume of information may be considered to be a factor affecting the communicability of the chart, the additional topographic information may be reacting with data already shown on the chart to either increase or decrease the legibility of the maps. It is likely that a chart with a minimum amount of topographic information and poor symbol design can be more difficult to use than a map with more information, but better symbol design and placement. This point is illustrated by an examination of the results obtained from the mean duration per fixation. It is interesting to note that the maps showing the two highest durations per fixation are Map 1 (least complex) and Map 5 (most complex). Map 4, which displays a high volume of topographic information, produced the lowest duration per fixation. This suggests that although there may have been many fixations, each was relatively short indicating that it was relatively easy for the subject to determine whether or not the fixation contained relevant information. The differences in chart design and the results these differences may have had on the subjects' performance will be discussed in greater detail in section 6.6. Besides the differences in design, another factor to consider is the number of MSA messages, which is discussed further in section 6.2.

6.1.4 Implications of the findings of Task 1

The results obtained from each variable have been discussed on an individual basis. To fully understand what each means and the implications of an increase in chart complexity on their use, the variables must be considered together. While number of fixations and durations of fixation increased as map complexity increased, their results were not significantly different with the exception of Map 5. As number and duration of fixation were increasing, average duration per fixation decreased. These results seem to indicate that while increasing volumes of topographic information may have a slight effect on subject performance, it is not the prime influence. The major factor seems to be the placement of the information and to a lesser extent, design of the symbol. These results seem to indicate that the pilot will have relatively little difficulty extracting MSA information from the chart as long as the information is on the chart, and the pilot knows where to expect to find it. In the context of Task 1, chart complexity did not appear to play a significant role in determining the relative efficiency of the chart. While Map 1 showed the least number of fixations and shortest durations of fixation, the results were not significantly different from those recorded for Maps 2, 3, or 4. On Maps 1 through 4, it should be noted, the MSA information was presented directly on the chart.

The data also indicate that for charts at the highest level of complexity, subjects are taking longer to make more fixations that are relatively short in duration. In the case of Map 5, there are significantly more fixations that are longer in duration. The increase in data presented on the map provides the subject with more to browse over while searching for information to complete the task. Subjects are making many fixations to search for the informative data, therefore, average duration per fixation tends to be relatively short. Longer duration of fixation and increased numbers of fixation indicate that charts with higher levels of complexity are not as efficient to use as less complex charts. Similarly, the results generated by Map 5 show that the subject is making many long fixations and taking a long time to complete the task. A high number of fixations and long durations of fixation have been shown to reflect inefficient chart use. When these parameters are combined with a long average duration per fixation, they indicate processing difficulty on the part of the subject.

6.2 Number of Minimum Safe Altitude Symbols

The results shown by the dependent variables (number of fixation, duration of fixation, and average duration per fixation) used in the eye-movement recording indicate that it is not only the volume of information that influences their values. While the volume of chart information may have an effect, another element to consider is chart design, particularly the number and position of MSA blocks. On Map 1, four MSA message blocks are fairly dispersed and relatively isolated from the remainder of the chart information. Like Map 1, Map 2 also had four MSA blocks. On Map 2, however, the blocks are surrounded by other chart information and have overprinted other graphic elements so that there is background chart information showing through the MSA data. The background information makes the MSA message block more difficult to read because of the overprints of textual information and chart line work. The problems caused by the conflicts of chart information and the display of additional chart data may account for the increased difficulty and errors.

Map 3 displays only two minimum safe altitude message blocks. The chart information has also increased from that shown on Map 2 making the MSA messages less obvious to the reader and more difficult to find. The increased amount of information appears to prompt the reader to make more fixations, searching for other possible MSA information. This is demonstrated by the increased number and durations of fixation on Map 3. The average duration per fixation, however, decreased only slightly indicating that the subject had a little less trouble interpreting the information on Map 3. Map 4 contains the same number of MSA message blocks as Map 3, but has additional symbols which are very similar in design such as navigation beacon ID blocks. The beacon ID blocks may be confused with the MSA symbols causing greater numbers and durations of fixation.

The MSA information for Map 5 is quite different with only one symbol shown in the margin of the map. The results shown by number of fixation, duration of fixation, and average duration per fixation indicate that the subject experienced great difficulty locating the information and interpreting the chart. Apparently the subject was not expecting to find the MSA information in the margin, but rather on the map itself. Subjects spent a great deal of time searching the chart, probably fixating on other symbols that were similar in design to minimum safe altitude messages of other charts. Once the subject located the single MSA symbol, however, the information was easily interpreted. Although this map contained the highest level of information, it recorded only one error. By locating one symbol, the pilot is able to obtain all information pertaining to minimum safe altitude. The problems experienced in finding the MSA symbol are probably due to a lack of experience with international charts. The pilots who participated in this experiment were mostly familiar with Canadian charts and reported very little experience with international charts. Since this information is presented directly on the map portion of the Canadian chart, subjects most likely expected to find the MSA information directly on the chart. Because of the high level of topographic information on the chart, it was not immediately discernible that this vital piece of information was not shown directly on the map.

To summarize, given current chart designs, the pilot can never be sure if all MSA information has been located. If there is more than a single minimum safe altitude diagram, there is the danger that the pilot may stop searching after only one diagram has been located. The number of minimum safe altitude diagrams should be standardized. Pilots have to know what to expect when using the charts. They need to know what information is on the chart and where it can be found. The results obtained from the investigation of Task 1 show that, clearly, the best option is to display only one MSA symbol.

In operational terms, minimum safe altitude is a vital piece of information that the pilot must acquire before entering the airspace represented on the chart. Accuracy, when interpreting MSA and all information on the chart, is imperative. Task 1 recorded some high instances of errors that may have been a result of the variable number of message blocks on the test charts. Possible causes for the numbers of errors committed on this task are discussed in the following section.

6.3 Number of Errors, Task 1

Subjects were asked to provide an answer for the task they performed while observing the charts. Their answers were recorded and compared with the level of chart complexity. It was thought that the number of errors would increase as chart complexity increased. The numbers of errors for Task 1 are summarized in Table 6.1. With the exception of Map 5, the number of errors recorded for Task 1 increased with increasing chart complexity. The number of errors made by the subjects was lowest (one error) for Map 1 and Map 5. On Map 1, with minimal topographic information, the MSA messages were clearly isolated from the remainder of the chart information, easily identified and interpreted. Map 5, in spite of having the highest level of topographic information, had only 1 MSA message diagram located in the margin. In this case, it took much longer to locate, but it was easily interpreted almost without error.

Table 6.1. Number of errors committed on Task 1.

	Map 1	Map 2	Map 3	Map 4	Map 5
Map Complexity	0.008242	0.022310	0.032968	0.04221	0.054788
Number of MSA Symbols	4	4	2	2	1
Number of errors	1	3	4	5	1

Most of the errors appear to be a result of the increasing levels of chart complexity. The additional topographic information on the chart may make the MSA messages harder to locate and interpret in some cases. On Canadian instrument approach charts, there is only one MSA diagram that is relatively isolated from the main body of information on the chart. Subjects participating in this experiment were familiar primarily with Canadian charts. Because of a lack of experience with international charts, subjects may have stopped searching the chart after locating the first MSA message block. As a result of the changing number of MSA messages and changing positions, the subject apparently missed some of these diagrams and therefore reported an incorrect answer.

To solve the problems that may be caused by missing vital information, several items should be addressed to improve the communicability of these diagrams. For example, there should be only one MSA diagram to ensure that the pilot receives all minimum safe altitude information by locating one symbol. Placing the MSA diagram in a standardized location, free from the other chart information will ensure that it is easily found and interpreted. If, for example, the diagram were located in the lower left corner of the instrument approach chart, the pilot would, with experience, look to that corner for the symbol.

6.4 Discussion of Task 2

Task 1 was a visual search in which subjects were asked to locate a piece of information. Task 2, however, called upon a different set of skills. This task required subjects to identify the highest obstacle within a five-kilometre radius of the aerodrome, then determine its distance from the flight path. Pilots work mostly in nautical miles, therefore, kilometres were chosen as the unit of measure to determine whether subjects were using the scale bar to assist in completion of the task. Of prime interest in Task 2 was the effect of the additional information on the pilot's ability to extract the chart information needed to perform the task. Of secondary importance was the significance placed on the scale bar for distance estimation. The main thrust was an examination of the hypothesis presented in section 6.0 that **as the volume of information presented on a chart increased, the effectiveness of the chart would increase until the optimum level of data has been reached. As the amount of chart data continued to increase, the effectiveness of the chart would diminish.**

6.4.1 Number of Fixations, Task 2

An examination of **number of fixations** showed that the results agreed with the hypothesis proposed in section 6.0. Subjects appeared to experience difficulty with Map 1, less difficulty with Map 2 and then greater difficulty with Maps 3, 4, and 5 (Fig. 5.4, p. 92). The high number of fixations for Map 1 is probably a result of the low levels of topographic information. The lack of topographic information may be causing the subject to struggle in the search for clues of obstacles and distance, because there may not be enough data to perform the required task. An increase in the level of topographic information, therefore, should produce a decrease in the number of fixations, resulting in more efficient chart use.

The decrease in the number of fixations shown on Map 2 over Map 1 suggests that the higher level of map information is improving the effectiveness of the chart. Map 2, most notably, recorded the lowest number of fixations among the charts used in the test session. In terms of number of fixations, therefore, this map contains the most effective level of chart information. As map complexity increases, the number of fixations for Maps 3, 4, and 5 increases over those recorded for Map 2. The number of fixations for Map 3, however, was greater than the number recorded for Map 4 and Map 5. This relationship indicates that there are other design factors to be considered besides the level of information. If the effects were simply due to the increase of topographic information, the number of fixations would show a direct relationship to the level of data portrayed. The information added to the chart may be producing a combined effect with existing information to make the chart more difficult to use. The other design factors that may be contributing to this problem will be discussed in greater detail in section 6.6.

The number of fixations recorded for Map 2 indicates that this is the most effective level of information to present. Tukey's HSD tests applied post-hoc showed that not all differences among the set of test maps are significant. Map 2 demonstrated the lowest number of fixations, which were only significantly different from the means for Map 1 and Map 3. It is interesting to note that subjects performed better on charts that did not have spot heights[22] indicated in the target area[23]. Map 2, which recorded the lowest number of fixations, did not contain any spot heights; while Map 4 did have spot heights, they were not located in the target area. Many spot heights

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22 On several of the test charts selected, spot heights are used to represent the height of land at a particular point (e.g., .1282). Similar symbols representing obstacles to navigation (e.g., ^209) provide the elevation of the top of the obstacle. In the course of this thesis, when the term spot height is used, it will refer to those symbols relating the height of land at a particular point and should be considered separate from the symbols representing obstacles.

23 The target area of the chart is defined as the five kilometre radius in which subjects were asked to search.

simply relate the height of land and do not symbolize significant hazards to navigation such as mountain peaks. When searching for obstacles to safe flight, spot heights may unnecessarily attract the pilot's attention to information that may not be as urgent to interpret. Chart 1-Ouarzazate, for example, shows the runway elevation at 1139m (from information in the margin) and the highest elevation shown as a spot height of 1874m, symbolizing relief of approximately 735m. Spot heights are distributed relatively evenly throughout the map representing relief of approximately 200m. The significant heights, 1874m, or the obstacle near the flight path, do not have the visual prominence they should have as hazards to safe flight. This result seems to suggest that spot heights, as they are symbolized on the test charts, are problematic for the subjects. If spot heights are to be shown on charts, they should be given less visual prominence than obstacles to safe flight. In addition to improved performance on charts without spot heights, it should be noted that subjects performed relatively better on charts where there was some device to focus the subject's attention. The 10NM ring shown on Map 4 and to a greater extent, the circular symbol representing the radio navigation aid on Map 2 seem to provide focus for the subjects' attention which is shown by fewer fixations. These devices provide the subjects with a greater figure-ground relationship, enabling subjects to focus their attention. The increased concentration of information, in this case, does not appear to clutter the map, but serves to catch the eye of the user and focus their attention to the most informative area for this task. The presence of the greater figure-ground, combined with clear obstacle symbolization and the lack of spot heights, provides an effective representation of this type of information.

6.4.2 Duration of Fixations - Task 2

The average **duration of fixations** recorded for Task 2 showed a similar trend to that displayed by the results for number of fixations (Fig. 5.5, p. 94). This trend showed a value for Map 2 that was slightly lower than Map 1, and values for Maps 3, 4, and 5 that were slightly greater than Maps 1 or 2. Analysis of variance conducted on the data, however, showed that the differences were not statistically significant. An increase in the duration of fixations would indicate that the subject is having greater difficulty visually processing the charts as the amount of topographic information increased. Lack of significant change in the duration of fixations indicates that an increase in topographic information does not really affect the overall time pilots require to use the charts to locate obstacles and estimate distances. Once again, as for number of fixations, the influence of the devices to focus subject attention (10NM circle and radio-navigation aid symbol) is present on Maps 2 and 4, although the results were not statistically significant.

6.4.3 Average Duration per Fixation - Task 2

The results obtained for **mean duration per fixation** do not show a direct relationship to increasing map complexity (Fig. 5.6, p.95). There is, however, a general trend toward an increase in the mean duration per fixation. Map 1 generated the lowest average duration per fixation, indicating that the information presented on this map was not very difficult for the subject to process. The average duration per fixation on Map 2 was dramatically higher than on Map 1, indicating that the subject experienced a great deal of cognitive difficulty. It is also interesting to note that while Map 2 showed the highest average duration per fixation, it had the lowest mean number of fixations for Task 2. The data show that Maps 2 and 4, which did not have spot heights in the target area of the map, had the longest average durations per fixation. It appears, then, that the subject was not distracted by the spot heights representing potential obstacles as on other charts, but was able to concentrate directly on information vital to the completion of the task. Although the ANOVA showed that there were significant differences, Tukey's HSD test revealed that not all maps were statistically different. Map 2, which generated the highest durations per fixation, was significantly different from maps 1, 3, and 5, but not Map 4. Similar to the results shown by number of fixations for Task 2, the influence of the greater figure-ground to focus subject attention is also demonstrated in the results of average duration per fixation on Maps 2 and 4. Subjects performed relatively better when spot heights were not displayed, and when some symbol such as the 10NM circle or radio-navigation aid symbol was displayed. Subjects seemed to be able to focus their attention to specific areas and make fixations that were relatively longer in duration, enabling the subject to extract more information from fewer fixations.

6.4.4 Implications of the Findings of Task 2

While the results of the mean duration of fixation did not show a significant increase as map complexity increased, the remaining dependent variables, number of fixations and mean duration per fixation, displayed trends that support the hypothesis stated earlier in section 6.0. The data recorded for mean duration per fixation may not show a distinct trend, but do, however, complement the results obtained from number of fixations. In fact, the relationship shown by mean duration per fixation is the inverse of that shown by number of fixations. In other words, when the number of fixations is high, the average duration per fixation is low, and when the number of fixations is low, average duration per fixation is high. The findings of Yarbus (1967), Tversky (1974) and Antes (1974), indicated that subjects make many fixations searching for informative pieces of information. These results must be considered with the findings of Antes, Chang, and Mullis (1985) and Antes and Chang (1990), who showed that longer durations per fixation indicate increased cognitive processing by the subject. Map 2 and Map 4 showed the lowest mean numbers of fixations, but the longest average duration per fixation. These results seem to indicate that the subject did not spend much time fixating information that was not relevant to the task at hand. More specifically, the information was easily located, and subjects were able to concentrate their efforts on completing the task. The mean duration per fixation on Map 2 is slightly, although not significantly, greater than for Map 4. When these results are considered with the number of fixations obtained in Task 2 (Map 2 recorded significantly fewer fixations than Map 1 and 3), it appears that Map 2 allows more efficient data extraction and use.

6.5 Number of Errors, Task 2

Task 2 showed a considerably higher number of errors than Task 1. The number of errors that subjects committed for the test maps used in Task 2 is summarized in Table 6.2.

Table 6.2. Number of errors committed on Task 2.

	Map 1	Map 2	Map 3	Map 4	Map 5
Map Complexity	0.008242	0.022310	0.032968	0.04221	0.054788
Number of errors	13	15	17	16	18

Task 2 was designed to examine the effects of increasing topographic information on a pilot's ability to make use of both aero-navigational and topographic information. More specifically, it was intended to investigate a pilot's ability to locate a symbol and then correctly estimate a distance. Preliminary discussions with pilots revealed that distances are mostly measured in nautical miles, while all charts show scale bars graduated in both kilometres and nautical miles. In many cases, the units of measure shown on the scale bars are abbreviated as NM (nautical miles) and km (kilometres). It was thought, therefore, that the scale bar showing both units may be a potential source of error. Pilots operating under high-pressure conditions may make a quick glance at the scale bar and confuse the two units (NM and km).

The results from Task 2 show that the increase in the amount of topographic information did have an effect on the subject's ability to extract data from the charts correctly. Map 1, the least complex, recorded thirteen errors while Map 5, the most complex recorded eighteen errors. Task 2 recorded a considerably higher number of errors than Task 1 suggesting that there is another problem, which appears to be an inability to estimate distances correctly. Candid comments from a number of pilots regarding distance estimation seemed to indicate that they did not experience much difficulty with the estimation. These comments would suggest that subjects did not think that working in kilometres was a problem. When asked about the scale bar, few reported difficulty determining one measure from the other, although, subjects readily admitted that they were not accustomed to using kilometres. It is not fully understood, at this point, if the poor performance is a result of an inability to estimate distances correctly, or if it is a result of not being accustomed to working in kilometres. With the exception of the scale bar graduated in kilometres, all other distances referenced on the charts are measured in nautical miles. If pilots primarily use nautical miles, why show kilometres when this measure is not really used? When information that seems to provide such little utility is presented on the chart, it appears to only add clutter to the map and should be removed.

6.6 Design Differences

An increase in the amount of information on an instrument approach chart does not have a simple effect on its utility. It was anticipated that increasing the amount of topographic information would have a double effect on the chart's communicability. Initially, the chart should become more effective as more information was added. After the optimum level of topographic data had been reached, the chart's effectiveness would diminish as important data was masked by additional detail. An examination of the mean values of the dependent variables in this experiment show that this is not always the case. In some instances, the means do not exactly fit the suggested trend. The distribution of values for mean number of fixations in

Task 2[24], for example, suggests that there are other factors, such as a design change, influencing the effectiveness of the chart.

An increase in chart information usually results in a change in the layout of chart information which may affect how the reader searches the chart. In most cases, design change is a result of non-conformity to the standards outlined in the ICAO *Aeronautical Chart Manual* (ICAO, 1987). This type of change is primarily characterized by differences in symbol design. The design change necessitated by an increase in the amount of information depicted on the chart is characterized by many more items. For example, message blocks displayed on the chart have no geo-positional requirement. They are most often placed where they will cause the least interference with the topographic information presented on the chart. As a consequence of adding more information to the chart, non-geographic information, such as, navigational beacon ID messages, radio frequency notices, and minimum safe altitude symbols are often moved to other locations, which may cause further confusion to chart users. Because the position of this information is not standardized and varies from one chart to the next, the pilot must needlessly search the chart to find information that should be readily available and easily identified. The problems introduced with non-standardized designs and varying amounts of topographic information among charts can be summarized as follows:

1. **Placement of the information** - As the amount of information increases, placement of the non-topographic information, message blocks and minimum safe altitude symbols, for example, may change. The cartographer, when currently constructing a chart, tries

[24] See Figure 5.4, page 92.

to place the additional information where it will least conflict with the topographic information.

2. **Overprints of aero-navigational and topographic information** - Although great effort is taken to minimize the amount of overprinting, it can not always be avoided. The overprints actually decrease the legibility of the data by printing two or more separate symbols in the same space.

3. **Symbol Design** - The designs of the symbols frequently vary from one chart to the next. The MSA symbols, for example, vary in terms of language, how the information is expressed, line-weights and size of the symbol. The symbols can be quite unique, or very similar to other message blocks used on the chart. The MSA symbols that are more unique in design from other symbols used on the map are more easily identified which could aid the communication of their data.

Given these problems, an examination of the design differences that exist among the test charts should provide a better understanding of the effects of adding topographic information. Map 1, Ouarzazate, contains a sparse amount of topographic information. There are four MSA blocks, one located in each of the four corners of the chart. These minimum safe altitude symbols are all relatively isolated from other types of chart information mostly located in the centre of the chart. The MSA information does not physically interact with the other information on the chart and therefore, the MSA symbols are easily identified. This factor is reflected in the low number of fixations and short duration of fixation for Task 1, Map 1.

The MSA symbols on Map 2, Narsarsuaq, are placed in similar locations to those on Map 1. On Map 2, however, there is more topographic information which covers the entire map area. The MSA symbols overprint the topographic information so that the background information shows through the symbol. Usually, when one symbol overprints a line, the line is broken so that it does not interfere with the legibility of the symbol. The lines and other topographic information have not been blocked from the background of the MSA symbol. As a result, the MSA symbol does not present its information as effectively as it could. Map 2 has other message blocks similar in design to the MSA blocks which initially may be confused with the MSA symbols. Each symbol should be designed so that there is a more distinct difference to avoid any possibility of confusion.

While Map 3, Mariehamn, differs from Map 2 with respect to the amount of topographic information, there are also differences in the number and placement of the MSA message blocks. This map contained only two MSA symbols located on the left and right-hand sides of the map. The background topographic information was blocked from the area of these symbols. As a result of eliminating the overprint, the conflict between MSA blocks and topography was minimal. In the lower right-hand corner of the chart there is a list of cautionary notes which, because of its size and appearance, may initially draw the attention of the reader. While some information on the chart can be disregarded by the subject when searching for MSA information, the caution note block is probably scanned for useful information. In normal chart use, it is desirable for pilots to read these caution notes. In this case, however, the cautionary notes are detrimental to the main task and should be reserved for extremely important information.

On Map 4, Hannover, the subject is presented with a great deal of information. The additional map data, especially the message blocks, appear to be visually categorized with each type of message block having a design unique to that type of information. This type of standardization is very beneficial to efficient data extraction since symbols of a distinct design would be more easily located, eliminating a need to check each message block for relevant data. The subject, therefore, should be able to confine the search to blocks with similar design. The number of fixations for Task 1-Map 4, however, does not necessarily reflect the increase in visual complexity from that shown on Map 3. In other words, given the difference in complexity between Maps 3 and 4, one would expect the number of fixations on Map 4 to be much higher. By making use of the categorization of the data, the search area can be limited which reduces the number of fixations required, resulting in more efficient use of the chart.

The volume of information contained on Map 5, Banak is significantly greater than on the other maps presented in the test series, a fact reflected in the high number of fixations and long durations of fixation for the map in Task 1. The volume of information, however, is not the only contributing factor. The MSA message block is presented with other ancillary information in the top margin area of the map. Although the search target is not located directly on the map, the volume of information undoubtedly influences the results. If the information had been on the chart, the subject might have experienced difficulty finding the message among all the other information. Similarly, the presence of all the additional information may have concealed the fact that the MSA block was <u>not</u> on the chart. The high mean duration of fixation would suggest that the subject may have extended the duration of the search to ensure that the information was not on the map. When the information could not be found on the map, the subject was forced to extend the search area to include the margin information of the chart. If the MSA symbol were more visible, the subject may have located it sooner which would therefore, make this chart more efficient than others used in the testing. There are many differences in the symbology used to represent the minimum safe altitude. Table 6.3 contains an example of each symbol, to illustrate these differences.

The test maps also have differences that influence the effectiveness of the charts for Task 2. The symbols that are of prime interest for this task are those representing obstacles. An example of each obstacle symbol is displayed in Table 6.3. The differences among these symbols and the differences in the amount of information that the subject must process are evident.

Table 6.3. Representation of some differences in symbol design.

	MAP 1	MAP 2	MAP 3	MAP 4	MAP 5
OBSTACLE SYMBOLS	1282 H: 282m	Mast Fl. W 1 sec 861 (278); Mast 295 (278)	None	508	670
SPOT HEIGHTS	1270	None	2591; 2027'	None in target area	2035
MINIMUM SAFE ALTITUDE	ALT MNM SECT 2350m 25NM	MNM SECT ALT 1600 25 NM	MSA 178°-358° 7100/25 NM	MSA 2100 25 NM	MNM SECT ALT 4500 270° BNK 090° 5000

On Map 1, obstacles are represented by an elaborate symbol which consists of an obstacle symbol, an angled leader line and a height. Map 2 provides two different symbols to represent a similar feature. One symbol includes a label, an elevation and a height. These three pieces of information provide a lot of data to process for a single point symbol. The second type of obstacle symbol is more elaborate, consisting of a star shaped figure on top of a tower shaped symbol. Along with the label, elevation and height, the descriptive information displayed with this symbol includes the characteristics of the flashing light at the top of the mast. While Map 3 does not have symbols to represent obstacles, it contains spot heights symbolized as a single dot with a label which is quite easy to read and interpret. It should be recalled, however, that when spot heights are shown on a map, there is more information for the subject to process.

The results from Task 2 indicate that spot heights attract the subject's attention when searching for obstacles. If the spot heights do not provide information pertaining to obstacles such as mountain peaks, they provide more information to process while not contributing a great deal to the chart. It has been shown by the results recorded for Task 2 that subjects performed more poorly on charts that displayed spot heights. In fact, spot heights are discouraged in the ICAO chart manual (ICAO, 1992). The chart production manual recommends the use of contour envelopes, defined as smoothed contour lines that omit smaller features and enclose terrain above a specified elevation. To better clarify the concept of a contour envelope, the ICAO chart manual (1992:7-11-23) states that "The contour envelope line is better considered NOT AS A LINE ENCLOSING GROUND ABOVE A CERTAIN

ELEVATION BUT AS A LINE OUTSIDE WHICH THE GROUND IS LOWER." Contour envelopes are favoured to be more informative to the pilot over conventional contours which may be more difficult to interpret in a high-pressure situation on the flight deck. Taylor and Hopkins (1975) reported that pilots favoured maps that did not show the clutter associated with conventional contours. Spot heights, likewise, should be avoided if only displayed to provide an indication of height of land and not to symbolize a significant hazard to navigation. Approach to an airport and landing is one of the most dangerous phases of flight. As the aircraft gets closer to the airport, it naturally decreases its altitude where it can come into contact with obstacles on the ground. These obstacles are of extreme importance to the pilot and need to be identified as quickly as possible. Adding greater figure-ground to the map by showing a 10NM, or perhaps a 5NM distance circle, would provide more focus and possibly greater ease in identifying hazards.

6.7 Information from Questionnaire:

Following the eye-movement recording, subjects were given a questionnaire to complete. The questionnaire provided information from each subject to supplement the data collected in the eye-movement recording session. Information such as: background data; subjects' perceptions of map complexity; and opinions on the amount of information contained on the test maps provided valuable insight into some of the problems experienced on instrument approach charts. The questionnaire is presented in full in Appendix D.

The first part of the questionnaire provided some background information on the subjects and their experience with instrument approach charts. Subjects were asked to provide their age and the number of years of flying experience, which were used as factors to categorize the data for additional analysis. A list of the different types of aircraft that each subject had flown was requested. Each subject listed a number of various types of aircraft; none had reported having their flight experience limited to a single type of aircraft. The aircraft flown by this group of subjects did not show any trends that may have been used for additional analysis of the eye-movement data. The questionnaire also asked subjects to report the highest level of education attained. Each subject reported completion of high school, but four of the twenty had gone on to post-secondary education. Of the subjects with post-secondary education, one was an MD and two of the four had Masters degrees.

One topic addressed in the questionnaire was language. The language of aviation is English, but some charts are produced in languages other than English. On the questionnaire, eighteen of twenty subjects reported that they were not familiar with other languages, one understood French, while another spoke and understood French. As demonstrated by the information gathered in the questionnaire, these pilots do not speak a multitude of languages. Using different languages on charts can cause some serious problems for the pilot. This problem may have been demonstrated by the results of Task 1, Map 1 where the language used in the minimum safe altitude symbol was French, further complicated by abbreviations. Map 1 contained the lowest level of information, but, the average durations per fixation were relatively high indicating cognitive difficulty on the part of the subject. The results for duration per fixation should have been much lower since there was little topographic information competing with the MSA symbol. The results, therefore, point to language as a possible reason for the problems experienced by the subjects on Task 1, Map 1.

The premise of the experiment was that this was the first exposure to the test charts. Subjects were asked if they had used charts other than Canadian charts, or if they had used any of the charts presented in the test session. Twelve of the twenty subjects had only used Canadian charts, the remaining eight subjects reported using charts for American aerodromes, more specifically charts produced by Jeppesen Corporation. None of the subjects reported any prior exposure to the charts used in the testing session. The limited exposure to international charts is quite significant. Pilots become accustomed to charts of a specific design. When confronted with a non-familiar chart design, they are unsure of what information the chart contains and where it is located. Because of the differences among charts, it takes longer to extract the necessary information, as was demonstrated on Map 5 (Banak). As the subject searched for the MSA information, their focus was primarily limited to the map area of the chart. Because the subject was not expecting to find the MSA information in the margin, it took significantly longer to find this data.

Castner and Eastman (1984) maintained that perceived complexity was a useful measure of map complexity. Their measure of complexity, it was thought, would provide an interesting comparison to the measured values of complexity in this current study. It was thought that charts with less graphic information, while not considered complex through measurement, may be difficult for subjects to use and, therefore, perceived as complex. Subjects were asked to rank each chart in order of increasing perceived complexity. The perceived ranking of complexity was compared with the measured ranking of chart complexity. The rankings of complexity matched almost exactly with one exception, subjects placed Map 2 above Map 3. These results show that subjects do not perceive charts with lesser amounts of graphic information as more complex. Subjects agree that as the amount of topographic data on the chart increases, the chart becomes more complex and more difficult to use. In addition to perceived complexity, subjects were asked to relate their opinion on the amount of topographic information that each chart contained. A weighted average value was calculated for each chart, reflecting that subjects thought there was not enough topographic information on Map 1, while Map 5 contained too much. Maps 2, 3, and 4 all produced values ranging from 3.05 to 3.8 (3 was used to indicate "Just Right"), which would suggest that subjects thought these charts contained an appropriate level of topographic information.

The information obtained from the questionnaire, when considered with the experimental results, provides a complete evaluation of the subjects' performance and perceptions for each of the test charts. The evaluation of these data provides a clear indication of the most effective level of topographic information, which should then be translated into more refined standards for aeronautical chart production.

The results of this experiment have been presented and interpreted. A summary of the experimental findings and the implications for chart design are presented in the following section.

6.8 Summary

The experimental results show that the volume of topographic information does have an effect on the pilot's ability to make efficient use of the charts. More evident, however, is the effect of non-standardized charts. There were two separate tasks that required the pilot to use different information presented on each chart. Each task, therefore, generated results that differed with respect to the most efficient amount of information. Since both tasks are representative of the types of tasks that are normally performed using these charts, both must be considered to play roles in determining the most effective design with respect to topographic information and standardized symbology.

Task 1 showed, generally, that as map information increases, the number of fixations and total durations of fixation per chart increase while average duration per fixation decreased. This does not completely agree with the hypothesis that effectiveness would initially increase with map complexity, later decreasing with a continued increase in topographic information. If effectiveness is determined solely on the basis of number of fixations and duration of fixation, the results do not agree with the hypothesis. Considering the number of errors committed, however, there is a decrease in chart effectiveness.

The reduced effectiveness demonstrated on Task 1 is a result of the subject having a more difficult time locating or identifying data pertinent to the task, but not necessarily more difficulty in its interpretation. When the charts depicted the lowest level of topographic data, the subjects were able to concentrate their efforts on the information pertinent to completing the task. As topographic information increases, the subject may have more information on which to fixate, but, the subject is able to easily dismiss the information as not relevant to completing the task. While the increase in topographic information may not have contributed to a significant increase in number and duration of fixations as conspicuously as the location of the relevant data, it may be responsible for the increased number of errors. More importantly, it was demonstrated that the number of symbols must be known and they must be placed in a location where the pilot will expect to find them. Knowing how many symbols that will be encountered on the chart will significantly reduce the chance of an error due a search for this information ending prematurely.

In Task 2, increasing the information presented on the chart produced results that, to a degree, correspond with the hypothesis presented in section 6.0. The results show that subjects experienced difficulty at the lower levels of map complexity, which is most likely owing to the chart not providing enough information. The subject is forced to make decisions normally considered simple, but due to the lack of information, the task is apparently more difficult. Subjects' performance improves as chart information increases, but then diminishes as the information continues to increase and the chart becomes overloaded with information. Duration of fixation showed no significant change indicating that the subject required approximately the same amount of time to extract the information from the chart. The decreasing average duration per fixation is indicative of an increase in the amount of information that is not pertinent to the task. A decrease in the average duration per fixation is, in part, indicative of a decrease in cognitive difficulty, and therefore, less cognitive processing as subjects quickly scan the additional chart data. The greatest increase in performance on the experimental tasks was realized by the addition of the radio-navigation aid symbol on Map 2 and the 10NM distance circle on Map 4 to provide the subject with the additional focus and greater benefit in more easily identifying significant obstacles.

There are maps that demonstrate increased cognitive difficulty on the part of the subject, which cannot be explained simply through an increase in the volume of topographic information. Many other items come into play such as number of symbols, design of symbols, and the additional figure-ground relationship implied through the 10NM distance circle and the representation of the radio navigation aid. Clearly, the biggest enemy to efficient chart use by the pilot is the lack of standardization shown on such charts.

This experiment shows that there is a problem with non-standardized presentations of instrument approach charts. The current designs and varying amounts of topographic information cause problems for pilots. From the experimental results and the questionnaire, the most effective level of chart information has been identified. The low number of fixations and short durations of fixation for Task 1 point to Map 1 as the most efficient. While differences among Maps 1, 2, 3, and 4 for Task 1 were not significantly different, results recorded for Map 1 were slightly better. The results of Task 2, however, indicate that Map 2 has the best representation of topographic information. It should be noted that there was no significant difference between the results of Map 1 and Map 2 for Task 1. Considering the results from both tasks, Map 2 can be considered to show the most effective amount of topographic information.

Subjects indicated on the questionnaire that they were comfortable with charts that indicated a moderate (Map 3) level of topographic information. In other words, subjects thought that some topographic information was useful, but too much data, as shown on Map 5, was unacceptable. Subjects tended to agree however, that the amount of topographic information should be kept to a minimum. While the focus of the chart is the aero-navigational information, they felt that there should be sufficient topography to provide a 'frame of reference'. Although pilots usually try to disregard all references to topography and concentrate on the aero-navigational data, subjects seemed to be uncomfortable with the lack of topographic information. Subjects also indicated on the questionnaire that the amount of topographic information on **Map 2** was in the 'just right' range. The data collected from the questionnaire were subjective in nature and were intended to supplement the findings of the eye movement recording data. This information from the questionnaire appeared sufficient to corroborate the eye-movement data which indicated **Map 2** contained the most effective amount of topographic information.

Apart from non-standardized chart designs, there were other problems identified by the results of this research. One significant problem is the high instance of error recorded by subjects in Task 2 - estimation of a distance in kilometres as opposed to nautical miles. The high error rate may be due to an inability to work in kilometres, or it may indicate a problem in estimating distances. The results of this experiment should be followed up by interviews with groups of pilots who will be asked to perform a similar task, but, comparing the results of distance estimations in nautical miles and kilometres. Examining the results obtained in this follow-up investigation should help identify the aspect of distance estimation causing pilots to experience the most difficulty.

6.9 Conclusions

The results of the eye-movement recordings have identified a significant problem concerning the depiction of topographic information on instrument approach charts. The amount of topographic information depicted on the chart is an extremely important design factor that must be considered by cartographers. To maximize the efficient communication of the chart, the correct amount of information must be shown and the design of the chart standardized.

Aeronautical chart production is governed by guidelines established by the International Civil Aviation Organization (ICAO). Although each chart used in the test session was designed to conform with ICAO standards, there was still a great variation in both volume of information and chart design. The effectiveness of chart standards, therefore, must be examined. While some of the standards and guidelines for chart production are adequate, many need to be made more specific. There is a need for more rigorous inspection of charts and closer adherence to standards for production. With firmer regulation, some of the standards that are already in place may be acceptable with some minor revisions. Member countries of ICAO need to be encouraged to follow the standards more closely. Some smaller countries, however, concede that the technology is not available to produce charts of comparable quality to some of the more advanced nations. Assistance could certainly be offered to developing countries to allow them to comply with the production standards. Such an agreement would most certainly benefit all countries. The developing country would get high quality charts while the country providing the service would have first rate material to use in flight. Secondly, the standards can be improved to reduce ambiguity and differences of interpretation. How standards are interpreted by cartographers in different countries may itself be largely responsible for many differences in chart design. Revising the wording and giving example graphics, showing acceptable ranges of the standards, therefore, would leave no room for individual interpretation and, hence, avoid many of the problems of inconsistencies on aeronautical charts.

Most importantly, this research has identified the most effective representation of data to be depicted on instrument approach charts. The experimental results indicate that overall, **Map 2** is considered to contain the most effective level of topographic information. It must be reiterated that subjects were asked in a questionnaire to indicate their perceived complexity of the charts, as well as their opinion concerning the amount of information.

Subjects responded that they thought topographic information should be kept to a minimum. Most subjects, however, agreed that some topographic information is required to provide a frame of reference for the aero-navigational information. Provision of topographic information may provide some psychological benefit to pilot. In other words, providing a 'grounding' to aero-navigational data may have a calming or reassuring effect by furnishing the pilot with some indicators of what they are facing on the approach. These charts are sometimes used in a transition from instrument to visual flight. While it may not be proper procedure on an instrument approach, topography on charts allows the pilot, if conditions permit, to visually verify their location. Given the experimental results and these conditions of use, chart standards can be revised to include:

1. Charts will show all information pertinent to the aero-navigational data of the approach. Instrument Approach Charts will be printed in black and white. Aero-navigational information will be printed in solid black, topographical information will be printed in a 30% tint screen of black. Line weights for each symbol used on the chart will follow specifications set down by ICAO. For example, the approach procedure track will be shown as a solid black line 0.035" wide, with an arrowhead 0.155" long and 0.140" wide to indicate direction of travel.

2. The topographic information to be shown will include: land-water boundaries including maritime coastlines, major lakes and rivers. Where water features are not present, major cultural features, such as urban areas and significant buildings will be shown. Contour envelopes, as defined in the ICAO chart manual, will be used to show height of land. Spot heights, when not symbolizing a significant hazard to navigation will be avoided.

3. Charts will be represented at a scale of 1:250,000 with a distance circle of 5NM centred on the aerodrome for which the procedure is specified.

4. There will be **ONE** minimum safe altitude diagram to be printed in the lower left hand corner of the map. The diagram will be printed in a format similar to that shown below in Figure 6.2.

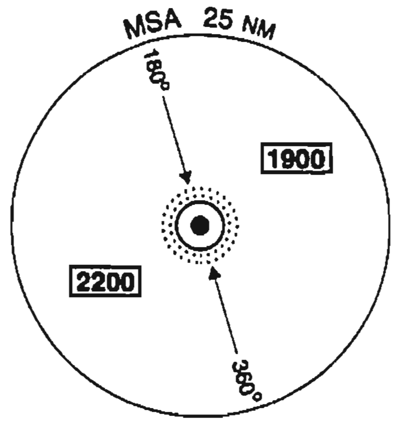

Figure 6.2. Suggested design for the minimum safe altitude diagram.

The great variability that exists in current instrument approach charts must be reduced. This research has shown that a pilot's performance is diminished if the correct amount of information is not presented on the map with standardized symbology and location. Instrument approach charts, and aeronautical charts as a whole, MUST be standardized. Air crew have enough information to contend with without worrying about what information may or may not be on the map, not to mention searching to find information on the map. Some countries tend to turn a blind eye and insist that there is no problem with their charts. This research, however, clearly shows that there are benefits to be achieved with standardized chart design. The most appropriate level of information for depiction and problems of non-standard designs have been identified. It is now in the hands of the agencies that produce aeronautical charts to improve their products, enhancing safety and making the task of the flight crew much easier. At a higher level, the ICAO must first of all, provide the refined standards for chart production. These changes must be followed up with rigorous inspection to ensure that production agencies are adhering to the production standards. Many times it is too easy for the cause of accidents to be ruled as human error without determining the actual reason for the error. Providing pilots with high-quality, standardized charts will surely make their job easier and allow them to concentrate more fully on the task at hand. In the name of safety, this is a problem that should not be ignored!

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APPENDIX A
Calculation of Complexity Values for the Test Charts.

An assumption has been made that maps will increase in complexity with the addition of more topographic information. A visual inspection was conducted on a series of charts to select several that appeared to increase in complexity. A grid, 0.25" x 0.25" was placed over the map images and the number of graphic elements contained in each cell were counted and entered into a matrix that corresponded to the chart and grid. On all charts used in testing, water bodies or rivers were symbolized in a shade of black; land, therefore, was white. In each cell, would always contain a value for land or water, so the minimum value of each cell is one. For example, a cell which contained a river (white background with a shaded line symbol) would be given a value of two. The values in the matrix, reflecting the volume of information on the chart were used to calculate a score for the complexity of the charts. To obtain this score, the following equation from Simms (1992) was used:

$$\sum_{i=1}^{k} \frac{(E_i - O_i)^2}{n(E_{max} - E_{min})^2}$$

Where:	E_i	=	Expected value - Can always expect at least 1
	O_i	=	Observed Value - Actual value occurring in a cell
	n	=	Number of cells
	E_{max}	=	Maximum cell value from all charts
	E_{min}	=	Minimum value

Following this procedure, scores were obtained for each chart to reflect it's complexity. The values obtained are shown in Table A.1.

Table A.1 Selection of charts tested and measured values of complexity

CHART TITLE	COUNTRY	COMPLEXITY
Antwerpen-Deurne	Belgium	0.023603
Banak	Norway	0.054788
Hannover	Germany	0.042212
Jessore	Bangladesh	0.008580
Kastoria	Greece	0.025696
Mariehamn	Finland	0.022310
Maun	Botswana	0.021844
Narsarsuaq	Greenland	0.032968
Ouarzazate	Morocco	0.008242

The complexity values for each chart were examined and several charts were selected to maximize the differences in complexity between charts. Chart selection was also based on the progression of the topographic information. In other words, it was also important that a set of charts was selected to reflect the increasing levels of topographic information. The charts selected were subjected to further testing to ensure that the differences were significant. As a result of the initial investigation, the following charts were selected: Ouarzazate; Mariehamn; Narsarsuaq; Hannover; and Banak. Using the values of complexity calculated, a mean value of 0.032096 and standard deviation of 0.0146215 was calculated. Establishing class breaks, one standard deviation in width centred on the mean value of complexity scores produces a set of classes. Each class contained only one score from a chart. Additional analysis was performed on each chart. The mean cell value and standard deviation was calculated for each chart.

Table A.2. Final selection of charts and profile of cell values

CHART	NUMBER OF CELLS	MEAN	STANDARD DEVIATION	STANDARD ERROR
Ouarzazate	840	1.6286	0.9995	0.0345
Mariehamn	784	2.5026	1.2307	0.0440
Narsarsuaq	754	2.9509	1.3296	0.0484
Hannover	754	2.7321	1.6313	0.0594
Banak	841	3.5410	1.6750	0.0578

Analysis of variance produces a value of $F= 209.9908$, $p<.01$. This result demonstrated that there is a significant difference in the charts. As a result of the significant F score, Tukey's HSD procedure was selected to determine where this significance occurred. It was determined that each chart was statistically different from the next.

APPENDIX B
Sequence of Presentation of the Test Charts.

Test charts were presented to the subjects in a balanced sequence. Each chart was presented in each position an equal number of times.

1. Ouarzazate, Morocco
2. Mariehamn, Finland
3. Narsarsuaq, Greenland
4. Hannover, Germany
5. Banak, Norway

Table B.1. Chart presentation sequence

SUBJECT	Presentation Sequence				
	1	2	3	4	5
1	3	2	1	4	5
2	2	5	3	1	4
3	4	1	2	5	3
4	1	2	3	5	4
5	1	4	5	2	3
6	5	4	1	3	2
7	5	3	1	2	4
8	3	5	4	1	2
9	4	2	5	3	1
10	2	5	3	4	1
11	5	1	4	3	2
12	2	4	3	1	5
13	4	3	1	2	5
14	2	1	5	4	3
15	1	5	2	4	3
16	3	4	2	1	5
17	5	2	4	3	1
18	1	3	4	5	2
19	4	3	5	2	1
20	3	1	2	5	4

APPENDIX C

Subject Instructions[1]
For participants in the eye-movement study on the design of Instrument Approach Charts

Introduction

This experiment is designed to evaluate the effects of varying amounts of topographic information contained on instrument approach charts. It involves measuring and recording your eye-movements while using the charts; and then completing a short questionnaire following the eye-movement recording session. Before participating in this experiment you are asked to sign the informed consent form provided, so please read this procedural information carefully.

During the testing session, you will be shown instrument approach charts for five different aerodromes. These charts have been produced by different countries and all conform to International Civil Aviation Organization (ICAO) standards. The basis of this experiment is to examine how the map user reads each map when given a particular task. The tasks that you will perform while viewing the charts are intended to simulate a common usage of instrument approach charts. You will be briefed on the task that you are to perform prior to the eye-movement recording session. The entire testing session should take approximately 1 to 1.5 hours.

The Arts Research Committee at Memorial University has reviewed the procedures and has approved this experiment. Please note that your identity will remain anonymous. You will be assigned a subject ID number at

1 Based on procedures described in: Wood, C.H. The influence of figure and ground on visual scanning behaviour in cartographic context. [Unpublished Ph.D. dissertation]. Madison, Wisconsin: University of Wisconsin, Madison; 1992

the start of the test session and all materials used will require your subject ID number.

Pre-Test Set-up

Once seated at the system, it will be necessary to adjust the equipment to suit you. This will optimize the data collection conditions and help to make you more comfortable. This process may take some time, but is essential to ensure that top quality results are obtained. Once the system adjustment is complete, you may relax a minute before the data collection phase begins. At this time, the experimenter will review the procedure to be followed during the data collection. You will also be briefed on the tasks to be performed while viewing the maps. Once the experimenter is satisfied that you are ready, the data collection phase will begin.

Data Collection

The data collection phase involves the presentation of a pre-calibration chart, the target map, and then a post-calibration chart. Each part of the data collection phase will be explained more fully in the following sections.

To prepare for the data collection, take your place at the eye-monitoring system and make yourself as comfortable as possible. Once you are set, please avoid as much movement as possible.

1. Pre-Calibration

   You will be asked to close your eyes while the calibration chart is loaded into the display. The calibration chart contains nine numbered dots that correspond to the four corners, the centre of the chart and the midpoint of each side. When told to do so, open your eyes and fixate on the numbered dot at the centre of the display. The experimenter will ask you to fixate on one of the nine dots. Please fixate on that dot and DO NOT SHIFT YOUR GAZE UNTIL TOLD TO DO SO. The experimenter will ask you to fixate on another, please fixate on that dot until told to move your eyes to the next dot. This process will be repeated until all nine points have been sampled at least twice. If the two samples for a given point do not fall within the tolerances set for the calibration, that point will be sampled again until the tolerances are met. When the calibration procedure is complete, you will be told to close your eyes and the first map will be loaded into the display.

2. Map Use

The experimenter will signal the start of the map observation by the verbal command BEGIN. Open your eyes and commence the task. Once you have enough information to complete the task, signal to the experimenter by pressing the button on the light switch. On the command STOP, close your eyes and remain still. The experimenter will prompt you for your response by stating several possible answers to the question posed in the task. You are to signal the experimenter when you hear the most appropriate answer. Information extracted from an aeronautical chart, as you may already know, needs to obtained quickly and accurately. It is important, therefore, to complete the task as quickly as possible, but please ensure that you take enough time to verify your answer. The observation of the map will be followed by a calibration routine.

3. Post-Calibration

The post-calibration procedure is the same as that for the pre-calibration. The experimenter will ask you to "Fixate on number 1, number 2, number 3", and so on. As you are requested to fixate on each point, please concentrate on that point until you are asked to move to another. The calibration routines precede and follow the viewing of each map. Comparing the pre-calibration with the post calibration will help determine whether or not any head movement has taken place during the testing procedure. Once the post-calibration routine is complete, you may relax slightly before beginning the next series. While relaxing, however, it is important that you avoid as much body and head movement as possible.

The entire procedure: pre-calibration; map use session; and post-calibration; will be repeated a total of ten times. Once for each of five navigational tasks, and once each for five topographical tasks.

Post-Test Questionnaire

Once you have completed the eye-movement recording phase of the experiment, you will be given the charts from the first part of the experiment to use in the completion of a brief questionnaire.

Summary of Instructions

Note: UPPER CASE TYPE - Instructions from experimenter
Upper/lower case type - Notes or descriptions of action required

1. Pre-Calibration

Close your eyes and remain absolutely still.

OPEN YOUR EYES - FIXATE ON NUMBER 1

Fixate on number 1 and do not shift your gaze until told to do so.

NUMBER 2

Fixate on number 2 and on each subsequent point as requested until the experimenter says:

CLOSE YOUR EYES

Close your eyes and remain absolutely still while the target map is being loaded into the display. Keep your eyes closed until the experimenter tells you to begin the task.

2. Map Observation

The experimenter will remind you of the task that you are to perform while looking at the charts.

BEGIN

Open your eyes and commence the task, obtain the information as quickly as possible, but take enough time to visually verify your answer. Press the button on the light switch to signal to the experimenter that you are finished.

STOP - CLOSE YOUR EYES

Please remain absolutely still until after the post-calibration.

IS YOUR ANSWER A B C D

Signal when you hear the answer that is closest to yours, if you would like the list repeated, please wait, it will be repeated after a short pause. Once again, please remain absolutely still until after the post-calibration.

3. Post-Calibration

The post-calibration procedure is the same as that for the pre-calibration. The experimenter will ask you to "Fixate on number 1, number 2, number 3", and so on. As you are requested to fixate on each point, please concentrate on that point until you are asked to move to another. Once the post-calibration routine is complete, you may relax slightly before beginning the next series. While relaxing, however, it is important that you avoid as much body and head movement as possible.

If you have any questions about the procedure to be followed in this experiment, please ask the experimenter before commencing the test session.

Thank you for your co-operation.

APPENDIX D
Post -Test Questionnaire

Subject ID Number:________________

Age:_______ Sex: M F

Years of Flying Experience:______________________________

Types of Aircraft flown:________________________________

Highest level of education attained:______________________

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1) Do you speak and/or understand any languages besides English?

YES / NO

If yes, list them ____

2) Do you read music?

YES / NO

3) Have you ever used instrument approach charts other than those for Canadian aerodromes?

YES / NO

If yes, list some of the more frequently used ones ________________
____
____

4) Before participating in this experiment, did you ever see or use the charts that were displayed?

YES / NO

If yes, which ones ____
____

5) Given the tasks that you have just performed, rank each chart in order of increasing complexity:

Least complex 1.________________________

2.________________________

3.________________________

4.________________________

Most complex 5.________________________

How did you decide on this ranking?

4) For the charts that you have observed, rank your opinion on the amount of topographic information that each contains (Circle one).

	Not Enough		Just Right		Too Much
Banak	1	2	3	4	5
Hannover	1	2	3	4	5
Mariehamn	1	2	3	4	5
Narsarsuaq	1	2	3	4	5
Ouarzazate	1	2	3	4	5

If you would like to make any comments on the charts that you have viewed as part of this test session or aeronautical charts in general, please feel free to do so in the space provided:

APPENDIX E
Subject Profiles

Subject Number	Sex	Age	Experience (years)	Responses to Post-test Questionnaire			
				Question 1	Question 2	Question 3	Question 4
1	M	28	10	NO	YES	NO	NO
2	M	28	9	NO	NO	YES (US)	NO
3	M	20	1.5	NO	NO	YES (US)	NO
4	M	20	2	NO	YES	NO	NO
5	M	19	1	NO	NO	NO	NO
6	M	19	1.5	NO	YES	NO	NO
7	M	21	2	NO	NO	YES (US)	NO
8	M	38	20	YES (UF)	NO	YES (US)	NO
9	M	26	6	NO	NO	NO	NO
10	M	27	3	NO	NO	NO	NO
11	M	25	4	NO	NO	NO	NO
12	M	39	10	NO	NO	NO	NO
13	M	41	20	NO	NO	YES (US)	NO
14	M	34	12	NO	YES	YES (US)	NO
15	M	38	21	NO	NO	NO	NO
16	M	35	15	NO	NO	NO	NO
17	F		5	NO	NO	YES (US)	NO
18	M	30	3	NO	NO	NO	NO
19	M	35	4	YES (F)	NO	NO	NO
20	M	26	8.5	NO	NO	YES (US)	NO

UF - Understands French
F - Understands and Speaks French

US - United States