HUMAN FACTORS
IN AIR-TO-GROUND
TARGET ACQUISITION

by

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SUMMARY

This thesis provides a general background to the experimental studies of air-to-ground target acquisition reported in the Appendices. An introductory chapter outlines some of the human factors problems associated with high-speed, low-level flight with particular reference to visual tasks, including visual and televisual target acquisition. The remainder of the work falls into three main parts; a review of the literature relating to target acquisition performance; an account of the techniques available for the study of target acquisition; and an evaluation of the present author's experimental work.

A review of experimental findings relating to target acquisition occupies the main part of Chapter 2. In this chapter the many complex and interacting variables which affect target acquisition performance, including those associated with television viewing systems, are discussed with reference to unclassified work published in Britain and the United States. The limitations of the available data, and the problems of formulating predictive models of acquisition performance are considered.

In the following chapter, the relative merits of the techniques available for the experimental study of target acquisition are discussed. The advantages and limitations of flight trials are considered first, and a general discussion of simulation methods follows. Current high-fidelity terrain simulation techniques are described, with particular reference to their suitability for the study of visual and televisual target acquisition tasks. Finally, the use of simplified visual displays as a means of studying some aspects of target acquisition performance is considered.

The contribution made by the present author's work, and the limitations inherent in the static display technique used, are reviewed in Chapter 4, in the light of the preceding discussion. This work, in which the effect on target acquisition performance of a number of factors (including range, navigational uncertainty, viewing distance, visual noise, exposure time and briefing information) was investigated, is described in the series of reports which form Appendices 1, 2 and 3. The final chapter of the thesis is largely concerned with a more general discussion of the role of human factors work in the development of guided weapon systems.

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The author would like to acknowledge the generosity of the following organisations in providing photographs for inclusion in this thesis: British Aircraft Corporation, Warton; Hawker Siddeley Dynamics, Hatfield; Martin Marietta Corporation, Orlando, Florida; Naval Weapons Center, China Lake, California; North American Aviation, Columbus, Ohio; The Boeing Company, Seattle, Washington.

1. GENERAL INTRODUCTION

The conditions under which military aircraft can penetrate hostile territory to carry out operations such as visual reconnaissance, ground support and weapon delivery are severely constrained by the need to avoid detection by modern radar defence systems. In order to maximise the probability of avoiding radar detection, it is essential that attacking aircraft fly at very high speeds and low altitudes. Operating under these conditions gives rise to a number of particular problems and hazards which must be taken into account when planning high-speed, low-level missions so as to ensure, as far as possible, survival of aircrew and equipment, and maximum effectiveness of the mission in accomplishing its objectives.

In determining optimum operational parameters for any particular mission, four main factors must be considered in order to maximise the probability of survival. Firstly, altitude must be kept as low as possible to take maximum advantage of terrain masking, so as to avoid early detection by radar. Under high-speed, low-level conditions an attacking aircraft need only enter radar cover for fractions of a minute, and thus the defender is faced with the problem of identifying the aircraft and operating surface-to-air missiles in this severely limited time.

Secondly, the minimum altitude at which the aircraft can fly is determined by the need to ensure that the probability of it colliding with the terrain is as low as realistically possible. The task of maintaining this minimum clearance altitude requires continuous attention since a slight downward deviation may result in an immediate crash, while a slight upward deviation greatly increases the probability of radar detection.

Thirdly, the maximum speed is limited by the need to avoid sound-barrier effects, and to ensure that vibration and buffeting are within the limits of human tolerance for the required exposure time. The lower the aircraft altitude, the less is the maximum tolerable speed. Finally, minimum penetration speed is limited by the need to make interception difficult if radar detection should occur and to avoid small-arms fire from the ground. The lower the aircraft altitude, the lower is the minimum penetration speed since the penetrating aircraft will be within view of the ground for a shorter time.

It can be seen that these four considerations impose very severe constraints on the speed and altitude profile of an attacking aircraft. High-speed, low-level missions of this type place heavy demands on the aircrew, who must not only maintain the required flight profile with great accuracy, but must also navigate visually during the course of the flight, identify the required targets and carry out either photographic reconnaissance or actual weapon-delivery procedures. In addition, auxiliary tasks such as operating electronic counter-measures further add to the aircrew workload. All these procedures must be carried out successfully in order to ensure maximum mission effectiveness.

A number of sophisticated devices have been developed to aid the aircrew in carrying out these tasks. For instance, automatic terrain-following systems can be used to maintain the required terrain clearance, and the introduction of inertial systems has greatly increased the accuracy of navigation. Nevertheless, it is still necessary for the pilot or navigator to obtain confirmation of the exact aircraft position by visual identification of en route checkpoints with reference to maps and other briefing materials. As the target area is approached this precise geographic orientation becomes even more important to facilitate accurate target acquisition at as long a range as possible.

These visual tasks form a considerable part of the aircrew workload and their successful execution is vital to the overall success of the mission. Whilst high-speed, low-level flight offers the optimum chance for avoiding detection by enemy radar, it results in extremely adverse conditions for visual navigation and target acquisition. The outside world as viewed from a high-speed, low-level aircraft is seen very obliquely, giving rise to severe masking and perspective effects, and objects move through the observer's field of view with very high angular velocities. Target detection and identification thus present extremely difficult visual problems. The detailed nature of these problems and ways in which they may be studied are the major concern of this thesis.

It is clear that even under optimum conditions, high-speed low-level flight over heavily-defended hostile terrain is a hazardous operation and one in which a severe workload is imposed on the pilot. Although careful calculation of speed, altitude and track for any particular mission can maximise the probability of overall mission survival, the success of such a mission can never be entirely guaranteed. Some hazard to the aircraft and the aircrew inevitably remains.

In view of this risk to life and equipment it is natural that alternative methods of weapon delivery should have been sought. One alternative is the use of stand-off missiles which are launched in the direction of the target while the aircraft is still some miles away, thus avoiding the need for the aircraft to enter the immediate vicinity of the target, which is likely to be heavily defended. In some cases radar-seeking devices may be used to cause the missile to seek out a radar-emitting source and home onto it. Similarly, infra-red detectors can be used to home onto heat-emitting sources. Missiles of this type cannot be controlled once they have left the aircraft. If launched inaccurately they may fail to reach the target, or in the case of a radar or infra-red detecting device, home onto a target other than that intended.

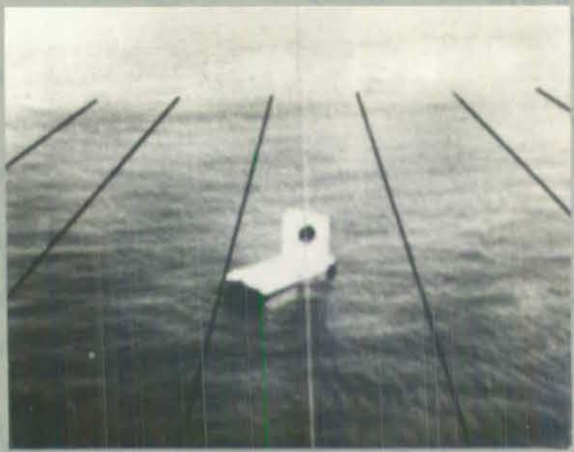
During the past decade, stand-off weapons of a more sophisticated type have been developed. These can be directly guided by means of a television display which relays to the aircraft cockpit a view of the terrain over which the missile is flying as it travels towards the target. As soon as the missile has been launched the aircraft can head away from the launching point, carrying out any manoeuvres necessary to avoid detection and interception, while the navigator visually navigates the missile to the target. The use of this type of weapon combines the advantages of accurate visual guidance with those of keeping the aircraft itself away from the heavily-defended area around the target.

Examples of television-guided weapons developed in the United States are the Walleye glide bomb and the Maverick missile while, on this side of the Atlantic, Britain and France have cooperated in developing the Martel missile, which is designed to be fitted with interchangeable heads for television guidance or anti-radar homing missions. Much of the research described in later parts of this thesis has been carried out in connection with the television-guided form of the Martel. Figure 1.1 shows the Buccaneer, a low-level strike aircraft, equipped with this version of the missile. Three Martels are carried, the fourth position being occupied by a guidance pod. A sequence of photographs taken during a test-firing of the Martel against a sea target is shown in Figure 1.2.

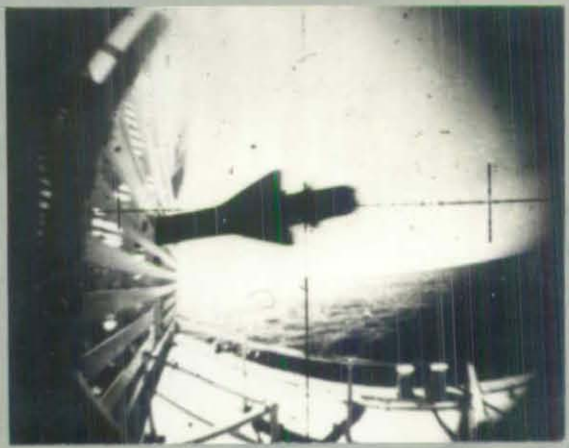
In its television-guided form the Martel follows a pre-programmed course immediately after launch while it climbs to its operating altitude. It then starts to relay to the monitor screen in the aircraft cockpit a forward view of the terrain over which it is flying. The weapon operator navigates by means of this display as the missile travels towards the target area. If required, he can bring about parallel displacement of the missile track in steps of 1000 ft. to either side, and there is also facility for increasing or decreasing the altitude, if

FIGURE 1.1
Buccaneer aircraft carrying three
Martel television-guided missiles

(a) Launch from aircraft



(b) Television view two seconds from impact



(c) Impact on the target

FIGURE 1.2
Test firing of Martel against a sea target.

necessary to obtain a better view of the terrain or to avoid cloud.

When the target has been visually acquired, the terminal phase is initiated and electronically-generated crosswires appear on the display. Using a joystick, which controls both the position of the crosswires and the slewing of the television camera in the missile, the operator tracks the target as the camera movement brings it to the centre of the display. Alignment of the body of the missile follows that of the camera axis and thus, provided the operator maintains the crosswires superimposed on the target, the missile impacts with a high degree of accuracy.

The exact stand-off range of the Martel is still classified but Taylor (1970) quotes it as 'tens of miles' which enables the aircraft to remain out of visual and radar range throughout the mission. Whilst stand-off missiles undoubtedly reduce the hazards to aircrew and aircraft during weapon delivery, television displays add considerably to the difficulty of visual navigation and target acquisition. A monochrome television display is greatly inferior to a direct view of the terrain as a source of information about the real world. In particular, the field of view covered by the television camera is very much less than that which can be seen directly from the aircraft. This makes visual navigation and geographic orientation considerably more difficult.

If the operating altitude of television-guided missiles were limited to the same degree by the restrictions which apply to high-speed, low-level aircraft, then severe perspective and masking effects coupled with the small field of view would make visual navigation impossibly difficult. However, the small size of the missile as compared with an aircraft makes it much more difficult to detect by radar, and thus rather higher altitudes and lower speeds can be used than in the case of aircraft. Furthermore, even if detection and destruction should occur, it does not involve the same hazard to life as in the case of a manned aircraft.

Television-guided missiles can therefore operate at altitudes of approximately 2000 ft. as compared with 200-500 ft. for high-speed, low-level aircraft. This increased altitude substantially lessens the severity of perspective and masking effects, and also increases the area of terrain covered by a particular camera field of view, thus making televisual navigation and target acquisition a feasible proposition.

In addition to the restricted field of view other characteristics of the television display system, particularly resolution, contrast and visual noise all influence target acquisition performance. Thus the use of television systems introduces a number of additional factors into the already complicated visual problems involved in direct air-to-ground target acquisition. In developing a television system for a guided missile the aim must be to optimise target acquisition performance, while taking into account size and weight limits imposed on the camera system by the structure of the missile, and any constraints on the television display system, for instance, monitor size, which may result from space limitations in the cockpit. Furthermore, the cost of the system must be closely considered.

It is essential therefore that research should be carried out into factors affecting televisual target acquisition performance. Whilst many of these factors are the same as those which affect direct-view target acquisition tasks, the additional variables associated with the television system are particularly important. Televisual target acquisition performance has been studied experimentally in both the United States and in Britain and the work reported later in this thesis is a small part of a much wider research program involving the Royal Aircraft Establishment, the British Aircraft Corporation and Nottingham University.

Whilst this work is concerned only with the use of standard television systems as a means of target acquisition it should be emphasised that other sensor systems such as infra-red, radar and low-light television are also being developed for this purpose. These systems have the advantages of being suitable for use under conditions of darkness or near-darkness, but the displays produced are less realistic than television displays. As research progresses it is likely that a whole range of sophisticated sensor systems, used alone or in combination, will become available. It will then be possible to choose any particular type or types of sensor to meet the requirements of a particular mission.

So far this discussion has been concerned with systems in which the human operator forms an integral part of the control loop. However, research is also being carried out into automatic computer-aided target recognition. This would have the effect of removing man from the control loop, but the current state-of-the-art is such that it is likely to be at least a decade before an effective system for the recognition of ground targets is developed in the laboratory, and considerably longer before it becomes operational.

In terms of flexibility, effectiveness and compactness, the human visual system, 'the Mark 1 eyeball' as it has been termed, is unrivalled as a means of target acquisition and is likely to remain so for many years to come. The performance of the human operator at both visual and televisual target acquisition tasks is therefore of vital importance. The purpose of this thesis is to review the factors which affect target acquisition performance, and to consider the techniques available for studying these factors, as a background to the author's own experimental work reported in Appendices 1, 2 and 3. These appendices include six detailed experimental reports, numbered Parts I - VI, and two shorter Study Notes. In the text of this thesis these reports are referred to by their individual numbers.

The material in this thesis has been arranged in the following way. A review of experimental work concerned with factors affecting target acquisition performance occupies the main part of Chapter 2, following a brief introduction in which some points of general relevance to the interpretation of this experimental work are discussed. The next chapter describes the use of flight trials, high-fidelity simulation techniques and laboratory experiments in the study of target acquisition. The advantages and limitations of these techniques are considered in relation to the type of research for which they have been used. The present author's experimental work is considered in Chapter 4, with reference to relevant points discussed in the two previous chapters, while the final chapter presents some general conclusions.

2. FACTORS AFFECTING AIR-TO-GROUND TARGET ACQUISITION

2.0 INTRODUCTION

The ability of the human observer to carry out air-to-ground target acquisition tasks under high-speed, low-level flight conditions is affected by a large number of complex and interacting variables. These variables are associated with the visual characteristics of the outside world, particularly the nature of the target and the terrain in which it is situated, the dynamic effects resulting from the aircraft's motion, the cockpit environment, and the visual skills and background experience of the observer. In the case of a remote television-guided missile, additional variables are introduced by the characteristics of the television display system.

The purpose of this chapter is to outline the main variables which affect target acquisition performance and to review relevant experimental work. Although most of these variables have been investigated in a number of experiments, from which it is possible to obtain a general picture of the likely effects of a particular factor, it is very difficult to make any detailed or quantitative comparisons between the results obtained in different experiments. The main reasons for this are considered below.

Part of the difficulty arises from the fact that, as Bliss (1966) has pointed out, the problem of visual acquisition of ground targets is actually five different problems, associated with five different types of mission; (i) reconnaissance or surveillance; (ii) navigation; (iii) attacks on targets of opportunity; (iv) attacks on targets identified in pre-briefing; and (v) vectored attack in which no search or only limited search is required.

For a given target against a particular background at a particular time, and all other things being equal, there is no reason to expect the same target acquisition ranges for any of these five missions. It is therefore essential that any discussion of target acquisition performance must be related to the precise nature of the mission concerned. In practice, even if two studies are concerned with the same type of mission, there are almost invariably differences in fixed experimental conditions, for instance, speed or altitude, nature of targets or terrain, or experience level of the subjects, which make any quantitative comparison of the effects of a particular variable in the two experiments of little value.

A further problem arises from the large number of different experimental techniques used in target acquisition experiments. Many of the experiments from which data have been obtained are carried out under greatly simplified conditions which do not represent the complex visual and dynamic characteristics of air-to-ground target acquisition tasks. The most important characteristic which the five types of mission described above have in common is that, at the time when acquisition is attempted, they each involve a visually changing target in a changing background. In his bibliography of target acquisition studies Bliss (1966) comments that only 36% of the 213 reports he cites meet this requirement for a changing target in a changing background.

In the present review attention has been concentrated more specifically on published work of direct relevance to air-to-ground target acquisition, and particularly that which relates to missions of the type defined under (iv) above, i.e. missions involving the acquisition of specific pre-briefed targets, which are the primary concern of this thesis. Although the exclusion of all classified work inevitably restricts the completeness with which research in this area can be reviewed, approximately 66% of the research papers referred to in this chapter relate to field trials or dynamic simulation techniques in which real-world targets and backgrounds are used, and a further 10% relate to studies involving realistic static imagery, for instance, aerial photographs, while the remaining 24% are concerned with laboratory experiments of a simpler type which nonetheless reflect some aspects of the visual problems in air-to-ground target acquisition.

A study of the literature reveals that a considerable amount of confusion exists between the terms detection, recognition and identification in relation to the visual problems of finding ground targets. The commonly accepted definitions of these terms are as follows: detection is the determination that some object is present in the visual field in a location compatible with its being the target; recognition is the determination that the detected object is a member of the subclass of objects for which the observer is looking; and identification is the determination of which member the target is of the subclass of interest. In some cases, depending on the nature of the target and the type of briefing provided, recognition and identification may occur almost simultaneously. For this reason many of the experiments referred to in this section are concerned with recognition probability rather than identification probability.

The term target acquisition is usually taken to be a generic one covering any or all of the terms discussed above. If the observer's task in any particular situation is target detection, then the target has been acquired when it is detected; if, on the other hand, identification is required, then target acquisition only occurs when identification is achieved. In this thesis when referring to work carried out by other research workers the practice adopted has been to use whatever term is used by the original authors, while indicating those instances in which the term given does not appear to correspond with the definitions above.

One possible source of variation in target acquisition data arises from the different interpretations that can be given to the terms detection, recognition and identification, not only by different experimenters in giving instructions to the subjects, but by different subjects in carrying out the instructions given in a particular experiment, especially in relation to the degree of certainty required before responding.

A further difficulty in comparing the results of different experiments is the variety of performance measures used. Range and probability of detection, recognition or identification, which can be combined into a single cumulative curve giving the proportion of targets correctly acquired by any particular range, are the most commonly used but there are others.

In the case of cine-film simulation techniques various performance measures which depend on detailed analysis of the visual imagery can be employed. For instance, in the United Kingdom a measure known as the potential range is frequently determined in addition to recognition range (see, for instance, Mardon, 1969b and 1969c, Milnes-Walker, 1969). The potential range, which depends on the physical characteristics of the target, terrain, atmosphere and illumination, is the range at which the target can just be detected under perfect briefing conditions. As such, it represents the range beyond which the target cannot be detected by the human eye under the viewing conditions used. It is usually measured by repeated slow-motion viewing of the film in forward and reverse directions.

A performance measure known as the search ratio, defined by Gilmour (1964), is more frequently used in the United States. The search ratio is derived from the acquisition range and the total available range, the latter being similar in concept to potential range except that it is determined by the experimenter under static viewing conditions. In simulation experiments involving the use of static imagery, such as aerial photographs, range cannot be used as a performance measure and normally search time is used instead.

In target acquisition experiments it is usually possible to achieve longer acquisition ranges (or shorter search times) at the expense of a loss in accuracy i.e. a lower acquisition probability. Thus a degradation in performance due to a particular condition may be reflected in either lower acquisition probabilities, or shorter ranges, or a combination of both. Which of these effects predominates depends on the instructions given to subjects and the extent to which they are willing to make a response at a lower level of confidence. Again, this makes comparison between different experiments difficult.

Other factors which must be taken into account when assessing the results of a particular experiment are the experience level of the subjects, especially whether or not they are skilled aerial observers, and the total workload imposed during the target acquisition experiment. For instance, an experimental condition which causes a deterioration in the performance of unskilled subjects might not affect that of skilled subjects. Similarly, a factor which does not appear to affect performance under low workload conditions, such as simply observing a cine-film simulation, might have more serious effects if a realistic workload was imposed by requiring the pilot to control the aircraft in addition to carrying out the target acquisition task.

The problems discussed above, together with the fact that some of the parameters affecting target acquisition are extremely difficult to quantify, make it virtually impossible to combine existing data from flight trials and/or simulation experiments into a meaningful predictive model of target acquisition performance. It is for this reason that those concerned with mathematical models of acquisition performance tend to resort to the use of basic data from simple well-controlled laboratory experiments, which bear little relation to the realities of air-to-ground target acquisition. The purpose of the present discussion is not to search for mathematical formulations but to present a general picture of the effects on target acquisition performance of a number of important factors, with particular reference to studies carried out under realistic conditions.

In this chapter, the main factors which affect target acquisition performance are grouped under the following headings: flight variables; target/background variables; meteorological conditions; seasonal/diurnal effects; the cockpit environment; crew composition; briefing information; visual skills,training and experience; and television display variables. The data presented are restricted to those specifically applicable to air-to-ground target acquisition. Standard human factors data including, for instance, general recommendations about environmental conditions, and the size, position and illumination of displays, are not given as these are available in a number of text-books, such as that by Morgan, Cook, Chapanis and Lund (1963).

2.1 FLIGHT VARIABLES

2.1.0 Introduction

The factors considered in this section, particularly speed and altitude, are among the most fundamental variables affecting air-to-ground target acquisition performance. Many of the main problems in the detection, recognition and identification of ground targets, for instance, perspective and masking effects, short target exposure times and high angular velocities, arise directly from the need to fly at very high speeds and low altitudes to avoid detection over hostile terrain.

It is therefore essential to know how variations in speed and altitude, within these high-speed, low-level constraints, affect target acquisition performance. Both these parameters have been the subject of a number of studies. In addition to being of considerable importance, they are also relatively easy to study since they can be reasonably accurately controlled and measured in both flight trials and simulation experiments.

Other factors considered in this section are navigational uncertainty, which is of importance because it determines the extent of the area which must be searched to locate the target, and a closely associated factor, geographic orientation. The effect of the direction from which the target is approached is also discussed. In this section, as in others in this chapter, diagrams have been included to illustrate typical experimental findings for some of the more important factors.

2.1.1. Speed

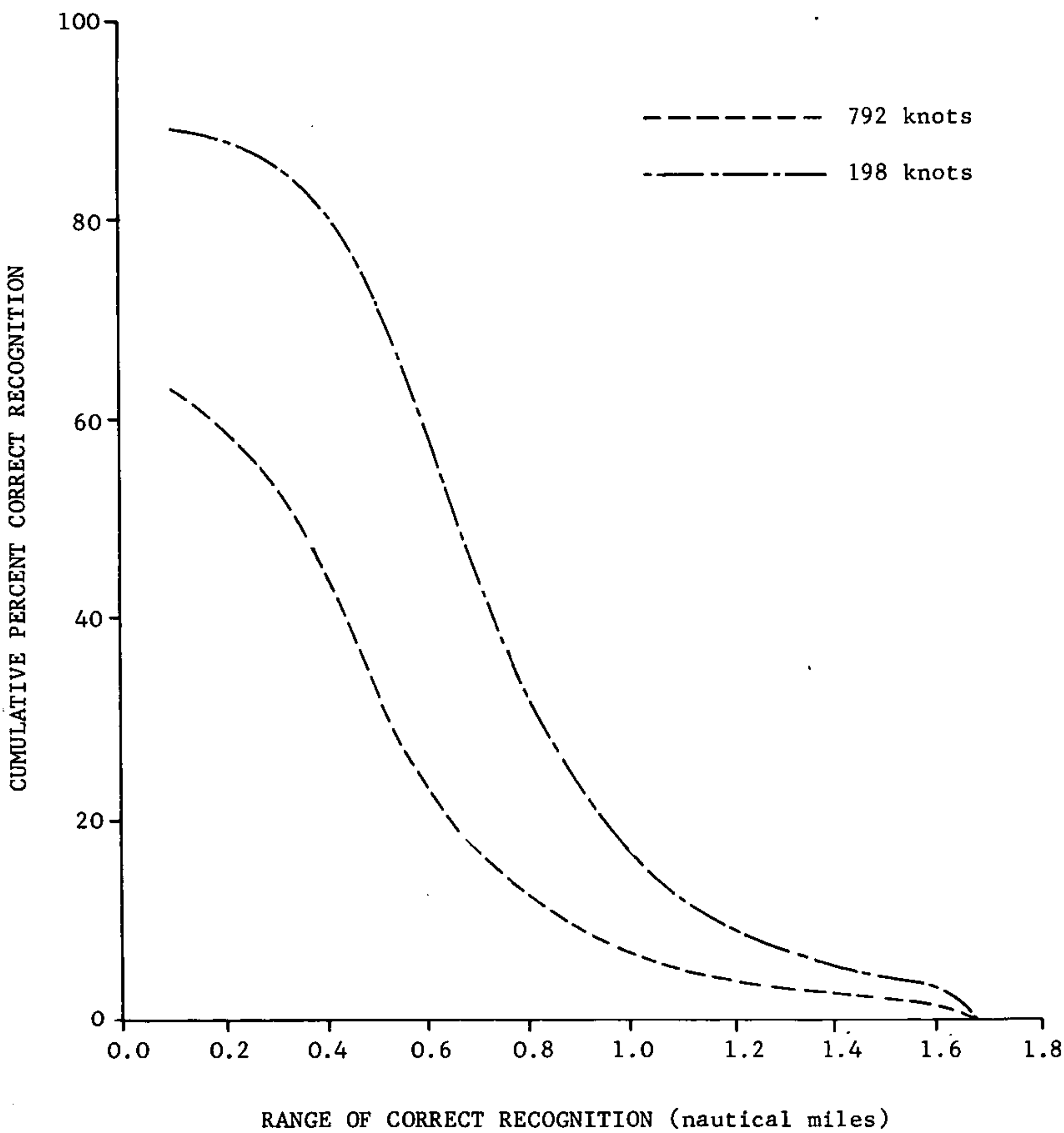
Increase in aircraft speed results in a decrease in the time available for target detection and recognition and, therefore, would be expected to result in some deterioration of performance. This is the general finding of experiments which have investigated speed effects, although the magnitude of the performance decrement, and whether it is apparent in acquisition range or acquisition probability, or both, appears to depend very much on the test conditions studied. In some cases only marginal and non-significant results have been obtained.

Dyer (1964) reports that in flight trials carried out at an altitude of 500 ft. there was no effect on acquisition probability as a result of increasing airspeed from 350 kns. to 700 kns. However, the mean acquisition range at the 700 kns. speed (11,250 ft.) was significantly less than those for the 550 kns. and 350 kns. speeds (15,200 ft. and 16,300 ft. respectively) although the latter two values were not significantly different. Pilots' comments recorded during these trials indicated that, particularly for a first pass over a target, the majority of them regarded speeds of 550 kns. or less as optimum. A later study using tactical targets, showed some deterioration in acquisition probability at 700 kns. but no effect on range (Dyer, 1965).

Results from two experiments which used cine-film simulation techniques showed that at an altitude of 500 ft. performance was significantly better, in terms of both acquisition probability and acquisition range, at a speed of 198 kns. than at 594 kns. (Calhoun and Snyder, 1965), or at 792 kns. (Rusis and Calhoun, 1965). Data from this latter study are illustrated in Figure 2.1.

FIGURE 2.1

The effect of speed on target recognition performance



Source: Rusis and Calhoun (1965)

Further cine-film simulation data relating to speed effects are reported by Jones, Lane and Gilmour (1967). This experiment showed that for single observers acquisition probability was significantly poorer at a speed of Mach 1.2 than at either Mach 0.4 or Mach 0.8, but the tactical targets and test conditions used in this study resulted in little change in mean acquisition range for the speed values tested. For teams of two observers some improvement in acquisition range occurred with decrease in speed. Two experiments in which televisual target acquisition performance was studied under varying speed conditions at an altitude of 2000 ft. both failed to show significant effects on either acquisition probability or range (Mardon, 1969a; Shurmer, 1969).

2.1.2 Altitude

The effect of altitude on target acquisition performance has been the subject of a large number of studies, from which divergent results have been obtained. These discrepancies can be ascribed at least in part to the fact that increase in aircraft altitude affects the visual evironment in a number of ways, some of which facilitate target acquisition while others are detrimental. The relative importance of these effects in any particular situation will determine the extent and direction of any changes in performance due to altitude.

The region in which increases in altitude bring about the most marked changes in performance is from ground level to approximately 1500 ft. The main effects on the visual environment of increasing altitude in this critical region are:

(i) Increase in the extent of the terrain that can be seen. In general this facilitates geographic orientation and target acquisition by increasing the number of cues available for relating the outside world to information shown on maps and other forms of briefing.

(ii) Reduction in the effects of terrain masking. This facilitates both geographic orientation and target acquisition.

(iii) Change in the apparent size of the target. In the simplest case, when a target is viewed from vertically above, increase in altitude must result in a decrease in the angle subtended by the target at the observer's eye. But since air-to-ground target acquisition involves oblique viewing, the extent and direction of the change in apparent size with increase in altitude depends on the shape of the target and, in particular, whether vertical or horizontal areas predominate. For instance, an airfield will subtend a larger visual angle when viewed from a higher altitude, other things being equal, whereas for a predominantly vertical feature such as a chimney the reverse is true.

(iv) Reduction of the rate of apparent motion of terrain features through the observer's field of view. This decrease in angular velocity facilitates target acquisition.

(v) Increase in atmospheric attenuation effects. The extent of atmospheric attenuation depends on the distance between the observer and the target, and on the nature and density of the intervening atmosphere. Density decreases as altitude increases and thus the appearance of a target viewed from a given distance vertically downwards will be less affected by attenuation effects than one viewed obliquely from the same distance.

The combined effect of these factors is such that the relationship between altitude and target acquisition performance is one in which there is an optimum altitude for a particular set of conditions, and above and below this altitude there is liable to be some deterioration in performance. In general, the larger the target the higher the optimum altitude if all other factors remain constant.

In most of the reported work on altitude effects the range of values tested has been relatively limited and usually rather lower than the optimum altitude. This is because military aircraft must fly at the lowest possible altitudes compatible with safety in order to reduce their vulnerability to enemy radar defence systems, in spite of the fact that these low altitudes are less than optimum for target acquisition tasks.

For this reason the result most commonly found from studies of the effect of altitude is that performance tends to improve as altitude increases. For instance, Dyer (1965) showed that recognition ranges obtained from in-flight passes against tactical targets at 200 ft. altitude were less than half those obtained at 500 ft. to 1500 ft. There was also a tendency for the probability of acquisition to be greater at the higher altitudes.

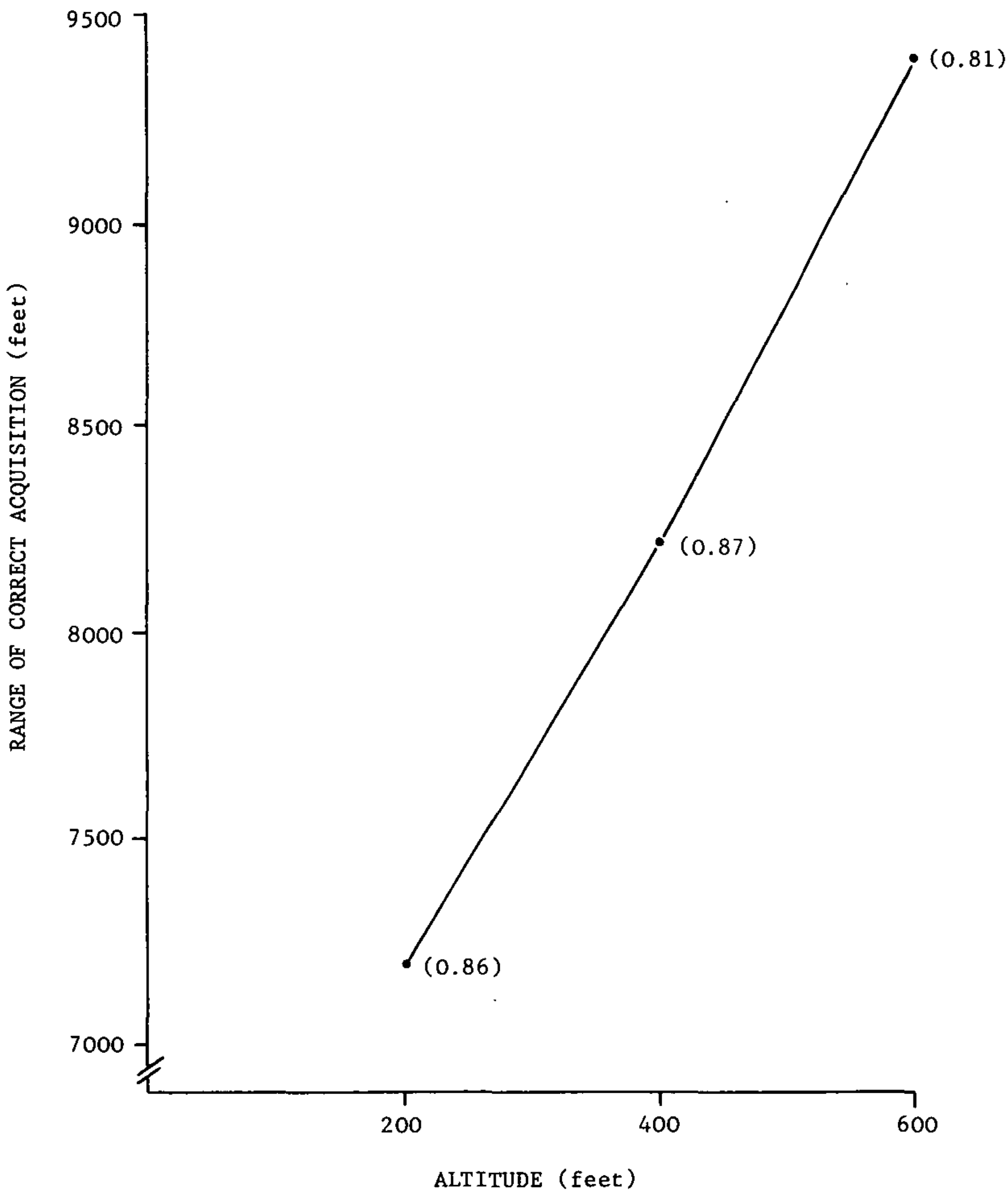
Results obtained from simulation experiments show similar trends. For instance, using a flat terrain belt and four types of homogeneous background, Wyman, Rawlings and Sturm (1965) showed that altitude had a significant effect on both the probability and range of acquisition, increase in altitude from 300 to 500 and to 1000 ft. resulting in improved performance.

Using a more realistic cine-film display, Gilmour and Iuliano (1964) found essentially analogous results with altitudes of 200 and 400 ft. Similar data are reported by Snyder et al (1966) using two altitudes, 500 ft. and 1000 ft. At altitudes of 200 to 600 ft. Wyman et al (1967) showed a significant improvement in acquisition range but not in acquisition probability, as altitude increased.

The same finding is reported by Gilmour et al (1968) from an extensive study carried out in connection with the Joint Task Force Two program in which altitudes of 200, 400 and 600 feet were studied under realistic simulation conditions using wide-angle cine-film imagery. Figure 2.2 shows the overall effect of altitude on acquisition range as found in this study. The acquisition probability values at each altitude are also shown but these were not found to be significantly different.

FIGURE 2.2

The effect of altitude on acquisition range



The figures given in brackets are the acquisition probability values at each altitude.

Source: Gilmour et al (1968)

Higher altitudes, ranging from 2000 ft. to 7500 ft., were used by Blackwell, Ohmart and Harcum (1958) in a comparison of target acquisition data obtained from field and simulator studies. Under both conditions altitude had a significant effect on slant range at acquisition, which increased by approximately 75% as altitude increased from 2000 to 7500 ft. The effect on acquisition probability, however, was both less marked and less consistent.

2.1.3 Navigational uncertainty

Target acquisition performance is affected by the accuracy with which the geographic position of the aircraft is known during the final approach to the target, and how closely this corresponds to the planned track. Both of these are largely dependent on the accuracy of the navigation system used, and the ability of the navigator to identify terrain features along the track.

The term navigational uncertainty covers both along-track errors, which result in uncertainty about how far the aircraft has flown along the track, and also cross-track errors which result in lateral displacement from the planned track. In the latter case, provided there is no azimuth error, the actual track is parallel to the planned track and the aircraft does not pass directly over the target. The ground distance between the target and the point of closest approach of the aircraft is known as the target off-set.

Errors in range and/or cross-track both have the effect of increasing the area within which the navigator must search for the target, and thus are liable to cause deterioration in both probability and range of acquisition. A study carried out by Milnes-Walker (1970) showed that increase in target off-set from zero to ½ mile and to 1 mile increased the proportion of omissive errors, but had little effect on acquisition range. In this case the subjects were told which off-set condition was being used, but in a second part of this study it was found that introducing uncertainty in the lateral position of the target, by not giving the subjects off-set information, reduced acquisition ranges.

A significant deterioration in acquisition probability as a result of increasing lateral target off-set without introducing any range error has also been demonstrated by Wyman, Rawlings and Sturm (1965). In this case off-set was varied from 500 ft. to 1500 ft. The author's own work, reported in Part III, failed to show any effect due to a simulated angular off-set but this was almost certainly due to the limitations of the experimental technique used, which made it unsuitable for this type of experiment.

More usually, lateral and cross-track errors are studied in combination. For instance, Heap (1965) reports a study in which a start-point uncertainty, which varied between 1 and 6 miles in range, was associated with parallel off-set error values varying between zero and ±1 n.m. Range uncertainty did not appear to have a significant effect on performance, but there was a significant deterioration in acquisition probability with increase in off-set error (from 90% for zero off-set to 40% for 4000 ft. off-set).

Since navigational uncertainty results in a deterioration in performance any means which reduces the effects of navigational uncertainty should bring about an improvement in performance. One of the most common ways of reducing range uncertainty is by providing time-to-go information, i.e. informing the navigator of the expected time, based on dead-reckoning procedures, of the target's appearance. Rusis and Calhoun (1965) found that the provision of time-to-go information, in the form of a countdown every 5 seconds over the last $3\frac{1}{3}$ n.m. to the target, significantly improved acquisition probability as compared with the 'no countdown' situation, but there was no effect on acquisition range.

As noted previously, one effect of navigational uncertainty is to increase the area which must be searched in order to locate the target. Sturm, Snyder, Wyman and Rawlings (1966) studied the effect of target pre-designation, that is, displaying to the pilot on a cockpit sensor display, e.g. television, the expected location of the target computed dynamically from the aircraft inertial navigation system. The results showed significant improvement in both acquisition probability (from 42% to 62%) and acquisition range (from 4704 to 6876 ft.) for the predesignation conditions as compared with the no-predesignation conditions.

Closely related to navigational uncertainty is the general problem of geographic orientation, that is, the observer's awareness of his geographic position in relation to prominent terrain features. In general, the smaller the navigational uncertainty, the greater is the chance that the observer will be able to orientate himself by reference to his expected position and the terrain information shown on a map. However, even if an aircraft is exactly on track, this in no way guarantees that the observer will be able to orientate himself geographically, particularly in conditions of poor visibility.

There is ample evidence that under visual flight conditions geographic disorientation is a frequent occurrence. For instance, analysis of the records of almost 1000 low-altitude attack training missions showed that 27% failed or were seriously compromised because the pilot got lost, while over a five-year period (1958-1962) geographic disorientation led to accidents in which 122 aircrew were killed and 82 military aircraft were destroyed (McGrath and Borden, 1963).

Further evidence comes from Thomas (1964) who reports that field studies of low-level navigation in the U.S. Army showed that 19 out of 20 pilots experienced some degree of geographic disorientation during the test flights. There is also evidence that geographic orientation affects target acquisition performance. McGrath (1969) reports that a study carried out under the Joint Task Force Two program showed that pilots who were orientated on the final target run made fewer commissive and omissive errors, and acquired targets at longer ranges than pilots who were not geographically orientated.

Since the basic problem in geographic orientation is relating the view of the terrain seen from the cockpit to the information given on the map, the design of maps for high-speed, low-level navigation is of great importance. The effect of a number of cartographic variables on geographic orientation during simulated high-speed, low-level flight has been studied by McGrath and his colleagues in the United States as part of an extensive investigation into problems of geographic orientation. These studies have been summarized in a JANAIR Symposium report edited by McGrath (1969). Cartographic variables studied included map scale and content (McGrath, Osterhoff and Borden, 1965; Osterhoff and McGrath, 1966), presence or absence of place names (McGrath, Osterhoff and Borden, 1964), and colour coding (Osterhoff, Earl and McGrath, 1966).

The final study in this series of investigations into geographic orientation was an analysis of the information requirements of pilots in relation to the information content of standard aeronautical maps. This study, reported by McGrath and Borden (1969), compared the 'cartographic utility' of various types of features with their 'visual utility'. The term cartographic utility referred to the extent to which the 58 military pilots, who studied the maps under conditions similar to pre-flight planning, judged that the features would be visible and useful or very useful as fixpoints during the flight. The term visual utility referred to the corresponding judgements made by a further group of 81 pilots who viewed the cine-film simulation without studying the maps.

One important result found from this analysis was that pilots greatly over-rated the value of features as navigational fixpoints when they made judgements from the maps, as compared with judgements made from the cine-films, i.e. cartographic utility scores were consistently higher than visual utility scores for every category of feature. This implies that the clarity with which features are depicted on a map tends to make pilots expect that they will be readily visible in the real-world, whereas in practice this may not be so. Analysis of the visual utility data in relation to selection rate, that is, the proportion of features of a particular type depicted on the map as compared with those present in the real world, suggested that the selection rates were too high for railways, structures (including bridges, dams, power lines and tunnels), and watercourses, while they were too low for paved roads and water areas.

These, and the other results obtained from the detailed analyses carried out in this study, were applied in the development of an experimental map intended specifically for high-speed, low-level navigation (McGrath and Osterhoff, 1969). Use of this chart significantly improved geographic orientation performance. In particular, it was found that pilots using the experimental map made significantly more positive identifications of fixpoints along the route than pilots using any other type of map.

These studies clearly indicate the importance of map design in visual navigation. Whilst much research has been carried out into general aspects of map design and display, very little of this has been specifically related to the problems of high-speed, low-level flight. Detailed consideration of the nature and content of map displays is outside the scope of this thesis but many aspects of these topics were covered in an earlier JANAIR Symposium entitled 'Aeronautical charts and map displays', edited by McGrath (1966).

2.1.4 Direction of approach

The appearance of a target changes with the direction from which it is approached. Two factors contribute to this change. Firstly, for all but circular targets, apparent shape depends on the direction of approach. Secondly, in real-life situations, the background against which a target is seen, and the degree of masking due to other objects, almost invariably change for different approach directions.

It follows therefore that the direction of the flight path to the target is liable to affect acquisition performance and this has been demonstrated by Gilmour and Iulano (1964). They found significant differences in performance depending on whether the targets were approached from East or West, other controlled factors remaining constant. Variations in sun angle are not reported but they may have contributed to these effects.

2.2 TARGET/BACKGROUND VARIABLES

2.2.0 Introduction

This section is concerned with the effects on target acquisition performance of variables associated with the targets themselves, and with the backgrounds against which they are situated. Some of these variables, such as size and shape, are specifically target characteristics. A second group, including vegetation and clutter, relate to the background; and the remainder, for example, contrast and masking, are inherently associated with both target and background. Although target characteristics can be varied independently of the background, and vice versa, target detection and recognition depend on the combined effect of the target and background variables. This interactive relationship must be taken into account when considering the effects discussed in this section.

The main target/background variables, for instance, target size, contrast, masking and terrain type, are among the most important and the most extensively investigated variables affecting air-to-ground target acquisition performance. Some of the variables, such as target size and shape, have been the subject of many laboratory studies, simulation experiments and field trials. Others, such as target/background contrast and background clutter, have been studied extensively in carefully controlled laboratory experiments, but the absence of flight trial data relating to these factors reflects the difficulty of controlling and quantifying them under field conditions.

Conversely, the effects of vegetation and terrain type can only be studied experimentally by high-fidelity simulation techniques or in field trials.

In this section the effects of target characteristics, together with two secondary variables, angular velocity and exposure time, are considered first. Variables associated with both target and background are then discussed and finally those depending only on the nature of the background.

2.2.1 Target size

In relation to air-to-ground acquisition tasks, target size may be measured either in terms of actual ground size, or more usefully, in terms of apparent size, defined as the visual angle subtended by the target at the observer's eye. Apparent size depends on the ground size of the target, the angle at which it is viewed, the range of the target, and the characteristics of the viewing system, if any, interposed between target and observer.

A target becomes available for detection when its angular subtense reaches the visual acuity threshold, but in practice most targets are not detected until the angular subtense is considerably above threshold. This indicates the importance of search problems rather than visual acuity limitations in air-to-ground target acquisition.

Work carried out by Jones and Bergert (1970), using simple two-dimensional targets against a terrain-model background, showed that the angular subtenses required for both detection and recognition tasks involving search within a simulated ½ mile square area were greater than the corresponding threshold values obtained under conditions in which search was not required. For instance, the detection task involving search required an angular subtense almost twice as great as the corresponding threshold value, the absolute values depending on contrast. Typical values, relating to a 20% contrast level, were 2.7 minutes of arc for the detection task under search conditions and 1.4 minutes of arc under threshold conditions.

Further evidence that the angular size of targets at the time acquisition occurs is substantially higher than the acuity threshold comes from in-flight acquisition data reported by Moler (1962) and simulation data reported by Snyder and Greening (1963). In both of these studies each target's major dimension subtended an angle of more than 10 minutes of visual arc at the median range of recognition. This is in general agreement with the finding of Steedman and Baker (1960) that an angular subtense of at least 12 minutes of arc is required for the accurate recognition of complex forms.

The general laboratory finding that, other things being equal, larger targets are more readily detected and recognised than smaller ones (for instance, Boynton and Bush, 1957; Miller and Ludvigh, 1960) has been confirmed by field trials and high-fidelity simulation experiments. For instance, Whittenburg, Schreiber and Richards (1959b) studied apparent target size in a field trial and found a positive relationship between size and identification probability. For small apparent sizes, up to about 25 sq. mils (a square mil being the polyhedral angle subtended by an area of one square unit at a distance of 1000 units), identification probability was highly related to size, but above this value size had little effect. A field trial carried out by Hicks and Moler (1966) also showed that large targets were more readily identified than small ones.

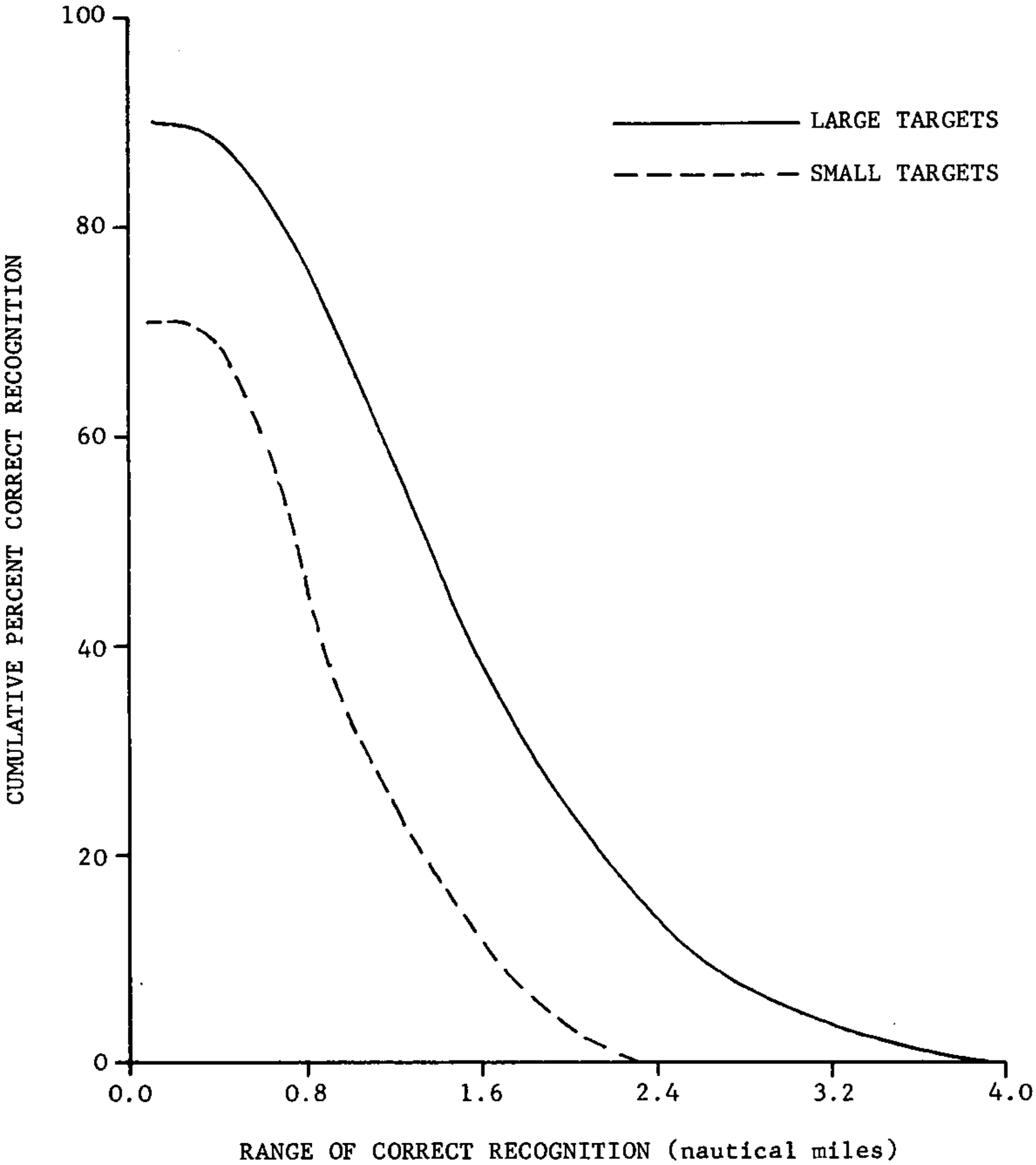
Rusis and Snyder (1965) used a cine-film technique to investigate the effects of target size, which was assessed in terms of the percentage of the film frame covered by the target at a fixed range of 1000 ft. They found that for small targets (average subtended angle 0.003 steradians) acquisition probability was significantly lower, and acquisition range, errors of omission and errors of commission significantly higher, than for targets of large apparent size (average subtended angle 0.089 steradians). Data from this study are shown in Figure 2.3.

2.2.2. Target shape

Several target acquisition studies have shown that targets of very similar sizes can give rise to substantial differences in performance. For instance, Moler (1962) and Snyder, Greening and Calhoun (1964) both found differences in recognition probability between military vehicles roughly equal in size, even when, as in the second of these studies, the targets were located in the

FIGURE 2.3

The effect of target size on recognition performance



Camera field of view: $10^{\circ} \times 7.5^{\circ}$

Source: Rusis and Snyder (1965)

same place and approached from the same direction. Similar results were found by Snyder and Greening (1963) who compared recognition performance for rectangular parallelipipeds and cubes of equal frontal area.

These performance differences could be accounted for by target shape. Laboratory findings (National Defence Research Committee, 1946) suggest that targets characterised by a relatively large length-to-width ratio are more difficult to detect than those that are more nearly square, but this does not appear to have been investigated in relation to air-to-ground target acquisition.

The shape of a ground target, in terms of whether vertical or horizontal extension predominates, is important in relation to aircraft altitude. Whereas a predominately vertical target will, in the absence of masking effects, appear larger at low altitudes, predominately horizontal targets will subtend a greater angle when viewed from higher altitudes. These effects have been analysed by Greening (1964).

2.2.3 Target type

Target acquisition experiments normally include a number of different types of targets, for instance, bridges, buildings, vehicles. However, these functional characteristics do not appear to play an important part in determining acquisition performance. Whilst differences between targets are one of the largest sources of variation in target acquisition data, this variation can be attributed more to factors such as size, contrast and the presence of 'lead-in' features, than to differences in target type per se.

In one study of target effects, four target types (segments of pipeline, road intersections, small areas of water and petroleum storage tanks) were compared using a cine-film simulation technique, but the results suggested that subjects paid more attention to gross characteristics of the target situation, for instance, the presence of a nearby road, than to the experimenters' functional classification (Calhoun and Snyder, 1965).

It appears that such classifications are of very limited utility unless they also correspond to large differences in visual characteristics, such as size. This was the case in an earlier study of target type in which differences in acquisition performance were found for four different target types, categorised as trucks, jeeps, tents and men. (Snyder, Greening and Calhoun, 1964).

Whether or not the target type is familiar to the observer can have an important effect on target identification, particularly when a number of different targets are situated close together. For instance, Thomas (1962) found that observers unfamiliar with the name of a particular target tended to maintain prolonged visual contact with it causing them to fail to detect other targets in the area. Similarly, Whittenburg et al (1960a) report that lack of knowledge of the names and appearances of military objects appeared to be a major factor limiting more effective target identification. They suggest that a possible solution to this problem would be specialised training in the identification of enemy weapons, vehicles and other types of equipment by name.

2.2.4. Stationary or moving targets

The only reported field experiment in which air-to-ground target acquisition performance has been studied in relation to whether vehicular targets are stationary or moving at the time of acquisition is that by Dyer (1965). He found no difference in acquisition performance between stationary and moving targets during flight trials at 1000 ft. altitude and speeds of 550 kns. and 700 kns., although at a lower altitude (500 ft.) or lower speed (350 kns.) it appeared that moving targets were more easily acquired than stationary ones. Direction of vehicle motion relative to the flight path seemed to be an important factor.

Erickson (1965) has pointed out three ways in which target movement may enhance the probability of detection. Firstly, a new target may be created by the motion, such as the wake of a ship, or a dust cloud behind a vehicle. (It is interesting to note that this latter effect appears to have been responsible for the apparent sighting of a Jeep on an unpaved road by an astronaut orbiting 100 miles above the earth's surface. Calculations by Taylor (1964) show this to be an entirely credible sighting.)

Secondly, change in the location of the target due to its motion may be noted. Thirdly, the motion, per se, of the target may attract the observer's attention. However, unless the angular velocity due to the movement of the target over the ground is discriminable from the apparent angular velocity of the ground at that point, due to the aircraft's motion, then target movement, per se, cannot account for any enhancement in detection performance.

2.2.5. Target grouping

When a number of small targets are situated closely together, the effect is one of a target complex, rather than one of individual targets. Dukes and McEachern (1955) found that grouped targets were detected more often than ungrouped ones. If all the targets in the group are the same then identification is no more difficult than identification of a single target but problems may arise in the case of a heterogeneous group.

For instance, Whittenburg et al (1960a) report that placing a series of different targets less than 3 seconds apart, relative to flight speed, tended to reduce identification scores. They suggest that this may have been due to a tendency for observers to 'lock on' or fixate one target at the expense of others nearby. It appears therefore that the effect of grouping heterogeneous targets is to facilitate detection but to impair identification of its individual members.

2.2.6 Target confusability

Target confusability can refer to the similarity between a target object and the non-target objects in its vicinity, or to that between several target objects. Laboratory studies have shown that the greater the similarity of target and non-targets, in terms of size, shape and contrast, the greater the search time required for recognition of the target (Bloomfield, 1970; Smith, 1961). It would be expected that similar effects would occur in air-to-ground target acquisition, particularly in the case of small tactical targets, but this has been relatively little investigated.

Hicks and Moler (1966) studied the extent to which confusion occurred in the identification of five different tactical targets in a field situation. They found a wide variation in the percentage of times a target was misidentified, the greatest confusion occurring between the three largest targets but these were also the targets that were most likely to be detected. It appears that size and shape differences were largely the cause of these results.

An experiment of a rather different type, also relevant to the problem of confusability, was carried out by Whittenburg, Schreiber and Richards (1959b). They conducted a series of trials to determine the extent to which real tactical targets could be distinguished from dummy replicas of actual equipment under high-speed, low-level flight conditions. The results showed that dummies could be discriminated from the real targets much more readily for large targets, such as a 2½ ton vehicle, than for small targets such as a ¼ ton vehicle. It is difficult to draw any conclusions from this experiment without knowing the extent to which the dummies resembled the real targets but it appeared that colour, structure, texture, and signs of operational use and weathering helped the subjects to distinguish the real from the dummy targets.

2.2.7. Angular velocity of target

The angular velocity with which a target passes through the field of view is a secondary variable which depends on aircraft speed and altitude, and the distance of closest approach to the target, i.e. target off-set. As the aircraft approaches the target angular velocity increases first slowly and then very rapidly, reaching a maximum at the point of closest approach (the overhead point if the aircraft approaches the target head-on), and subsequently decreases symmetrically as the aircraft continues beyond the target.

The higher the aircraft speed, the lower its altitude and the smaller the target off-set, the greater is the maximum angular velocity reached. The angular velocities of an object at a particular point in the visual field can be calculated from a knowledge of aircraft altitude and speed, the off-set distance of the object, and its range, as discussed by Erickson (1965). This paper includes a complex nomogram from which angular velocities can be read off, given values of these four parameters.

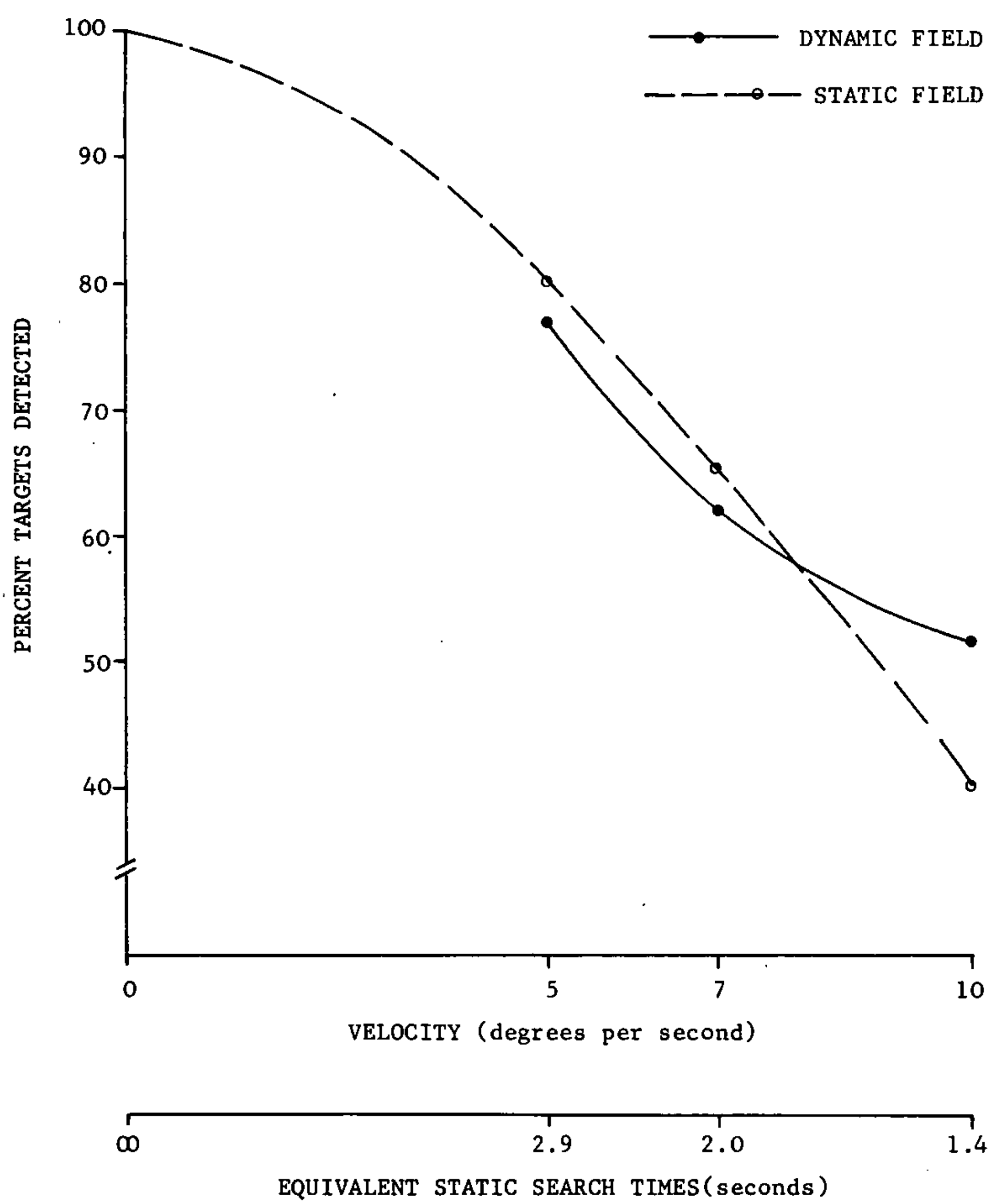
Laboratory experiments show that an increase in angular velocity tends to lead to a deterioration in search performance and in visual acuity (Miller and Ludvigh, 1962; Snyder and Greening, 1965; Williams and Borow, 1963) but the angular rate at which performance begins to fall off depends very much on the nature of the task. Data obtained by Erickson (1964a) suggest that in the Landolt C search task he used, for velocities of up to 10° per second, it was reduced exposure time rather than movement, per se, which resulted in performance deterioration since approximately the same proportions of targets were found in corresponding times under static display conditions, as shown in Figure 2.4.

High angular velocities give rise to blurring effects. Snyder (1964) presents a diagram giving typical blur area contours showing that blur may commence at angular velocities of between 15° per second and 30° per second depending on the distance away from the aircraft of the area being observed, and its direction relative to the aircraft track. Experiments carried out by Klingberg, Elworth and Kraft (1964) show that blur effects significantly degrade target identification performance, while Enoch (1958) reports that blur causes the average duration of fixations to increase, and the average interfixation distance to decrease, thus reducing the area searched per unit time.

In a study of the effects of blur on the recognition of realistic and abstract targets, military vehicles and Landolt C's respectively, Hoffmann and Greening (1965) found that the effect

FIGURE 2.4

Comparison of search performance in static and dynamic fields



Source: Erickson (1964a)

of blur on target recognition depended on the ratio of the blurred area to the critical dimension of the target. If the amount of blur was less than twice the critical dimension, accuracy of recognition was unaffected but when the ratio reached 2.0, performance began to fall off rapidly and reached a near-chance level at a ratio of 5.0. The time required for recognition increased rapidly when the amount of blur equalled the critical dimension of the target. Although recognition performance was affected, there was no effect of blur on the observer's ability to position a designation reticle over a specified location on each target.

The effects of angular velocity, sometimes referred to as apparent target motion, do not appear to have been studied specifically in either field trials or high-fidelity simulation experiments, although the factors determining angular velocity, speed, altitude and off-set, have been extensively investigated.

2.2.8. Exposure time

Target exposure time, that is, the interval between the time at which the target first becomes available for detection and the time at which it leaves the observer's field of view, is a secondary variable largely determined by aircraft speed, masking effects, and the apparent size and contrast of the target. Although exposure time, as such, has not been studied in field trials or high-fidelity simulation experiments, a number of laboratory experiments have investigated its effects.

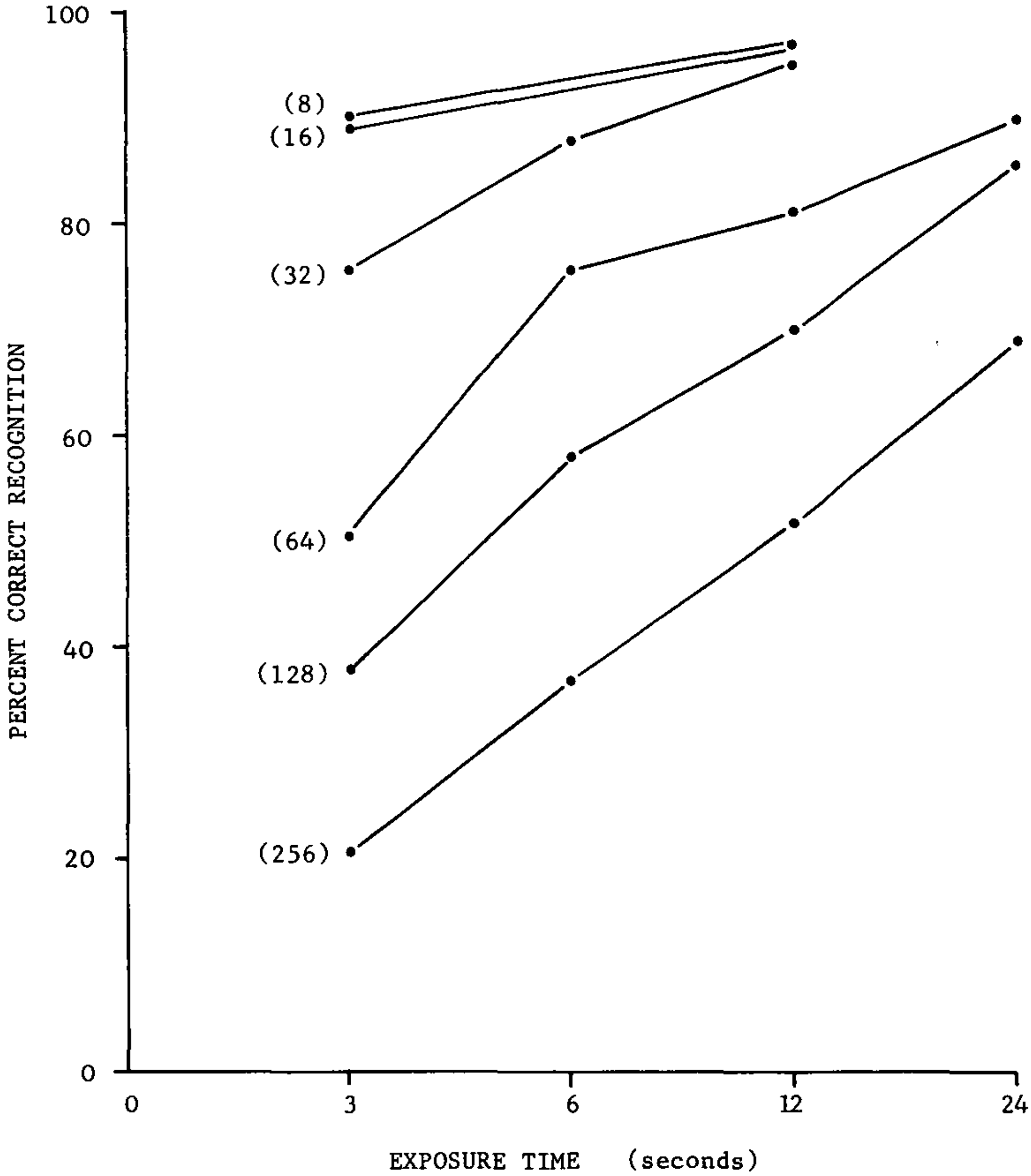
For instance, Boynton (1960) studied the effects of four exposure times, ranging from 3 to 24 seconds, on the recognition of rectilinear shapes against a background of curvilinear 'struniforms'. The number of non-target objects was also varied and, as illustrated in Figure 2.5, it was found that reduction in exposure time had little effect when the number of background forms was small, but the deterioration in performance became much more marked as the number of non-target forms increased.

Other experiments in which reduced exposure time has been found to lead to a deterioration in performance are those carried out by Simon (1965) in which the acquisition of targets from static and dynamic radar imagery was compared; by Richman, Enoch and Fry (1958), who studied the effects of exposure time on search patterns; by Bernstein (1971) in a dynamic simulation study of a real-time airborne reconnaissance mission; and by the present author using static terrain scenes as described in Part V.

If a television-viewing system is used, target exposure time is likely to be reduced, as compared with direct-view conditions, by the limited field of view. The exact range at which the target disappears from the lower edge of the display depends on the vertical field of view and the camera depression angle, and thus under television viewing conditions these factors also influence target exposure time. These effects are further considered in Sections 2.9.1 and 2.9.2.

FIGURE 2.5

The effect of exposure time on recognition probability



The figures given in brackets refer to the numbers of non-target forms in the background.

Source: Boynton (1960)

2.2.9. Target/background contrast

Target/background contrast refers to the difference in brightness between the target and its immediate background and is usually defined as:

$$\text{Contrast} = \frac{B_t - B_b}{B_b}$$

where B_t is the brightness of the target and B_b the brightness of the background. Contrast defined in this way may be positive or negative according to whether the target is brighter than its background or vice versa.

For the purposes of target acquisition studies, inherent contrast, that is, the target/background contrast measured at the real-world target, is of less significance than apparent contrast. Apparent contrast is the contrast between target and background measured at the observer's eye. This depends on the inherent contrast, the slant range of the target, the characteristics of the intervening atmosphere and, if an intermediate viewing system such as television is used, the characteristics of this system. In general, the greater the slant range of the target, the greater the loss of contrast due to atmospheric attenuation, but the extent of the loss also depends on the density of dust and water particles in the atmosphere. Problems of vision through the atmosphere are extensively discussed by Middleton (1952), and data presented by Duntley (1948) are often used to calculate the loss of contrast in relation to slant range and atmospheric attenuation.

The effects of target/background contrast have been extensively studied analytically and in laboratory experiments (see, for instance, Blackwell, 1946; Lamar et al, 1947; Taylor, 1960(a) and (b); Vos, Lazet and Bouman, 1956). These studies are primarily concerned with contrast thresholds for simple targets of different sizes against uniform backgrounds.

These conditions are vastly different from those of air-to-ground target acquisition tasks and, although attempts have been made to incorporate basic contrast threshold data into predictive models of target acquisition performance, relatively few field trials or simulator studies have been carried out in which apparent target/background contrast has been systematically studied in relation to air-to-ground target acquisition. Thackham, Wade and Clay (1966) report a field trial in which target vehicles were positioned under conditions designated high, medium or low contrast, but no contrast measurements are reported. The results showed for static targets that the high contrast condition gave significantly longer identification ranges than the low contrast condition.

A simulator experiment carried out by Ozkaptan et al (1968) studied target/background contrasts ranging between 5% and 35%. The results showed that the extent to which contrast affected target detection depended on both camera field of view and type of briefing. In a further simulation experiment Jones and Bergert (1970) studied the effect of target/background contrast under closely-controlled conditions in which the subjects viewed the terrain model directly. The contrast values of the targets against their backgrounds ranged from 5% to 50%. The results showed that low contrast levels (5 - 15%) resulted in a large decrement in target detection and recognition performance. This can be seen in Figure 2.6, which shows the effect of contrast on the visual angle requirements for the recognition task carried out under search and no-search (threshold) conditions. Further work, which investigated the effects of contrast under television viewing conditions, indicated that increase in contrast facilitated performance to a greater degree under television-viewing conditions than it did under direct-viewing conditions (Bergert and Fowler, 1970).

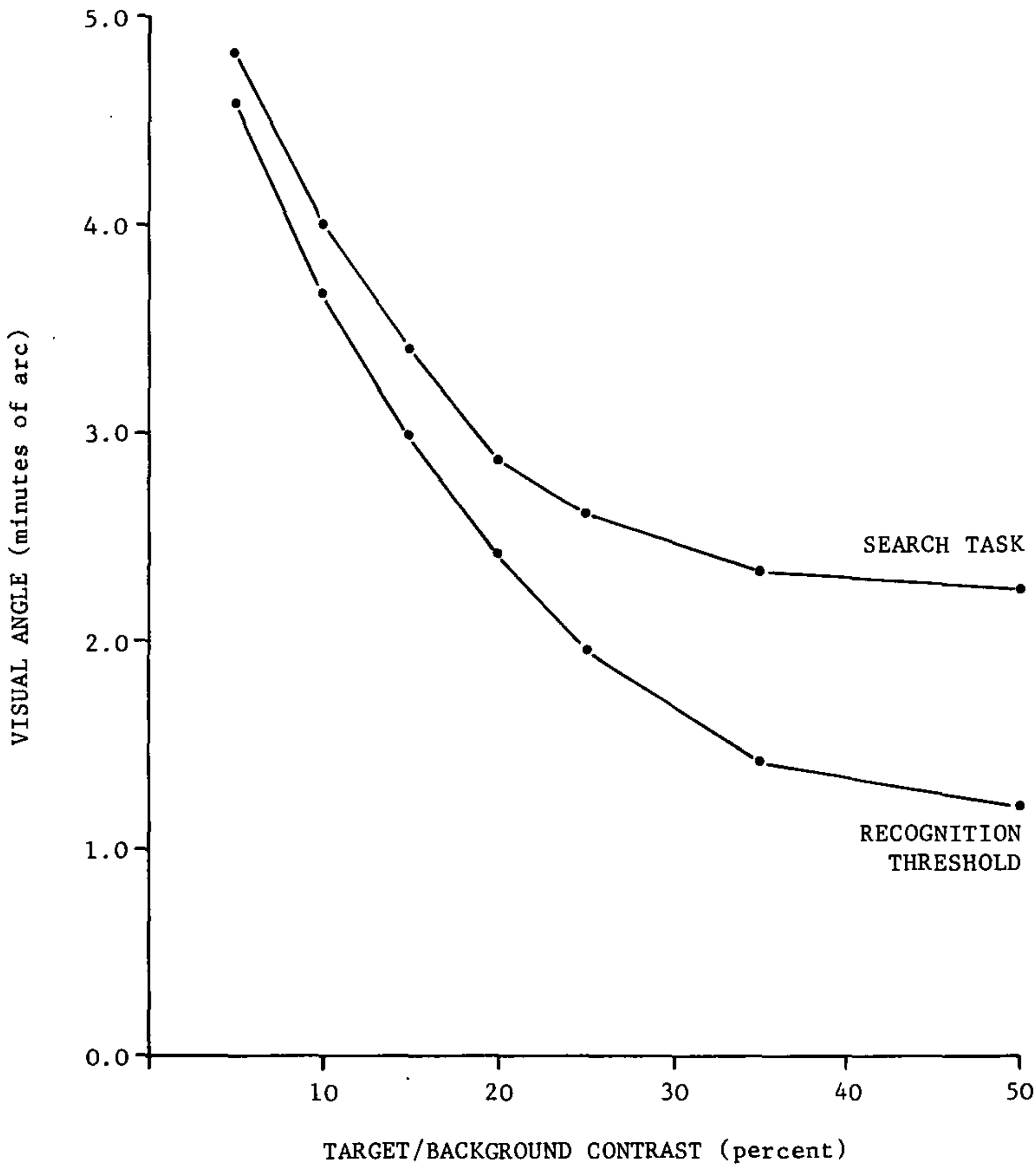
2.2.10 Masking

A target only becomes available for detection when there is a clear, unobstructed line-of-sight between it and the observer. If a target is partially or completely obscured by intervening objects, it is said to be masked. As an aircraft approaches an obscured target, a point will come at which the target ceases to be completely masked and, after a further interval, finally becomes completely exposed.

The range at which unmasking occurs is critical as this, together with aircraft speed, determines the length of time available for target acquisition, provided that the apparent size of the target is large enough, at the time of unmasking, for detection to be possible. If the target becomes completely unmasked at a range such that its apparent size is still too small for detection to occur, problems of masking are not relevant.

FIGURE 2.6

Visual angle requirements for a recognition task as a function of target/background contrast.



Source: Jones and Bergert (1970)

At a given range the extent to which an intervening object will mask a target depends on the relative sizes and positions of object and target, and the altitude at which the aircraft is flying. The lower the altitude the greater is the likelihood that masking will occur. The main cause of masking is obstruction by hilly terrain, but buildings and vegetation in the vicinity of the target can also give rise to masking effects.

From a knowledge of the geometry of a particular situation, i.e. size and position of object and target, and aircraft altitude, it is possible to calculate the degree of masking which will occur at any particular range, and the range at which complete unmasking occurs. Erickson (1961) produced a series of curves showing the probability that a particular point on the terrain is in view as a function of ground range for altitudes of up to 3000 ft.

The curves show that, in general, the probability that a point on the terrain will be in view decreases as the ground range increases (since a greater range is liable to contain more intervening hills) and as altitude decreases (since at lower altitudes smaller hills will give rise to masking effects). These effects become more marked as terrain roughness increases, as discussed in Section 2.2.13.

Masking effects as such do not appear to have been systematically studied in field trials or by simulation techniques although Whittenburg et al (1960a) report that target detection and recognition scores dropped substantially when targets were deployed so as to utilise natural concealment. However, exposure time, which depends partially on masking, has been studied experimentally and is considered in Section 2.2.9.

2.2.11. Vegetation

The type of vegetation in the vicinity of the target affects both the nature of the background against which the target is seen and the degree of masking likely to occur. These effects can lead to variations in target acquisition performance. For instance, Wyman, Rawlings and Sturm (1965) using a simplified terrain simulator found that forested backgrounds led to significantly fewer target acquisitions than three other backgrounds tested, plain, rural and desert. Similar results were obtained by Brake (1955) in a field study of air-to-ground target acquisition. His results showed that targets in the open were detected approximately 1.8 times as often as those located in wooded areas.

The extent to which targets are masked by surrounding vegetation depends to some extent on the thickness of foliage, which itself depends on the time of the year. Studies of masking effects (Ballistics Analysis Laboratory, 1959) have shown that the probability that a target is exposed at any particular range differs greatly depending on whether or not foliage is present. For instance, at a range of 3000 ft. the probability of a 7 ft.

target being exposed was approximately 90% under no-foliage conditions, but this fell to about 30% if foliage was present. Those values relate to an altitude of 324 ft. At lower altitude the effect was even more marked.

2.2.12. Clutter

Laboratory experiments have shown that as the number of objects in a complex visual field increases target recognition performance deteriorates (Boyton and Bush, 1957; Christner, Schutz and Ray, 1959; Williams and Borow, 1963). In air-to-ground target acquisition tasks the terrain is always to some extent cluttered with objects other than the target and it is likely that the same effects would occur, a greater degree of clutter leading to a deterioration in target acquisition performance. A related factor, also likely to cause performance deterioration, is that as the number of objects in the visual field increases, so does the possibility that, during low-level approach, one or more of these objects will partially or completely mask the target.

In a field study of clutter effects Whittenburg et al (1959a) compared the acquisition of targets placed in relatively open areas with that of targets placed close to, but not concealed by, natural terrain objects. No difference in performance was found. Similarly, a simulator study carried out by Bergert and Fowler (1970) showed that a background cluttered by non-target objects such as trees or rocks did not affect the subjects' ability to distinguish the targets, as compared with open field backgrounds.

The main problem in studying the effects of terrain clutter is that of making a quantitative assessment of the degree of clutter in a real-world context. This has been attempted indirectly by Nygaard et al (1964) using various forms of sensor imagery, including aerial photographs. Using a stimulus-complexity analyser to measure overall background complexity, they found a curvilinear relationship between the analyser measure of total object count and recognition performance for both photographic and infra-red imagery. An inverse relationship was found between target recognition time and mean object size and object-size variance. These results suggest that it is possible to quantify some aspects of background complexity in relation to the real-world and further research is needed in this area.

Another important factor closely related to clutter is the degree to which objects in the surrounding terrain resemble the target itself. This factor, usually referred to as target confusability, is considered in Section 2.2.6.

2.2.13 Terrain type

The extent to which the visual acquisition of a target is affected by the nature of the terrain in which it is situated has been studied both analytically and experimentally. Analytical studies (see, for instance, Ballistics Analysis Laboratory, 1959; Erickson, 1961; Greening and Sweeney, 1962; Snyder, 1964) have concentrated on evaluating the probability that a target will be potentially visible, that is, not masked by intervening terrain, from any particular range, in relation to the altitude of the aircraft and the type of terrain.

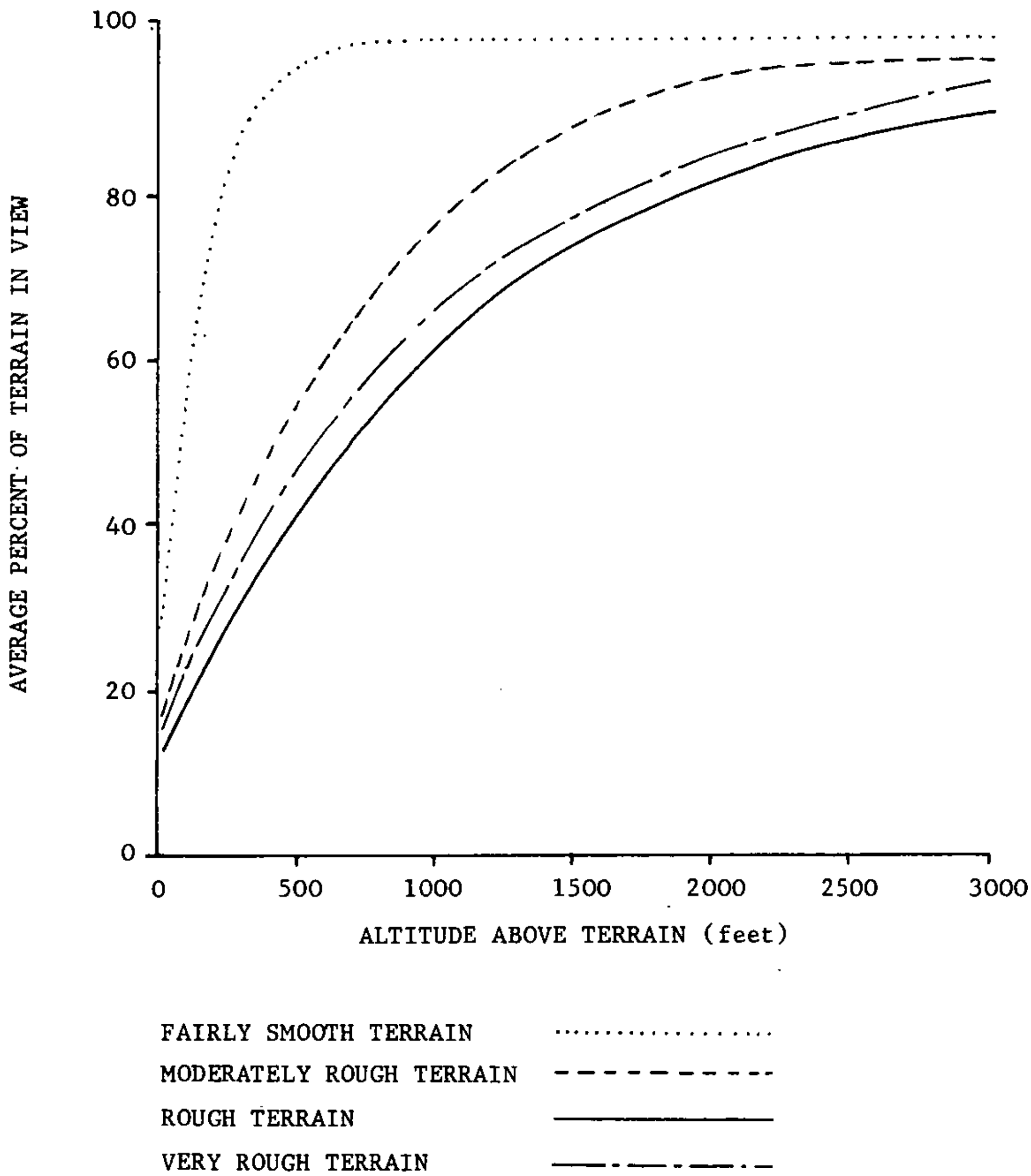
In this case terrain type refers to the degree of ruggedness of the terrain, for instance, fairly smooth, moderately rough, or very rough, defined in terms such as average gradient and average number of slope changes along sections of fixed length. The presence of mountainous or hilly terrain between the aircraft and the target greatly reduces the probability that there will be a direct line of sight to the target, and hence that the target will be available for detection, particularly at very low altitudes.

Figure 2.7, which illustrates data from Erickson's study, shows the proportion of terrain in view as a function of altitude for four terrain types, determined from detailed analysis of contour maps. Whether or not a particular target will be in view at a given altitude depends on terrain type and on ground range. For instance, at an altitude of 400 ft. and a ground range of 3500 ft., the probability of the target being in view is approximately 0.70 over moderately rough terrain but this falls to 0.30 over very rough terrain. Data such as these are of value in determining optimum altitudes for particular missions.

Experimental studies of terrain type have been mainly concerned with the effects of different kinds of vegetation

FIGURE 2.7

Proportion of terrain in view as a function of altitude for four terrain types.



Source: Erickson (1961)

and surface covering, which form a background to the target. As these effects arise at least in part from variations in target/background contrast and in the degree of target masking which occur with different terrain types, it would be expected that the effects of terrain type would interact with target effects. This result was found by Wyman, Rawlings and Sturm (1965) in a simulator study of four different terrain types, plain (i.e. grey), rural, desert and forest. The overall results showed that masking effects due to the simulated forest background brought about a fall in recognition probability of approximately 20% as compared with the other three backgrounds.

In another simulation study of background effects, Blackwell Ohmart and Harcum (1958), also using a terrain model, studied the recognition of vehicular targets against three backgrounds, asphalt, grass and dirt. Slant range of recognition was significantly affected, the dirt background giving the longest ranges and the asphalt background the shortest. The asphalt also resulted in a substantially lower recognition probability than the other two backgrounds. These results can be ascribed to contrast differences rather than masking effects.

Field trials have shown that terrain type also affects visual navigation performance. Heap (1965) reported that a significantly lower proportion of successful navigation runs were made over terrain in North Germany than in Southern England, and a still lower proportion over South German terrain. A possible reason for this finding is the high proportion of mountainous and forested terrain in South Germany with a resulting increase in masking.

2.3 METEOROLOGICAL CONDITIONS

2.3.0 Introduction

This section is concerned with the effects of meteorological conditions on target acquisition performance. By far the most important of these is visibility which has been extensively treated in analytical studies of target detection, particularly in relation to the detection of ships at sea, and rather less precisely investigated in field studies.

Other meteorological factors, such as temperature, wind velocity and cloud cover, appear to have little effect on target acquisition performance although they may affect the handling of the aircraft. Small amounts of precipitation also seem relatively unimportant although it is reasonable to suppose that extreme weather conditions such as fog, heavy rain or snow-fall will seriously degrade performance, and possibly render target acquisition impossible.

2.3.1 Visibility

Middleton (1952) outlines four factors which influence how far one can see through the atmosphere: (i) The optical properties of the atmosphere; (ii) the amount and distribution of light; (iii) the characteristics of the objects being viewed; and (iv) the properties of the eye, alone or aided by instruments. Any definition of visibility must be related to these factors. In practice, the term visibility has a number of meanings.

As used by meteorologists, visibility refers to the greatest distance towards the horizon that prominent objects, such as mountains and buildings, can be seen and identified by the normal unaided eye. This interpretation of visibility, sometimes called meteorological visibility, is often used as the basis for the visibility values quoted in target acquisition studies. A more precise term, known as meteorological range, is defined as the range at which the contrast of a large black object seen against the horizon falls to 0.05, where 0.05 is the value given to the threshold contrast. According to Middleton, threshold contrast values can range from 0.005 to 0.100, but internationally meteorological range is now defined in terms of the 0.05 value (World Meteorological Organisation, 1958) although a value of 0.02 is still sometimes used. Since the attenuation characteristics of the atmosphere vary with altitude, meteorological range which is a slant range measurement, also varies with altitude, increasing as altitude increases.

Since an object cannot become potentially available for detection until it is at a range equal to or less than the visual range, visibility would be expected to have some effect on target acquisition performance. Field study results, however, indicate that, provided visibility is above a minimum level of about 3 miles, then it has little effect on target acquisition. For instance, Heap (1965) reports that target detection probabilities showed no distinct differences when visibility was 4-10 miles, as compared with when it was more than 10 miles. Similar results are reported by Whittenburg et al (1960a).

On the other hand, Dyer (1964) found that poor visibility caused by haze had a marked effect on the pilot's ability to navigate and detect targets, and that in these hazy conditions the angle of the sun relative to the flight path was particularly critical. This latter effect is in accordance with analytical studies by Goldberg, Lufkin and Penndorf (1952) which show that visibility in the direction of the sun is always reduced, as compared with that in the half circle opposite the sun which remains approximately constant.

The effect of haze on search time has been studied under static simulation conditions by Townsend, Fry and Enoch (1958). They found that the effect of haze, simulated by contrast degradation of the aerial imagery, was to increase the search time required to locate critical details and lengthen the duration of fixations.

2.3.2 Cloud cover

Cloud cover appears to have little or no effect on target acquisition performance. Whittenburg et al (1960a) report that cloud cover tended to slightly improve observer efficiency, while Dyer (1964) found that it made little difference.

2.4 DIURNAL AND SEASONAL EFFECTS

2.4.0 Introduction

This section is concerned with the effects on target acquisition performance of the changes which take place in the appearance of the terrain and target during the course of a single day, and during the course of a year. Seasonal changes are complex and little is known about their overall effect on performance. Diurnal effects arise largely from changes in the sun's position and in the general level of illumination. Some experiments have studied overall time-of-day effects, whereas in other cases sun angle, that is, the direction of the sun relative to the aircraft track, and illumination effects have been investigated separately.

2.4.1 Diurnal variation

Time of day affects both the general level of illumination on the earth's surface, and the position of the sun, in azimuth and elevation, thus altering the nature of the shadows cast. It is therefore possible that target acquisition performance could be affected by the time of day at which field trials are carried out, although little systematic work has been carried out to investigate this variable.

Data that have been analysed to investigate time-of-day effects have yielded largely negative results. Both Hicks and Moler (1966) and Snyder et al (1966) failed to find any significant effects due to time of day in studies conducted under daylight conditions.

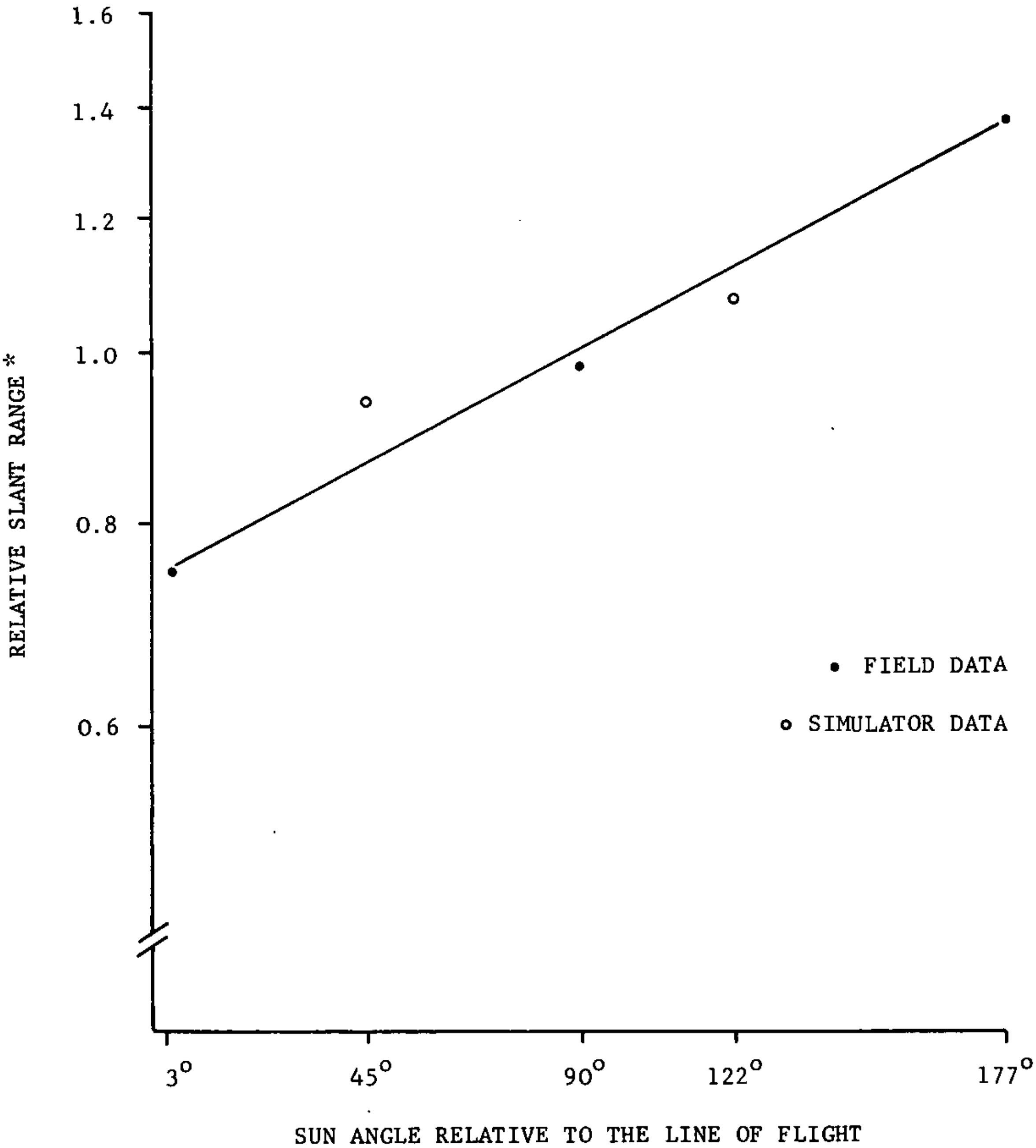
There is evidence that the decrease in illumination occurring shortly after sunset is very important in determining the range at which targets can be detected (Hecht et al, 1944) but, although studies have been carried out to evaluate low-light sensor systems, there are no reports of studies in which direct, unaided target acquisition performance has been compared for daylight and twilight conditions. Results quoted by Whittenburg et al (1960a) indicated that under night-time illumination conditions the detection and identification of targets was almost totally ineffective.

2.4.2 Sun angle

Sun angle refers to the direction of the sun in relation to the aircraft's track. The effect of sun angle on target recognition performance has been studied by Blackwell, Ohmart and Harcum (1958) in both field studies and simulation experiments. Combining the results of both studies, giving a total of five sun angle values, an approximately linear relationship was found between slant recognition range, plotted on a log scale, and sun angle, as shown in Figure 2.8. Ranges were greatest when the aircraft track was directly away from the sun's position, and least when the aircraft was flying in the direction of the sun and forward observation was most

FIGURE 2.8

The effect of sun angle on slant recognition range



*Relative slant range refers to range expressed as a proportion of the overall mean range under field or simulator conditions.

Source: Blackwell, Ohmart and Harcum (1958) seriously affected by glare.

Similar results were found by Gordon and Lee (1959), who studied the effect of illuminant azimuth and elevation on the detection and identification of targets in a miniature battlefield. Elevation appeared to have a greater effect on performance than azimuth. For instance, at 175^o elevation the targets could be detected at 3.5 times the range at which they could be with the illuminant at 45^o elevation.

These results are in accordance with the findings of Dyer (1964) that the position of the sun relative to the flight path affected target acquisition ranges during a series of flight trials, particularly when visibility was restricted by haze.

2.4.3. Illumination level

The effect of the level of incident illumination on target detection has been studied in a number of laboratory experiments, with the general finding that as the level of illumination increases performance improves until an asymtotic level is reached beyond which further increase in illumination has no effect (see, for instance, Miller, 1958; Weston, 1953).

Under field conditions the level of illumination depends mainly on the time of day, the degree of cloud cover and the presence or absence of shadow. However, there is evidence from a field trial reported by Whittenburg et al (1959b) that short-term variations in incident illumination do not have a significant effect on acquisition performance. In this study no relationship was found between the incident light intensity at the time of identification and the accuracy of target identification during the two days of field trials, but the amount of data available did not allow the importance of shadow effects to be evaluated.

2.4.4. Seasonal variation

The time of year at which field trials are carried out affects a number of parameters relevant to target acquisition performance including meteorological conditions, target/background contrast and vegetative masking. The most noticeable seasonal change occurs when the terrain is covered with snow and many of the minor features which normally create a cluttered appearance are no longer visible. In addition, numerous shades and textures are obliterated and replaced by a covering of snow which has a much higher brightness. For instance, the weighted reflection factor for fresh snow, taken from Erickson (1965), is 0.77 as compared with 0.03 for black earth, 0.09 for paved roads and buildings, and 0.50 for open sea.

The effects of snow covering on navigation and target acquisition are not known but in some cases navigation might be facilitated by the reduction of clutter, which allows some important features, such as railways, to stand out more clearly.

The effect on target acquisition performance would depend on whether critical detail of the target was hidden, and on changes in target/background contrast.

Whilst the effects of factors associated with seasonal changes, for instance, vegetative masking and target/background contrast have been studied individually, it appears that no systematic study of the effects of seasonal variation has been carried out. The reason for this probably lies in the inevitably long-term nature of such a study and in the fact that, since several variables are involved, it would be difficult to determine the exact cause of any effects found.

2.5 THE COCKPIT ENVIRONMENT

2.5.0 Introduction

The cockpit environment during high-speed, low-level flight gives rise to problems which may affect aircrew peformance. The most serious of these is vibration, the effects of which have been investigated in a number of experiments, but noise, lighting and the thermal environment should also be considered. However, apart from studies of vibration effects, little appears to be known about the effects of the cockpit environment in relation to air-to-ground target acquisition performance. For this reason this section is concerned only with the effects of vibration on target acquisition performance.

2.5.1 Vibration

Under high-speed, low-level flight conditions severe vibration of the aircraft may occur. Some of this vibration depends on the characteristics of the aircraft and is of a cyclic or repetitive nature, while more complicated random buffeting movements are caused by turbulent air. The vibration frequencies most likely to be encountered during high-speed, low-level flight are those in the 1-20 Hz range, (Harris and Schoenberger, 1964). There is a considerable amount of experimental evidence, recently reviewed by Grether (1971), to indicate that vibration in this frequency range can bring about decrements in several types of human performance, particularly those such as tracking which require precise muscular control.

Visual acuity is also affected by vibration, the extent of the performance decrement depending on the frequency of the vibration, the peak acceleration levels and the nature of the visual task. This deterioration in visual acuity is thought to be largely due to blurring of the visual image but vibration may also cause motor difficulties in maintaining the accommodation and fixation necessary for maximum visual acuity. The deterioration in acuity is most marked in the 10 - 25 Hz frequency range. The reasons for this are not entirely clear but Grether suggests that resonance of the eyes or their supporting tissues may be greatest in this frequency range and that this amplifies the vibration. Although vibration causes a deterioration in acuity, the results found by Teare and Parks (1963) suggest that details which exceed the visual threshold by a factor of 3 would be resolvable at vibration levels near the human tolerance limit.

In spite of the deterioration in visual acuity there is no evidence that vibration causes a significant deterioration in air-to-ground target acquisition performance. Schohan, Rawson and Soliday (1965) used a simulator with a vertical travel of 12 ft. and an acceleration capability of $\pm 6g$ to study pilot performance during high-speed, low-level surveillance missions of three-hour duration. As one of several tasks simulated during the mission the pilot had to identify nine ground targets. Three slides of each target were flashed sequentially on to a screen in front of the cockpit to represent views of the target at three ranges, the duration of the exposure depending on simulated range and speed. For both pilots and observers it was found that increase in simulated RMS gust velocity in the range 2-10 ft./sec. had no significant effect on target acquisition performance. Using the same equipment Soliday and Schohan (1965) showed that vibration also had no effect on navigation performance.

Similar results were found by Milnes-Walker (1967a and 1967b) and by Shurmer (1968) who studied televisual target acquisition performance for vibration levels corresponding to TSR2 flight in RMS gust velocities in the range 2-6ft./sec. Shurmer also notes that the vibration levels used did not seem to affect the subject's ability to follow his course on a map. It appeared that when viewing either the television display or the map, both of which were securely located and moved with the seat, the oculomotor system could compensate for the head movements induced by the vibration.

One suggestion that vibration does affect acquisition performance comes in a paper by Finkelstein (1965). This states that 'a pilot's navigational target-spotting and bombing abilities begin to degrade rapidly after he experiences 10 minutes of accelerations beyond 0.25g', but the source of this data is not quoted. In general, however, the studies reviewed in this section suggest that vibration, even of relatively severe levels, does not affect acquisition performance. If this is so then the use of fixed-base simulators for target acquisition studies would appear to be justified.

2.6 CREW COMPOSITION

2.6.0 Introduction

Provision for more than one aircrew member inevitably increases the size and weight of an aircraft, but the severe workload imposed on aircrew during high-speed, low-level missions makes it essential that aircraft operating under these conditions should be designed for two aircrew, rather than a single crew-member, if maximum versatility in the high-speed, low-level role is to be achieved. A further problem of single-seat aircraft is that of accommodating in the cockpit the avionic systems necessary to enable a single-crew member to carry out a low-level attack mission. In view of these limitations, most modern combat aircraft, such as the F111 and the proposed European multi-role combat aircraft (MRCA), are designed for two-man crews.

Some cockpit simulators allow more than two crew members to be accommodated. For instance, the Boeing multi-mission simulator has provision for a four-man crew. However, for the purposes of this discussion the main consideration is the extent to which target acquisition performance depends on whether a one-man or two-man crew configuration is used.

2.6.1 One-man versus two-man crew

A number of experiments have been carried out to determine whether two crew members, carrying out a target acquisition task as a team, perform better than a single crew-member. In an initial study of the effects of crew-composition Zaitzeff, Jones and Jahns (1966), using cine-film simulation of high-speed, low-level flight, studied target acquisition performance for single observers and two-man teams. They found that teams of two observers acquired targets at significantly greater ranges than single observers, on average 24% greater on the first pass and 15% greater on the second pass. Teams also made fewer omissive errors.

Similar results were found from a further study, this time using small tactical targets, except that at the fastest speed tested, 1.2 M, the acquisition ranges of the two-man teams were not significantly different from those of single observers, (Jones, Lane and Gilmour, 1967). Calculations showed that in both these experiments team performance was comparable to that predicted for two independent observers. Similar results were reported by Hornseth and Davis (1967) who found that for two static search tasks team performance resembled that predicted for two independent observers, rather two observers sharing the task.

In each of the two cine-film experiments described above the workload of the crew members was not representative of high-speed, low-level flight as they were only required to observe the visual simulation. A more realistic experiment, in terms of crew workload, was carried out by Zaitzeff (1969) using a high-fidelity multi-mission simulator. He found that when realistic flight management tasks were imposed on the crew, two-man crews acquired targets at 30% greater ranges than one-man crews, whereas the comparable figure for missions where the only task was target acquisition was 26%.

There is no evidence from these studies as to whether high-speed, low-level navigation performance is also improved when a two-man crew is used, although this is likely. However, a study carried out by Lewis et al (1968) showed that under low-speed, low-level conditions dual navigation performance was not significantly better than solo in terms of the number of end-points reached although there were some advantages of a secondary nature, including fewer initial heading errors, and en route 'sit-downs', and smaller errors in landings beyond the criterion circle, which was ⅛ mile in radius.

A study carried out by Murch, Greening and Sullivan (1966) to investigate crew-size requirements for future multi-mission aircraft found that a single-crew member was overloaded during certain critical parts of a typical tactical mission. In one task, bomb delivery, this overloading amounted to 270% where the 100% loading level represented the maximum at which an operator could perform man/machine interface tasks without potential degradation in performance. They concluded that one man can adequately perform the penetration and attack portions of an air-to-ground mission only with rigidly planned and executed missions, and that much greater versatility can be achieved with a second crew member.

2.7 BRIEFING INFORMATION

2.7.0 Introduction

The nature of the briefing information available to the pilot both prior to and during a high-speed, low-level mission is an important factor determining its success. Under visual flight conditions the pilot must maintain a continuous awareness of his geographic position by relating the information given on maps and other briefing materials to the terrain features visible either directly from the aircraft, or by means of a television viewing system. As the pilot approaches the target area he must use this knowledge of geographic position, together with the available briefing materials, to detect, and subsequently recognise and identify, the target as early as possible. Problems involved in geographic orientation have been considered in Section 2.1.3. The primary purpose of this section is to consider the effect of briefing materials on target acquisition performance.

The standard form of briefing for high-speed, low-level missions is a map or chart, giving a symbolic plan-view representation of the earth's surface. Various types of photographic briefing material which give a realistic view of the terrain, either from a vertical or an oblique viewing angle, may also be provided. In addition to these forms of visual briefing information, which are considered in the following sections, verbal descriptions of the target and surrounding area, and other intelligence information may be provided. A more detailed discussion of the effects of briefing on target acquisition performance is given in Part VI (i), in which the present author's experimental work on the effects of briefing is described.

2.7.1 Maps

During pre-flight briefing, and during the actual flight, the pilot or navigator normally has available one or more maps of the route to be flown, marked with pre-planned checkpoints and the target area. It should be noted, however, that detailed map coverage of the world is far from complete. Burton reported in 1966 that only 20% of the world had been mapped at a ¼M scale, and only 10% at 1:50,000, and that much of this coverage was out-of-date. It is not known how much progress has been made since then, but the increasing availability of satellite photography should facilitate map-making.

Much research has been carried out into the design of navigation aids, and map display techniques are becoming increasingly sophisticated. Some important developments in this area are reviewed in a JANAIR Symposium report 'Aeronautical charts and map displays' (Ed. McGrath, 1966). As discussed in Section 2.1.3, a number of reported studies have been concerned with the effect of map scale and content on visual navigation performance. Although the extent to which the nature of the map specifically affects target acquisition performance has been relatively little studied it is reasonable to suppose that, other things being equal, maps that facilitate visual navigation will also facilitate target acquisition, although targets are usually smaller and more difficult to acquire than en route checkpoints.

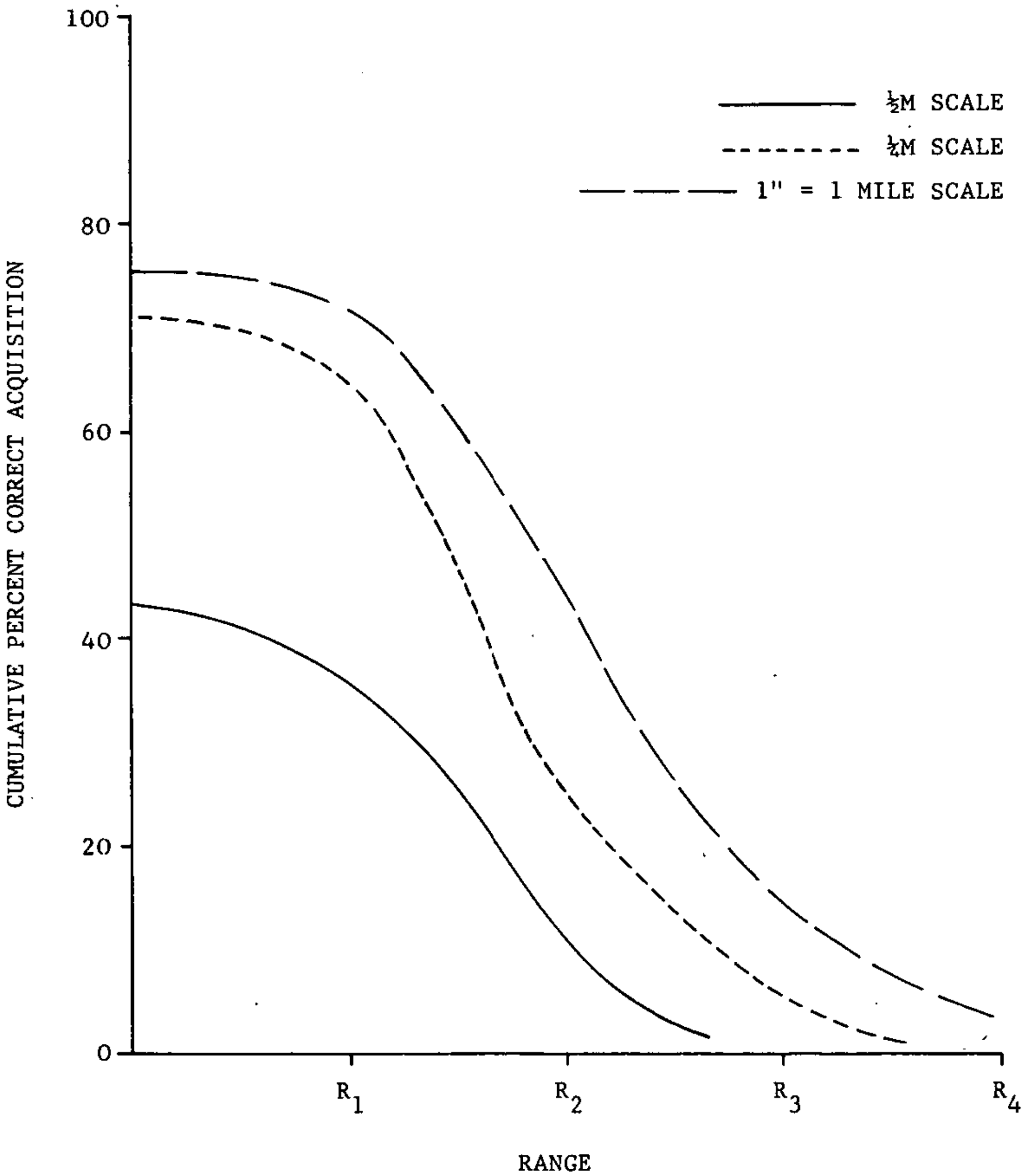
A study of televisual target acquisition carried out by the present author showed that, in general, addition of a section of 1" = 1 mile map covering the final approach to the target, to the standard ¼M route map did not improve target acquisition performance. The only significant difference found was that the proportion of targets correctly identified at a range of 10,000 ft., just before the targets left the lower edge of the display, was higher when the 1" = 1 mile maps were also used, (Parkes and Rennocks, 1971a). However, field trials reported by Heap (1966b) showed that both navigation and target acquisition performance were improved by increasing map scale from ½M to ¼M, and to 1" = 1 mile. The target acquisition data are shown in Figure 2.9.

2.7.2 Photographs

Medium or high-altitude vertical photographs, including satellite photographs, can be used to provide additional briefing material. Photographs of this type show a realistic plan view of the terrain, the scale depending on the altitude from which the photographs are taken, the field-of-view of the camera and the actual size of the print. Vertical photographs show considerably more detail than would be shown on a map, even one of relatively large scale. They also show textures and tones which cannot be

FIGURE 2.9

The effect of map scale on target acquisition performance



Source: Heap (1966)

represented on a map. However, as pointed out by Thomas (1962) the wealth of detail provided by aerial photographs can in some cases prove to be confusing.

Low-level forward oblique photographs show a view of the terrain that corresponds much more closely to that seen during high-speed low-level flight since perspective and masking effects, not shown on vertical photographs, are accurately represented. For this reason oblique photographs are particularly valuable as briefing material. However, they do have a number of drawbacks. Firstly, they are less likely to be available than vertical imagery, since it is difficult to obtain low-level photographs over hostile territory.

Secondly, the view of the target shown in a forward oblique photograph depends critically on the altitude from which it is taken, the depression angle of the optical axis of the camera lens and the direction of approach. Differences in altitude and depression angle result in changes in the apparent convergence of the terrain due to perspective effects. Differences in track cause differences in the position of features appearing within the field of view, and in their apparent spatial relationship to the target, in addition to differences in the appearance of the target itself. Thus, unless taken under conditions closely approximating to the actual mission, oblique photographs may lose some of their value and could prove misleading. Furthermore, oblique photographs often have a very cluttered appearance which can make important features difficult to discern. Perspective convergence makes these effects even more marked than in the case of vertical photographs.

The quantity and quality of briefing material available for any particular mission varies widely. For highly pre-planned missions a complete range of photographic and other sensor imagery may be available, together with vegetation heights and other intelligence information. However, it is sometimes necessary to carry out missions under conditions in which the available briefing material is very incomplete consisting, perhaps, of only a map and a brief verbal description of the target. It is therefore important to know the extent to which briefing information affects target acquisition performance.

One such study is reported by Rusis and Rawlings (1966). They compared five different briefing conditions: (i) ground map + oblique photographs + vertical photographs; (ii) ground map + oblique photographs; (iii) ground map + vertical target photographs + notes on the track; (iv) ground map + vertical photographs and (v) ground map + notes on the targets. The oblique photographs were taken from an altitude of 500 ft., corresponding to that of the simulated flight, and the vertical photographs from 1000 ft. altitude.

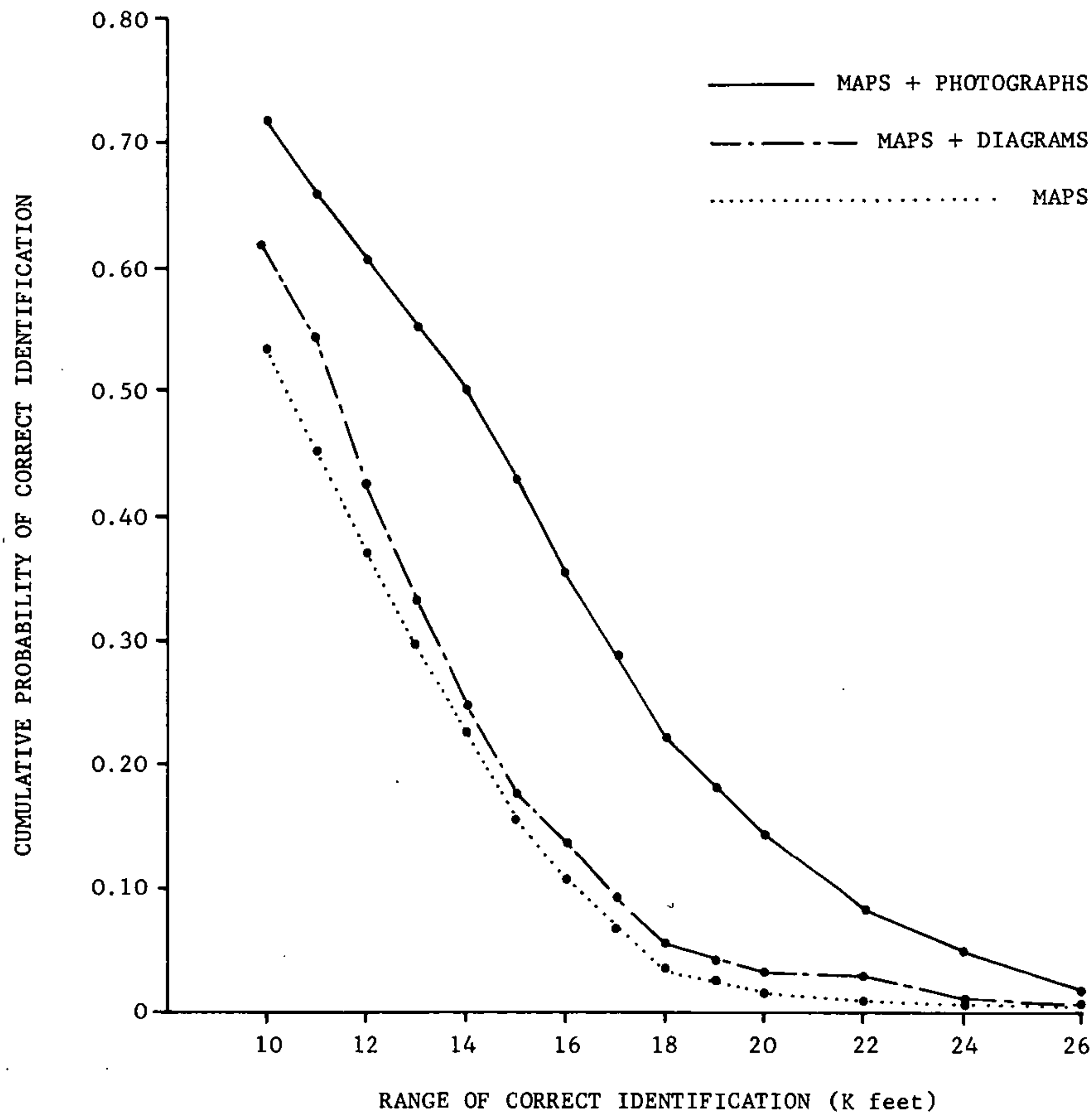
Conditions in which oblique photographs were provided were superior to all others in terms of probability and range of correct recognition, but the provision of vertical photographs in addition to oblique photographs did not facilitate target recognition, as compared with the condition in which only oblique photographs were available. The other three conditions, in which oblique photographs were not used, resulted in considerably lower levels of performance. Similar results are reported by Jahns (1969) from a study carried out as part of the Joint Task Force Two program.

Work carried out by the present author also showed that oblique photographs, even if they were slightly off-track relative to the cine-film simulation, were more effective than other types of briefing, including perspective diagrams (Parkes and Rennocks, 1971a), as shown in Figure 2.10. The diagrams, which were derived solely from map information, resulted in some improvement in acquisition probability as compared with the map only conditions, but this appeared to occur mainly at relatively short ranges, and there was no overall improvement in acquisition range. The use of perspective diagrams in a static experiment is described in Part VI, and other aspects of this work are reviewed in Section 4.7 of this thesis.

In part, the superiority of oblique photographs as briefing material derives from the fact that they can accurately depict shapes, tones and textures of features in the vicinity of the target, and their spatial relationship to the target itself. A study carried out by LaPorte and Calhoun (1966) indicates the importance of surrounding features in providing clues to the target position. The most significant finding of the study was that, for most of the targets, non-target clues were more important to successful target recognition than were target clues, roads being the most frequently reported non-target clues. It was also found that target recognition was related

FIGURE 2.10

The effect of briefing on target acquisition performance



Source: Parkes and Rennocks (1971a)

to the observer's ability to encode the visual world, that is, to memorise elements of the environment and to describe them verbally.

Recent research reported by Mitchell (1971) has also shown that non-target features are as important, if not more important, than target features in determining acquisition performance. This work, a study of subjective estimates of important parameters in target acquisition, indicated that the following three characteristics were of major subjective importance; whether or not the target was visually prominent against its background; whether the target was in a complex or simple environment; and whether there were mapped identification features around the target.

2.8 VISUAL SKILLS, TRAINING AND EXPERIENCE

2.8.0 Introduction

The variables considered in this section are those that relate to the basic visual skills of pilots and observers, and to their training and experience in high-speed, low-level target acquisition. Experimental and operational data show marked individual differences in the ability of people to acquire and recognise targets in a dynamic visual environment. This raises the questions of how far these differences are related to basic visual abilities such as static and dynamic visual acuity; whether they are associated with different search techniques or different levels of experience; and to what extent they could be minimised by more effective training procedures.

A review of the literature relating to these topics suggests that the information currently available is somewhat patchy and that additional research is required in this area. As Miller (1964) points out, target acquisition is the crux of most high-speed low-level missions and accordingly, attention should perhaps be given to selecting pilots for such missions on the basis of skills other than those concerned solely with flying the aircraft. Research into training and selection might well be an area from which substantial benefits could be gained at relatively little initial cost since much of the data required could be obtained from flights being made for other purposes, if the appropriate data were recorded.

2.8.1 Visual acuity

A large amount of research has been carried out to determine how visual acuity is affected by parameters such as size, contrast and position of the target, and whether there is relative motion between target and observer. However, visual acuity tasks are very different in nature from the complex search tasks involved in air-to-ground target acquisition, and the purpose of this discussion is not to review factors which affect visual acuity, but to consider the relationship between visual acuity measures and search performance.

There are few reports of flight trials in which air-to-ground target detection performance has been analysed in relation to visual acuity, but one carried out by Goodson and Miller (1959) found that laboratory measures of dynamic visual acuity discriminated between observers' detection performance in actual flight tests at high speeds. Further evidence of a relationship between visual acuity measures and performance comes from laboratory experiments. Erickson (1964a) found a correlation between foveal visual acuity and mean search time for a Landolt C in a moving field containing a number of closed rings. In a further experiment (Erickson, 1964b), he found a correlation between peripheral acuity, measured at 3.6° and 4.8° eccentricity, and search time in a static field containing 16 or 32 non-targets.

Johnston (1965) has also studied search performance in relation to visual acuity measures. Her findings show a correlation between mean search time in ring displays, and a measure she terms visual field size, which relates to peripheral visual acuity in horizontal and vertical directions through the fovea. Similar results were found for displays containing complex military silhouettes.

2.8.2 Search techniques

The general scanning pattern followed by an observer in searching an area can affect the efficiency of the search process. Studies of static reconnaissance imagery have shown that observers do not spend an equal amount of time on all sections of the display, but tend to concentrate mainly on the centre portion (Enoch, 1960).

Eye-movement patterns in air-to-ground target acquisition have been studied by Wyman et al (1967), who also found that a high proportion (80-90%) of the fixation points fell in a small portion (5%) of the visual scene. These fixations were concentrated near the horizon in the centre of the field of view. It was also found that shorter fixations were associated with larger acquisition ranges. As described below the natural search tendencies revealed by these experiments can be influenced by instruction and training in scanning techniques. Both experimental and analytical studies have been carried out to determine the effectiveness of different search strategies.

Thomas et al (1959) tested air-to-ground detection performance using four visual search techniques. The side-movement method in which the observer scanned an area of 90^{o} from the line-of-flight by sweeping his gaze inward towards the aircraft and outward towards the horizon, resulted in higher detection performance than did static or forward-looking methods. It appeared that head movement was more important than the actual head position of the observer. Thomas and Caro (1962) also report that sideways search was more effective than forward search or undirected search. An example of analytical determination of optimum search techniques in air-to-ground target acquisition is that by Dugas (1962) in which area search patterns are compared with linear search patterns.

Of vital importance in determining search behaviour is the extent to which location of the target is known, since this determines the search area. Several studies have investigated air-to-ground target detection in relation to the radius of the search area. For instance, Heap (1963) found that average range and detection probability were consistently reduced as search radius was successively increased from 0 to 400 yds. Similar results were found at the Ballistics Analysis Laboratory (1962). Time-to-go information, which has the effect of reducing the search area, has also been found to improve target recognition performance (Rusis and Calhoun, 1965).

More sophisticated techniques of designating the expected location of the target can also be used. Sturm et al (1966) studied a technique, known as target pre-designation, in which the expected position of the target, computed by the automatic navigation system, was displayed to the pilot thus limiting the search area. The provision of this pre-designation information significantly improved recognition range and probability as compared with the 'no pre-designation' condition. Recognition range was significantly affected by the size of the pre-designated area.

2.8.3 Training in high-speed, low-level observation

Although a large amount of time and effort has been spent in devising effective procedures for training military aircrew, relatively little of this has been directed towards improving aerial observation skills, in spite of the fact that geographic orientation and target acquisition are essential aspects of mission success.

The first step in devising effective training for aerial observation tasks, as with any other task, is to determine exactly what skills are required. Thomas (1962) devised a realistic field test which simulated combat intelligence missions, and from performance data and information obtained from interviews identified four necessary skill areas: (i) detecting targets by methodical visual search; (ii) identifying targets quickly; (iii) maintaining geographic orientation; and (iv) determining the location of targets.

Various techniques of classroom instruction and practical flight exercises to develop these skills were evaluated and finally incorporated into an experimental aerial observation training course, which was then evaluated in a simulated combat test against the conventional training. The results showed that the experimental students with 32 hours of training matched the performance of conventionally trained observers with an average of 117 hours.

The experimental course of instruction was incorporated into a training package for use by unit training officers, as described by Hesson and Thomas (1962) and later developed as a series of programmed texts incorporating verbal material, maps and photographs (Dawkins, 1964). Evaluation showed that the programmed texts were as effective as classroom methods in teaching aerial observation skills, with the added advantage that training could take place in field locations without a skilled instructor.

Wood (1968) reports a research program concerned specifically with training for tactical target recognition. Three primary training variables were evaluated including the role of vision and search in the reconnaissance task, together with the value of incorporating theoretical background material into the instruction; the merits of providing detailed instruction in the target signature as compared with allowing the trainee to conceptualise it for himself through frequent exposure; and the use of motion pictures as compared with static displays for training purposes. Unfortunately the full paper giving details of these evaluations, on the basis of which the most effective sequence of training events was selected, is not as yet available.

Training aircrew to carry out televisual target acquisition tasks presents particular problems owing to the narrow field of view and the poor quality of the display as compared with a direct view of the outside world. A specialised research program carried out by Hagen, Larue and Ozkaptan (1966) with particular reference to television displays, was intended to determine whether detailed training in perspective geometry would improve the observer's ability to locate target areas. The training consisted primarily of working out a series of target area location problems on statically-simulated TV displays. The results showed that this training, when given in addition to conventional training, significantly improved performance as compared with the conventional training only, the percentage of target areas correctly located being 81% as compared with 68%.

These experiments show that improvements in geographic orientation and target acquisition performance can be achieved by means of suitable training and, in view of the increasing demands made on aircrew by higher speeds and the use of sophisticated sensor displays, specialised training is likely to become increasingly important.

2.8.4 Experience level

A number of reported experiments into air-to-ground target acquisition performance have included experience level as a variable. This usually refers to whether the subjects taking part in the experiment are aircrew with experience in high-speed, low-level flight or other personnel, such as students, of comparable age and intelligence but little or no experience of flying. Alternatively, the term experience level is sometimes taken to mean whether the subject has previously been exposed to a particular route. Another factor which can be included in the general heading 'experience level' is the extent to which the pilot is familiar with the general test area in which the flight trials take place. Some of the published work in which these various aspects of experience have been studied are considered below.

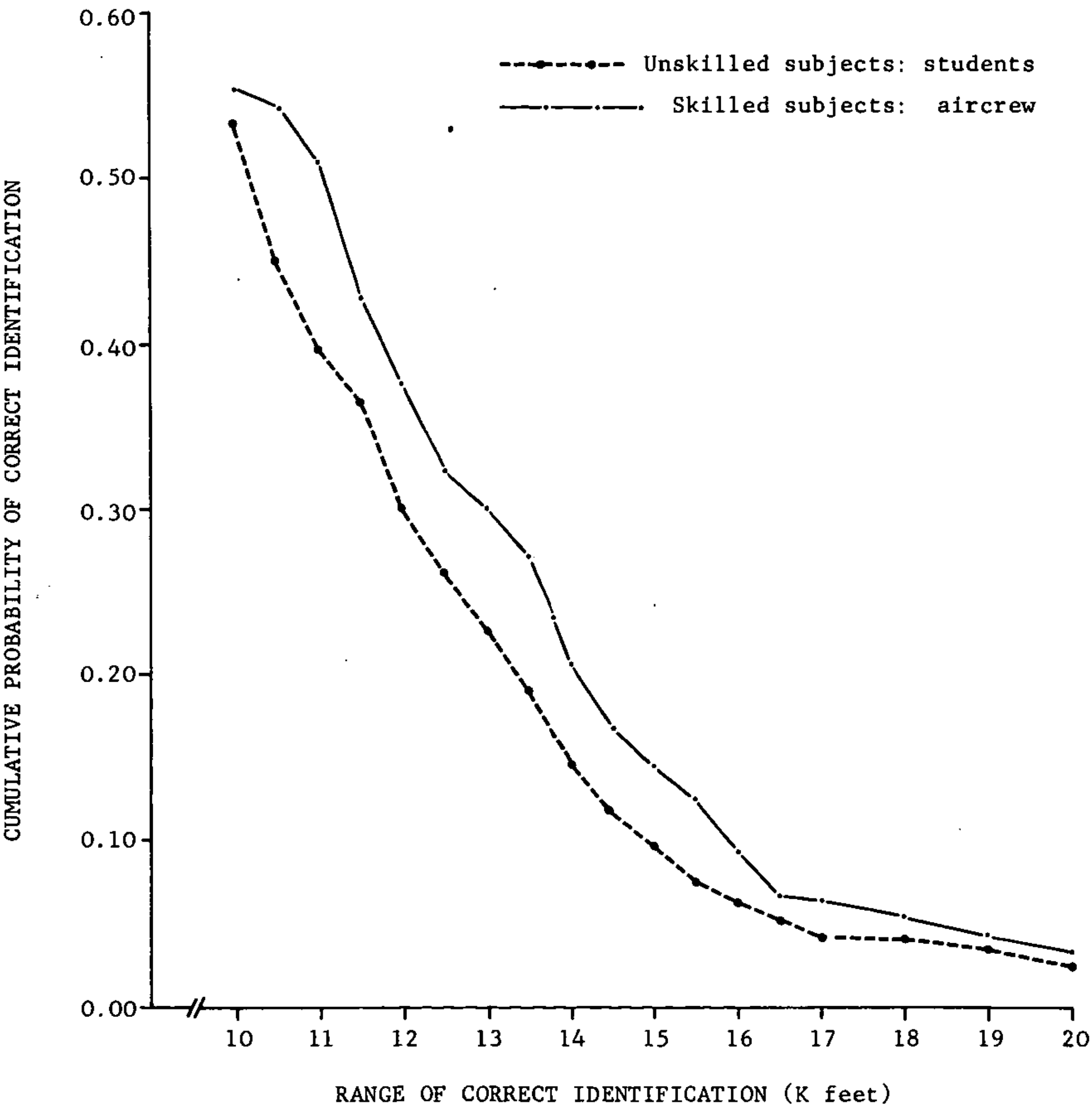
Differences between skilled aircrew and unskilled subjects with little or no flying experience, in air-to-ground target acquisition performance have been studied by Gilmour (1964), by Whittenburg, Schrieber and Richards (1959b), and by the present author, as described in Part I, and in a later report (Parkes and Rennocks, 1971a). As would be expected these studies show that, in general, experienced pilots achieve performance levels superior to those of unskilled subjects. For instance, Gilmour found that experienced pilots had higher probabilities of acquiring assigned targets than non-pilots, but there was no significant difference in the range at which acquisition occurred. The opposite result was found by Parkes and Rennocks. In this case acquisition probabilities were not significantly different for the two groups, but skilled subjects achieved longer acquisition ranges, as shown in Figure 2.11.

Results reported by Whittenburg et al (1959b) were obtained from flight trials in which skilled and unskilled aerial observers took part. The data showed that skilled observers were significantly more accurate in target identification than unskilled observers. In general, it seems likely that the different results found in these experiments reflect differences in the instructions given to the subjects since these can be very critical in determining the trade-off between speed, in this case measured by range, and accuracy.

Experiments in which repeated exposure to a particular track have been studied have shown performance improves over the first few runs and then levels out with little or no further improvement. For instance, Milnes-Walker (1968) found that target recognition performance on the fourth run could not be distinguished from that on any subsequent runs. A further experiment (Mardon and Milnes-Walker, 1969) suggested that the improvement in recognition range over the first four runs was due to learning of the target and its immediate surroundings rather than learning of the route. Other studies which have shown significant improvement as a result of a second exposure to the run include those by Gilmour (1964)

FIGURE 2.11

Target acquisition performance of skilled and unskilled subjects



Source: Parkes and Rennocks (1971a)

and Dyer (1964), the latter relating to flight trials rather than simulation experiments as in the previous cases.

Flight trials in which the performance of pilots familiar with the test area was compared with that of pilots who were not familiar with the area are reported by Thackham, Wade and Clay (1966). The results showed no significant differences between the numbers of targets acquired and identified by the two groups.

2.9 TELEVISION DISPLAY VARIABLES

2.9.0 Introduction

If target acquisition is carried out by means of a television viewing system rather than by direct view of the terrain, as in the case of a television guided missile, a number of additional variables which may influence target acquisition performance are introduced into the situation. This section is concerned with the effects of these variables, which are largely dependent on the characteristics of the television system.

Experimental comparisons have shown that, in general, the effect of introducing a monochrome television system between the observer and the terrain is to bring about a deterioration in performance as compared with that achieved when the observer can see the terrain directly (Gorham, 1963; Snyder, Greening and Calhoun, 1964). This has been confirmed by more recent work in which it was found that in-flight televisual acquisition probabilities were lower than the corresponding visual acquisition probabilities, the values being 0.90 and 0.98 respectively. There was little difference between the televisual and the visual ranges for targets acquired at relatively short ranges (about 10,000 ft), but for those acquired at longer ranges mean televisual ranges were approximately half the corresponding visual ranges (Fielding, 1971).

The deterioration in performance associated with the use of television displays arises from a number of factors including the relatively narrow field of view and the loss of contrast and resolution. There is also evidence that television displays degrade observers' ability to estimate distance as compared with direct-view conditions (Oatman, 1963). However, the use of television allows a magnification of the apparent target size, and the possibility of introducing a display-freeze capability, both of which can improve some aspects of performance, as discussed later in this section.

The main parameters affecting televisual target acquisition performance are considered below. It should be noted that these television variables act in addition to, and may interact with, the variables associated with direct-viewing conditions considered in the previous sections.

2.9.1. Camera field of view

The size of the camera field of view used in televisual target acquisition tasks can have a marked effect on performance. The effects of field of view interact with those of display size and resolution but, assuming these remain constant, increase in the field of view affects the nature of the display in the following ways.

(i) A greater extent of terrain is shown on the monitor thus facilitating geographic orientation and navigation.

(ii) The apparent size of the target, that is, the visual angle subtended by the target at the observer's eye, decreases making detection and recognition more difficult.

(iii) The number of TV scan lines cutting the target decreases, again making detection and recognition more difficult.

(iv) The apparent angular velocity with which the target moves through the display decreases, thus facilitating detection and recognition.

(v) Target exposure time, that is, the time between the target first becoming potentially detectable by virtue of its apparent size and contrast, and its leaving the lower edge of the display, is usually increased by increase in field of view. In some circumstances, however, a reduction of target exposure time may occur. This happens if the shortening of potential detection range, brought about by the reduction in apparent size, is not compensated for by the shortening of the range at which the target leaves the lower edge of the display. This is largely dependent on camera depression angle. (See Section 2.9.2.)

Thus the overall effect of field of view on target acquisition performance depends on a number of opposing factors. This may explain why reported work on field-of-view effects has produced some conflicting results. For instance, Rusis and Snyder (1965) studied the effects of three fixed field-of-view sizes ($25^\circ \times 34^\circ$, $7.5^\circ \times 10^\circ$ and $6.2^\circ \times 8.2^\circ$, in each case the longer side being horizontal) on target acquisition performance and found that as field of view decreased probability of correct recognition decreased but the mean range of correct recognition increased, as shown in Figure 2.12. On the other hand, Ozkaptan et al (1968) studied four different fields of view (4.8^{o}, 7.3^{o}, 9.7^{o} and 14.5^{o}) with the finding that detection probability was not affected by field of view when the subjects were briefed about the position of the target, but that under unbriefed conditions detection probability decreased with increasing field of view.

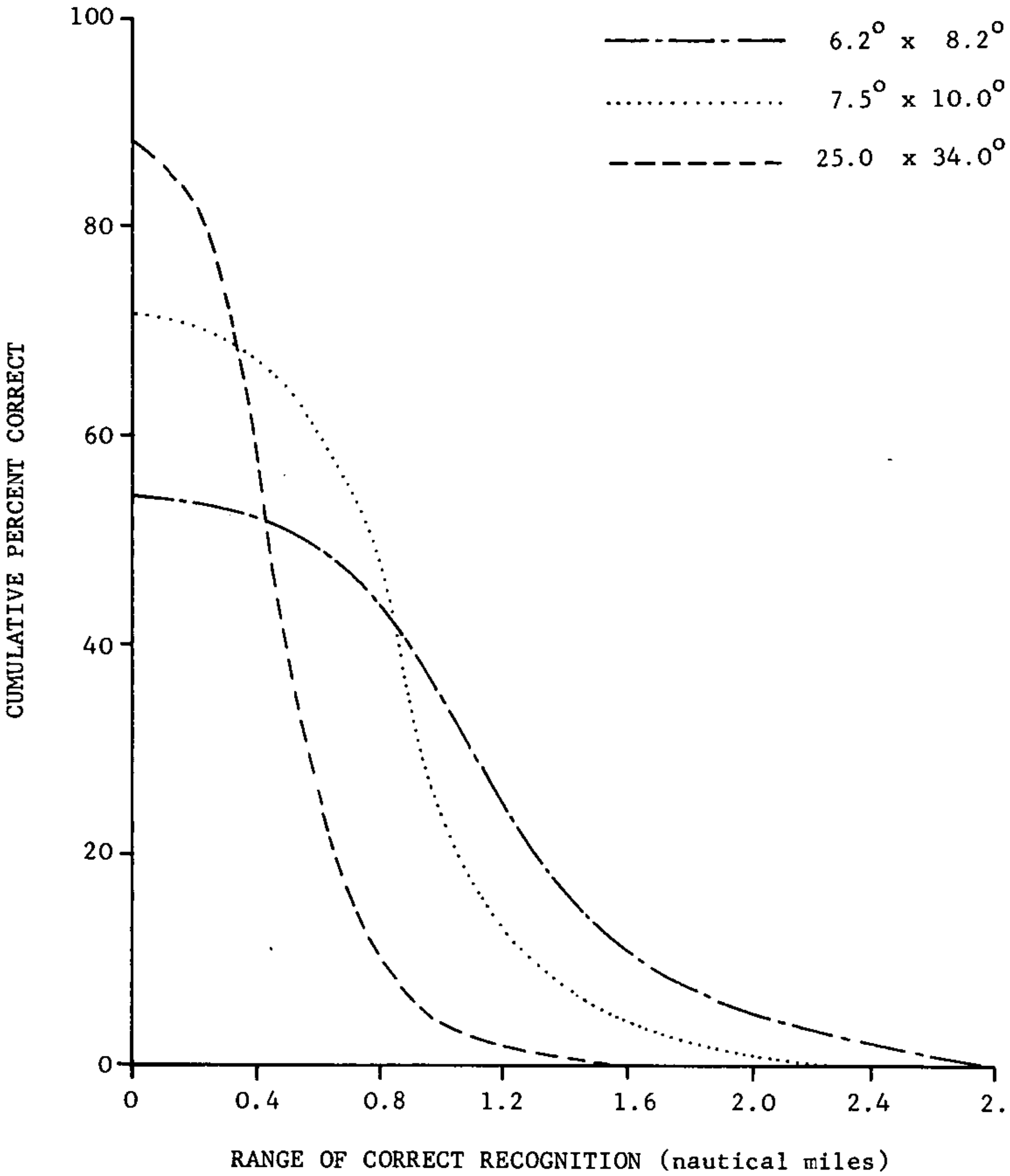
These apparently opposing results probably arise from differences in the experimental conditions, particularly in the effect of field of view on target exposure time in the two studies. In the experiment carried out by Rusis and Snyder target exposure time was directly proportional to field of view, whereas under the conditions used by Ozkaptan et al the relationship was an inverse one, larger fields of view resulting in shorter exposure times.

It appears therefore that exposure time is the critical factor affecting target acquisition probability, which is in accordance with the findings of a number of laboratory experiments, as described in Section 2.2.8. On the other hand, recognition range is affected by the apparent size of the target and in both the experiments discussed above range increased with increasing magnification, i.e. with decreasing field of view.

In an experiment carried out by Michael (1970) vertical field of view was reduced from 17^{o} to 14^{o} and to 11^{o} by successively masking off the lower parts of the field of view, thus increasing the range at which objects disappeared from the lower edge of the screen from 7500 ft. to 10,000 ft. and

FIGURE 2.12

The effect of camera field of view on target recognition performance.



The camera was arranged so that the longer field of view was horizontal in each case. These data relate to small targets.

Source: Rusis and Snyder (1965)

15,000 ft. The results showed only small and not entirely consistent effects on recognition range.

Other studies concerned with field of view effects are those by Leiniger et al (1963) who showed that larger fields of view facilitated geographic orientation, and by the present author who found some improvement in the detection of small targets with an increase in field of view from 30° to 50°, as reported in Study Note 2.

To summarize the work discussed above, it can be said that, in general, a wide field of view favours navigation performance and recognition probability, while a narrow field of view improves recognition range. In practice a compromise is usually adopted in which the field of view selected, usually 20°-30° horizontal, is less than optimum for navigation purposes and greater than optimum for achieving maximum recognition ranges. Alternatively, as discussed below, a lens of variable focal length may be used, giving the advantages of both narrow and wide fields.

In the experiments considered so far in this section, the camera field of view was always fixed, and no provision was made for altering the focal length of the lens thus allowing magnification of a target to facilitate recognition. The results of field trials reported by Heap (1965) suggest that provision of a zoom lens results in some improvement in performance, as compared with the corresponding fixed focal-length lens (in this case 1" focal-length lenses were compared), and that a zoom lens with search facility still further improves performance. Whilst the use of a zoom lens can combine the advantages of a large field of view to facilitate navigation and increase recognition probability, and a small field of view to improve recognition range, the additional cost of such a system, and the loss of resolution as compared with a fixed focal-length lens must be taken into account.

A different approach to overcoming the opposing field-of-view requirements was made by Wyman and Sturm (1966) who evaluated a dual TV system which provided the observer with a wide and narrow field of view simultaneously. A rectangular cursor could be positioned on any area of the main wide field-of-view display and operation of a switch produced a magnified view of the area under the cursor in the top corner of the main display. Use of this system reduced recognition time by 17% but had no effect on recognition probability as compared with the fixed wide-angle field of view.

2.9.2. Camera depression angle

The depression angle of the television camera, that is, the extent to which the optical axis of the camera is depressed below the horizontal, determines, together with the camera field of view and altitude, the extent of the terrain shown on the display and the minimum range at which target acquisition can occur before the target leaves the lower edge of the field of view. The smaller the depression angle, the greater the depth, or range, of the picture and the more marked the perspective effects.

The depression angle is usually chosen to show the horizon, which provides a useful reference line, near the top of the display so that the picture includes the greatest possible extent of terrain. However, in selecting a depression angle the vertical field of view and the expected acquisition range of the targets must be taken into account. Clearly, the combination of depression angle and field of view must be such that the targets can be detected and recognised before they leave the lower edge of the display.

There appear to be no reported experiments concerned with the effect of camera depression angle on acquisition performance, although one study by Elam (1964) is of some relevance. He found no difference in helicopter navigation performance between conditions in which a television camera, field of view $22^{o} \times 28^{o}$, was fixed horizontally or movable $\pm 20^{o}$ in pitch. In general, it appears that, provided the field of view is reasonably large, say 15^{o} vertically, depression angle will have only small effects as long as the horizon is in the field of view, and the minimum range is such that target acquisition can take place before the target leaves the lower edge of the display.

2.9.3. Display size/viewing distance

Space limitations inside the cockpit may impose constraints on display size and/or viewing distance. It is therefore important to know how target acquisition performance is likely to be affected by variations in these factors, particularly by displays which subtend a relatively small angle at the observer's eye due to small size and/or long viewing distance.

In discussing display-size requirements for multi-sensor displays, Slocum, Hoffman and Heard (1967) state that the minimum ideal display size depends on the resolution of the display, the resolution of the eye and the normal viewing distance. Assuming a normal viewing distance of 24 inches, a display resolution of 1000 TV lines and a minimum separable eye resolution of 1 minute of arc, they calculate that the display should be at least 6 inches in diameter. However, in relation to television displays camera field of view is also an important consideration in determining the optimum size and distance of the display.

For television displays, size and viewing distance are normally fixed so that the angle subtended at the observer's eye is the same as the camera field of view, usually about 20° across. Thus the terrain seen on the display subtends the same viewing angle as it would when seen directly. Reduction of the camera field of view relative to the angle subtended by the display produces an apparent magnification of the target and surrounding terrain while increase in the camera field of view relative to the angle subtended by the display has the opposite effect.

Experiments in which the angle subtended by the display at the observer's eye is varied, while the camera field of view is kept constant, can be carried out either by altering the display size or by altering the viewing distance. For instance, Shurmer (1968) investigated the effects of two viewing distances giving real-world and half real-world viewing angles for one display size, while Milnes-Walker (1967b) and Crawley, Silverthorn and Snailum (1966) between them studied three display sizes 7" x 5", 5" x 4" and 4" x 3", at a constant viewing distance of 29". These experiments showed that although there was a tendency for performance to deteriorate as the angle subtended by the display at the observer's eye decreased, the effect was not significant. These findings are in good agreement with those reported by the present author in Part II, in which three viewing distances, 13", 21" and 30" were studied, while display size was kept constant.

It appears, therefore, that in itself the angle subtended by the display is not an important factor, as compared with other closely related factors such as camera field of view, apparent target size and the number of scan lines cutting the target.

2.9.4. Display orientation

Ideally, a display should be positioned within 15^{o} of the normal line of sight, taken as being 15^{o} below horizontal for a seated observer and falling on the mid-sagittal plane, since within this solid angle any point can be fixated with speed and accuracy by eye-movements alone (Sanders, 1963). Ideally, too, the display orientation should be perpendicular to the line of sight.

Little is known in relation to television displays as to the effects on performance, if any, when these ideal conditions are not met. Studies carried out by Williams (1949) suggest that radar scopes can be positioned up to 30° from the position normal to the line of sight without affecting target detection. Further experimentation would be required to determine whether this also applies to television displays, but it seems likely that any effects of display orientation would be only marginal unless the operator was very uncomfortably positioned in relation to the display, or the viewing angle was very oblique.

2.9.5. Resolution

The amount of detail potentially discernible in a display is determined by the resolving power of the display system, which can be regarded as a measure of its ability to render a clearly-defined image. Resolution is conventionally measured by some procedure involving the discrimination of closely-spaced lines, and expressed as the number of lines per unit distance which can be distinguished. The term ground resolution refers to the corresponding ground size of the smallest detail discernible in the display.

In the case of a line-scan display system, such as television, the overall resolution depends on the combined effects of the resolving power of the sensor, the transmission system, and the scanning process by which the image is formed on the tube.

Vertical resolution of the image depends mainly on the diameter of the scanning spot since this determines the width of each scan line. Horizontal resolution is limited by the bandwidth or rise time of the amplifiers. A measure of the resolving power of a television imaging system is given by the total number of scan lines over the display surface, and the relationship between number of scan lines and target acquisition performance has been the subject of a number of studies.

Several laboratory experiments have found a relationship between target identification performance and the number of scan lines passing through the target. For instance, Erickson and Main (1966) found that geometric symbols cut by at least 6 scan lines could be located 100% of the time, but about 10 lines per target were necessary for 80% correct identification. In a later experiment it was found that 12 lines per symbol resulted in 90% correct identification (Erickson, Main and Burge, 1967). An approximately linear relationship between the probability of correctly identifying targets and the number of scan lines through each target was found by Brainard, Hanford and Marshall (1965). Results reported by Larue and Bertocci (1964) suggest that the greater the similarity between a target and other objects from which it must be discriminated, the greater is the number of scan lines required for recognition.

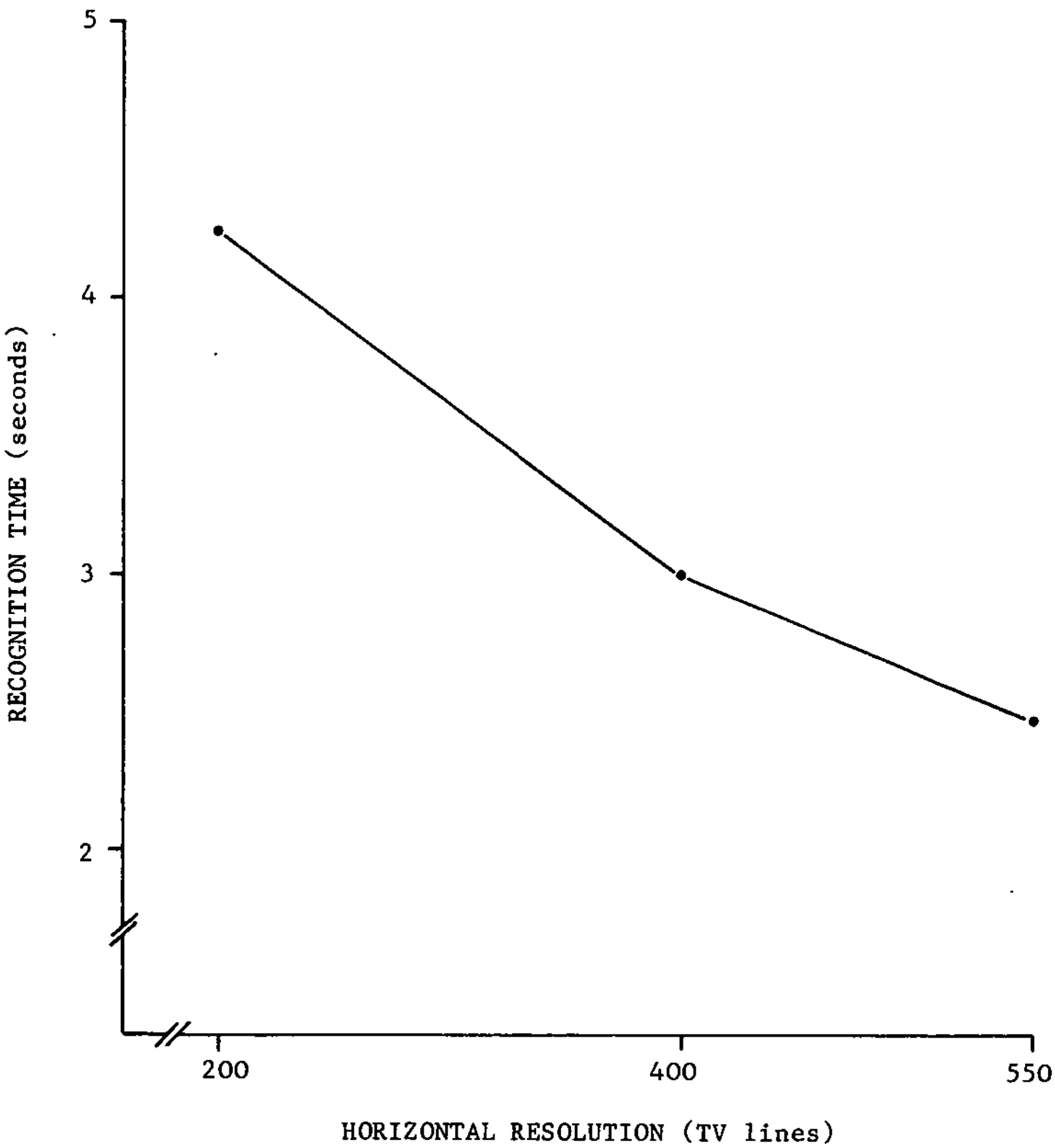
Other experiments have been carried out using realistic terrain imagery. For instance, Johnston (1968) showed that the time required to recognise a target in a static terrain scene, displayed on a television monitor, increased with a decrease in resolution from 550 to 200 lines, as shown in Figure 2.13. A study carried out by Rusis (1966), also using realistic terrain imagery, indicated that vertical orientation of the television scan lines increased the probability of correct target recognition as compared with horizontal scan lines.

While no direct comparisons can be made between the results obtained from the many studies which have investigated the effect of number of scan lines, it appears that as the number of lines are increased performance improves up to an asymptotic level beyond which further increase has no effect. The level at which this occurs depends on the nature of the target, including its size, shape, complexity, aspect ratio and location in relation to other objects, and the exact nature of the task involved, particularly whether detection or recognition is required.

Although the number of TV scan lines has conventionally been used to provide a simple measure of resolving power, a much more complete specification of resolution can be given in terms of the Modulation Transfer Function (MTF) characteristics of the system. This approach, as outlined for instance by Jensen (1968), has been increasingly widely-adopted during recent years. The system MTF, defined in terms of the response of the system to a sine-wave input, provides a measure of the image contrast obtainable in relation to the size of the target detail to be resolved. Since the detection threșholds of the human visual mechanism can be expressed in terms of similar size/contrast parameters, the specification of systems and imagery in terms of MTF characteristics allows more meaningful relationships between performance and image quality to be developed than is possible using conventional measures.

FIGURE 2.13

The effect of horizontal resolution on target recognition time



Source: Johnston (1968)

2.9.6. Grey scale, display brightness and ambient illumination

The accuracy with which a television system can represent the shades and tones of a terrain scene depends on its ability to reproduce a range of brightness levels. This can be measured in terms of the number of shades of grey which can be discerned on the television display when a standard grey scale is viewed by the camera.

Slocum, Hoffmann and Heard (1967) suggest that to facilitate target recognition in complex images the television system must be capable of reproducing at least seven shades of grey. This is in accordance with experimental data reported by Johnston (1968) which showed that a reduction in the number of shades of grey reproduced by the television system, from seven to five, resulted in a significant increase in the search times required for the recognition of targets in a static terrain scene.

The relationship between the tones of the scene viewed by the camera and those displayed on the monitor is determined by the system brightness transfer characteristic, 'gamma'. A gamma value of unity indicates that the brightness output of the system is directly proportional to the input, i.e. the grey-scale reproducing capability of the system is distributed evenly over the greys in the terrain scene. Increasing the gamma value above unity compresses the dark end of the brightness continuum thus allowing finer brightness discrimination at the light end of the spectrum, while reduction of the gamma level has the opposite effect. Thus increase in gamma tends to darken the general appearance of the display and reduction in gamma tends to lighten it as compared with the gamma value of unity.

Typically, the gamma value is set at unity and relatively little work appears to have been carried out to determine whether televisual target acquisition performance is affected by changes in gamma level. One such experiment is reported by Fowler et al (1971) who studied the effects of gamma levels of 2.2 and 0.55, as compared with the unity value, on a simulated air-to-ground target acquisition task. The results, which were complicated by the fact that gamma interacted with target/background contrast values, indicated that for positive contrast targets the higher gamma level tended to enhance recognition performance.

The discrimination of contrast levels imaged on a television display depends on the brightness of the display, on the ambient illumination conditions and on the relationship between these two factors. Laboratory data show that size/contrast thresholds decrease as display illumination increases, and thus it would be expected that target detection performance, in terms of potential range, would improve with increase in display brightness. This has been confirmed in an experiment carried out by Mardon (1969b) in which potential ranges were measured using cine-film simulation techniques. The results showed that significant increases in potential range were associated with increases in display brightness from 0.19 to 4.15 ft. Lamberts.

For optimum discrimination of contrast, standard texts recommend that the ambient illumination should be such that surround brightness is at least 10% less than that of the display. Under these conditions an overall contrast ratio of 8:1 is typically required for the discrimination of seven shades of grey on a television display. However, if the ambient lighting is such that the general surround brightness is orders of magnitude higher than the display brightness, then a much higher contrast ratio, approximately 30 : 1, is required to obtain the same grey scale discrimination. Clare (1970) found that screen brightness/surround brightness ratios of 48/15, 48/1.5 and 4.5/1.5 did not significantly affect televisual target acquisition performance, but data could not be obtained for a ratio of 4.5/15 because of the severe reduction in contrast.

In an aircraft cockpit extremely high ambient illumination levels due to sunlight may be encountered and correspondingly high display brightness, together with contrast enhancement filters, must be used to obtain adequate contrast discrimination. Further difficulties may arise if the observer has to divide his attention between two displays, for instance, a television display and a map display. In this case the two displays should be of approximately equal brightness to avoid any performance decrement due to adaptation problems.

2.9.7 Visual noise

The presence of visual noise on a television screen degrades the display and would therefore be expected to cause a deterioration in target acquisition performance. This decrement in performance with increase in visual noise has been demonstrated in a number of experiments using both abstract displays and realistic terrain scenes. For instance, Crook and Coules (1959) found that visual noise resulted in a deterioration of performance in form identification on a simulated television display, while a study carried out by Coules, Duva and Ganem (1960) showed that judgements of the complexity of irregular shapes were affected by visual noise level, the effect being different for different forms.

French (1954), using a simple measure of target-to-noise ratio (the number of dots forming the target pattern as compared with the number of random dots), found that increasing the number of noise dots produced a progressive decrement in target recognition. The results showed that, as the ratio of target dots to noise dots increased to a value of approximately 3:1, recognition performance improved but beyond that there was little further improvement.

This experiment illustrates the general point that as signal-to-noise ratio increases, performance improves to a maximum value beyond which no further improvement occurs with increase in signal-to-noise ratio. The problem therefore is to determine the signal-to-noise value at which this maximum performance is achieved. This will obviously vary with the nature of the task and the data must be determined from an experimental situation which resembles as closely as possible that in which they are to be applied.

An experiment carried out by the present author, reported in Part IV, studied the effect of four levels of visual noise, 30, 24, 19 and 14 db signal-to-noise ratio, on the subjects' ability to locate ground targets in oblique terrain photographs, displayed on a television monitor. The results showed that the two higher signal-to-noise ratios did not significantly degrade performance as compared with that when the photographs were viewed directly, but there was a highly significant deterioration in performance between the 24 and 19 db levels. It appeared, therefore, that for this type of task the signal-to-noise ratio could be as low as 24 db without any significant performance decrement occurring.

Another experiment in which the effect of visual noise on target acquisition performance was studied using static displays was that reported by Kause (1965). He used oblique photographs of ground targets displayed on a television monitor to investigate the effects of noise and no-noise conditions on target acquisition. Performance was found to deteriorate under the condition of low signal/noise ratio, this deterioration being more marked under optimal conditions of contrast and resolution, than under degraded contrast and resolution conditions.

There is no direct evidence from these studies as to how visual noise would affect target acquisition performance under dynamic conditions. No published work could be found in which the effects of visual noise had been studied under dynamic conditions, but a number of other experiments in which visual noise has been studied under static conditions have been reviewed in Part IV.

2.9.8. Colour/monochrome displays

The use of colour displays in televisual target acquisition tasks appears to have been relatively little investigated. The main reason for this would seem to be that the increased cost, weight and complexity of colour television, as compared with black and white, could only be justified if the performance levels achieved using monochrome displays were unsatisfactory, and there was reason to believe that substantial improvements could be achieved by the use of colour television. There is little evidence to suppose that this is the case.

Snyder, Greening and Calhoun (1964) carried out a direct comparison between the target recognition performance achieved using colour cine-film and using a black-and-white duplicate made from it. The results showed that neither recognition probability or recognition range were significantly improved by the use of colour displays, although recognition probability was marginally higher for colour than for black-and-white. A recent experiment carried out at the Weapons Department, Royal Aircraft Establishment (Davies, 1970) also found that there was no advantage, in terms of acquisition performance, in the use of colour displays.

These results suggest that in air-to-ground target acquisition tasks colour contrast is very much less important than brightness contrast. This is not unexpected in the case of targets recognised at relatively long ranges since atmospheric attenuation effects render coloured objects almost colourless at long ranges. For small tactical targets which may suddenly be unmasked at relatively short ranges, it is possible that the use of colour displays would be advantageous.

2.9.9. Stereo displays

Natural stereoscopic vision, which depends on the lateral separation between the eyes, and has the effect of giving depth to a visual scene, extends to a range of approximately 1500 ft. from the observer (Graham, 1965; Ogle, 1962). If photographic techniques are used to produce stereo-pair displays, the natural stereo-base may be retained or, alternatively, the length of the stereo-base may be increased by increasing the separation of the cameras, beyond the normal inter-pupillary distance. This has the effect of magnifying the depth cues and thus enabling stereoscopic effects to be obtained at much greater ranges than allowed by natural stereoscopic vision.

This technique is potentially applicable to the television displays used in air-to-ground target acquisition if the problems involved in maintaining the registration of the two cameras could be overcome, but this would only be worthwhile if it could be shown that the use of such a system led to substantially improved performance. The available evidence, most of which has been obtained from studies of the effectiveness of stereo-displays in aiding the interpretation of photo-reconnaissance imagery, is not encouraging.

For instance, de Loor et al (1968) found that stereo imagery, obtained using a simulated stereo-base of 70ft. did not aid detection and discrimination tasks, and in fact led to a 32% increase in interpretation time. Hudson and Cupit (1968), also found that, in general, performance at a task involving judgements of the size and distance of objects under conditions of visual noise was not improved by the use of stereo displays.

However, a study carried out by Giarretto (1968) showed that stereo displays reduced the extent to which the discrimination of three-dimensional abstract forms deteriorated with increasing visual noise. Another experiment using stereo displays which achieved positive results was that by Weldon, Slingerland and Myers (1968). They found that continuously varying the stereo-base of stereo cine-film, which induced apparent pulsated movements in tall objects viewed against a flat background, led to marked improvement in the time and accuracy with which the tall objects were located.

2.9.10. Display freeze

A standard television system presents the observer with a continuously moving display as the missile approaches the target. Several studies have been carried out to determine whether improved target acquisition performance can be achieved by the use of television systems incorporating a display freeze capability. This allows the display to be periodically stopped, either automatically or as initiated by the observer, thus presenting a static display to facilitate search.

Experiments carried out by Rusis, Snyder and Greening (1965) and Rusis, Snyder, Greening and Rawlings (1965) to investigate various parameters associated with a freeze capability clearly showed the advantage of this capability as compared with a conventional television system, although the results of the two experiments were not entirely consistent. The main findings were that a display freeze capability resulted in longer recognition ranges and/or improvement in recognition probability; that the actual duration of the freeze, 1, 3 or 5 seconds made little difference to performance; that display freeze initiated by the computer navigation system at certain ranges from the target was more effective than observer-initiated freeze; and that a continuous freeze mode in which a series of static displays, changing automatically after a fixed interval of time, was presented was less effective than either observer-initiated or computer-initiated intermittent freeze.

2.10 CONCLUSIONS

The experimental work reviewed in this chapter gives an indication of the way in which the many variables associated with the dynamic and visual characteristics of the outside world, the internal cockpit environment, and the experience and skill of the observer, affect target acquisition performance during high-speed, low-level flight. Whilst the main effects of some important variables have been reasonably well documented, it is clear that relatively little is known about the effects of many other variables, which do not lend themselves so readily to experimental investigation.

In the great majority of the experiments reviewed only two or three variables have been studied. As there is no meaningful way in which data from these independent and uncoordinated experiments can be related, it is difficult to know which variables are of primary importance in air-to-ground target acquisition and which, in comparison, would give rise to only marginal effects on performance. Furthermore, there are undoubtedly numerous interactions between the many variables involved and the existing data do not allow the importance of these interactions to be evaluated.

It is evident from the studies reviewed that experimental coverage of different factors is by no means even. In general, variables which have been frequently investigated are those which are relatively easy to control and vary such as speed, altitude and target size, or those which reflect the particular interests of one research group, such as visibility and atmospheric effects, which have been extensively studied at Scripps Visibility Laboratory, San Diego.

Analysis of the various techniques that have been used to study different variables reveals that flight trials and high-fidelity simulation studies have tended to concentrate on a number of important factors that can readily be systematically varied under real-world conditions, for instance, speed, altitude, and target size and off-set. Whilst the effects of a number of other factors such as visibility, masking, vegetation and sun angle have been reported from field studies, these have not in general been systematically investigated. Conversely, laboratory experiments involving complex, abstract, and usually static displays, have frequently been used to study factors such as target shape, background complexity and target confusability, which are extremely difficult to quantify under realistic conditions.

In the general area of target detection and visual search studies there is an overwhelming predominance of experiments using relatively simple displays under highly-controlled conditions. The lack of more realistic operational data obtained under controlled conditions has led to the use of analytical techniques by which data from laboratory experiments have been included in mathematical models of air-to-ground target acquisition performance as, for instance, by Heap (1966a), Linge (1961), Ornstein, Brainard and Bishop (1961) and Silverthorn (1970). The purpose of such models is to predict performance under operational conditions but, in general, few attempts have been made to validate these predictive models against field data.

One reason for this is the lack of adequately controlled field data covering a wide enough range of parameters to allow meaningful comparisons between predicted and actual values. A second problem is that many of the parameters used in predictive models are difficult to measure accurately under field conditions. Where attempts have been made to validate models,the predicted values have usually been compared with data obtained under highly simplified conditions. For instance, Evans, Levy and Ornstein (1965) used block targets against a terrain platform to obtain experimental data to validate the model derived by Ornstein, Brainard and Bishop (1961).

However, in some instances models have been validated against more realistic simulation data with some degree of success. In one such study Greening and Wyman (1970) found that using a relatively simple model they were able to account for a substantial amount of the variance in target recognition data obtained from a cine-film simulation experiment. However, there remained a substantial amount of variance associated with factors not represented by the model. Examination of individual target data failed to show any apparent differences between targets for which good predictions were obtained and those for which the predictions were poor.

One example of a study in which a predictive model was validated against field data is that reported by Erickson (1969). This model, derived some years earlier from laboratory data obtained at the Scripps Visibility Laboratory, enabled predictions to be made for air-to-ground detection and recognition ranges at various altitudes. It incorporated a 'field factor', which could take one of three values, to allow for performance degradation due to field conditions. One limitation of this model was that it did not include provision for search in two dimensions, but in the field trials very little search was required since the target vehicle was placed directly on the flight path beycnd a conspicuous marker point. Both detection ranges and recognition ranges were obtained for two different targets, a total of 94 passes being made.

The results showed that for detection ranges reasonably good agreement (maximum error 17%) was obtained between the field data and the predicted values when the small 'field factor' was used, but the recognition range predictions over-estimated the actual values by between 200% and 300%. In operational situations recognition range is usually more critical than detection range, and the current state-of-the-art in the predictive modelling is still some way from achieving the validity necessary for operational use, particularly in relation to recognition performance.

While it is possible that further refinements to modelling calculations will improve the accuracy with which target acquisition performance can be predicted, there are serious difficulties inherent in analytical techniques based on laboratory data obtained under simplified conditions. One obvious difficulty is the need to introduce some sort of 'field factor' to take account of the fact that the real-world task is carried out under very much more complex conditions than the laboratory studies. In general, it has been found that performance is worse under field conditions than in the laboratory, although data reported by Davies (1968) indicated that field data on the size/contrast thresholds of ground targets viewed from the air were slightly better than the laboratory data. This could have been due to the particularly prominent nature of the ground targets concerned.

Another difficulty in the use of predictive models is that there are a number of important factors which cannot as yet be precisely quantified in a real-world context. These include background clutter, target confusability and the effects of different types of briefing materials, which can markedly affect performance. Unless modelling techniques can be developed to take account of factors such as these, the accuracy obtainable in inevitably limited.

Whilst attempts have been made to derive models of acquisition performance from flight and simulation data on an empirical basis using multivariate techniques (Franklin and Whittenburg, 1965; Heap, 1966b; Williges and Simon, 1971), such models have been restricted to a relatively small number of variables as a result of the limited amount of suitable data available. There is clearly a need for a systematic, co-ordinated and well-defined research program to obtain a cohesive set of data under realistic conditions so as to reduce the present dependence on abstract laboratory data in the derivation of mathematical models. In addition, attempts would have to be made to quantify those factors which cannot at present be expressed in quantitative terms.

Reliable predictive modelling of target acquisition performance, particularly the range and probability of recognition, must be regarded as the eventual aim of such work, but it is one that is unlikely to be realised for a number of years. Meanwhile, there is a need to clarify the role of a number of important variables which, as the review presented in this chapter shows, are at present not well understood. In particular, since target differences account for a large proportion of the variance in target acquisition data, the development of a method of classifying targets into categories which reflect more precisely the relative difficulty of acquisition than the functional or size groupings often used at present, would be a significant step forward.

It is clear that, in order to maximise the effectiveness of future weapon systems, research into target acquisition must continue, particularly in relation to television and other sensor systems which are becoming increasingly important. During the past decade, target acquisition research has been greatly facilitated by the development of sophisticated techniques for simulating the visual environment during high-speed, low-level flight, thus enabling many aspects of performance to be realistically studied in the laboratory. These techniques, and their advantages and limitations as compared with the use of flight data in the study of target acquisition, form the subject matter of the following chapter.

3. TECHNIQUES FOR THE STUDY OF TARGET ACQUISITION PERFORMANCE

3.0 INTRODUCTION

Two different approaches are open to the researcher concerned with the study of factors affecting air-to-ground target acquisition performance. He may either obtain data directly from operational situations or he may use some form of simulation to represent the operational situation, or certain limited aspects of it, in the laboratory. These two approaches are essentially complementary since data obtained from actual air operations are clearly more realistic, but simulation techniques allow a much greater degree of experimental control.

The need for operational flight data has frequently been emphasised. For instance, Miller (1964) reporting a conference on problems of high-speed, low-level flight stated that '...... operational data collection is an absolute must and the feeling of the group was that not enough operational data were available'. The lack of operational data relating specifically to the problem of visual acquisition from aircraft was described as 'appalling'. Although some progress has been made since then, a high proportion of published work is concerned with simulation techniques or with laboratory experiments in which only a limited part of the overall target acquisition task is studied.

This situation reflects the difficulty and expense of obtaining valid data under real-world conditions. Whilst high-fidelity simulation techniques can provide a very realistic simulation of the operational task, the equipment required is both complex and costly. For this reason, many experiments have been carried out under greatly simplified simulation conditions in which only a part of the real-world task is represented. Although simpler simulation techniques may have advantages in terms of greater experimental control and reduced cost, the data obtained cannot be directly related to the operational situation.

In this chapter the advantages and limitations of various techniques which have been used to study target acquisition performance are considered. The material falls into two main parts. Firstly, the use of operational flight data is discussed with particular reference to problems of experimental control and performance measurement in flight trials. Secondly, general problems of simulation are considered and a number of visual simulation techniques are outlined. Examples of various different types of equipment are described together with a brief review of the research for which they have been used.

3.1. OPERATIONAL FLIGHT DATA

3.1.0. Introduction

Possible sources of operational flight data include combat missions, training missions and flight tests but only one of these, flight tests, allows the systematic collection of target acquisition data. Little information is available about the use of data relating to combat situations for research purposes since, understandably, such data are not normally published in unclassified documents. However, although representing the ultimate in realism, the use of combat data would appear to be of limited value to the research worker concerned with the detailed study of factors affecting acquisition performance.

There are a number of reasons for this. Firstly, target acquisition research is frequently concerned with the effectiveness of specific weapon systems still in the development stage and for which, therefore, no field data are available. Secondly, even if the system concerned is already operational or the research is of a general nature, only a limited amount of information is likely to be retrievable from records of combat missions. While data such as mission objective, type of aircraft, altitude, meteorological conditions and time of day are routinely recorded, detailed and quantitative data about the nature of the target and background and the conditions under which the acquisition task was carried out are unlikely to be available. Furthermore, although success rates for target acquisition may be known, the accurate determination of acquisition range, an important aspect of performance, requires special instrumentation and ground facilities, and is therefore not feasible under combat conditions.

The analysis of the limited data which can be obtained from combat missions may give rise to further problems, since such data are inherently lacking in experimental control. Although sophisticated techniques have been developed for the analysis of uncontrolled data, as described by Armitage (1971) and Cox (1970), target acquisition performance is affected by so many complex and interacting variables, about many of which little or no information would be available under combat conditions, that such an approach could not be comprehensively implemented. Whilst analyses could be carried out on the data available the information derived would, at best, only reflect certain limited aspects of the overall problem, and would depend very much on the particular situation from which the data were obtained.

Thus, data derived from combat missions would seem to have little application in the systematic study of target acquisition performance. However, such data do provide information of a more general nature about factors affecting mission success in the field which could be of some value to military commanders in the planning of tactical operations and, in the longer term, in indicating where existing equipment is unsatisfactory or inappropriate to the conditions encountered, and in specifying training requirements.

Many of the limitations which apply to the use of data from combat missions also apply to those from routine training missions, with the added disadvantage that pilots carrying out these missions are not fully experienced, and are therefore unlikely to achieve the same performance levels as fully qualified pilots. Nevertheless some studies, largely of a survey nature, have been carried out utilizing data obtained from training missions. For instance, McGrath and Borden (1963) studied the records of 959 training missions to determine the extent to which geographic disorientation was a serious factor affecting mission success.

In a further study of navigation performance, Borden (1966) devised a data-collection method to meet the following stringent requirements; 'The method of getting the data must be simple, inexpensive and routinely usable by squadron personnel. It cannot impose any inflight tasks or test conditions on the aircrew, it cannot require special equipment to be installed on the ground or in the aircraft and it cannot require special test sorties to be flown'.

The method devised required the pilots to fill in details of navigation performance on specially designed forms after each sortie was completed. Quantitative performance measures could be determined from these records, and a field evaluation of the method (Borden and McGrath, 1968) showed that the data obtained agreed closely with objective data obtained from chase pilots and from navigation records.

It is clear therefore that some useful information can be obtained from pilots without in any way interfering with normal flying procedures, but it should be noted that the data obtained by Borden and McGrath related to navigation performance, in particular to navigation accuracy and the use of visual check-points, rather than to target acquisition performance for which a different type of information is needed. In particular, there is evidence that pilots cannot accurately estimate acquisition range(Richardson, 1962; Wade, 1964), and therefore a self-report method would not be a reliable technique for obtaining this information.

3.1.1. Flight trials

In view of the limitations of combat missions and training missions as potential sources of operational target acquisition data, it is usually necessary to obtain such data by means of flight operations carried out specifically for research purposes with appropriate aircraft instrumentation and ground facilities. The use of systematic flight trials, which allow some degree of experimental control to be combined with a high level of operational realism, provides a link between genuine operational situations and laboratory simulation experiments.

Flight trials allow a very close approximation to actual operational conditions to be achieved in terms of factors such as the cockpit environment, the work-load on the pilot, the effects of buffeting and vibration, the dynamic characteristics of the external visual environment, and atmospheric effects, although the stress of flying over heavily-defended hostile terrain cannot be entirely generated in an experimental situation, and in this respect flight trials must be regarded as a form of simulation. The high degree of realism obtainable from flight trials inevitably gives rise to serious problems in achieving adequate experimental control, and in obtaining accurate measures of performance, particularly acquisition range. These difficulties are considered in the following two sections, while in a third section some examples of flight trial programs are described.

3.1.1.1. Problems of experimental control

The basic principles of experimental design require that, while systematic changes are introduced into the particular variables under investigation, other factors which might significantly affect performance are kept constant. Both these requirements give rise to serious problems in the planning and execution of flight trial programs. Not only are there some conditions which cannot be maintained constant throughout a series of trials, e.g. meteorological conditions, but there are also limitations in the extent to which systematic variation can be introduced into the factors under investigation.

The main problems in achieving experimental control during flight test programs arise from (i) difficulty of flying repeated passes over the same track; (ii) variation in meteorological conditions during the trials; (iii) diurnal variation in lighting conditions; and (iv) seasonal variation in the appearance of the terrain. These factors are considered below.

(i) In order to obtain sufficient data for reliable analysis it is usually necessary for several pilots to fly one or more passes over a particular track at a specified speed and altitude. In order to avoid extraneous variation arising from random track errors, it is important that exact navigation along the required track is achieved during each trial. In practice this is not easy to attain although navigation difficulties can be minimised by choosing conspicuous, well-defined fixpoints along the routes, and providing the pilots with detailed briefing about them, together with the exact magnetic headings to be flown Even if this is done some track errors may occur and it is an advantage to have available radar tracking facilities which enable the exact position of the aircraft to be accurately determined at any time. Radar tracking is also a useful means of determining acquisition range. (See Section 3.1.1.2.)

(ii) Changes in meteorological conditions during flight trials are a potential source of uncontrolled variation in target acquisition performance. They may give rise to rapid and unpredictable changes in visibility, cloud cover, illumination and contrast levels, all of which are liable to affect performance. Whilst this problem is less acute in parts of the world where meteorological conditions are relatively stable, for example California, than in the United Kingdom where changeable conditions prevail, it must always be taken into account when planning flight trials.

The approach usually adopted to minimise meteorological effects is to establish minimum cloud ceiling and visibility conditions below which no trials are carried out. These minimum values depend on the nature of the trials and particularly the altitude at which they are flown but typical values would be a 3000 ft. cloud ceiling and 5 miles visibility for a flight altitude of 500 ft. Providing the minimum conditions established are well above the threshold at which performance starts to deteriorate, it is reasonable to assume that there will be no effect on performance even if cloud and visibility conditions fluctuate above the minimum levels. As a further check however records should be kept of meteorological conditions during the trials, in case they should prove of value in explaining unexpected anomalies in performance.

(iii) Changes in the position of the sun, in both azimuth and elevation, during the course of the day give rise to substantial variation in illumination and shadow effects, which can affect target acquisition performance. Since these diurnal changes are predictable they are more readily controlled during flight trials than meteorological effects. To eliminate the effects of diurnal changes care must be taken to ensure that trials are flown as far as possible at roughly the same time each day.

(iv) Seasonal changes are rather more complex than diurnal effects but, since they take place over weeks or months rather than hours, they need only be taken into account if the trials are carried out over an extended period. The main seasonal effects which need to be considered are the increase in foliage occurring in Spring and Summer, and the occurrence of snow, or perhaps flooding, in Winter, in certain parts of the world. Increase in foliage has the overall effect of changing the appearance of the terrain, in general from predominantly brown colouration to predominantly green, but more specifically it tends to increase the amount of masking which results in an adverse effect on target acquisition.

Snow, even a light covering, has a marked effect on the appearance of the terrain, particularly if it is cluttered with many features. In some cases, snow may actually make navigation easier by obscuring the clutter and leaving only the more important features visible. Whilst flight trials carried out over snow-covered terrain may be of importance in themselves, the presence or absence of snow must be a controlled factor rather than an inadvertent part of trials intended to investigate other factors. In general, provided that the flight trials program does not extend over a lengthy period of time then seasonal effects are not likely to pose serious problems.

So far this discussion of flight trials has been concerned with possible difficulties in maintaining background conditions constant during the course of the trials. A different type of problem may occur in systematically varying factors under investigation. In particular, if the acquisition of targets such as buildings, bridges or airfields is being studied, it is not feasible to systematically vary target size, shape or colour in a way that would be possible if, say, a terrain-model simulation technique was used.

Furthermore, if approach direction is kept constant, each target is specifically associated with a particular route and a particular background. One way in which these difficulties can be overcome is to use vehicular targets which can be readily moved to different locations and painted different colours. Alternatively, artificial targets such as large symbols displayed on the ground can be used but these, although they have the advantage of allowing unlimited variation in size, shape and colour, bear little relation to real-world targets.

Other limitations in carrying out flight trials arise from the need to avoid potentially hazardous situations. Thus, certain combinations of high speed and low altitude might be required by the experimental design but have to be omitted from flight trials because of the risk to aircrew and equipment. These conditions can, however, be studied under simulation conditions which are free from such real-life hazards.

3.1.1.2. Measurement of acquisition performance

The most commonly used performance measures in target acquisition research, both in flight trials and simulation experiments, are the probability and range of target acquisition since these largely determine whether weapon delivery can be successfully accomplished. It is necessary therefore to have some means of ascertaining whether the target has been correctly acquired, and the exact distance from the target, either ground range or slant range, at which acquisition takes place. Whilst this poses no particular problems in the laboratory, it is considerably more difficult under field conditions.

Acquisition probability can be determined by asking the pilot to report verbally a description of the target and its position as soon as he acquires it. This is an adequate method providing that the target can be unambiguously described in a brief verbal message. For example Blackwell, Ohmart and Harcum (1958) used vehicular targets in a field trial of acquisition performance and verbal reports of the type 'target in South-West corner heading North with jeep first, 2½ ton truck second and panel truck last' were sufficient to indicate whether the target vehicles had been correctly identified. For targets such as bridges and buildings this procedure is liable to be less satisfactory owing to the possibility of confusing the real targets with other similar features.

An alternative method of determining whether a target has been correctly acquired is by means of either still or cine-film photography. For instance, in trials reported by Thackham, Wade and Clay (1966) the aircraft was equipped with a 16 mm. gunsight camera which the pilot activated when he first acquired the target. The approach to the target was recorded on cine-film which could be analysed to determine whether the correct target had been acquired and also the point at which the aircraft was aligned with the target. In general, photographic techniques provide a more reliable method than verbal reports of determining whether a target has been correctly acquired but they also require more costly instrumentation and greater time for analysis.

The accuracy with which acquisition range can be measured during flight trials varies widely with the technique of measurement used. A number of different techniques have been reported including radar tracking, vertical photography, time/speed measurement, optical tracking, calculation from altitude and dive angle when the aircraft is pointing directly towards the target, and pilot estimates. It would be expected that precision radar-tracking would provide the most accurate range values. Thackham, Wade and Clay, for instance, report accuracies of ± 200 ft. for the tracking radar used in their studies, but greater accuracies can be achieved if required.

Vertical photography can also provide accurate information about the position of the aircraft when the target is acquired, providing a vertical photomosaic of the test area is available to determine the ground coordinates of the in-flight photograph, and providing the camera is pointing vertically downwards when the photograph is taken. In one experiment the determination of slant range by vertical photography and by optical tracking gave values which did not differ significantly when both readings were made successfully, although the average difference between them was 13%.. (Blackwell, Ohmart and Harcum, 1958). This is one example of the use of two measurement techniques as a means of increasing the accuracy of range data.

In another experiment three different techniques were used, radar tracking, time-distance checks and pilot estimates, (Richardson, 1962). The results showed some discrepancies between the values obtained from different measurement techniques, comparable values being 8.6 miles for radar measurements, 6.6 miles for time/distance checks and 6.2 miles for estimated ranges.

Further evidence that estimated and measured ranges may differ substantially comes from an experiment reported by Wade (1964). He found an average discrepancy of 3581 feet between the two types of assessment, although there was no consistent tendency to under-estimate or over-estimate. These results indicate not only the need for precise techniques of measurement but also the importance of reporting the accuracy of the range data presented, which is overlooked by many authors.

3.1.1.3. Examples of flight trial programs

It is obvious that the planning and execution of flight trial programs must be carried out with great care if valid results are to be obtained. This is particularly important in view of the substantial cost involved in the use of aircraft, ground equipment and personnel for flight trials. Large amounts of time and money can be expended with little or no useful results if the experiment is inadequately controlled.

For instance, Bliss (1966) cites a report which, he states, 'illustrates the problems of conducting and reporting flight tests when thorough planning has not been done. There is no experimental design of any kind, no control of pilot ability, no control of learning, no check or assessment of the accuracy of range measurements, no check on the validity of the pilot's detection and identification reports, no review of previous work on the same problem, and no statistical tests. A totally inappropriate altitude for search for these types of targets was selected. The report is internally inconsistent in description of procedures and draws conclusions not consistent with the reported results.'

Work reported by Dyer (1964) provides one example of a carefully planned and conducted flight trial program. The purpose of this research was to study the effect of speed on low-altitude target acquisition distances under conditions designed to maximise the probability of target acquisition. The targets used in this study were military vehicles, newlypainted in olive-green, three each of three different types. Three clear, open areas giving as nearly equal contrast as possible were chosen, and one of each of the three types of target vehicle was placed in each target area, in a line perpendicular to the planned flight path.

The nine pilots who took part in this trial each flew three sorties against each target group. Speed order and target order were balanced so that the pilots flew at different speeds against targets in a different order on each of their sorties. Three speeds were tested (350, 550 and 700 kns), while altitude was maintained at 500 ft. Acquisition distances were measured by tracking radar, which had previously been tested to ensure that acceptable accuracy could be obtained.

Standardised briefing and debriefing procedures were used throughout the trials and the pilot's comments on each sortie, including any particular difficulties encountered were recorded. Although there was some variation in meteorological conditions, target area ceiling and visibility minimums were established at 3000 ft. and 5 miles, and the actual meteorological conditions and target illumination were recorded for each sortie. Take-off times were scheduled for approximately the same time each day.

The results of this trial showed significant speed and learning effects but these need not be considered here. For the purposes of the present discussion the relevance of this work lies in the fact that a real attempt was made to control a number of important factors in the experimental situation, including background type, target/background contrast, altitude, approach direction, minimum meteorological conditions, time-of-day, pre-mission briefing and learning effects. In addition, care was taken to obtain accurate measurement of acquisition range, and to ensure that aircraft altitude was maintained at the required level. In a further study the same techniques were used to investigate the effects of altitude, target/background constrast, and stationary or moving targets (Dyer, 1965). Unclassified flight trial data have also been reported by Brown (1960), Wade (1964), Whittenburg et al (1960a), and Whittenburg, Schreiber and Richards (1960b) but the majority of flight trials are reported in classified documents.

The problems involved in obtaining real-world target acquisition data can be greatly reduced by the use of static ground observation posts rather than moving aircraft but a corresponding reduction in realism must be accepted, together with severe limitation in the type of variables that can be studied. One such study is reported by Hicks and Moler (1966). In this experiment subjects viewed a target range, on which ten military vehicles were positioned in pre-determined locations, from the crest of a hill approximately 2100 yds. from the furthest target. The performance measure was the number of correct identifications made, the criteria being locating the target correctly in relation to nearby terrain features and other targets in the field, and giving correct identifying information.

In general, studies of this type are more applicable to ground operations than to air-to-ground acquisition tasks, but they can be used to provide some information about relative performance under different conditions, for instance, different targets and backgrounds, which would be relevant to air-to-ground target acquisition.

3.2 SIMULATION

3.2.0 Introduction

As discussed in the previous section, obtaining valid performance data under operational conditions is both difficult and costly. Consequently simulation techniques play a vital part in the study of target acquisition, and many other tasks which cannot readily be studied under operational conditions. In general terms, simulation can be regarded as 'the representation of an actual or conceptual physical object, process or situation, or of a theoretical construct ' (McCormick, 1964).

The means by which the representation is achieved may be either physical or symbolic, or some combination of these two techniques. Physical models have a degree of physical similarity to the objects they are intended to represent, but the extent of this resemblance varies considerably in different simulators. In some cases the similarity may be so great that the simulator is virtually identical in physical appearance to that which it represents.

Symbolic simulators may reproduce equally exactly the underlying processes of the real-world system, but in this case there may be little or no apparent resemblance in physical characteristics. For instance, a mathematical model in which the system and its environment, together with their input and output parameters, are all represented symbolically by mathematical equations, may exactly simulate a real-world system without any form of physical simulation whatsoever. The simulation of complex systems frequently involves the combination of physical and symbolic representation. Simulators of this type, which can be extremely sophisticated, consist basically of equipment simulators programmed by computerised mathematical models to respond to control inputs in the same way as the real-world equipment.

There are many different purposes for simulation but basically they can be divided into two categories; training, and research and development. Training simulators include skills trainers, which are primarily intended for training operators in the required perceptual and motor skills, and procedures trainers, the main purpose of which is to familiarise operators, either individuals or multi-man crews, with sequences of operations. The particular problems associated with the design of training simulators need not be considered in detail here since this work is essentially concerned with simulation for research purposes.

Research and development simulators have a wide range of uses and potential uses which have been listed by Fraser (1966) as follows: (i) design engineering; including the development of criteria for vehicle engineering, sensor and display engineering, and human engineering; and feasibility studies; (ii) evaluation of systems, components and materials; (iii) evaluation of man's capacities; and (iv) allocation of function to man and machine, determination of procedures, and personnel requirements. While this list was drawn up with reference to space flight simulators, it is equally applicable to other flight simulators and to many military and industrial systems.

Regardless of the type of system being simulated, a well-planned simulation program allows design and performance data to be obtained in a controlled environment at relatively low cost. An additional advantage is that potentially hazardous operations can be carried out in complete safety by operators or experimental subjects. Whatever the purpose of the simulation, the value of any simulation system depends on it being sensitive to significant input parameters and providing the appropriate response in terms of a set of output parameters. It is important that these output parameters should be capable of translation into some measure of performance relevant to the real-world system.

The type of performance measure required depends on the purpose of the simulator. If it is intended mainly for training then it is essential that the response of the system is displayed to the operator in such a way as to enable him to understand the effects of his control actions. Ideally, some measure of individual performance should be computed while the simulator is in operation and displayed to provide an immediate feedback loop. On the other hand, if the primary purpose is system evaluation then care must be taken to ensure that the information obtained is relevant to the system response and that, if possible, the data can be automatically reduced to suitable overall measures. As Ruby, Jocoy and Pelton (1963) point out it is often necessary to carry out a preliminary experiment to verify that the performance measures genuinely represent the aspects of performance they are intended to measure, and that they provide adequate sensitivity throughout the range of variables to be tested.

A primary concern in the development of a simulator is the question of fidelity, that is, the similarity between the simulator and the system being simulated. More specifically, simulation fidelity is concerned with the degree of accuracy of a simulated task, element or situation in reproducing the real counterpart (Adams, 1957). In general terms, the greater the fidelity of the simulator, the greater is the accuracy with which the real-world system behaviour can be investigated. However, a completely realistic representation of the real-world system is obviously not feasible. Not only would it defeat the ends of economy, safety and control of variables which are the main advantages of simulators, but, if carried to the ultimate, it would no longer be simulation but an actual reproduction of the real-life situation.

In considering simulation fidelity it is useful to distinguish between physical fidelity, that is, the degree of similarity between the physical features of the system being simulated, and psychological fidelity, which can be regarded as the extent to which the human behaviour involved in the simulation is the same as that which would be involved in the real-life situation. Whilst similarity of physical characteristics is not likely to detract from psychological fidelity, it does not actually ensure that human behaviour in the simulator will be similar to that under operational conditions. On the other hand, it is possible for a reasonable degree of psychological fidelity to be achieved even though the degree of physical fidelity is very limited. Unfortunately, the conditions under which psychological fidelity can be obtained without physical fidelity cannot readily be specified.

In the absence of such information there is a tendency to design simulators incorporating a very high degree of physical fidelity on the assumption that this will result in an acceptable level of psychological fidelity. This approach is particularly in evidence in the United States' aerospace industry, where vast amounts of money, time and effort have been expended on building extremely complex high-fidelity simulators. Westbrook (1961) has pointed out some of the dangers of the increasing trend towards complex simulation. In particular, he warns against simulation carried out without due thought to the problem at hand, and the tendency to look on a simulator facility as a goal in itself rather than as a means of solving problems.

It is difficult to see how this trend towards complex simulation can be avoided until more is known about the conditions under which psychological fidelity can be achieved with lesser degrees of physical fidelity, particularly in relation to complex systems. Also relevant to the consideration of simulation fidelity is the question of 'face validity'. However satisfactory the level of psychological fidelity in a simulator, a low degree of physical fidelity does not inspire confidence either in the subjects who use it, or, perhaps more importantly, the management personnel responsible for funding the program.

For this reason the face validity of the simulator in the form of a reasonable degree of physical similarity to the real-world system may be of considerable importance. Fogel (1963), pointing out that support for a particular program may depend on the emotional belief of administrative personnel, suggests that 'it may well prove worthwhile to include certain specific details in the simulator which offer readily interpretable read-out, colour or sound response to particular inputs, and generally obey the rules of showmanship and public relations' in order to gain acceptance for a simulator program.

The assessment of simulator fidelity must be related to the use for which the simulator is intended, in particular, whether it is primarily for training purposes or for system evaluation and research. In simulators intended for training purposes the main concern is the degree of transfer of training from the simulator to the real-life equipment. Degree of transfer is frequently accepted as a direct measure of simulator effectiveness without introducing the question of fidelity, (see, for example, Hammerton, 1967; McCormick, 1964; Osgood, 1949). However, this pragmatic approach is not entirely satisfactory, particularly as it cannot be applied to systems which are not yet operational, and other approaches to fidelity assessment such as the analytical and subjective evaluation techniques described by Mudd (1968) must also be considered.

In the case of simulators intended for research and development purposes the primary question in considering simulation fidelity is the extent to which the performance data obtained are representative of those which would be obtained under real-life conditions. Providing the simulator experiment is carefully designed and executed very reliable information can be obtained about what the simulator shows but, unless careful validation against operational data is carried out, there is no guarantee that the same information would be obtained from the real-world.

The limitations of data obtained solely from simulation experiments can be illustrated by considering the type of information which might be required in evaluating, for instance, two different displays. Whereas questions of the type 'How does performance with the two displays compare?' can be answered by simulation experiments, questions such as 'What is the operational performance with the two displays?' cannot be resolved in this way.

The first question requires only relative performance data, whereas the second requires an absolute answer which depends on many variables that cannot be simulated, and whose effects and interactions are unknown. Testing under real-world conditions is essential if a valid answer is to be obtained to questions of the second type, although if a definite relationship can be established between the simulator data and those obtained from the real-world then it is possible to extend the real-world data by further simulator studies.

The foregoing discussion has been concerned with general aspects of simulation which are relevant to industrial and military situations, in addition to aerospace applications. Against this background, the discussion can now be focused more specifically on flight simulation and, in particular, on the simulation of high-speed, low-level flight, which is the primary concern of this chapter.

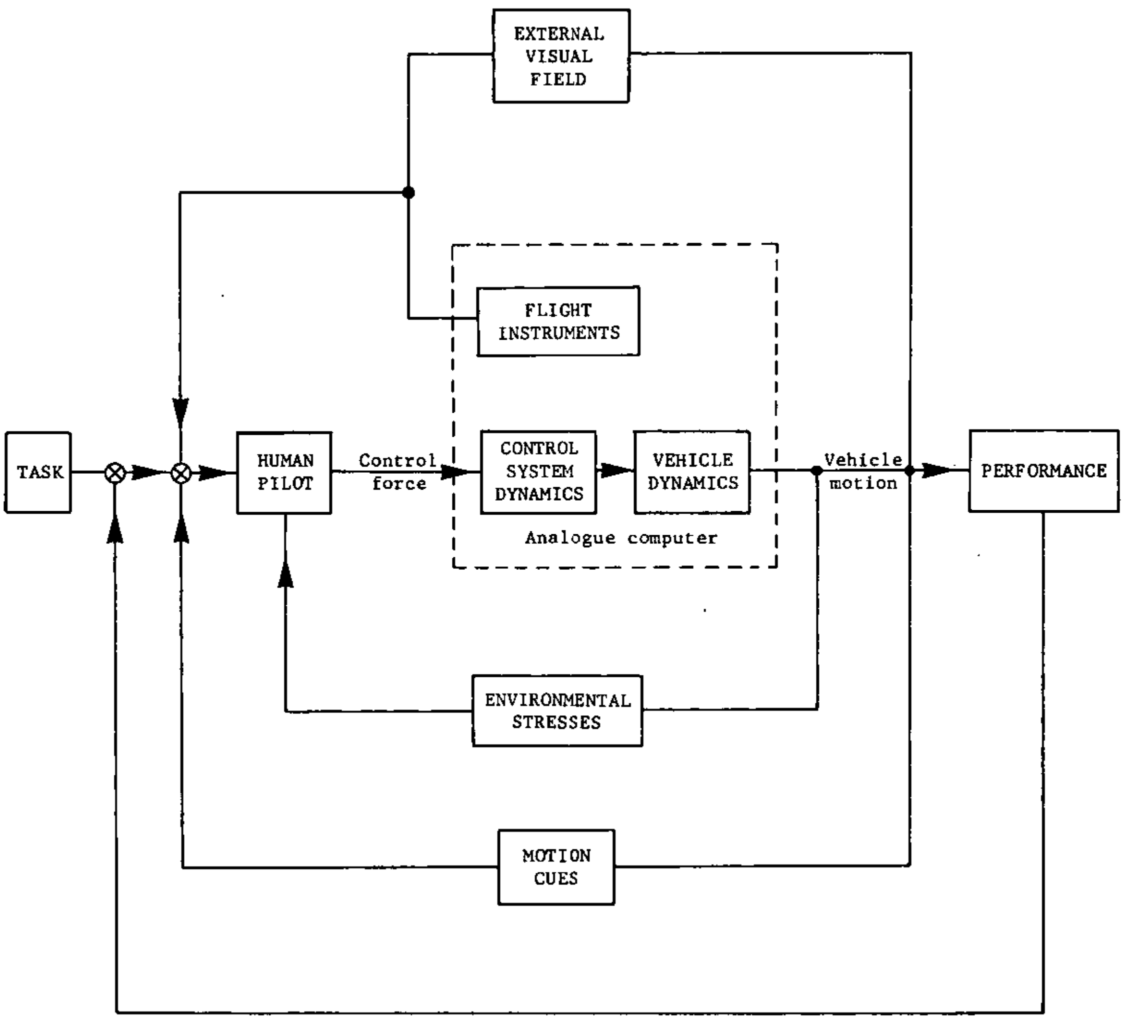
In military aviation, piloted flight-simulators are used for an increasingly wide range of research including the assessment of handling qualities, display and control problems, the effects of environmental stress, navigation and terrain-following performance, target acquisition and weapon-delivery procedures. The current state-of-the-art is such that it is possible to accurately simulate almost all aspects of an operational mission, including realistic visual and motion cues, but partial simulation techniques can be used to study more limited aspects of overall performance.

Whilst closed-loop simulators differ considerably in individual design and construction they are basically similar in principle, consisting of an aircraft cockpit in which the controls and displays are activated by means of analogue computers programmed in such a way that when the pilot makes a control input the cockpit systems respond in the same way as they would under genuine flight conditions. In addition, cockpit motion and/or visual simulation of the outside world may be incorporated. The block diagram given in Figure 3.1 shows the basic elements of a full-mission simulator.

In studying some aspects of overall mission performance it may not be necessary to include in the simulation all the elements shown in Figure 3.1, provided that elements relevant to the tasks under consideration are included (Fraser, 1966; Mudd, 1968). The problem is to determine which are the relevant elements or, at least, which are the elements which do not affect performance and may therefore be omitted. In some cases this may be obvious. For instance, in studying pilot performance under instrument flight conditions no external visual display is required. In other cases it may be possible to determine experimentally which elements of

FIGURE 3.1

Block diagram of a piloted flight simulator.



Source: Belsley (1963)

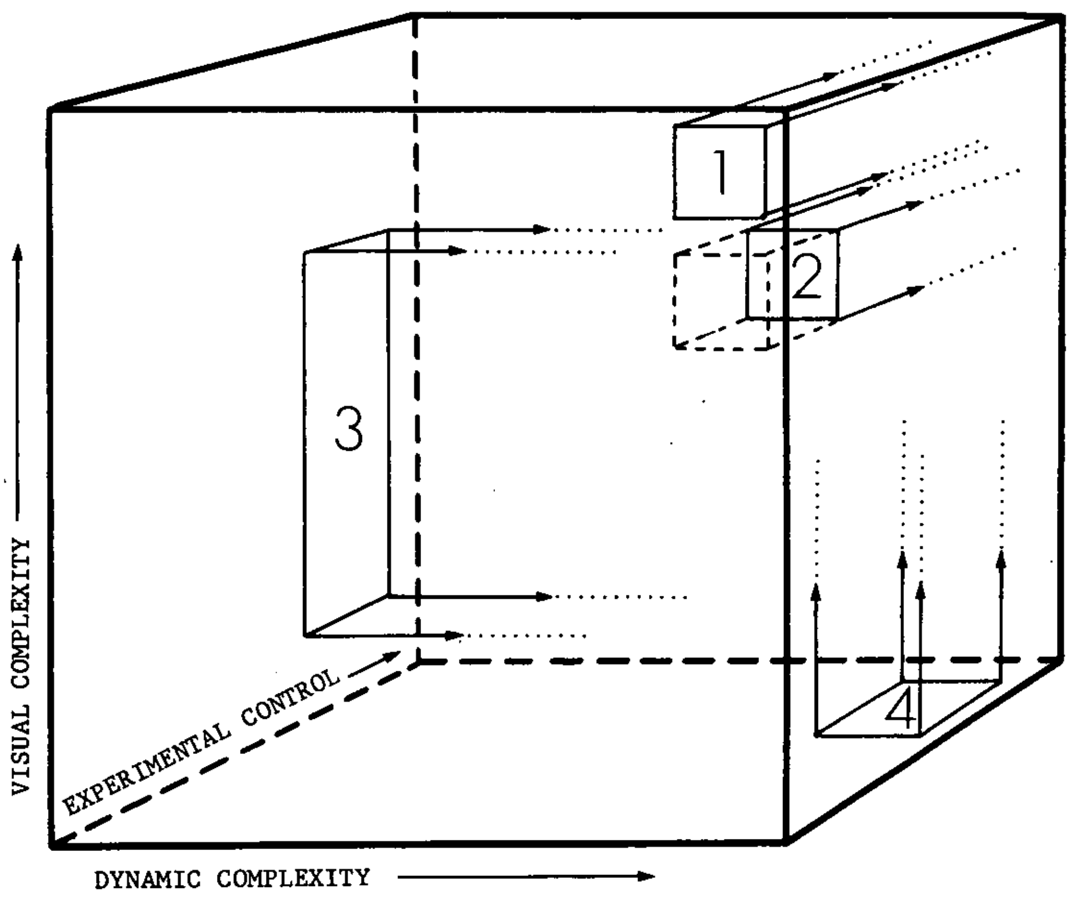
the simulation can be omitted. For example, some aspects of handling performance can be adequately studied using fixed-base simulators, or simulators with limited motion, which do not provide realistic motion cues (Sadoff and Harper, 1962). However, marked discrepancies between visual and motion cues, when both are providing important information to the pilot, must be avoided since conflict between these cues can prove extremely confusing.

Although visual navigation and target acquisition can be most realistically studied under full-mission simulation conditions, these tasks are essentially visual ones and high-fidelity simulation of the visual environment is the major requirement. Providing this is achieved, full closed-loop simulation of other aspects of the flight situation is of lesser importance and, indeed, many aspects of visual navigation and target acquisition performance can be studied with little or no cockpit simulation. The discussion which follows is therefore primarily concerned with techniques for the visual simulation of the terrain during high-speed, low-level flight.

The problem of obtaining reliable target acquisition data under conditions which incorporate the dynamic and visual characteristics of the real-world, as seen during high-speed, low-level flight, has been illustrated by Greening (1964) in the form of a qualitative three-dimensional diagram as shown in Figure 3.2. Two axes of the diagram represent the fidelity of the experimental situation in terms of the visual and dynamic complexity of the environment, and the third axis represents the degree of experimental control. Visual complexity refers to the intricate patterns of colours, tones, textures and shapes which make up the appearance of the terrain as seen from the air. These

FIGURE 3.2

Schematic representation of dynamic, low-altitude vision research



1 - FLIGHT TRIALS

2 - TERRAIN SIMULATION

3 - STATIC EXPERIMENTS

4 - DYNAMIC EXPERIMENTS

Source: Greening (1964)

patterns are further complicated by perspective effects which become more marked as altitude decreases.

Dynamic complexity refers to the changing appearance of the terrain due to the movement of the aircraft over it. Changes in perspective, in masking effects, and in the apparent size of objects as the aircraft approaches them are examples of dynamic effects. The third axis in Figure 3.2 represents experimental control, that is, the extent to which the factors under investigation can be systematically varied, whilst other significant factors are maintained constant.

Ideally, target acquisition research is aiming at the far top right-hand corner of this diagram, i.e. realistic visual and dynamic complexity combined with a high degree of experimental control. In practice this is virtually impossible, but the different techniques used in target acquisition research approach this ideal situation in different ways. Flight trials, as discussed in the previous section, achieve maximum visual and dynamic realism but are relatively low on experimental control. High-fidelity simulation techniques are less realistic in terms of the visual and dynamic characteristics of the outside world but are much more amenable to experimental control.

Two different types of laboratory experiment, which can also be regarded as methods of simulation, albeit very limited ones, are also represented in Figure 3.2. Static experiments allow a high degree of visual complexity to be associated with a high degree of experimental control, while no attempt is made to represent the dynamic characteristics of the real-life situation.

Conversely, dynamic experiments accurately represent some of the dynamic aspects of the target acquisition task under conditions in which good experimental control is possible, while greatly simplifying the visual complexity of the task. The main problem with the somewhat piecemeal approach to target acquisition research represented by these different techniques is the difficulty of relating data obtained by one technique to those obtained from other techniques.

For the purposes of this discussion it is convenient to divide simulation techniques into three categories, high-fidelity terrain simulation, static display experiments and dynamic display experiments. A discussion of the advantages and disadvantages of these techniques, together with examples of their use, is given in the following sections.

3.2.1 High-fidelity terrain simulation

Visual navigation and target acquisition tasks are usually carried out by direct observation of the terrain from the aircraft. For the simulation of these tasks the main requirement is the provision of a visual display which reproduces as accurately as possible the appearance of the terrain as seen from the cockpit during high-speed, low-level flight. Alternatively, as in the case of a television-guided missile, target acquisition can be carried out by means of a sensor system that relays to the aircraft a view of the terrain in the immediate vicinity of the missile, which may be some distance remote from the aircraft.

For this type of task the simulation requirement is for a televised view of the terrain.

In either case it is necessary to provide a source of terrain imagery and a means of transmitting it to the cockpit, but the display requirements for the two types of simulation differ in certain important respects. For direct-view simulation the requirement is for a wide-angle, full-colour and high-quality display outside the cockpit, whereas the simulation of television viewing conditions requires a small in-cockpit display of a relatively narrow field of view (rarely above 30° horizontal), usually in black and white only, and of a quality comparable to that of a live TV transmission. These different requirements have significant implications in terms of the simulation techniques by means of which they can best be achieved.

Two fundamentally different techniques are in common use for high-fidelity terrain simulation. The first utilizes projected cine-film imagery obtained by filming the real world from a low-flying aircraft, whereas the second depends on the use of a terrain model over which a TV camera is 'flown' relaying an appropriate view of the terrain to the cockpit. Alternatively, the terrain model may be viewed directly. Each of these techniques has certain advantages and disadvantages, which are considered in detail in the following sections, and choice between them depends on the nature of research to be carried out, and the amount of time and resources available.

3.2.1.1 Cine-film simulation techniques

If a direct-view target acquisition task is to be simulated the primary requirement is accurate and realistic visual simulation of the terrain over as wide a field of view as possible. This can best be achieved by direct projection of wide-angle cine-film imagery, which is the method chosen by most of the research workers concerned with the study of factors affecting direct-view target acquisition performance, (see, for instance, Gilmour, 1964; Gilmour et al, 1968; McGrath and Borden, 1964; Snyder and Calhoun, 1965).

The main advantage of using cine-film imagery is that it enables not only major terrain features, such as woodland, towns, lakes, railways and mountains, to be accurately simulated but also much more subtle effects such as textures, contrast, illumination and shadows, masking and seasonal changes. These factors can, as discussed in Chapter 2, markedly affect target acquisition performance and it is clearly important that they should be realistically represented. A further advantage is that cine-film simulation facilities tend to be less complex and less expensive to set up than terrain-model systems. In particular, cine-film simulation does not necessarily involve the use of computer facilities, and usually requires less space than terrain-model simulation.

Since the cine-film is, in effect, a visual record of the appearance of the terrain during an actual flight, visual and dynamic realism are ensured providing that adequate colour rendering and image resolution can be achieved. For maximum realism the field of view should be comparable to that actually seen from the aircraft under operating conditions. Methods for determining the ground area visible from different types of aircraft with particular reference to visual reconnaissance, have been described by Kennedy (1968). However, even if this field of view approaches 180°, it may be that values less than this can be used for simulation purposes without affecting acquisition performance.

Evidence quoted by Aronson (1963) suggests that a field of view of 60° gives full cockpit vision performance but the task studied in this case did not involve navigation or target acquisition. The field-of-view requirements for the simulation of direct-view target acquisition tasks do not appear to have been determined, but it is feasible to obtain by means of cine-film a high-resolution colour display extending over 160° horizontally and 60° vertically as in the Boeing multi-mission simulator (Zaitzeff, 1969). However, the substantial expense involved has led most research workers to compromise with rather smaller fields of view.

The advantages of the high degree of visual realism obtainable from directly-projected cine-film imagery are associated with a number of disadvantages which severely limit the applications of this technique. The most serious of these is that altitude and track of the simulated flight are effectively fixed by the conditions under which the film was taken. Thus the pilot is not able to make control inputs affecting these variables, although appropriate flight information can be provided by activating the cockpit displays to correspond with the film imagery, or, in a more limited way, by pre-flight briefing.

If suitable instrumentation is available it is possible for the pilot to directly control the speed of the simulated flight by adjusting the speed of film projection but in many cases no provision is made for this, the projection speed being set at a fixed value by the experimenter for the entire run. Even if variation is possible it is restricted to a certain range of adjustment determined by a minimum speed at which the display begins to flicker, and a maximum speed at which manoeuvres carried out during the simulated flight, for instance, turns, appears to be unrealistically rapid and severe because the projection speed is several times as fast as the original exposure speed.

Since the pilot cannot make inputs to altitude or track and can only make limited adjustments, if any, to speed, he effectively observes rather than controls the simulated flight. As a result of this limitation, only partial simulation of the pilot's task can be achieved, since full-mission simulation must necessarily include provision for the pilot to directly control the simulated flight, which is only possible with closed-loop simulation techniques. In this respect it can be argued that, in terms of workload, the subject's task in a cine-film simulation experiment more closely resembles that of the navigator in a two-crew aircraft than that of the pilot. As pointed out by Sadoff and Harper (1962) provision of a realistic workload is an important aspect of simulation and cine-film techniques, particularly if used with no cockpit simulation, may not adequately represent the workload under genuine flight conditions.

The use of cine-film simulation techniques allows very accurate measurements to be made of acquisition range since the film frame count can be recorded at the moment the subject makes a response indicating that he has acquired the target. This frame count can be converted into a range value from knowledge of the distance moved by the aircraft per frame and the total length of the run. The frame count can be recorded either by an observer or by photography, the camera being activated by the subject's response key.

Similarly, whether or not the target has been correctly acquired can be determined either directly by the experimenter or by photographing the display, and subsequent analysis of the film record. In either case the subject must have some method of indicating the position of the target and this can conveniently take the form of a cursor light. Alternatively, if the display is close to the subject, a small pointer may suffice. In some cases, when the target can be unambiguously described, a verbal description is adequate to indicate whether it has been correctly acquired.

A simulator used by McGrath and Borden (1964) in a series of studies intended to investigate geographic orientation and the use of visual checkpoints during high-speed, low-level flight provides an example of the application of cine-film simulation techniques. The imagery consisted of four 16 m.m. cine-films showing the forward visual field of an aircraft flying at 200 ft. over tracks of approximately 150-200 n.m.

During the initial stages of the research program all the cockpit instruments were inactive, but for the later experiments the airspeed, heading and altitude indicators were activated to correspond to the visual imagery, with a resulting increase in realism. No control inputs could be made by the pilot except small adjustments to the simulated aircraft speed. The pilot's basic task was to navigate visually along the routes marking his track on a strip map and indicating his exact position along this track when required.

Studies carried out using this simulator included the evaluation of pilot navigation performance in relation to the scale, content and colour of maps, and an extensive analysis of the use of visual checkpoints in geographic orientation. For these studies maximum fidelity of visual cues was essential, and the limitations of cine-film simulation techniques had to be accepted. In this case, in addition to the inevitable impossibility of the pilot controlling altitude or track, further limitations were imposed by the 16 m.m. film format, which limited image resolution, and by the relatively narrow field of view, which reduced visual realism. The fixed-base cockpit precluded the introduction of any motion cues but this was not thought to be a serious limitation for the purposes of this study.

The problems caused by the limited resolution and the narrow field of view were overcome in a very much more complex simulator, also developed in the United States, for use in the Joint Task Force Two research program. Three simulators were constructed, one of which is shown in Figures 3.3 and 3.4, to use the 70 mm. colour cine-film imagery collected during the JTF2 program, which gave excellent resolution over a field of view extending

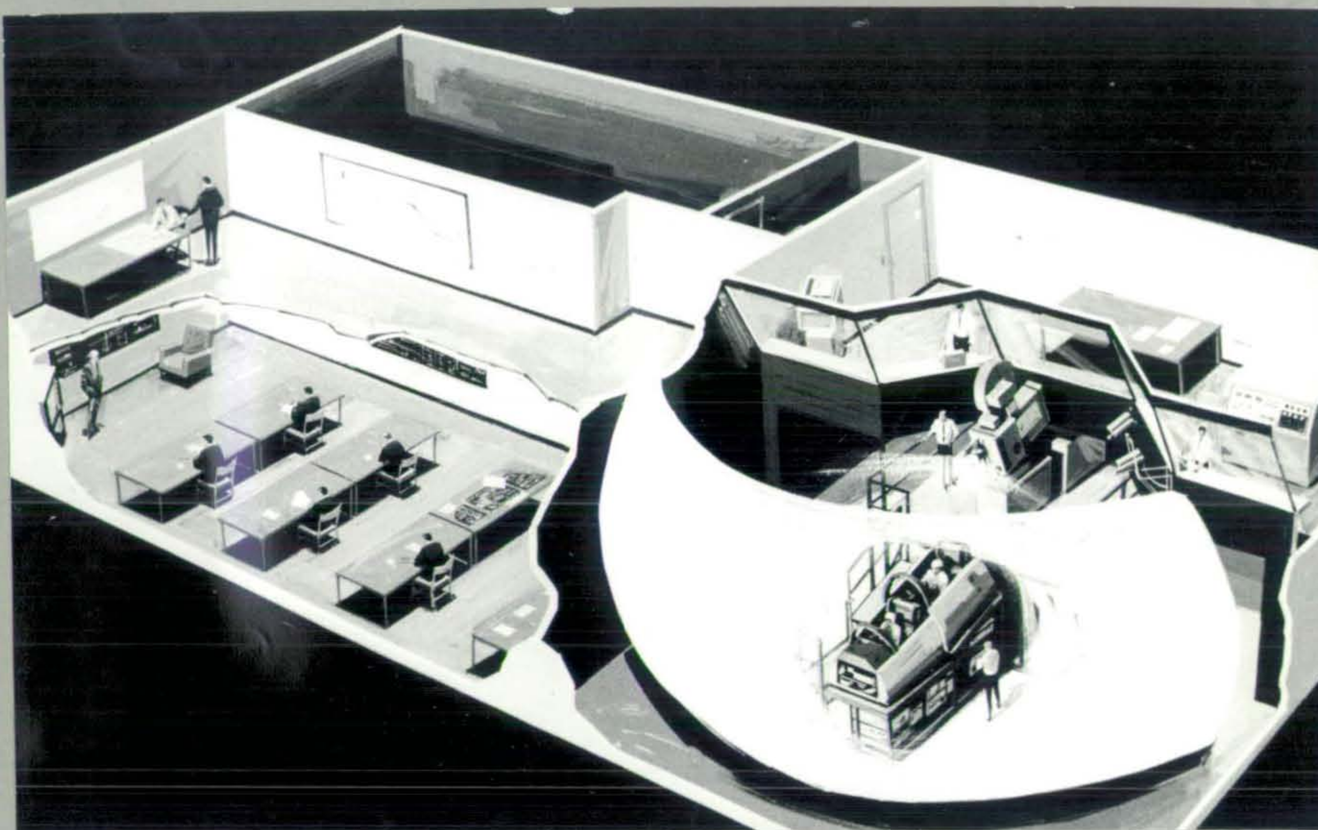


FIGURE 3.3
Artist's impression of the simulation facility at The Boeing Company, Seattle.

FIGURE 3.4
The Boeing multi-mission simulator showing the cockpit, the projection system, and part of the visual display.

for 160^{o} in front of the cockpit. In this simulator, which can be used to simulate either Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) conditions, the cockpit is fully activated and equipped for a number of different types of studies including VFR target acquisition, the evaluation of sensor displays, terrain-following and ground attack.

Under visual flight conditions the flight path of the simulator is determined by an autonavigation system in conjunction with pre-set checkpoints along the test course. In the instrument flight mode the pilot can control his own flight path within a 25-mile wide corridor. This simulator is computer-driven and represents perhaps the most sophisticated application of cine-film simulation techniques currently in operation. The simulation technique has been extensively validated against flight trial data with encouraging results, as described in Section 3.3.

Whilst this discussion has so far been concerned with only the simulation of direct-view target acquisition tasks, cine-film techniques can be used equally successfully to meet the rather different requirements for the simulation of televisual target acquisition tasks. In this case, as noted previously, a black-and-white in-cockpit display showing only a relatively narrow field of view is needed to represent the terrain view transmitted by a television-guided missile. Suitable imagery is usually obtained by direct filming of the real-world at an altitude and speed appropriate to that of the missile concerned, but it can also be derived from wide-angle colour imagery used for direct-view simulation.

The Royal Aircraft Establishment film library described by Fielding (1969) is an example of imagery primarily intended for the study of televisual target acquisition performance in relation to a particular missile system, in this case the Anglo-French Martel. This film library has been used by a number of research workers for studying various aspects of target acquisition performance including the effects of speed (Mardon, 1969a) repeated viewing of the route (Mardon and Milnes-Walker, 1969); restricted field of view (Michael, 1970); different types of briefing materials (Parkes and Rennocks, 1971a); and choice of navigational fixpoints (Parkes and Rennocks, 1971b).

The use of cine-film techniques in simulating television displays is subject to exactly the same limitations as discussed previously in relation to direct-view simulation, in particular, using normal projection techniques it is not possible to achieve closed-loop simulation. For this reason cine-film is used primarily to study visual aspects of televisual target acquisition, often with little or no cockpit simulation, whereas terrain model systems are used when guidance and control problems are involved.

Whilst cine-film is not normally used as a source of terrain imagery for closed-loop simulation experiments, it is possible to use it for this purpose. As noted previously this cannot be done by normal projection techniques, but only by means of a complex system which moves the projected image to correspond to the pilot's control inputs. A system of this type was used to provide a visual display for a weapon-aiming simulator at the

Royal Aircraft Establishment (Whybray and Manville, 1969).

Apparent forward flight of the simulator was provided by successive frames of the cine-film in the conventional manner. Movement in the horizontal and vertical planes, simulating yaw and pitch respectively, was obtained by movement of the projection lens in a plane parallel to the film frame. Roll was simulated by rotating a suitable mirror assembly in front of the lens. Movement of the projection lens and rotation of the mirror were servoed to the cockpit controls so that the visual display corresponded to the pilot's control movements.

To accommodate a 30° field of view at the cockpit, the field of view of the cine-film had to be not less than 60°, to allow for pitch and yaw freedon of ±15°. In fact 35 m.m. cine-film was used giving a field of view of 63° x 90°. In the roll plane the rotating mirror gave ±90° of movement. As with other cine-film simulation techniques no variation in altitude could be obtained, although speed variation was possible through control of projector speed.

This system enabled changes in pitch and yaw angle to be accurately portrayed, but deviations from the real flight path resulted in some anomalies in perspective, although these were only evident when the deviation was greater than 10°. Thus, within a relatively limited flight envelope, this simulator provided a realistic visual display by reference to which the pilot could manually fly the attack phase of a low-level mission.

Although it provides a much lesser degree of navigational freedom than terrain-model systems, this type of simulator has a number of advantages. In particular, the amount and accuracy of detail in the visual scene is not limited by TV resolution and the quality of the modelling as in the case of terrain-model equipment. The cine-film equipment also requires less space and is less expensive to install and maintain. Furthermore, a variety of targets and terrains can be readily obtained, and are more easily stored than models.

3.2.1.2. Terrain-model simulation techniques

The limitations on the pilot's freedom to choose track and altitude imposed by film imagery simulation techniques make them unsuitable for simulating tasks which require the pilot to make control inputs to these variables, thus affecting the dynamic visual environment and, conversely, to receive information from the environment which influences these control decisions. This type of closed-loop simulation usually necessitates the use of some form of terrain model.

Although in some cases visual simulation is achieved by the observer viewing the terrain model directly, more usually a televised view of the terrain model is relayed to the cockpit. The basic principle behind the use of this technique to provide a visual representation of the outside world in the simulation of high-speed, low-level flight is that the cockpit controls are linked, through analogue computers, to a television camera moving over a three-dimensional terrain model. Each control input made by the pilot not only activates the cockpit instruments but is relayed to the television head, which transmits the appropriate visual display back to the cockpit.

Providing that the television sensor is mounted on a transport system allowing full movement in six degrees-of-freedom, a visual display corresponding to any manoeuvre made by the pilot can be obtained. Alternatively, one degree of translational movement may be provided by movement of the terrain model itself with respect to the sensor head. Appropriate motion cues, also synchronised with the pilot's control movements, can be simulated by the use of a moving-base cockpit but this adds greatly to the expense of the system.

The fidelity of the visual imagery obtained by means of terrain-model simulation techniques is limited by a number of factors, the most important of which are the resolution obtainable, the field of view, the apparent distance of the terrain scene, and the scale of the terrain model. The current state-of-the-art is such that an adequately realistic, external visual display can be obtained for simulating tasks such as terrain-following, which require only generalised reference to terrain cues, but the visual fidelity is not sufficient for the simulation of direct-view target acquisition tasks, particularly if small targets are involved.

However, for the simulation of television guided-missile displays the limitations of terrain model imagery are less important. Since only an in-cockpit television view of the terrain is required, the apparent distance of the terrain scene is not relevant, and field-of-view limitations cause no problems since in the case of a television guided missile the field of view rarely exceeds 30° horizontal. The main requirement is for a black-and-white television display of a quality comparable to that which would be obtained under operational conditions. Since the detail discernible under television viewing conditions is substantially less than that discernible directly, differences between terrain scenes originating from the real-world and those originating from terrain models are minimised.

Thus the application of terrain-model techniques in the study of target acquisition problems can be considered primarily in relation to the simulation of television displays rather than direct-viewing conditions. As compared with cine-film techniques, which can also be used to simulate TV displays, the use of terrain models has a number of advantages. Full-mission, closed-loop simulation allowing the pilot to directly control the path of the simulated missile is the most important of these but there are others.

The use of a model to provide the source of terrain imagery, rather than the real-world, allows much greater experimental control to be exerted over the nature of the terrain studied, in terms of factors such as vegetation, mountains and position of conspicuous terrain features. Similar control can be exerted over the nature and position of targets. In particular, the use of a suitably designed terrain model, which allows normally fixed targets such as bridges or buildings, to be moved from one position to another, enables target and background effects to be evaluated independently whereas this is not possible by any other technique. Alternatively, the model can be designed to exactly duplicate a particular area of terrain so that performance under simulator and real-world conditions can be directly compared.

The realism with which the dynamic complexity of the real-world can be simulated by means of a terrain-model system depends on the television head exactly simulating, in response to control inputs, the movement characteristics of the missile over the terrain. On the other hand, the fidelity with which visual complexity can be achieved depends on the nature of the terrain model itself, and on the quality of the television transmission.

The main factor that affects the degree of realism that can be obtained from a terrain model is the scale of the model. The smaller the scale the greater is the area of terrain that can be simulated in a given space. Whilst this leads to greater navigational freedom and reduces the possibility of pilots becoming over-familiar with the terrain, it also makes the problem of achieving realistic representation of detail, which is of great importance in target acquisition tasks, much more difficult. For instance, at a scale of 3000:1, a vehicle 30 ft. long in the real world would measure only 0.12 inches, which obviously does not allow scope for any detailed modelling. For this reason scales smaller than 2000:1 are not satisfactory for target acquisition studies, and scales such as 1200:1 or even 600:1, depending on the size of the targets to be studied, are preferable.

However, the advantages of a large scale in terms of the better modelling obtainable must be considered in relation to the increased space and the increased cost required to simulate a given area of terrain. A compromise in the form of the combined use of models of two different scales is sometimes possible, for example, 3000:1 for the navigation part of the task and 600:1 for the final stage of the route, during which the target acquisition task is carried out.

The second factor influencing the fidelity of the visual display is the quality of the television transmission. The nature of the optical system, particularly the size of the entrance pupil, the depth of field obtainable and the optical resolution are important factors determining display quality. However, as Kaestner (1967) has pointed out in a discussion of optical systems for visual simulation, even with a relatively wide field of view, optical resolution comparable with the television state-of-the-art can be obtained. Thus television resolution is likely to be the critical factor. This is a major limitation in relation to direct-view simulation, particularly as a wide field of view is also required, but the limitation is less critical in the simulation of television-guided missile displays. In this latter case, the requirement is for resolution comparable to the maximum likely to be achieved under operational conditions.

Although a very-high-resolution, 2000 scan-line television system capable of approximately 5 minutes of arc resolution over a $60^{\circ} \times 60^{\circ}$ field of view has recently been reported (Lockwood and Noble, 1970), visual simulation equipment currently in operation rarely exceeds 1029 TV scan lines and the display resolution achieved is inevitably much less than that obtainable from cine-film simulation techniques. The colour fidelity of television displays is also much poorer than that of cine-film imagery. However, in the simulation of TV-guided missile displays colour is not normally required, although it is clearly of importance in relation to direct-view terrain simulation.

The simulation facilities at the North American Rockwell Corporation, Columbus, Ohio provide a good example of the design and use of closed-loop terrain model simulation equipment. This equipment includes:

a) A six degree-of-freedom sensor transport which moves over a 3000:1 scale terrain model, representing an area of approximately 25 x 47 miles and including mountainous, hilly and flat terrain. The sensor transport and part of the model are shown in Figure 3.5. A section of this model exactly duplicates a standard Air Force test route thus allowing comparisons to be made between simulated and real-world conditions.

b) A variety of interchangeable terrains up to 12ft. x 36ft. in size with scales ranging from 1200:1 to 400:1, together with associated sensor transport systems.

c) A four degree-of-freedom moving-base cockpit with fully-activated controls and displays. This is shown in Figure 3.6. A large rear-projection screen is mounted in front of the cockpit and movement of the projected display synchronised to that of the cockpit.

d) Black/white and colour television monitor displays, and black/white television projection facilities.

e) Analogue/digital computing facilities.

One particular advantage resulting from having more than one terrain model and associated TV equipment is that it is possible to simultaneously provide two different displays, one representing the outside world viewed directly from the aircraft and the other providing an in-cockpit monitor scene such as might be relayed from a TV guided missile. This allows a very close approximation

FIGURE 3.5
Sensor system and part of 3000:1 scale terrain model at North American Aviation.

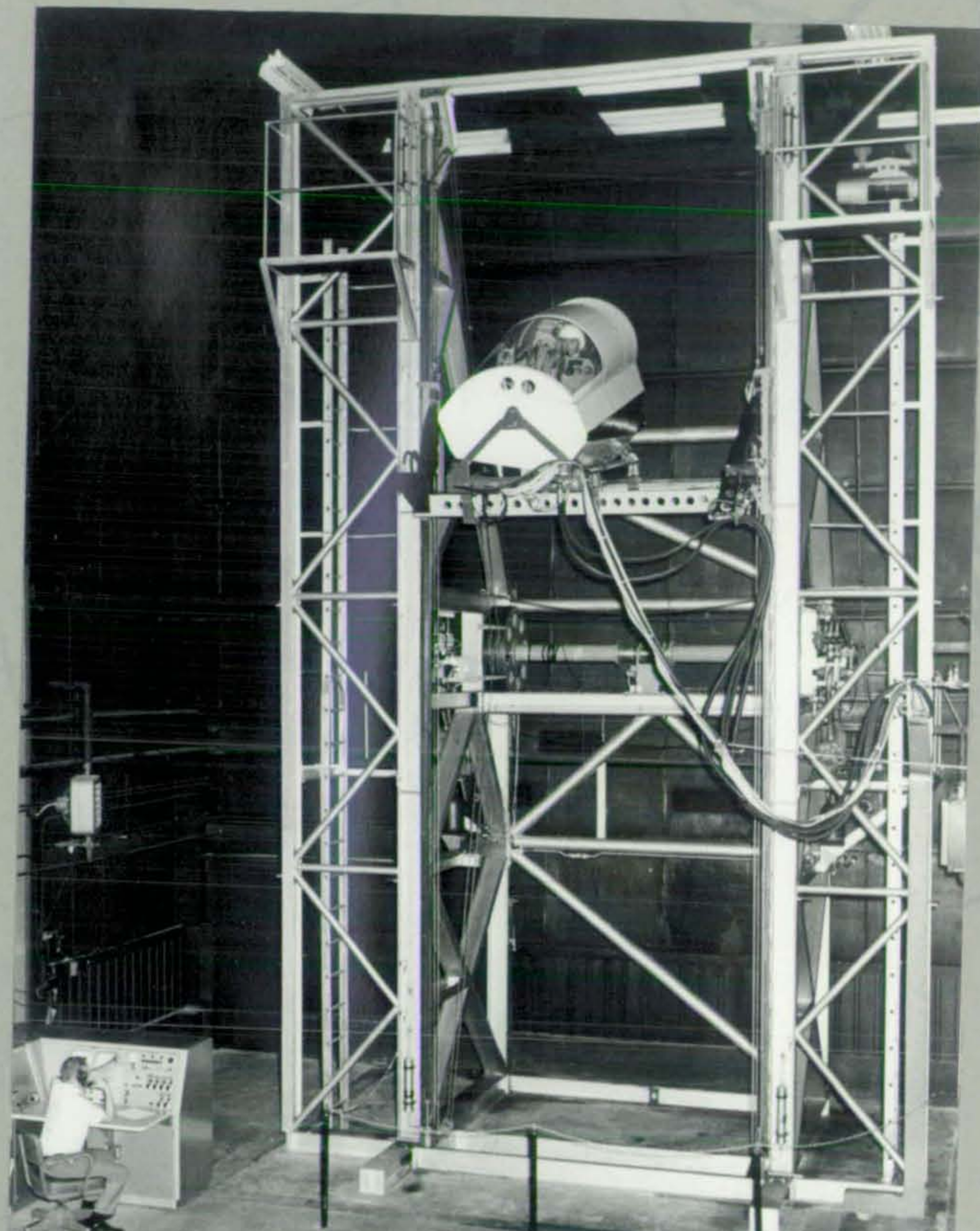


FIGURE 3.6
Six degree-of-freedom moving-base cockpit at North American Aviation.

to the task of launching and guiding a TV missile during high-speed, low-level flight to be achieved.

These facilities have been used for studies of missile guidance and control, and research into problems of televisual target acquisition. The equipment is also particularly suitable for studies of terrain-following performance, the evaluation of head-up displays, the effect of task loading and fatigue, and work relating to the design of displays and controls for high-speed, low-level flight, and has been extensively used for these purposes, as described by Schohan et al (1965); Soliday and Schohan (1965); Soliday and Milligan (1968).

Sophisticated terrain-model simulation facilities are also available at the Martin Marietta Corporation, Orlando, Florida. A particular feature of these facilities is that they include provision for the observer to view the terrain model directly as an alternative to a television viewing system. When used indoors the model is illuminated by artificial lighting, but it can also be moved outside the building so that studies can be carried out under natural lighting conditions. The model, measuring 40 ft. x 40 ft., represents 20 sq. miles of terrain, at a scale of 600:1 which allows very realistic modelling. The terrain simulated includes a wide variety of topographic features such as mountains, rivers, lakes, built-up areas, desert and farm land.

In this system the sensor head (and/or the observation platform when the direct-view mode is used) is mounted on a beam which moves vertically and laterally with respect to the terrain model. The third degree of translational motion is provided by longitudinal movement of the model towards the beam, while the gimballed sensor head is capable of three degrees of rotational movement. Motion in all six degrees-of-freedom may be pre-programmed, or controlled from the simulated cockpit giving closed-loop simulation.

Recent work carried out using these facilities, which are shown in Figure 3.7 - 3.9, has included the evaluation of angular subtense and contrast relationships for detection and recognition tasks under both television-viewing and direct-viewing conditions (Bergert and Fowler, 1970; Jones and Bergert, 1970); a comparison of two-dimensional and three-dimensional targets, and a study of the effects of changes in gamma, the TV brightness transfer characteristic (Fowler et al, 1971).

As an alternative to a rigid terrain model the use of a flexible terrain belt mounted on rollers is sometimes preferred. In a system of this type translational motion along one axis is provided by movement of the belt, the remaining five degrees-of-freedom being provided by movement of the television head. Terrain belts, which are usually mounted vertically, have the advantage of requiring less space than terrain models and, since they are continuous, they allow greater freedom of navigation than a corresponding area of rigid model.

One disadvantage of terrain belts, as compared with rigid models, is the difficulty of achieving adequate three-dimensional modelling of mountainous terrain since the belt must remain flexible enough to move easily over the rollers. A further drawback is the tendency of the belts to deteriorate, particularly by cracking, when not in use.

FIGURE 3.7
Sensor system and observation platform moving over the 600:1 scale terrain model at the Martin Marietta Corporation.

(a) Natural lighting

(b) Artificial lighting

FIGURE 3.8
The terrain model at the Martin Marietta Corporation seen under two different lighting conditions

FIGURE 3.9
Oblique view of terrain model showing realistic three-dimensional modelling.

The simulation facilities at the British Aircraft Corporation, Warton, shown in Figures 3.10 - 3.12, provide a typical example of the use of terrain belts. Interchangeable belts of scales 1:1000, 1:3000 and 1:10,000 are available to meet different requirements. The 1:10,000 scale belt allows terrain up to 2000 ft. high to be simulated whilst still maintaining adequate flexibility. To simulate a direct view of the terrain the picture relayed from the terrain belt by the TV camera is presented on a 14" monitor screen directly in front of the cockpit. This is viewed through a collimating lens system so that the terrain appears to be an infinite distance ahead of the pilot. The quality of this display is not adequate for studying direct-view target acquisition performance, but there is also provision for a small in-cockpit monitor to simulate TV displays, and for video-tape recordings to be made so that particular routes can be viewed more than once.

3.2.1.3 Other terrain simulation techniques

Whilst the two simulation techniques already considered, cine-film simulation and terrain-model simulation, are most frequently used in the study of target acquisition, a further technique which has been used for the simulation of television-guided missile displays should also be mentioned. This technique combines the use of television with photographic imagery to provide a closed-loop simulation in which cine-film or, in some case, still photographs are used instead of a terrain model.

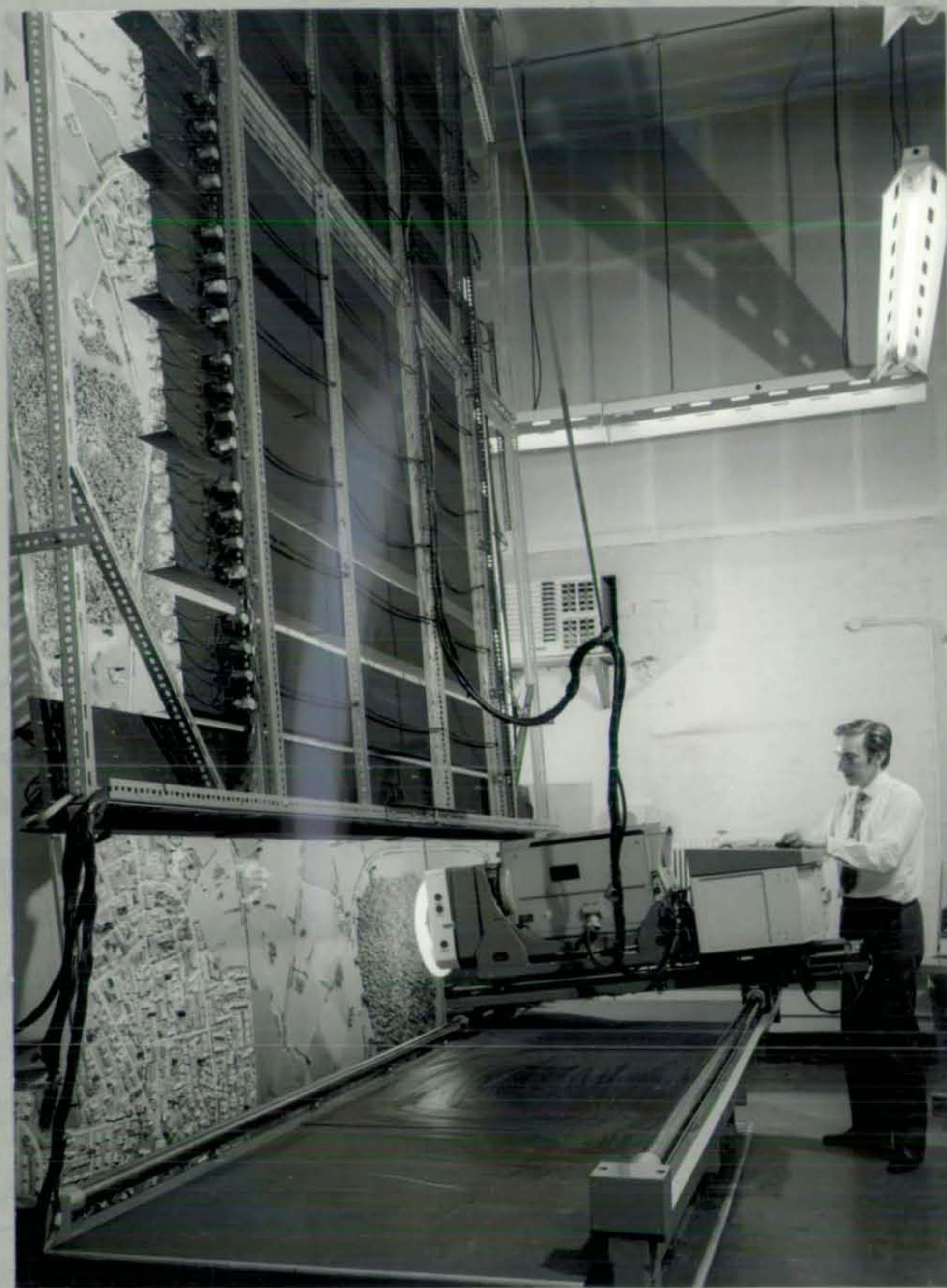


FIGURE 3.10
1000:1 scale terrain belt and television system at the British Aircraft Corporation, Warton.

FIGURE 3.11
Oblique view of the terrain belt shown in Figure 3.10.

FIGURE 3.12
Cockpit simulator with
television display at the
British Aircraft Corporation.

Although this technique can give rise to a visual display which appears realistic over a narrow field of view, it should be noted that the use of two-dimensional photographic imagery rather than three-dimensional models, inevitably results in inaccurate representation of perspective and masking effects. These effects are correct only for the exact angle of view from which the original photograph or cine-film was taken, the extent of the distortion depending on how far removed the simulated angle of view is from the original angle of view.

A simulator described by Lopresti and Dunmire (1963) illustrates how this technique can be used in the mid-course simulation of a television-guided missile. The source of the visual display was wide-angle cine-film, which was projected in front of a television camera with a field of view approximately one-tenth that of the film. The camera could move laterally and vertically, thus scanning the entire film-frame, the motion being commanded by the operator by means of a control stick. Apart from slight perspective distortion, the view seen on the television display closely simulated what the operator would see when operating a television camera in a missile.

As an alternative to cine-film, a photographic transparency can be used as the source of a visual display for missile simulation. In this case, movement over the terrain is simulated by relative motion between the transparency and the sensor. The photograph may be a continuous vertical or oblique strip covering an extended area of terrain at a constant angle of view; or, if only a limited area of terrain is required, a single photograph may suffice.

The Martel simulator, in which the visual display is derived from an oblique strip transparency, is one example of a system of this type. Movement over the terrain is simulated by relative motion between the transparency and the sensor, and the required angle of view is generated electronically by appropriate distortion of the image. This system, which allows closed-loop simulation of both mid-course and terminal-phase operation, provides an adequately realistic visual display for training purposes and for some aspects of research, but the visual realism is limited by two factors. Firstly, perspective and masking effects are noticeably distorted at low altitudes; and, secondly, the resolution of the display deteriorates markedly during the terminal-phase simulation, in contrast to the real-life situation in which the target becomes more clearly defined as range decreases.

If only terminal-phase simulation is required, single photographs showing a relatively limited area of terrain can be used instead of continuous strips. For instance, Hledik (1963) used oblique photographs mounted on a carridge with one degree of translational motion, viewed by a television camera on a three-axis rotational mount. This system also resulted in some perspective distortion, in this case due to the limited degrees of freedom as well as the two-dimensional imagery. Vertical photographs can be used to simulate vertical closure of a missile towards a ground target (see, for instance, Kearney and Holliday, 1963) without the drawback of perspective distortion, but any other simulated angle of view is subject to some distortion.

It can be seen from these examples that the use of photographs as the source of visual displays in closed-loop missile simulation, while having the advantages of being less complex and consequently less expensive than terrain model systems, suffers from several drawbacks which limit the application of the technique. In particular, terrain models allow greater flexibility and better representation of perspective effects than can be achieved by means of photographs.

3.2.1.4 Summary and comparison of high-fidelity simulation techniques

As discussed in this chapter, the two most commonly used techniques for the simulation of the visual environment as seen from the cockpit during high-speed, low-level flight are the direct projection of cine-film and the use of terrain models (or belts) viewed by servo-controlled television systems. Choice between these systems depends primarily on the nature of the research to be carried out, although space and cost must also be considered.

Ideally, a system is required which will allow full closed-loop simulation together with a wide-angle, high-quality visual display to represent the outside world. The current state-of-the-art is such that the navigational freedom associated with closed-loop simulation can only be achieved at the expense of visual realism and, conversely, high-fidelity simulation of the visual environment as seen directly from the cockpit can only be obtained if navigational freedom is sacrificed by the use of pre-programmed visual imagery.

Therefore, in simulating direct-view target acquisition tasks, a compromise has to be made. For studying visual problems this usually takes the form of relinquishing navigational freedom in favour of realistic representation of essential visual cues, obtainable by cine-film techniques. However, in the study of tasks which require the pilot to control aircraft altitude and track, terrain-model techniques must be used in spite of the comparatively poor quality of the visual display and the limitations on the field of view. Neither of these approaches allows all the relevant aspects of the overall task to be completely realistically represented, but the only way of overcoming the limitations imposed by these techniques is to resort to flight trials, which are themselves subject to a number of limitations, as discussed in Section 3.1.

The study of televisual target acquisition tasks allows greater freedom in the choice of a simulation method since, in addition to cine-film and terrain-model techniques, both of which can provide an adequately realistic visual display, other methods in which the display is derived indirectly from photographic imagery are also suitable. If the primary requirement is accurate visual simulation, then the use of black and white cine-film is usually the most convenient and simplest method, but if guidance and control problems are to be studied closed-loop simulation is essential. In this case, while terrain model systems are capable of providing greater flexiblity and realism, the use of displays derived from photographic imagery, as described in the previous section, can furnish an acceptable alternative (and one that is both cheaper and requires less space) providing that precise representation of perspective and masking effects is not essential.

3.2.2. Static display experiments

For the purposes of this discussion static display experiments can be regarded as those in which the subject views a display that, whatever its visual complexity, does not change with time. In these experiments no attempt is made to represent the dynamic complexity of the real-world as seen from a low-flying aircraft. Thus the data obtained are not realistic in terms of the operational target acquisition task. However, the simplification of the situation allows experiments to be carried out using much less complex experimental techniques than if both dynamic and visual realism are simulated. Furthermore, it enables a greater degree of experimental control to be exerted over the experimental situation.

The nature of the visual imagery used in static experiments ranges from aerial photographs, which provide a highly realistic representation of the real-world, to abstract symbols against unstructured backgrounds, which bear little or no obvious resemblance to the visual scene in air-to-ground target acquisition tasks. The use of aerial photographs can be regarded as a limited simulation of real-time air-to-ground target acquisition tasks, especially those carried out by means of television.

Static terrain displays are particularly appropriate for investigations into the effectiveness of 'frozen' television displays, that is, displays which, instead of changing continuously, change in a series of discrete steps, remaining static for several seconds between each step. Indeed, sequences of aerial photographs can be used as a realistic simulation of the visual aspects of a target acquisition task carried out under these particular conditions.

Data obtained from experiments using simplified abstract displays are not directly relevant to air-to-ground target acquisition problems although they can contribute to an understanding of the basic processes involved. Numerous experiments have been carried out into the visual detection and recognition of targets in static abstract displays. Most of these experiments are not specifically concerned with military applications but are fundamental studies of processes such as perception, visual search, pattern recognition and eye-movements. A detailed review of this work is outside the scope of this discussion, the purpose of which is simply to outline some of the static techniques that have been used to study visual problems, particularly those with direct relevance to air-to-ground target acquisition, and to indicate their advantages and limitations for this purpose.

The use of static terrain scenes as visual imagery for target acquisition experiments allows the effects of certain parameters, for instance, display size, viewing distance, resolution, camera field of view, target size and contrast, to be evaluated more rapidly and at less cost than with realistic dynamic displays. Owing to the lack of dynamic realism, the results must be interpreted cautiously but they provide a basis for initial assessment of the importance of a particular factor. Whilst the data obtained cannot be related to real-world conditions in absolute terms, they may enable relative evaluations to be made.

Thus, although it is not possible to predict from static experiments what levels of performance will be achieved under certain real-world conditions, it is possible to estimate the extent to which a deterioration or improvement in performance is likely to result from a particular change in the factors under investigation, but any such predictions should obviously be validated under more realistic conditions.

A number of different techniques have been used to obtain realistic static displays. The simplest method is the direct use of aerial photographs, either vertical or oblique, depending on the nature of the simulated task. Use of this technique has been reported by Thomas et al (1959) in a study of visual search techniques in air-to-ground recognition. The series of experiments carried out by the present author using oblique aerial photographs is reported in the Appendices to this thesis and the use of this experimental technique is more fully considered in Chapter 4. One of the photographs used in shown in Figure 3.13(a)

A variation of this technique involving the use of closed-circuit TV is reported by Leininger et al (1963). They used vertical photographs viewed by a TV camera, which allowed various different fields of view to be displayed to the observer, to study orientation performance during the simulated terminal phase of a TV guided missile. A similar method was used by Kause (1965) in a study of the effect of visual noise on televisual target acquisition performance.

(a) One of a series of oblique aerial photographs of terrain in Southern England used by the present author

(b) A display originating from a 90:1 scale model representing terrain in South-East Asia. (U. S. Naval Weapons Center).

FIGURE 3.13
Two types of static terrain imagery used to simulate television displays in target acquisition research.

As an alternative to aerial photographs some workers have used terrain models, viewed either directly or by means of closed-circuit TV, to study certain aspects of target acquisition performance. For instance, Gordon and Lee (1959) used a model to study the effect of illuminant position on the detection and identification of objects in a battle field and a similar technique was used by Hamilton (1958) to investigate factors affecting the detection and identification of military vehicles. Johnston (1968) studied target recognition as a function of horizontal resolution and shades of grey by means of a static TV display originating from a small terrain model. Part of a terrain model used as a source of static terrain scenes is shown in Figure 3.13(b).

Whilst the greater simplicity and lower cost of static terrain simulation as compared with the high-fidelity dynamic techniques considered earlier in this section must be regarded as one of their main advantages, there are other advantages worth noting. In particular, the use of a static display removes many of the variables which greatly complicate the interpretation of data obtained from dynamic experiments. For instance, in a static display target/background contrast and apparent target size and shape remain constant, whereas in a dynamic display these factors are likely to be continuously varying. Furthermore, a static display can simplify the interpretation of eye-movement records, thus enabling studies of scanning patterns and the use of prominent features as target cues to be more readily carried out.

One important difference in the nature of the performance data obtained from static and dynamic terrain displays should be noted. In dynamic experiments the measures typically recorded are the probability and range of target acquisition. In the case of static displays the range is fixed by the range at which the photograph was taken and the performance measures made are usually acquisition probability and search time, or alternatively the performance levels achieved within a certain time limit can be determined. The latter method is probably more appropriate for simulating a real-time task such as target acquisition during high-speed, low-level flight, whereas the former method, in which search time is regarded as a performance measure, is more suitable for studies of the interpretation of photo-reconnaissance imagery.

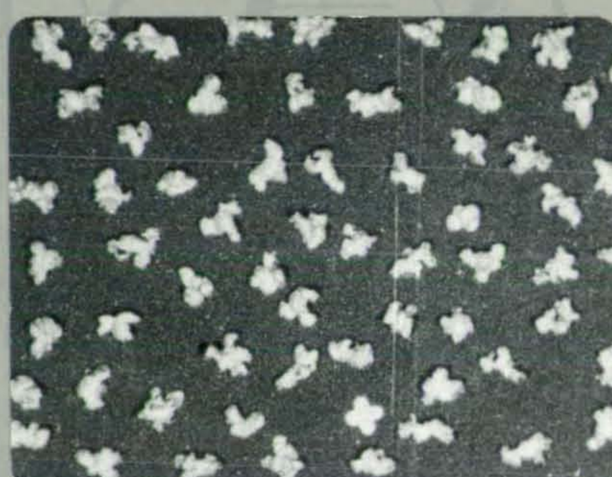
Whilst a static terrain scene presents a much less complicated experimental situation than a dynamic one, any form of terrain imagery is essentially a complex visual display in which it is virtually impossible to quantify or control target and background complexity. Little or no systematic control can be exerted over the tones and textures of the background; the nature, quantity and distribution of prominent terrain features; their similarity to the target; or their usefulness as cues to target position.

An attempt to simplify this situation was made in a series of experiments carried out at the Mapping and Charting Research Laboratory, Ohio State University (Enoch, 1959; Richman, Enoch and Fry, 1958; Townsend, Fry and Enoch, 1958). The imagery used for these studies was a set of aerial maps which contained only areas of white, black, and five shades of grey with the critical detail inserted in approximately equally weighted zones. The maps, one of which is illustrated in Figure 3.14, were equated for comparable contrast and content.

The target in these experiments was a Landolt 'C' placed on an area of uniform density. The use of an abstract target allowed size and contrast to be accurately controlled, and restricting the background to seven shades greatly reduced its complexity, while maintaining a good simulation of aerial photography. As Enoch (1959) points out this imagery represents an intermediate stage between the widely-used simple target arrays and the complex, largely uncontrolled type of display found in aerial photographs.

Although the displays used in these experiments closely simulated the appearance of aerial photographs, the nature of the visual task involved differed in certain important respects. In particular, the symbolic target used by Enoch and his colleagues bore no relationship to the background scene, in the way that a real-world target is related to the terrain around it both by briefing information and by certain obvious constraints, such as the fact that vehicles tend to be found on or near roads. Thus the task studied by Enoch was essentially one of visual search in which the background offered no cues to target position, but the target, once detected, could be readily recognised. This had important implications in that it allowed unskilled subjects to be used in the experiments with only a minimum of training, but it also made the task somewhat unrealistic in relation to real-world target acquisition tasks.

(a) One of a series of simplified aerial maps used as backgrounds for Landolt C targets (Enoch, 1959)

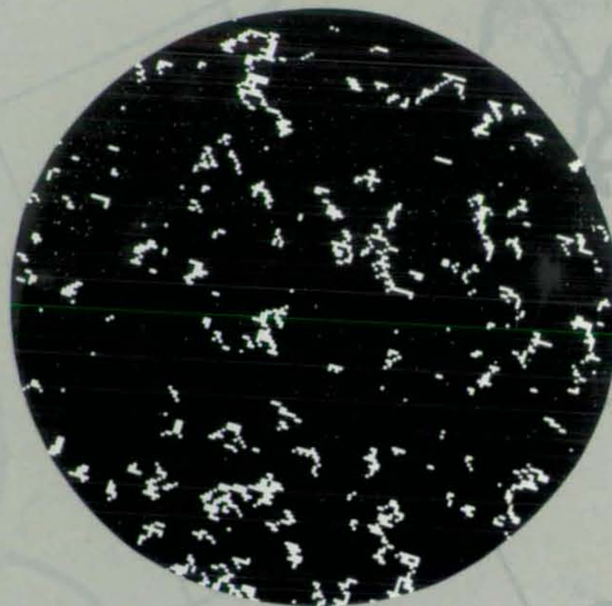


(b) A rounded-cross target against a background of non-target objects on a TV display. (Erickson, 1966).

FIGURE 3.14
Complex structured displays used as backgrounds to abstract targets in visual search experiments.

Other attempts to simplify background characteristics without going to entirely symbolic displays have been made by Erickson (1966) and by Hilborn and Conklin (1964). In these experiments no attempt was made to simulate a terrain scene. In each case the photographs used had a structured background showing randomly-arranged kernels of pop-corn. In Erickson's experiment, the purpose of which was to study the effect of visual noise on search performance, a symbolic target, (a rounded cross) was used, whereas in Hilborn and Conklin's study of eye dominance the subjects were required to locate a single kernel missing from one of a pair of stereo photographs.

Complex displays of a purely symbolic nature have been used by Baker, Morris and Steedman (1960) to determine how the speed and accuracy of form recognition depended on the amount of distortion between the reference form used for briefing purposes and the target form, and the number of non-targets displayed on the search area. The displays, one of which is shown in Figure 3.15(a), were generated from a 90,000 cell matrix, cells of which were filled in according to certain rules giving a display with 557 discrete forms. Search performance in displays of randomly-arranged, complex forms has also been studied by Boynton and Bush (1956, 1957), while a number of workers have used displays consisting of either random or ordered arrays of relatively simple forms, such as squares, circles or triangles, in which the target differed in either size, shape or contrast from the background array, (Brody, Corbin and Volkmann, 1960; Eriksen, 1954; Smith, 1964).



(a) Display of the type used by Baker, Morris and Steedman (1960) for studies of target recognition

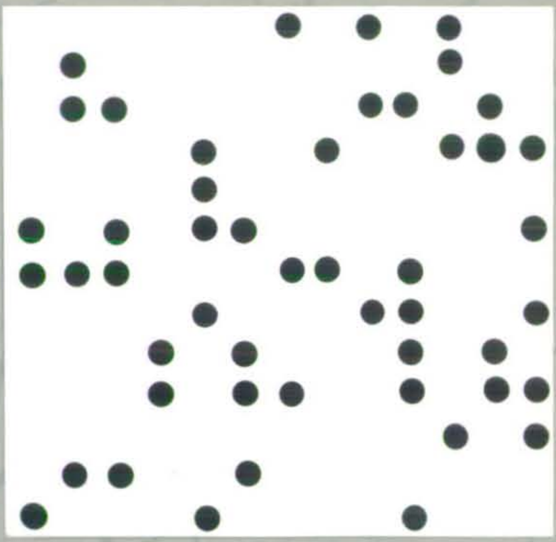
FIGURE 3.15
Two examples of displays of complex abstract forms.

(b) A complex background of 'struniforms' used in experiments by Boynton and Bush (1956, 1957)

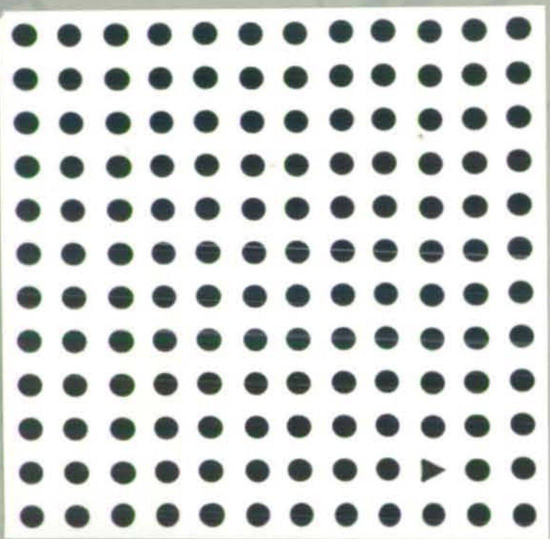
More recently, experiments of this type have been carried out by Bloomfield (1970), who has also reviewed other work in this area. One of the irregular arrays used by Bloomfield, and a regular array of the type used by Brody, Corbin and Volkmann, are shown in Figure 3.16.

In experiments of this type, target size and shape, target/background contrast, number of non-target forms, similarity of target and non-target forms and image quality can all be precisely and systematically varied, thus permitting a high degree of experimental control. However, in spite of the fact that these displays are vastly simpler than aerial photographs, it is still not easy to define quantitatively the target and background characteristics in such a way as to enable mathematical models of search performance to be formulated, although this has been attempted with some degree of success by Bloomfield and Howarth (1969).

As a result of this difficulty in interpreting the results obtained from displays containing a number of forms, many workers have chosen to study detection performance under both search and no-search conditions using very simple displays consisting of a single target against a homogeneous unstructured background. These highly abstract displays have been extensively used by Blackwell and his colleagues in a series of carefully-controlled and well-designed experiments. Factors such as target size and shape, target/background contrast, and target and background luminance have been exhaustively studied (see, for instance, Blackwell, 1946; Blackwell and Kristofferson, 1958; Blackwell and Smith, 1959; Kincaid, Blackwell and Kristofferson, 1958).



(a) An irregular array in which the target differs in size from the background forms (Bloomfield, 1970).



(b) A regular array in which the target differs in shape from the background forms (Brody et al, 1960).

FIGURE 3.16
Two examples of displays of simple forms used in visual search experiments.

The results obtained from these studies are elegant and provide useful information about the basic capabilities of the human eye, for instance, size and contrast thresholds, but since the nature of the experimental task is so different from that in air-to-ground target acquisition, the data must be regarded as of largely academic importance. The advantage of these highly simplified displays, which have also been used by other workers including Brown and Carl (1958); Corbin et al (1956); Krendel and Wodinsky (1960); Over (1963) and Vos, Lazet, and Bouman, (1956), is that the stimulus and background characteristics can be defined quantitatively to allow mathematical interpretation of the data.

It is clear from this brief review of the types of imagery used in static display experiments, some of which are shown in Figures 3.13 - 3.16,* that, as the degree to which experimental control can be exerted over the test situation increases, so the nature of the visual display becomes progressively further removed from the real world. At present, the experimenter has a choice between experimental precision without realism in the use of simple, abstract displays, and experimental realism without precision in using complex displays such as aerial photographs. Clearly the eventual aim must be to find some means of controlling and quantifying complex displays but very much more research will be required for this to be achieved.

* *It should be noted that Figures 3.13 - 3.16 represent only the type of imagery, and not necessarily the size or quality of the original display materials.*

3.2.3. Dynamic display experiments

The use of static displays, as discussed in the previous section, enables detailed investigations to be carried out into some of the processes involved in air-to-ground target acquisition, while making no attempt to represent the dynamic aspects of the task. An alternative approach is to study the dynamic effects, that is, effects due to relative motion between the target and the observer, while reducing visual complexity to a minimum by the use of simple displays. Whilst this approach has been less extensively adopted than the use of static displays, it has nevertheless provided useful information about some of the capabilities and limitations of the human visual system of relevance to airborne target acquisition tasks.

In carrying out air-to-ground target acquisition under high-speed, low-level conditions the observer must search a rapidly changing visual scene, and discriminate details in objects whose angular velocities increase rapidly as they move through his field of view. Thus laboratory experiments of particular relevance to the dynamic aspects of air-to-ground acquisition tasks are those concerned with dynamic visual acuity, and those intended to study more general problems of search in moving displays.

Dynamic visual acuity is affected by a number of factors including the angular velocity of the test object, the time available for viewing, the direction of the relative motion, and the illumination and contrast of the target. Experimental techniques which have been employed in the study of these factors have normally used very simple targets, such as Landolt C's, and in most reported work (for instance, Elkin, 1962; Foley, 1957; Ludvigh, 1949; Rose, 1952) the relative motion between target and observer has been brought about by moving the target rather than the observer. In experiments of this type, which have been reviewed by Miller and Ludvigh (1962), the target motion, whether vertical, horizontal or circular, has been in a plane such that the distance between the target and the observer's eyes remained constant.

Whilst there is some variation between the results of different studies according to the experimental conditions used, the general finding is that visual acuity decreases with increasing angular velocity. However, there is evidence that this deterioration can be reduced if exposure time is increased, particularly if both head and eye-movements can be used to follow the target (Crawford, 1960a), or if the subject has adequate time to track the target position before exposure (Elkin, 1962). Typical values indicate that for angular velocities in the range of 20 - 50^{o} per second visual acuity is approximately 2 minutes of arc, but at higher angular velocities the ability of the eye to track the target becomes impaired and a progressive deterioration in performance occurs, until at angular rates of 140^{o} acuity is approximately 10 minutes of arc.

In air-to-ground target acquisition the apparent movement of the target has a vector directly towards the observer, this vector being a maximum when the aircraft approaches the target head-on and decreasing as the extent to which the target is off-set from the flight path increases. To obtain data more directly applicable to this situation Snyder and Greening (1965) studied the effect of angular velocity on dynamic visual acuity in a situation in which the stimulus motion included a component towards the observer. The results of this experiment showed a deterioration in acuity thresholds with increase in angular velocity, in general agreement with those found by other workers. The rate of approach of the stimulus directly towards the observer had little effect on acuity threshold between zero and 3.0 ft/sec, but the threshold was slightly higher for the 4.5 ft/sec. rate.

In general, the results of the dynamic visual acuity experiments suggest that the discimination of target detail during high-speed, low-level acquisition tasks may be facilitated if the target is approached along an off-set track, thus increasing exposure time and decreasing the maximum angular velocity developed by the target for a given speed and altitude, and that the provision of pre-designation information, which allows the observer to track the expected target position, may reduce the adverse effects of high angular velocities. Other practical applications of dynamic visual acuity data in air-to-ground target acquisition have been discussed by Crawford (1960b) and Erickson (1965).

The need to search for the target in a continuously-changing visual scene is another important factor which must be taken into account when considering dynamic aspects of air-to-ground target acquisition. Problems of visual search in dynamic displays have been studied in a number of laboratory experiments. In some cases the detection of a single moving target against a homogeneous background has been studied, as for instance, by Miller and Ludvigh (1960), but of greater relevance to air-to-ground target acquisition are experiments concerned with search in moving displays containing target and non-target objects. Although these tasks are visually much simpler than air-to-ground acquisition tasks, they do represent some of the dynamic aspects of such tasks.

For instance, Williams and Borow (1963) used type-written capital letters, one of which was the target letter, in a display which moved at rates of up to 30^{o} per second in either a vertical or horizontal direction. The results of this experiment showed that display speeds faster than approximately 8^{o} per second angular velocity were associated with decrements in performance, and that horizontally moving displays resulted in shorter search times than vertically moving displays.

Rather slower rates of movement, from 0^{o} per second (static search) to 10^{o} per second, were used by Erickson (1964a) in a study of visual search performance in a vertically moving structured field. The targets were Landolt C's against a background of randomly positioned closed rings. The number of non-target rings ranged from 16 to 48 to each target ring. For the dynamic search experiments the display was mounted on a 150 ft. long belt which passed behind a window through which the subject viewed the moving display. From a comparison of the number of targets detected in the moving displays with those detected in equivalent times in static displays, Erickson concluded that, for the velocities studied in this experiment, motion, in itself, had no effect on search performance.

A similar experiment to compare static and dynamic presentation modes was carried out by Simon (1965) but in this case a more complex display, consisting of specially prepared film strips of high-resolution radar imagery in which a number of targets were embedded, was used. Thus the task was one of recognising simple well-defined patterns against a structured background. The results showed no differences in the number of targets found in the static and dynamic displays but targets were located more rapidly in the dynamic displays.

The use of simple dynamic displays in the study of factors affecting target acquisition can be regarded as complementary to the static experiments described in the previous section. In general, these dynamic techniques are of more limited application than the use of static displays since many dynamic aspects of air-to-ground target acquisition, for instance, changes in perspective and masking effects, can only be studied by means of more realistic simulation techniques. However, simple displays such as those described in this section have the advantage of allowing a greater degree of experimental control to be exerted over the dynamic aspects of the task, and do not necessitate the used of such complex equipment as realistic terrain-simulation techniques. For this reason they can be of value in contributing to the understanding of some of the processes involved in air-to-ground target acquisition.

3.3 COMPARISON OF FIELD AND SIMULATOR DATA

The proportion of simulation experiments in which any attempt has been made to validate the data against operational data obtained from flight trials is extremely small. Whilst there are undoubtedly many difficulties to be overcome in carrying out a validation study of this type, unless this is done simulation data can, at best, only provide relative information about performance under different conditions and even this may not be reliable. Since solutions to operational problems usually require absolute rather than relative data, it is extremely unwise to make major decisions solely on the basis of simulator data.

The most frequently cited experiment in which simulator data have been compared with flight trial data is that carried out by Blackwell, Ohmart and Harcum (1958). It is notable not only because it was the first study of its kind, but also because it illustrates the enormous discrepancies that can occur between simulator data and those obtained from flight trials. For the simulator trials a terrain model was constructed which accurately reproduced, at a scale of 600:1, the topography and detail of the ground area, approximately 1 n.m. square, chosen for the flight trial. The target, a line of three vehicles accurately scaled down, could be positioned where required on this terrain model in such a way that the line was either parallel of perpendicular to the simulated flight path.

The remaining equipment consisted of a 5000 watt incandescent lamp which could be positioned as required to simulate the sun, and an observation platform which could be mounted at several heights, simulating different altitudes, above a dolly which travelled along the track. Four altitudes (2000, 4000 5700 and 7500 ft.) were tested, recognition probabilities and slant ranges being obtained for several different sun positions. In all, 840 passes were made by the nine pilots who took part in the simulator experiment.

Flight trials were conducted against real targets located in the 1 n.m. square area which was reproduced by the terrain model. As in the simulator experiments the target could be located in any one of ten different positions within this area and the same nine pilots took part in the experiment. In these trials a total of 109 flight passes were made.

Comparisons between the field data and the simulator data showed large discrepancies. For instance, averaged over all passes the mean recognition probability from the simulator experiment was 0.89, whereas under field conditions it was 0.60. Corresponding slant recognition range values were 15,895 ft. and 11,006 ft. respectively. In each case the simulator data were significantly better than the field test data.

Blackwell, Ohmart and Harcum suggest a number of possible reasons for the lower performance under field conditions, including the additional work-load resulting from routine piloting tasks; vibration and turbulence of the aircraft; and the optical imperfections and distortions of the windscreen. The pilots themselves commented particularly on the cockpit configuration which made forward viewing impractical and thus field observations had to be made from the side to a point nearly forward.

This study has been reviewed at some length as it illustrates some of the problems of validating simulation experiments by field trials. In addition it is one of very few studies in which any attempt has been made to compare simulator and field data under reasonably well-controlled experimental conditions. In an experiment reported by Hamilton (1958) comparative data for field and simulator studies are also given but in this case the variables were not adequately controlled. However, it is interesting to note that this second study resulted in longer acquisition ranges under field conditions, the opposite result to that found by Blackwell, Ohmart and Harcum.

A similar result is reported by Snyder and Calhoun (1965) in a comparison of recognition ranges determined in the laboratory from cine-film simulation with those for the same targets determined during flight trials. In this case very large discrepancies were found. In the flight trials individual targets were recognised at ranges varying from twice as great to almost twelve times as great as in the simulation trials. Again, it seems likely that inadequate experimental control and/or different response criteria under the two conditions must have contributed to these results.

More recently, experiments have been carried out at R.A.E., Farnborough to compare televisual target acquisition probabilities and ranges, recorded during flight trials, with those determined from laboratory simulation. Cine-film imagery, obtained at the same time as the in-flight performance data were recorded, was used to simulate the television display in the laboratory. In general, good agreement was found between the in-flight televisual acquisition probabilities and ranges and the corresponding simulation data. For instance, overall mean acquisition probabilities were 0.90 for in-flight measurements and 0.87 for laboratory simulation. (Fielding, 1971).

In the United States, the most recent and most extensive comparison between field and simulator data was that carried out to validate the multi-mission simulator developed for use in the Joint Task Force Two program. The main purpose of this study, which has been reported by Gilmour et al (1968), was to evaluate the extent to which the simulator could be used as a valid means of predicting the effects of certain important target acquisition variables under field conditions. Additional objectives were to investigate the effects of speed and altitude under simulation conditions, and to derive functional performance relationships useful in a mathematical model of visual target acquisition.

The JTF-2 simulator, which incorporated a fully-activated cockpit, utilised 70 mm. colour cine-film imagery giving a horizontal field of view of 160°, which provided an extremely realistic representation of the test routes used in the field trials. In the simulator study three speeds, 190, 360 and 550 knots, and three altitudes, 200, 400 and 600 ft., were tested, together with the supersonic speed of 764 knots at an altitude of 400 ft., giving a total of ten conditions. Sixteen military pilots were assigned to each of these conditions and all mission briefings exactly duplicated the relevant parts of the field test briefings.

The comparison of field and simulator data was based on the performance measures (range and probability of acquisition) obtained for the eight targets, four along each of two test routes, common to both trials. Functional performance relationships derived from the field test and simulator data were compared to evaluate the capability of the simulation technique to predict speed, altitude and target effects found in the field tests. The main points derived from this comparison were as follows:

(i) In terms of acquisition probability for individual targets a product-moment correlation of 0.86 between the field and simulator data was obtained indicating that the simulator data were able to predict about 76% of the field test variation in acquisition probability. Corresponding values for acquisition range were 0.78 and 61%. When a weighted performance measure combining both acquisition probability and acquisition range was used the product-moment correlation coefficient was 0.96. This allowed prediction of a very high proportion (92%) of the observed variation.

(ii) Acquisition ranges as determined from the simulation experiments were consistently lower, in absolute values, than those obtained under direct-view field test conditions, a disparity which tended to increase with increase in acquisition range. This result suggests that increases acquisition ranges under simulator conditions would tend to underestimate the performance improvement likely to occur under field conditions.

(iii) When absolute acquisition range differences between field and simulator data were removed by a simple mathematical transformation, comparisons of simulator and field test performance relationships for the speed and altitude conditions studied showed a high level of correspondence.

In general, the results of this study indicated that the simulator technique was a valid means of obtaining empirical target acquisition data for the systematic evaluation of speed, altitude and target effects. Although the technique did not exactly duplicate in-flight direct-viewing conditions (and thus there were differences in absolute performance levels), when appropriate transformations were used to take account of viewing differences, the two methods were in close agreement on the effects of critical variables. Indeed, the closeness of this agreement can be regarded as an indication of the enormous progress made in the simulation of the visual environment during high-speed, low-level flight since the early work described at the beginning of this section.

3.4 CONCLUSION

It is clear from the review presented in this chapter that the techniques available for the study of air-to-ground target acquisition performance vary widely in the extent to which they accurately represent the visual and dynamic complexity of the real-world task; in the degree to which the experimental situation can be precisely controlled; and in complexity and cost. Each of the four main techniques, flight trials, terrain simulation and static and dynamic laboratory experiments, has particular advantages and disadvantages which must be closely considered when selecting a method for the study of a particular problem.

As discussed in Section 3.1, the use of operational data, whilst representing the maximum possible realism, can only yield reliable information if the trials are carefully planned and conducted so as to ensure adequate experimental control. Even if this is done, the variability of such data is inevitably large, as compared with data obtained under conditions in which more rigorous experimental control is possible. For instance, Gilmour et al (1968) report that the variability of flight trial data was approximately three times as great as that of the corresponding simulator data. To achieve the same level of significance, therefore, a much greater number of trials is required, but in practice this is very rarely possible since flight trials are extremely expensive in terms of personnel and equipment.

In view of the difficulty and expense of obtaining flight data, the use of simulation techniques is of major importance in the study of target acquisition tasks. As described in Section 3.2, a number of sophisticated techniques have been developed for the simulation of the terrain as viewed either directly, or by means of a television system, during high-speed, low-level flight. Accurate visual simulation is a primary requirement in target acquisition research but the degree to which other aspects of the operational situation, such as environmental effects or aircrew workload, must be represented in order to obtain valid data, that is, data which can be consistently and meaningfully related to real-world performance, has not been clearly established.

Consequently, even if the purpose of the simulator has been well-defined, deciding the extent to which the operational situation should be represented is by no means easy, particularly as the more closely the simulator task resembles the real-world task, the greater the complexity and cost of the equipment required. In theory, the aim must be to maximise the validity of the data obtained while minimising the complexity and cost, but in practice there are few guidelines as to how this can be achieved.

A further problem arises in relation to the flexibility of the simulator for use in a number of different types of experiment. Whilst flexibility in itself is an advantage, since it potentially allows better utilisation of the equipment, the additional cost involved must be taken into account. For instance, the use of moving-base cockpits in the simulation of target acquisition tasks is not generally though to be essential. However, a simulator which does incorporate a moving-base facility has the advantage of allowing a much wider range of studies to be carried out.

In some cases a decision may be made not to attempt to simulate the real-world situation, but to abstract certain aspects of the task and study them in isolation, in order to obtain information about the basic processes involved. Whilst this has the advantage of reducing the cost of the equipment and allowing greater control over the variables of interest, the data obtained from these simplified situations cannot readily be related to real-world conditions. Laboratory experiments of this sort, in which the visual complexity of the operational task is reduced by the use of simple abstract displays and/or the dynamic complexity eliminated by the use of static material, can make a valid contribution to the study of target acquisition problems but such an approach can only be regarded as complementary to, and not a substitute for, more realistic studies.

In selecting a technique for the study of a particular target acquisition problem, there are two important considerations in addition to those of cost, space and the availability of equipment. Firstly, the technique must be capable of providing the type of information required. Secondly, the technique must allow the factors of interest to be systematically varied.

If the information required relates to absolute performance levels under operational conditions, then flight data, or data obtained from a simulator which has been reliably validated against flight data, is essential. However, in many cases the requirement is for a relative evaluation of the performance levels associated with, for instance, two display systems or two operating altitudes. This type of evaluation, which is frequently concerned with new systems at an early stage of development, can be carried out entirely by simulation techniques but such results must be interpreted with caution, particularly if the simulator represents only a part of the operational task.

A problem of a rather different type, also encountered at an early stage in the development of a new system, is that of determining the conditions under which satisfactory performance cannot be achieved, so that they can be eliminated from further consideration. Evaluations of this sort, for instance, the determination of minimum acceptable signal/noise ratios for televisual target acquisition, can be carried out by means of simulation techniques. Since simulation conditions are normally more favourable than operational conditions, it can be assumed that, in general, if the system is such that acceptable performance cannot be achieved under simulation conditions, then the system will also be unsatisfactory in the operational role. Thus simulation techniques allow minimum standards to be established at an early stage in the development program.

While the examples given above necessitate the use of displays closely corresponding to those of the operational task, research of a more basic nature, such as studies of training, scanning patterns, display parameters, or briefing information, can often with advantage be carried out under much simpler conditions. In this case laboratory experimentation, possibly combined with more realistic simulation techniques, may be the most suitable approach.

In selecting a particular technique for the study of certain factors affecting target acquisition performance, the second requirement is that the technique must allow the variables under investigation to be systematically controlled and varied. This places certain constraints on the technique used. For instance, whereas flight trials allow adequate control of speed and altitude, they would be less suitable for the study of, say, apparent target/background contrast or clutter effects, which cannot be readily controlled or measured under real-world conditions. Similarly, basic studies of, for example size/ contrast thresholds, can only be carried out under highly-controlled laboratory conditions.

Many aspects of target acquisition performance can be adequately studied by means of high-fidelity simulation techniques which have become increasingly realistic during recent years, but, as discussed in Section 3.2, the two most commonly-used techniques, involving cine-film imagery and terrain-model systems respectively, each have certain limitations and care must be taken to ensure that the technique chosen is that most suitable for the studies to be undertaken. Within these constraints high-fidelity simulation techniques undoubtedly provide a most powerful tool for the study of target acquisition and other aspects of pilot performance during high-speed, low-level flight.

However, the substantial cost involved in constructing and running such systems, inevitably means that in many cases less sophisticated techniques must be used, with a corresponding reduction in the degree of realism and in the range of variables that can be studied. The present author's research, which is discussed in the following chapter, illustrates how very simple simulation techniques can be used to study some of the variables which affect target acquisition performance.

4. CONSIDERATION OF PRESENT WORK

4.0 INTRODUCTION

The experimental work reported in Appendices 1, 2 and 3 of this thesis was initiated in 1965 under a contract with the Ministry of Aviation, as it was then, and carried out in close co-operation with the Weapons Department of the Royal Aircraft Establishment. The purpose of the work was to study some of the factors which affect televisual target acquisition performance, initially by means of static imagery and very simple display equipment, with a view to later using film imagery from the R.A.E. film library then being planned. Although the original intention was to use the static imagery for only the first year or two of the contract this work was in fact extended over some four years due to the delay in collecting the film imagery.

Each of the individual experiments carried out using the static displays is fully discussed in the individual reports contained in the Appendices. The purpose of this chapter is to review more general aspects of this work in relation to some of the points discussed earlier in this thesis. The topics are considered in the following order; experimental technique, performance measures, choice of subjects, psychometric tests, statistical design and analysis, choice of experimental variables and cine-film simulation experiments.

4.1 EXPERIMENTAL TECHNIQUE

The use of static simulation techniques in these experiments had the advantages of simplicity and low cost, in comparison with more sophisticated dynamic techniques. The obvious disadvantage was the total lack of dynamic realism, which inevitably restricted the range of parameters which could be studied. In particular, any factors which depended directly or indirectly for their effect on motion of the target through the field of view could not be adequately investigated by this technique.

At an early stage of the work it was necessary to decide whether to use photographic imagery to represent the terrain, or to develop synthetic displays which would allow the nature of the targets and backgrounds to be more closely controlled. In general, the use of realistic synthetic displays appeared to have received little attention except at the Mapping and Charting Research Laboratory, Ohio State University, as described in Section 3.2.2, and it did not seem to be a suitable technique for the experiments envisaged.

It was decided therefore that oblique photographic imagery would be used. This had the advantage of providing greater visual realism, and avoiding the problems of devising synthetic imagery. It was further decided that the displayed material should be actual aerial photographs, rather than rear-illuminated transparencies, or projected slides. The use of rear-illuminated transparencies was rejected because of the difficulties of processing transparencies of the size required under controlled conditions. Photographs rather than slides were chosen so as to avoid problems associated with non-uniformity of the visual field liable to arise in projection systems.

Since the intention was to simulate televisual target acquisition tasks, black and white photographs of relatively narrow field of view were suitable. In fact the photographs obtained had a $50^{\circ} \times 50^{\circ}$ field of view but only a portion of these were displayed giving a field of view of 30° (horizontal) by $22\frac{1}{2}^{\circ}$ (vertical). The series of photographs represented some 20 targets, taken from an altitude of 2000 ft. Four photographs of each target were available corresponding to ground ranges of 1, 2, 3 and 4 miles along a linear approach track.

The maps used by the subjects to brief themselves on the target and surrounding area were sections of 1" = 1 mile Ordnance Survey maps marked with the approach direction and the simulated uncertainty in position. It was decided that subjects should familiarise themselves with the information on the map before seeing the photographic display, and not have access to the map while viewing the display, since under operational conditions the time available during the final approach to the target would not be sufficient to allow further study of the map.

Throughout the main series of experiments the map sections were fixed in a 'North-up' orientation whereas, in retrospect, it might have been preferable to have used the more common 'track-up' orientation. However, in an experimental comparison of 'track-up' and 'North-up' orientations, reported in Study Note 1, no performance differences were found, so this difference does not appear to have been an important one.

Basic display equipment was built which allowed automatic recording of the time the subject spent looking at the map, the time he spent viewing the display and the confidence level he assigned to his response. The equipment, although both simple and inexpensive, was flexible and allowed display size, viewing distance and the portion of the photograph displayed to be readily varied. Throughout the series of experiments the equipment functioned satisfactorily with a few modifications for particular experiments, in particular, the introduction of a closed-circuit television system to study the effects of visual noise on performance. The development of the experimental technique and procedures used need not be further considered here since these are discussed in Part I. In general it can be said that, within the limitations imposed by the resources available, the technique was satisfactory for the purposes for which it was intended.

4.2 PERFORMANCE MEASURES

Before considering the performance measures used in this series of experiments one point relating to terminology should be noted. As discussed in the Introduction to Chapter 2 the commonly accepted terminology in experiments concerned with the ability of the human operator to find real targets against a terrain background is as follows: a target is detected when a signal which could be the target is noticed in the field of view; it is recognised as one of a certain class of objects; and finally identified as a particular object within that class.

The nature of the task studied in these static experiments did not correspond with any one of these terms since the subject was asked to simply locate the target. At close ranges the target could be recognised, at longer ranges only detected, and at longer ranges still its position could in some cases only be deduced from more conspicuous features surrounding it. Providing the subject correctly indicated the position of the target the response was regarded as correct.

The proportion of correct responses is referred to throughout this work as the detection probability, the term 'correct detection' applying to all instances when the target position was accurately designated, and 'incorrect detection' to all other responses. In relation to commonly accepted terminology these terms are misleading and 'acquisition' would perhaps have been a more suitable term than 'detection' for the task studied in these experiments. However, to avoid further confusion the terminology used in the reports will be retained in the present discussion.

The basic performance measure used in this experiment was the obvious one, the proportion of targets found, referred to, as noted above, as detection probability. It was decided that in carrying out the detection task subjects should be allowed to respond when they were ready, rather than after a fixed time, although considerable emphasis was placed on speed of response during the preliminary training. Search time was therefore used as a second performance measure. This approach, while some way removed from the reality of the stringent time limits imposed by high-speed flight, allowed information to be obtained about difficult targets which would probably not have been detected in a brief, fixed search time. However, an experiment, reported in Part V, was carried out to determine how the proportion of targets correctly detected in a given time interval depended on paced and unpaced search conditions.

The results of this experiment showed that, as would be expected, overall performance deteriorated when time limits were imposed, but the performance achieved in the fixed search times was better than that achieved in the corresponding times during unpaced search. In addition there appeared to be a simple relationship between paced and unpaced performance. Although this may have been coincidental it raises the interesting possibility of whether it is possible to predict paced performance from unpaced performance. At any rate it is clearly unrealistic to simply assume that a distribution of unpaced search times can be cut off at a particular value, to give the proportion of targets which could be found in that search time under paced conditions.

A further performance measure used throughout these experiments was confidence level, subjects being asked to indicate on a scale of 1-7 how confident they were that their response was correct. It was found that confidence level varied in the way that would be expected with the different experimental conditions, indicating that it is a meaningful performance measure, and one that could be used to throw more light on the trade-off between accuracy and search time, or in the case of dynamic experiments, accuracy and range. Significant correlations were consistently found between high detection probabilities, low search times and high confidence levels for individual targets, indicating that target differences played a major part in determining all three aspects of performance.

The fourth measure recorded, the time the subject spent studying the map before looking at the photographic display, showed significant differences between targets but in general did not correlate with any of the measures of detection performance.

4.3 CHOICE OF SUBJECTS

During high-speed, low-level missions target acquisition is carried out by highly-skilled and experienced pilots. Ideally, therefore, experiments into target acquisition performance should use pilots of similar skill and experience as subjects. However, military pilots are rarely available to participate in such experiments and therefore an important general consideration is the extent to which valid data can be obtained from unskilled subjects of similar age and ability.

Skilled pilots took part in two of the eight experiments reported in this thesis and the results given in Part I clearly showed that, although their performance differed from that of unskilled subjects in that search times were significantly shorter, the proportion of targets correctly detected was the same for both groups. Later experiments, carried out using cine-film simulation techniques, have also shown similar results, except that in this case the longer search times required by unskilled subjects were reflected in shorter acquisition ranges (Parkes and Rennocks, 1971a).

This is an important finding since it suggests that, at least in terms of acquisition probability, data obtained from unskilled subjects, who are readily available to take part in experiments, closely approximate to those of skilled subjects who are rarely available. However, it is a finding that should be regarded with considerable caution since under more realistic simulation conditions it might not apply. In general, it can be assumed, that, other things being equal, the performance of unskilled subjects will be a conservative estimate of that which might be achieved by skilled subjects, so performance will if anything be underestimated, but this does not take into account differences in workload between an unskilled subject taking part in a visual simulation experiment, and a pilot flying a genuine mission.

An important problem is the extent to which experience interacts with different experimental conditions, for instance, doubling the simulated speed might cause performance deterioration in unskilled subjects but not skilled ones. Thus the argument that the use of unskilled subjects at least allows the relative effects of two conditions to be evaluated may be invalidated. However, in general, the results of the author's own work and that of others who have carried out experiments using skilled and unskilled subjects, as discussed in Section 2.8.4, suggest that realistic data can be obtained from unskilled subjects but wherever possible such data should be validated by use of a small group of experienced pilots.

4.4 PSYCHOMETRIC TESTS

All subjects who took part in these experiments underwent a series of psychometric tests intended to assess intelligence, personality and short-term memory. One purpose of this testing was to ensure that the two groups of subjects were not significantly different in intelligence and personality as measured by these tests, and the results obtained in Part I showed this to be the case, although the second group of skilled subjects, used in Part IV, were significantly less intelligent than the student group.

A further purpose of the tests was to determine whether any of these psychometric measures were correlated with target detection performance. The only correlation which reached significance in several experiments was a positive correlation between intelligence, as measured by Heim's AH5 test, and accuracy, as measured by the proportion of targets correctly located by each subject. This correlation was only significant for unskilled subjects and two possible reasons can be put forward to account for it. The more intelligent subjects were either quicker to learn a new and unfamiliar task or else they were better able to relate the map information to the oblique photographic display.

If this correlation is a valid one, then it provides a means by which unskilled subjects could be screened to select only those who are likely to be successful at the experimental task. In later experiments carried out using cine-film imagery there was no real evidence of a correlation between performance and score on Heim's AH5 test in a group of 42 pilots experienced in high-speed, low-level flight (unpublished data). This suggests that the effect of extensive training and experience is to minimise any differences that may arise from differences in intelligence. Furthermore these pilots can be regarded as a highly selected, and homogeneous group in which individual differences were relatively small.

4.5 STATISTICAL DESIGN AND ANALYSIS

A number of the considerations involved in the choice of the experimental design are outlined in Part I and need not be discussed here. The main constraint on the experimental design was the extremely limited amount of experimental material, which consisted of four photographs taken at ranges of 1, 2, 3 and 4 miles, for each of approximately 20 targets. The Latin Square experimental design chosen was based on each subject seeing only one view of each target.

One possibility considered only briefly at the time was that of presenting the subject with the sequence of four photographs of each target, starting with the 4 mile range and moving sequentially in to the 1 mile range photograph. In retrospect it seems possible that more realistic data might have been obtained had this approach been adopted. In addition, four times as much data could have been obtained, since each subject would have seen four views of each target rather than one, with relatively little increase in experimental time. This type of experiment would have approximated more closely to a realistic display 'freeze' capability in which the observer is presented with a sequence of static terrain scenes rather than a continuously moving display.

However, an experimental design of this type would have undoubtedly complicated the analysis problem. The experimental design used gave rise to data showing a consistent linear relationship between range and detection probability which had the advantage of providing a good basis for the comparison of different experimental conditions.

The detection probability data were mainly in the form of matrices with cell values of either 1 or 0, depending on whether or not the response was correct. Standard analysis of variance techniques cannot in theory be applied to such data, but an interesting aspect of the analysis was that the use of the normal analysis of variance gave results almost identical with those obtained from the more complex Logit analysis. It appears, therefore, at least in some situations, that standard analysis of variance techniques are robust enough to allow valid results to be obtained from quantal data.

4.6 CHOICE OF EXPERIMENTAL VARIABLES

The display variables chosen for study in this series of experiments included display size and viewing distance, visual noise, exposure time, camera field of view and map orientation. Other factors studied were navigational uncertainty and azimuth error, while range was a variable in all but one of the experiments.

In general, the studies of display variables were well-suited to the experimental techniques and useful data were obtained. For instance, performance was found to deteriorate with increase in visual noise, decrease in exposure time and increase in viewing distance, although in the case of viewing distance the effect was not significant. In each experiment increase in range led to a significant decrease in performance, the relationship being linear.

The least successful of these experiments was that in which the effects of camera field of view were studied. The reason for this lay in the unsuitable choice of field of view values, 30° and 50° horizontal. These values were both higher than the level at which an effect on performance would be expected. In relation to television-guided missiles, values of 30° and 15° would have been more appropriate for investigation.

In contrast to the reasonably successful outcome of the experiments involving display variables those in which attempts were made to investigate navigational uncertainty in range and azimuth both failed to show any effects. It seems likely that this was not because there are no effects, but because the static experimental technique and the limitations of the experimental material were such that these factors could not be adequately simulated. To obtain valid data about these effects more sophisticated dynamic simulation techniques would be required.

The earlier experiments in the series were carried out largely to meet the immediate requirements of the Weapons Department, Royal Aircraft Establishment for information about the effects of specific variables. During the course of these experiments it became clear that one of the major factors influencing target acquisition performance was likely to be the nature and quality of the briefing information provided. It was decided therefore that the final experiment in the series should attempt to assess the effects of different levels of briefing information, and that a further study of briefing would be carried out using the cine-film imagery when this became available.

The study of briefing was regarded as particularly important since this seemed to be an area where, under operational conditions, fairly large gains might be achieved at relatively small cost. A number of experiments have shown that, particularly for small targets, acquisition performance is not altogether satisfactory. Inadequate briefing could be one source of this difficulty. Although oblique photographs or, more likely, vertical photographs of the target area may be provided, in some cases the only briefing information available is a map and a verbal description of the target.

As discussed in the Introduction to Part VI(i), laboratory studies have shown that target recognition performance is strongly dependent on the degree of similarity between the briefing information and the target display. It is clear that map displays, being in the form of plan information, bear little immediate resemblance to oblique photographs. In order to relate the map information to the photograph the observer has to mentally transform the map information to the appropriate perspective view.

In a television viewing system altitude, field of view and camera depression angle are fixed, and thus it is possible by geometric means to accurately transform the plan view on the map to the corresponding oblique view, which resembles the television display more closely. One aim of the briefing experiment carried out by the present author was to determine whether these oblique representations facilitated target acquisition performance as compared with the map alone.

As described in Part VI (ii), two types of oblique representation were prepared, drawings and diagrams, and each target was represented as seen obliquely from ranges of 2 and 4 miles. These pictures were prepared solely from the information shown on the 1" = 1 mile map and knowledge of altitude, field of view and depression angle. In the experiment these briefing pictures were evaluated against the map only condition and against a condition in which oblique photographs themselves were used as briefing material.

In this latter case the series of briefing photographs used were duplicates of those used to simulate the terrain scene except that the former had the target position marked. In some instances the briefing photographs showed the target at a different range from the display photograph, but under some conditions the briefing photograph and the display photograph were identical, and thus a very high level of performance would be expected.

The results showed that the use of these perspective representations did facilitate performance as compared with the situation in which only the map was provided for briefing purposes, particularly at longer ranges, but, as would be expected, the diagrams were not as effective as the oblique photographs. This experiment was followed up using cine-film simulation techniques as described in Section 4.7.

4.7 CINE-FILM SIMULATION EXPERIMENTS

The study of the effects of briefing on televisual target acquisition performance was extended using cine-films from the R.A.E. cine-film library. The main purpose of this experiment was to evaluate the effectiveness of the briefing diagrams under dynamic simulation conditions using, in addition to diagrams prepared from maps of scale 1" = 1 mile, a corresponding set prepared from maps of ¼M scale. The latter were inevitably very much less detailed. In each case subjects were provided with a ¼M map for navigating along the track and in six of the seven conditions additional briefing materials were provided covering the target area. These materials ranged from a section of 1" = 1 mile map, through the two types of diagrams, to oblique photographs.

A total of 42 pilots and navigators took part in this experiment. All of them were experienced in high-speed, low-level navigation although none had experience of televisual target acquisition. The results showed that, although the different levels of briefing information did have significant effect on some measures of performance, in particular the probability and range of positive target identification, the effect was less marked than might have been expected. Overall mean probabilities of correct positive identification were 0.53, 0.62, and 0.72 for conditions involving maps, maps + diagrams, and maps + photographs respectively. The detailed results of this study have been reported by Parkes and Rennocks (1971a).

A further purpose of this cine-film experiment was to analyse the number and type of terrain features chosen as fixpoints for en route navigation, and to evaluate how many of these were actually seen and found to be useful for navigation purposes. The results indicated that the overall average distance between selected fixpoints was slightly less than 5 n.m, but this varied widely between routes.

It was found that all but approximately 8% of the chosen fixpoints were seen during the simulated 'flight' but only 54% of these fixpoints were positively reported as having proved useful for navigation purposes. In addition, a substantial number of features not initially chosen as fixpoints were reported subsequently as having been seen and found useful for navigation.

Analysis of the types of features chosen as fixpoints showed that built-up areas were the most frequently selected, relative to the number available, followed by railways running parallel to the track. Among the least frequently selected were roads and railways running across the track, river junctions and bridges. There was a high positive correlation between the proportion of features selected in each category and the probability of their being seen.

There were considerable variations between subjects in the numbers of fixpoints chosen, seen and missed but these did not appear to be related to variations in target acquisition performance. A more detailed account of the analysis of these data, which were obtained by means of 'pre-flight' and 'post-flight' questionnaires, has been published by Parkes and Rennocks (1971b). In general, although this study was inevitably limited in scope, it did provide useful information in area where relatively little experimental data are available.

4.8 CONCLUSIONS

Before the overall achievements of this research program are considered, two reservations should be noted. Firstly, the length of time spent on these static experiments was rather long in relation to that spent on the dynamic experiments which followed. Unfortunately this was largely outside the author's control as it was a consequence of the lengthy delay in the completion of the R.A.E. cine-film library.

Secondly, it was not possible to validate the results of the static experiments against data obtained under more realistic dynamic conditions. Again, this was outside the author's control as no cine-film imagery was available covering the same targets as used in the static experiments. Whilst it would have been possible to use the cine-films which became available later in the program to carry out a comparative static/dynamic experiment, this would have necessitated obtaining both static and dynamic performance data from the cine-film imagery and the time available for completion of the contract work did not allow this.

In spite of these reservations this research program appears to have achieved some degree of success both in obtaining information about the effects of certain specific factors and in relation to more general questions of experimental technique and choice of subjects. The main achievements can be summarised as follows:-

(i) The experiments provided performance data on a number of display variables including display size/viewing distance, visual noise and exposure time. These data, whilst unlikely to be directly applicable to real-world conditions because of the lack of dynamic realism, can be regarded as indicating at least in relative terms the main effects of the parameters involved. As far as can be determined the data are in general agreement with those of other research workers.

(ii) The two experiments in which the performance of skilled and unskilled subjects was compared showed that, after suitable training, data obtained from unskilled subjects approximates closely, in terms of detection probability but not search time, to those obtained from skilled subjects. The implication, that valid data can be obtained from unskilled subjects, is important in that skilled subjects are not readily available to take part in experimental work.

(iii) The general finding that static simulation techniques can yield consistent and meaningful data is of some importance in that it indicates that preliminary experiments can be carried out rapidly and cheaply using static techniques to give an initial indication of the significance of a particular factor on the basis of which more sophisticated experiments can be planned.

(iv) The major study in this series of experiments, an investigation into the effects of different levels of briefing information, involved not only the study of conventional briefing materials but also the development and evaluation of a novel form of briefing which could be of value, when, as is often the case, oblique photographs are not available. Whilst simple in concept, this technique of preparing oblique briefing material, corresponding to particular television viewing parameters from plan views of the target areas does not appear to have been attempted before, in spite of the fact that experimental data clearly indicate that oblique briefing materials are more effective than the corresponding vertical imagery.

In these experiments Ordnance Survey maps were used as the source of the plan view information about the terrain, but it seems likely that vertical photographs of the type now available from satellite photography would be more effective as the source imagery for the perspective views. Use of photographic imagery as the source material would allow more accurate representation of tones and textures than can be derived from a map, and would also provide much more information about the appearance of the target itself and its spatial relationship to other nearby features.

Further experimentation would be required to determine the effectiveness of oblique briefing materials produced from vertical photographs but the results of the work carried out during this research program suggest that, in situations where oblique photographs are not available, these synthetic oblique views could be of value, particularly as they can be prepared to correspond to any required field-of-view, altitude and approach angle. In view of the difficulties of obtaining oblique photographs over hostile terrain, further development of the techniques used in the present work, included perhaps the automatic generation of oblique displays from vertical imagery, might well prove to be a relatively inexpensive and effective means of improving performance.

5. GENERAL CONCLUSIONS

The purpose of this thesis has been to provide a wider background against which the author's experimental studies of air-to-ground target acquisition can be considered. To this end, the general problems associated with high-speed, low-level attack missions have been outlined, and attention has then been concentrated on two main areas. Firstly, an attempt has been made to present a comprehensive picture of experimental findings relating to target acquisition performance, with reference to unclassified work published in both Britain and the United States, and to indicate the limitations of these data.

Secondly, the techniques currently available for the study of target acquisition have been reviewed, with particular emphasis on the advantages and limitations of flight trials as compared with the use of high-fidelity terrain simulation techniques. In the light of these discussions the results obtained by the present author using a simple static simulation technique have been considered. Each of these chapters is largely complete in itself, and the purpose of this final chapter is to briefly present some conclusions of a more general nature.

It is clear from the discussion in Chapter 2 that much research remains to be done into the problems of target acquisition, not only in relation to direct-view conditions but also, and increasingly importantly, in relation to television and other sensor systems. Indeed, the development of sophisticated sensor systems, usable not only in daylight but under conditions of poor visibility and darkness or near-darkness, must inevitably increase still further the diversity and complexity of target acquisition tasks, and consequently the need for research.

Whilst much of this research is likely to be associated directly with the development of specific weapon systems, more fundamental research, aimed at enabling reliable predictions to be made of acquisition performance in any particular situation, must also continue. As discussed in Section 2.10, the current state-of-the-art in predictive modelling is still some way from achieving a satisfactory degree of accuracy, and there are inherent limitations to such models which will prove difficult to overcome.

Whatever the nature of the research work, it is essential that, at a time when defence costs are being increasingly critically examined in relation to other demands on national expenditure, the resources allocated to defence research should be used to maximum effect. In development work, the role of the human factors specialist in achieving this is to provide reliable and valid operator performance data which, when considered together with engineering feasibility and financial limitations, can be used as a basis for specifying the system design.

The first step in the development of any new system is the specification of the system objectives, which must include a detailed statement of the intended operational role of the system, the conditions under which it must operate, and the level of performance required. In the case of a complex weapon system, such as an air-to-ground guided missile, such a statement must provide information about the accuracy and range required of the missile, the types of targets against which it will be used, the nature of the terrain, the weather and visibility conditions under which it must be capable of operation, the type of aircraft from which it will be launched, and which aircrew member will be responsible for operating it.

Once the system objectives have been clearly defined, it is essential that the human factors aspects of the system are considered at an early stage in the development program. If major design decisions are made without due consideration of the capabilities and limitations of the human operator, the system may fail to meet its performance criteria. Consequently, it may require expensive modifications which could have been avoided, had due attention been given to human factors considerations at the initial design stage.

In providing human factors data for the design engineers, the human factors specialist must first determine which factors in the system are likely to prove critical in terms of human performance, and which are of only marginal importance. A study of the literature, and/or experience gained from previous systems, will often indicate which factors should be studied at this early stage. Indeed, in many cases, development work is concerned not with the design of an entirely new system, but with the improvement and modification of existing systems. Under these conditions, extensive field and test data may be available to indicate which are the critical parameters, and where modifications are particularly required.

Once the critical factors have been identified, more detailed and sophisticated experimental techniques can be used to determine exactly how operator performance is affected by these variables in the system under development. From this information it is possible to specify values for the critical variables which will enable the system to meet the required performance levels. In effect, the human factors engineer is providing information in the classical sense of the word, in that he is reducing the uncertainty in the design process by narrowing down the range of possibilities open to the design engineer.

This reduction in the possible options may take the form of specifying that maximum performance is achieved at a particular value of the variable concerned, or, more commonly, it may be in the form of specifying a maximum or minimum value of the variable for acceptable performance to be achieved. Either way, information is being provided which, although it does not in itself determine the final system design, since cost, feasibility and, in some cases, compatibility with other equipment, are also critical considerations, is of vital importance in the development process.

Whilst the human factors specialist has a significant contribution to make in carrying out short-term research associated directly with the development of specific systems, the importance of more fundamental research, potentially applicable to a wider range of situations, must not be overlooked. Such research can provide basic information about human performance, of value either as a guide to further experimentation, or, in some instances, in providing a complete answer to more routine problems. However, several major difficulties are liable to occur in the utilisation of basic research data.

Firstly, in many cases such data are obtained under conditions so abstracted from the real-world that there is no meaningful way in which they can be applied to practical problems. Secondly, the inevitably lengthy time-lag between the initiation of a research program, and the utilisation of the data means that, unless a requirement can be foreseen many years ahead, the basic research data may not be available when required. There are certainly no ready solutions to these problems, although the greater involvement of engineers and technologists in the planning of long-term research programs might well be desirable.

A different type of problem, and one that is more amenable to solution, arises in relation to data which are both available, and suitable for application to practical problems. For instance, basic anthropometric data, recommendations for the design of displays and controls for particular purposes, and data relating to optimum environmental conditions, can be found in a number of standard text-books. Unfortunately, much of this data is ignored by engineers and designers, who may fail to realise that it exists, or fail to make use of it because it is not in a form that they can readily understand and apply. The remedy for this failure in communication must lie partly with the human factors specialists, who should ensure that their data are published in a form in which they can be more easily utilised. Equally, engineers and designers should be made aware, particularly during their training, of the availability of such data and the advantages of applying them.

Whilst standard human factors data may make a contribution to the design of complex and specialised equipment, the development of such equipment must necessarily involve obtaining detailed performance data under conditions closely approximating to the operational situation. The cost and difficulty of obtaining such data from flight trials when the system is an airborne one, as in the case of a television-guided missile, has led to increasing reliance on simulation techniques. The sophisticated simulators currently in use allow a very close approximation to the airborne situation to be achieved under laboratory conditions, and also have the advantage of enabling a much greater degree of experimental control to be exerted over the test situation than is possible in field trials.

Whilst there is still a need to improve the visual fidelity of closed-loop simulation techniques, the problem of flight simulation appears to lie less in the technology of designing and building a simulator than in the fundamental decisions concerning which aspects of the overall task and environment should be included in the simulation, that is, in determining the overall degree of fidelity required of the simulator for a particular purpose. The main reason why simulation is still, as Fraser (1966) puts it, 'more than an art but not yet a science' is that there is no way of determining which aspects of the real-life task must be represented in order to ensure that the simulator elicits human behaviour similar to that which would occur in the real-life situation.

In the past decade there has been an increasing trend towards the use of complex and costly simulators which incorporate an impressive degree of physical similarity to the real-world system. To some extent this approach appears to have by-passed the basic problem of determining exactly what constitutes psychological fidelity, and whether such a high degree of physical resemblance is a necessary prerequisite for psychological fidelity.

However close the physical resemblance between the simulator and the real-world system, the relationship between operational performance and simulator performance cannot be predicted. Therefore, if a simulator is to be used to determine operational performance levels, the simulator data must be reliably validated against flight trial data at the earliest stage possible. The results of such a validation may show that the simulator data are directly comparable to those obtained during the flight trials or, more likely, that there is a definite relationship between the two sets of data, which allows operational performance to be determined from simulator performance. If there is little or no relationship between the two sets of data, then the simulation technique and the method of conducting the flight trials must be closely examined to determine the source of the discrepancies.

A validation study of this type must necessarily involve the extensive use of aircraft, pilots, ground facilities, support staff and research workers, and is therefore liable to be extremely costly. In some cases, visual imagery for use in the simulator can be collected at the same time as in-flight observations are made, thus reducing the overall cost, and ensuring maximum comparability between the visual display in the simulator and that seen by the in-flight observers. Although a high proportion of research studies of a more general nature are carried out using simulators which are not at any stage validated against field data, validation is an essential requirement in any work which involves determining absolute operational performance levels from simulator data.

A simulator that has been shown to give rise to performance data representative of, or which can be related to, those obtained under field conditions can be used not only as a convenient means of carrying out further development work, but also, at a later stage, for training purposes. Some research simulators may be suitable for use as training simulators with little or no modification. In other cases experience gained from a research simulator can facilitate the subsequent design and construction of specialised simulators for training purposes.

The need for high-fidelity training simulators is particularly critical in relation to advanced weapon systems, for which little or no real-life training is possible for the operators. In these circumstances, simulators must be used as the sole means of devising a training program, setting progressive performance standards, carrying out the basic training of operators, and assessing final performance; and, at a later stage, for continuation training to ensure that performance standards are maintained. Since an operator may carry out no more than one or two test-firings in his entire service career, effective simulator training is clearly of vital importance.

Whilst this discussion has been primarily concerned with the problems of visual and televisual target acquisition, and the role of the human factors specialist in studying operator performance at these tasks, many of the same considerations apply to the study of other problems associated with high-speed, low-level flight. Indeed, it should be emphasised that target acquisition, although of vital importance to the success of the mission, is only one aspect of the severe workload imposed on the aircrew during low-level operations over hostile terrain. The urgent need to reduce this workload has led to the automation, or partial automation, of certain critical tasks, for instance, navigation and terrain following, in advanced strike aircraft, and this will inevitably be an increasing trend.

The eventual aim must be to reduce the demands on the air-crew by relieving them of the responsibility of carrying out tasks which can more effectively be performed automatically, thus leaving them more time to concentrate on tasks for which the human operator has particular skills, not matched by purely automatic systems. Although many of the functions at present assigned to the aircrew are amenable to an increased degree of automation, air-to-ground target acquisition is a notable example of a task at which the performance of the human operator cannot be surpassed by automatic devices. The present state-of-the-art in automatic target recognition suggests that this situation will not readily be changed. Although the detailed nature of the visual tasks involved may change, as sensor systems are further developed, and increasingly sophisticated aids become available, it seems likely that the human visual mechanism, as yet unrivalled in terms of efficiency, flexibility and compactness, will continue to play a vital role in target acquisition. For this reason, the study of the capabilities and limitations of the human operator in carrying out these complex visual tasks, will remain of importance for many years to come.

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7. DETAILS OF APPENDICES

The Appendices to this thesis are bound in three volumes and contain the following reports of experimental work:

APPENDIX 1

Part I	The effect of navigational uncertainty and target difficulty on detection performance.
Part II	The effect of viewing distance on target detection performance.
Part III	A limited experiment on the effect of simulated azimuth error on target detection performance.

APPENDIX 2

Part IV	A study of target detection performance in relation to the signal noise ratio of the television display system.
Part V	The effect of limited search time on target detection performance.

APPENDIX 3

Part VI(i)	Briefing materials for low-level target detection: a comparison of five briefing types.
Part VI(ii)	Briefing materials for low-level target detection: techniques for preparing perspective drawings from maps.
Study Note 1	The effect of map orientation on target detection performance.
Study Note 2	The effect of camera field of view on target detection performance.