Human factors in air traffic control: a study of the ability of the human operator to predict dangerously close approaches between aircraft on simulated radar displays

HUMAN FACTORS IN AIR TRAFFIC CONTROL: A STUDY OF THE ABILITY OF THE HUMAN OPERATOR TO PREDICT DANGEROUSLY CLOSE APPROACHES BETWEEN AIRCRAFT ON SIMULATED RADAR DISPLAYS.

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SUMMARY

The aim of this thesis was to investigate experimentally the ability of observers to make predictions of the future relative positions of aircraft on simulated radar displays, and to observe how this ability was affected by differences in the situation or in the types of simulation or observer.

Two experiments are described, in which a carefully selected set of simulations was shown to groups of observers of differing experience. The first experiment used an elaborate radar simulator, in as close an approximation to normal operation as possible, the second used a simple paper simulation technique.

A number of different types of decision were recorded, classified and analysed. It was found that there were few differences in the accuracy with which decisions were made, except those due to the nature of the situation. There were considerable differences in the times at which decisions were made. These depended on the individual observer, and on the simulation technique employed. There were also differences in the average times over all simulations displayed by different means. Differences between individuals tended to be greater among unskilled observers, while skilled observers showed speeds comparable with the better unskilled observers.

The conclusions to be drawn from these experiments about the use of simpler simulation techniques or less skilled observers are summarised in Chapter IX (Sections 3 or 4). In general, they suggest that simpler simulation techniques are unreliable as far as timing of judgement is concerned, but may be acceptable if one is concerned with accuracy only. Unskilled observers are as accurate, but slower than skilled observers, and show more within-group variation.

In addition to the differences between observers, the differences between simulations have been investigated. An investigation of the mathematical and statistical relationships between certain aspects of conflict situations leads to a series of multiple regression analyses describing the behaviour of skilled observers watching electronic simulations. A choice of variates is made, the time to go to the time of closest approach being found most suitable.

It is found that the time of first decision can be predicted from an equation containing the speed of closing, the angle of approach and the order in which the aircraft reach the point of cross-over. Expressions are found for the accuracy of this decision in various respects, and these are combined to predict mean times and frequencies of correct decisions.

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I. INTRODUCTION

1. The origins of Air Traffic Control.

Traffic in the air is a recent phenomenom. Congestion in the air is even more recent. It might be expected that the authorities would be as unprepared for air traffic chaos as they are for ground traffic chaos. In fact this is not the case. The problems of the control of air traffic were recognised early; in fact regulations for the conduct of aircraft were made within a few years of the first flights being made. Within two years of the crossing of the channel by Bleriot, regulations had been made about the entry of aircraft into the United Kingdom. These were primarily intended to frustrate the smuggler and the spy, specifying customs procedures, areas of the country which were not to be flown over, and stretches of coast by which entry to the country could be made.

These regulations were, at the time, virtually unenforcable. In the absence of rapid wireless communication and sure means of detection, aircraft could go more or less where they liked and when they liked.

The importance of wireless equipment was early appreciated by military air authorities, and the ability of aircraft to communicate with the ground by this method soon led to the introduction of more formal procedures.

By the middle of the inter-war period, a system of air traffic control had been adopted for civil airfields and for the control in the air of military aircraft. At this stage, in the absence of radar, the only information available was that from the aircraft, which could only be as good as the navigator supplying it. At this time, the system of reporting points came into use. This system required aircraft to report when they passed over fixed points on their journeys. This made it possible to check that they were not deviating from their expected times of arrival, and to check that they had not come to grief in the interval. If they were in fact ahead of or behind schedule, or did not report, appropriate action could be taken. At this time, it also became necessary to provide some form of organised procedure for deciding who was to take off or land next when several aircraft were in the air at the same time. Regulations were adapted from the rules for the prevention of collision at sea to avoid the collision of aircraft. In practice, the avoidance of collision could be left to the discretion of the pilot, who in those days was able to maintain an adequate search of his surrounding air space.

Immediately before and during the war, the use of radar for military purposes made it possible for ground-based controllers to ascertain precisely where aircraft were, and what they were doing. This made it possible to guide intercepting fighters towards bomber formations, and to locate aircraft at their request, so that a constant stream of information, advice and orders flowed through the communication channels.

As the war ended, it was soon obvious that the techniques originated for military use would be equally useful in the field of civil aviation. The priorities might be different, and the aim might be to guide aircraft away from each other rather then into each other, but the principles were the same. The equipment adopted at the time was the existing military equipment, often not fully suitable for its new tasks. Subsequently new equipment replaced obsolete war-time equipment, and new systems were adopted. Certain airways were adopted for the flight of commercial aircraft, and restrictions were placed on the flight of light "uncontrolled" aircraft. The services co-operated in the organisation of air traffic control, and the connection between civil and service air traffic control in the United Kingdom remains intimate.

Although the radar systems provide much of the information required for air traffic control, they are not the sole channels of communication, and older techniques remain in use.

It may be instructive to consider the flight of an aircraft under normal civil procedures from, say, Kennedy Airport in New York to London (Heathrow) airport.

The flight, we will assume, is a scheduled one, part of a regular service. Long before the aircraft leaves its service area, the preparations for the flight will have been made. The Flight Plan will have been filed, specifying when the aircraft will take off, to what height it will climb, when and where it will report, what radio frequency it will use, and what call-sign it will employ, to name only some of the items involved. Some of this information will go to the control tower, some to the air traffic control centre, which may be some distance away, and will probably serve a number of airfields.

The aircraft, as soon as it is ready to depart, will be given permission to procede to the appropriate end of the appropriate runway by the control tower. Nowadays it may well find itself part of a queue of aircraft awaiting permission to take off. As soon as its predecessors have gone it will be instructed to take off at the next available opportunity. This may be considerably later than the planned time of take off. During the aircraft's take off and climb away from the airfield, it will be watched by an air traffic controller using radar, to ensure that it is on course and that no other aircraft is in danger of colliding with it.

After it has passed out of the immediate area of the airport, it will be handed over to an area air traffic controller, who will supervise its flight until it is out of the more congested area surrounding the airport. This controller is particularly concerned to see that the aircraft remains on its planned flight path, and to avoid the possibility of collisions with other aircraft entering the area, or taking off or landing on other adjacent airports. As the aircraft heads out over the Atlantic, the number of other aircraft will decrease, and the aircraft will pass out of the range of local radar equipment.

From this point until the aircraft re-enters radar range on the other side of the Atlantic, it will be responsible for its own safety. Since in practice it is impossible to see other aircraft in time to take avoiding action, the usual procedure is to assign an area of airspace to each aircraft, and not to allow other aircraft to enter this area. The size of the area will depend on the navigational accuracy that can be expected in the long run. The aircraft is traced by its reports during the course of its journey, and is advised of adverse weather conditions and other dangers.

When the aircraft approaches the opposite shore of the Atlantic, it will be picked up by the radar equipment of the United Kingdom, and given any necessary course corrections. It will then enter what is known as 'controlled air space', within which it will be under the control of an area air traffic controller. The aircraft will then fly along a specified corridor, taking its place in a stream of aircraft proceeding to various airports in the United Kingdom. If it is going to London Airport, it will almost certainly not be able to come in to land immediately. It will be directed to a 'stack'. It will fly to a predesignated area, such as that over Epsom, where it will be instructed to circle. As other aircraft below it are landed, it will be allowed to descend until it is at a suitable height to leave the stack and join the stream of aircraft preparing to land. At this point it will be handed over to an Approach Controller, whose task is to get the aircraft in line with the right runway, at the right height and speed, and not too close to the other aircraft.

The final landing may be made under a variety of different systems, depending on weather conditions, the equipment available and other factors.

This account is deliberately simplified, and differences in detail would occur on almost every flight. Some air traffic control organisations employ different divisions of responsibility, and at small airports it may not be necessary to operate a stack, for example. The processes used are under continuous review. Changes in procedure are made to adapt to different conditions, to different aircraft capabilities and to improved surveillance equipment. At the time of writing for example, the supersonic airliner is approaching service, and new high-speed radar equipments giving improved radar pictures are being introduced. The southern air traffic control centre is being moved away from London(Heathrow) Airport, and plans are being made for a third major airport in the London area.

One of the tasks of air traffic control which will remain, and must grow more important as traffic increases, is that of collision avoidance. This problem is discussed in more detail in the next section, where the different approaches to collision avoidance are discussed.

2. The problem of collision avoidance in the air.

Certain characteristics are required in any system for collision avoidance. The system must be physically feasible, comprehensible to its users, effective in avoiding collisions, not excessively costly, and it must be accepted by the user.

Most systems for collision avoidance represent compromises in terms of these requirements. The simplest system is to have no system. In some circumstances this is a perfectly satisfactory system. The pedestrian and the astronaut both use systems of this type.

The next most simple system requires the adoption of a convention, such as that implied by the "Keep Left" rule on the roads, or by the rules for avoiding collision at sea. These conventions tend to be arbitrary in nature, incorporating traditional features simply because they are generally accepted.

Where informal systems are found to be inadequate, either because they are found to contain inherent flaws, or because they are taking up too much time, space or effort, they are often replaced by regulations. The history of the Road Traffic Acts in almost any developed country will show a pattern of adaption to increasing traffic flow, with acts becoming more restrictive or more permissive to meet changing conditions.

Such conventions, whether laid down by regulations or by tradition, have in common that they are applied by the individuals concerned in the regulation and navigation of the vehicles concerned. This can, and does, lead to misunderstandings, misinterpretation of the situation,and sometimes to catastrophe. Technical changes may make regulations unworkable, or even physically impossible. Rules easy to apply for visual sightings may be completely inapposite to radar sightings, for example. The speed of aircraft is now such that visual collision avoidance is virtually impossible. The aircrew cannot carry out continuous all round observation, nor could they carry out appropriate course corrections in time to avoid collisions. There simply is not enough time available between sighting and impact. The situation that would exist under purely crew-organised collision avoidance in the region of major airports does not bear thinking about.

Four main approaches have been made to the problems of collision avoidance in the air. Although they are not mutually exclusive, they may be discussed separately.

The most straightforward approach to collision avoidance is to make the aircraft more visible. Accordingly aircraft may be equipped with special colour schemes, often involving the use of fluorescent paint, or with special lighting systems. An extensive experimental programme was carried out in the United States by the Applied Psychology Corporation of Arlington (Virginia) (Applied Psychology Corporation 1961 a - f, 1962 a - j, 1963 a - b, summarised in Cooke, Beasley and Robinson, 1962) and a number of other papers reviewed experience of various painting systems (Lazo and Bosee, 1961).

This approach is limited by the inherent difficulties of seeing through rain, cloud, fog and in darkness, and by the range at which detection must take place if adequate avoiding action is to be taken. Collision avoidance lights are fitted to aircraft, on the principle that they cost little, and might save a lot, but cannot by themselves provide adequate protection.

The second approach, again attempting to extend the range at which dangerous situations could be perceived by aircrew, was to consider the adoption of airborne radar devices, similar to those used for weather detection. This approach foundered on considerations of the size of the necessary radar devices, and their requirements in terms of bandwidth allocations.

Ratcliffe (1961) estimates that a beam width of 100 wavelengths would be required in a primary radar system (one in which the detected aircraft is detected purely by reflection, without providing any active assistance to the radar equipped airuraft). Such a radar would require an aerial system capable of looking all around the aircraft, Ratcliffe estimates an effective aperture of 40cm, and a consequent wavelength of 4mm. Such a radar beam would not have a range of ten miles in rain. In addition, there would be problems of detecting targets at ranges greater than the aircraft height, and problems of "Glint" - changes in reflected signal due to target movements - which make primary radar systems of this type nearly impossible in the present state of the art.

Power, range and space requirements are less restrictive for secondary radar systems, where the aircraft detected carry devices to transmit back information to the detecting aircraft. Such systems are useful only when a reasonable proportion of aircraft are equipped with them. Even the most basic systems cost a sizeable fraction of the cost of a light private aircraft, so that the prospect of their being made standard fittings for all aircraft is remote. Technical difficulties exist in the design of satisfactory devices for measuring relative heights, and systems which report the measured height of each aircraft can be seriously affected by inaccuracies in altimeters, such as often exist in practice. Secondary radar height finding devices are also liable to saturation. Ratcliffe (1961) points out that users are not likely to fit such costly equipment unless at least half the other users of the same airspace do so too. The organisational problems of adopting a system suitable for all shapes, sizes, types and nationalities of aircraft are such as to render the future of any such systems problematical at the best.

The third approach is radically different and is essentially procedural in nature. It involves reserving blocks of airspace for each aircraft. The block must be large enough to allow for errors of timing and positioning, so that aircraft do not stray into other aircraft's blocks often enough to involve major risks of collision. This policy, which resembles the practice of railway companies of reserving lengths of track for each train, (although a system of reporting points is usually used in air traffic control) is effective. It has a number of disadvantages, of which the most important is that it greatly restricts the number of aircraft which can use a given route, and becomes more restrictive when the relative speeds of aircraft differ considerably. It is also dependent on the accuracy with which aircraft can report their positions, so that it is possible for blunders to occur, and for disputes as to the responsibility for accidents to lead to a breakdown of confidence. (In practice this has not occurred).

The fourth approach, which is employed in crowded areas, such as the approaches to major airports, is that of radar air traffic control.

Aircraft of certain categories, flying within certain height limits, are controlled by ground Air Traffic Control centres. These centres, which may be civilian or military in origin, (in the United Kingdom both civil and military controllers operate in the same centres, although there are additional purely military centres) can observe the overall situation by using radar installations located on the ground. These radars are large, powerful, and accurate. The aerials may be many tons in weight, and tens of feet wide. They may be remotely sited, and may be 'ganged' so that the pictures presented are made up from signals from several different radar equipments. Extensive filtering and other aids are provided, including special height-finding radar equipments. It is, of course, quite out of the question to fit such equipment to any aircraft. The air traffic controller, on the ground, can observe on a radar Plan Position Indicator that an aircraft is heading for a position which threatens one of the aircraft for which he is responsible. He can call up the heights of one or both aircraft, and can decide what to do about the situation. The official requirement is that aircraft ought not to pass within five miles of each other at any time. Such a situation is called a 'conflict'. The Air Traffic Controller is not technically able to give orders to the pilots of aircraft, who are free to ignore his advice if they choose to do so, or to take action on their own initiative if they feel it is warranted. This does not often happen.

In the immediate neighbourhood of airports the role of the Radar Air Traffic Controller in collision avoidance is decisive. The ability of aircrew to detect and resolve conflicts visually is lessened by other tasks. On the procedural side, separation standards may have to be reduced to allow aircraft to land or take off in rapid sequence. The consequences of mistaken avoiding action are much more likely to lead to "chain-reactions" of disasters than in less crowded areas. The air traffic controller alone has an overall picture of what is happening and is the only agency in a position to detect all potentially dangerous situations and to advise aircrew when and what action is necessary.

Unfortunately, the Air Traffic Controller has to look after a number of aircraft and has many other duties to handle at the same time.

The overall aim of this study was to obtain quantitative measurements of the Air Traffic Controllers' ability to predict quickly and accurately whether aircraft were likely to pass dangerously close to each other.

Before experimental work was started a survey of the relevant literature was carried out. This is summarised in the next chapter.

II. LITERATURE SURVEY

1. Preliminary remarks on the organisation of the survey.

The existing literature on collision avoidance by radar is for the most part in the form of papers in scientific and technical journals, and research reports. There are few general reviews of the field.

Very little of the work carried out on the human aspects of radar operation has concerned the quantitative interpretation of radar traces, such as is required in the avoidance of collisions. Perhaps for historical reasons, most work on radar observation has concerned the detection of targets, often fleeting or intermittent ones. The specific problem of watching for targets which may appear unexpectedly is known as "vigilance", and an extensive literature exists on the human factors aspects of this subject. Unfortunately the literature on vigilance is of little use in the study of collision avoidance. In the study of vigilance the problem is one of attention, errors being made when the signal is in some way not perceived. In conflict avoidance, the attention of the subject is not a major factor, since the situation may be detected at any time and action taken subsequently.

The decision processes involved are applied consciously, although they need not be consciously formulated. The judgement required is quantitative, not qualitative, and the signals are not fleeting. Unlike the usual run of vigilance tasks, the signal does not appear suddenly and disappear equally suddenly, but grows from a low level to a level sufficiently high to be virtually unambiguous.

Since the topic of vigilance may be of interest to some readers, four relevant bibliographies (Warren Spring 1961, 1966 a - c) are included in the reference list at the end of this thesis.

Another possible source of relevant information is the literature of experimental psychology on the subject of the perception of motion. In practice, however, this is not much use, since it does not deal in any detail with the type of perception of motion here discussed. It is usually couched in terms of gestalt psychology, which are complex and daunting to the uninitiated, and tend not to repay study. Such relevant information as can be identified is included in Appendix 1, which lists the more important work in this field in chronological order, from 1759.

Such relevant literature as exists may be divided into a number of separate streams of research effort. Five of these streams are described in this chapter. These are:-

General surveys, mentioning collision avoidance.

Studies of visual collision avoidance.

Studies of radar collision avoidance, using static simulations.

Studies of radar collision avoidance, using dynamic simulations.

Other studies providing information relevant to collision avoidance.

Work in each of these streams will be taken as far as possible in chronological order, to illustrate the development of techniques.

2. General studies of collision avoidance.

Perhaps the best review of the problem of the avoidance of collision in the air is the January 1958 issue of the Journal of the Institute of Navigation (Volume XI, No.1) which contains a selection of papers covering the basic features of collision avoidance, from the mathematical (Morrel), physiological (Perdreil), psychological (Missenard) and historical (Roessger) aspects. Baker (1962) presents a good general introduction to the problems of human factors in radar operation, but does not deal with collision avoidance in any detail. Morris and Horne (1958) provide a useful survey of the field of visual search techniques, but again there is little direct reference to collision avoidance. Baker and Grether (1954) provide some details of accuracies of estimation to be expected with the types of radar display then available. Owing to subsequent technical development, this research is no longer relevant, as is the classical work of Fitts (1947, 1949, 1951). Although the general principles expressed in these works are acceptable, specific findings must be taken with some reserve as a consequence of the vast increases in the speed and density of air traffic in the past decades. Hollingdale (1961), Morrel (1958) and Crofton (1962) discuss the mathematics of collision avoidance, but do not deal with human performance.

A very useful, but inaccessible paper is that by Hopkin (1966), which discusses, in the light of practical experience, the techniques and trends in the use of visual display equipment in air traffic control. The companion paper by Rolfe (1966) on the assessment of airborne visual displays contains some valuable discussion of the more common faults of experimental studies in this field.

The Journal of the Institute of Navigation is primarily concerned with practical and administrative approaches to collision avoidance, and contains many proposals for the modification of the current rules for the avoidance of collision in the air and at sea. The bulk of the work reported refers to the avoidance of collision at sea, and almost all of it is mathematical in approach. An extended and occasionally heated argument has been sporadically in progress for the last ten years about the merits of various types of collision avoidance systems. These have been mainly concerned with the problems of ships employing the rules in conditions of no mutual communication, where both vessels manoeuvre independently. The arguments have contained little or no experimental information, and many of the assumptions made in the mathematical models presented contain unrealistic assumptions about human performance.

3. Studies of visual collision avoidance.

The study of schemes for visual collision avoidance will be discussed briefly to provide some background.

Gibson (1947) describes an estimation of velocity test used by the United States Air Force in aircrew selection. The subject was shown a motion picture of an aircraft flying into a cloud, followed by a shell-burst within the cloud. The subject had then to say whether the shell had burst ahead of, or behind the now invisible aircraft. Gibson did not quote any performance figures, being primarily concerned with constructing a selection test.

Warner and Blaisdell (1948) reported on a number of colouring schemes for aluminium coloured aircraft. They operated by testing proposed paint schemes applied to models of aircraft then in service. These models were viewed by a large number of observers. The study antedated the use of fluorescent paints, and suggested that a colour scheme using white paint overall, with glossy blue trailing halves of wings and tail surfaces was more visible than any other pattern. Lazo and Bozee (1961) discuss these results in the light of atmospheric dilution of colours, showing that at the theoretical limit of detection of aircraft - about 20 miles in clear visibility - the "blueing" of objects by the atmosphere would remove the effects of any colour scheme. In practice, however, this effect does not occur, because the aircraft are not detected until they are at one-quarter to one-fifth of the theoretical distance (4 to 5 miles) (Howell 1947) at which distance colours have a marked effect.

Following these initial explorations, a detailed and extensive research programme was undertaken by the Applied Psychology Research Corporation, whose reports are listed in the reference list by title (Applied Psychology Research Corporation 1961 a - f, 1962 a - g. 1963 a - c). These studies covered all aspects of paint and flashing light visibility aids, and established that the fluorescent paints now used on military aircraft were the most effective, and that it was brightness rather than colour which was what mattered. The actual colour schemes did not appear to be important, and paint gave little indication of the relative attitude of aircraft. A summary of the work of the Applied Psychology Research Corporation on paint is given in Cook, Breasley and Robinson (1962).

The works of Skeen (1959) on fluorescent paint, which antedated those of the Applied Psychology Research Corporation and of Marshall and Fisher (1959) on practical measurements of daytime conspicuity of aircraft have proved unobtainable to the present author.

4. Studies of radar collision avoidance using static simulations.

Experimental studies of collision avoidance may be divided into two types. These are "static" simulations in which no actual movement of targets takes place from moment to moment, and "dynamic" simulations in which movement occurs. In static simulations, the speeds and directions of motion of aircraft must be indicated by some more or less arbitrary convention. The dynamic simulation, while more naturalistic, requires more elaborate apparatus, and more effective recording techniques.

A special class of dynamic simulation is what may be called "close simulation". This type of simulation is that in which every effort is made to approximate to the operational situation, in the hope that the observers' behaviour will be as little disturbed as possible. The ultimate in close simulation would be to actually carry out experiments in the real situation. Where conflict avoidance is concerned such simulation is liable to be disproportionately expensive and, on occasion, dangerous.

The earliest static simulation investigations recorded are those of Bowen and Woodhead (1953, 1955). In the first of these studies the observer was shown a number of dots, forming a portion of a straight or curved track, and was asked to estimate where the track would hit a distant line, and to estimate the length of extension required. It was found that the length of the extension was underestimated, and that the length of track, in terms of the number of dots presented, did not affect the accuracy of prediction of direction. In fact, the only result of increasing the length of track was to decrease the variability of errors in direction estimates. The second study is primarily concerned with estimation of the relative ease of use of a number of displays using different co-ordinate systems.

Manglesdorf (1955a) summarises two unpublished reports (Manglesdorf and Fitts, 1954 a and b). In the first of these,subjects were required to adjust a simulated set of blips, which were presented on a screen, so that they were on a collision course compared with another set of blips, which were varied in position. Extrapolated time to arrive was of the order of eight minutes, and measurements were taken of deviations from the correct setting and of variability from position to position for each observer. It was found that there were differences due to speeds and courses of aircraft, but these are not described in detail, as the experimenters were primarily interested in display parameters, such as the length of trail visible. (It is likely that the task of adjusting trails to ensure collision is considerably different from estimating whether a course is in fact a collision course.)

The second study reported in Manglesdorf (1955a) involved judgements of collisions, and was primarily concerned with the type of trail used to indicate motion. The alternatives were a simple standard fading trail, and a storage-tube type of trail; providing constant brightness. Both types were simulated photographically. Important effects were observed for relative speed and for time-to-go, but the two types of trail did not differ significantly. Manglesdorf then describes a further experiment in which distances to go and target angles were varied, and subjects again moved a trail of points forward or back to cause the two aircraft to collide.

Manglesdorf found that the variability of judgements of collision increased systematically as the angle of intersection of the two trails became more obtuse, and as the speeds involved became larger. He suggested that under the conditions of this experiment, two different methods of adjustment were employed by the observers. Where angles were small, and speeds relatively similar, the two trails were adjusted to be equidistant from the point of intersection, which had to be estimated by the observer. There also appeared to be minimum error when the angle of intersection was 90 degrees. This was ascribed to a differential effect of the ratio of speeds involved. Where speeds of aircraft were discrepant, there was a greater error at smaller angles. Where speeds were more nearly the same, the error tended to be greatest at large angles.

Manglesdorf derived a mathematical model to explain his observed results, on the basis of which he predicted

a) at target distances of 20 miles and sweep rates of 10 r.p.m. variations of trail length and target speed in the region of 100-400 knots should have relatively little effect on variable error.

b) the slower the sweep rate, the greater the error.

c) close to intersection, high speed targets will contribute most of the error.

d) Distance to intersection is the greatest single source of variance in predicting simultaneity of arrival.

Schipper and Versace (1956) studied the effects of scope size, blip size and blip sharpness on judgements of relative arrival times. In this case the judgement required of the observer was which of two aircraft would reach a line first. Although Schipper and Versace were primarily interested in display variables, they did observe significant effects of time to go and of relative aircraft speeds.

Mcguire (1957) studied three traffic configurations using a method of adjustment technique, similar to that of Manglesdorf. He studied (a) targets approaching a marked point at the apex of a 45 degree angle, (b) targets approaching a line from the same direction, (c) targets approaching a line from opposite directions. The task was to estimate which aircraft would arrive first. In a first experiment, using only three skilled observers, configuration (a) resulted in greater errors than (b) or (c). In a second experiment, in which a storage tube type display was also employed, no significant differences between configurations was observed, although the storage tube display gave better performance. The latter study used six highly skilled U.S.A.F. radar controllers as subjects.

From here on reference will need to be made to different types of situation, and a useful convention of Buckley (1962) (reported in an undated experiment credited to Buckley, Maclaughlin, and Benson - called CODE) will now be introduced. This experiment was a pilot study for a conflict detection and prediction system evaluation, and it was necessary to refer to three types of event within the situations. These were actual conflicts which were detected, actual conflicts which were not detected, and non-conflict situations which were reported incorrectly to be conflicts. Buckley assigns appropriate animal names to these. For completeness a further case is needed in the discussion of experimental studies in general, the situation when a situation is not a conflict, and is correctly reported as not being a conflict. (This did not occur in Buckley's example.)

The following names will be adopted for discussion purposes:-

Actual Conflict - Correctly Detected	BLOODHOUND or HAWK
Actual Conflict - Not Detected	OSTRICH
No Conflict - Called Conflict	WOLF
No Conflict - Called No Conflict	DORMOUSE

The first three names are due to Buckley, the last to the present author. Buckley in fact used the descriptions to provide performance scores for observers, using an arbitrary scale of preferences. (Bloodhounds were desirable, wolves mildly undesirable, and ostriches very undesirable.)

Hopkin (1963a, 1963b, 1965) reports three interesting experiments using paper simulation in which widely different groups of observers were used. These varied from Institute of Aviation Medicine staff, through radar trackers inexperienced in conflict detection, to air traffic controllers skilled in the field. The first study dealt with the detection of conflicts between aircraft flying steady courses at uniform speeds and heights, where the number of conflicts actually present varied from 3 to 9, and the number of trails present varied from 15 to 30. The task was to detect conflicts, defined as actual collisions, and performance was measured in terms of the percentage of conflicts detected, (BLOODHOUNDS) this averaged 70%. In addition about 30% of conflicts observed were in fact not conflicts (WOLVES). Observers were allowed as much time as they desired. The amount of time required seemed to be proportional to skill, although there were wide individual variations between observers.

Hopkin's second study (1963b) concerned only two aircraft per trial, both aircraft flying straight line courses, and at constant speeds. Factors varied were track velocity, angle of approach, and distance between tracks. Hopkin found a significantly larger number of errors (both WOLVES and OSTRICHES) at large angles of approach, but only when indirect distance between the aircraft (via the point of track intersection) was held constant, errors were not affected by the angle of approach, and Hopkin concluded that the angle of approach did not affect the number of errors, except in so far as it increased the distance between the aircraft. Hopkin also found that the number of actual collisions missed (OSTRICHES) was not affected by the direct distance between the aircraft, while the number of false collisions reported (WOLVES) was increased, with increases in the direct distance between aircraft. In this experiment, Hopkin used a total of 24 subjects in each experiment, twelve being I.A.M. staff, and twelve being R.A.F. radar trackers. I.A.M. subjects were slower, but more accurate. Hopkin attributes the differences to the greater age, motivation and intelligence of the I.A.M. subjects.

Hopkin (1965) reports an experiment in which the effects of curvature of track were introduced. Twenty-four observers, half being from the I.A.M. and half from R.R.E. Malvern, were shown 108 situations drawn on cards. Performance was measured in terms of the errors made by observers, these errors being subdivided into "No" - conflict missed (OSTRICH), and "Yes" - conflict imagined (WOLF). It was found that these errors differed significantly in their distributions, OSTRICH errors were affected both by the relative velocity of the two aircraft displayed and by the curvature of their tracks. WOLF errors were not affected by these, but were affected by miss distance, and by the groups. More WOLF errors occurred with smaller miss distance, and more WOLF errors were made by R.R.E. observers, although they were the more experienced group. It appears that more errors were made where the tracks differed in curvature, although the significance of the effects observed were relatively low. Hopkin's work is the only study reviewed so far which cannot be faulted on the lack of or quality of experimental observer.

Two other studies may be dealt with at this point. Although primarily designed for other ends they provide some evidence for the general picture of conflict avoidance. The first of these is Howell and Tate (1964). They studied the differences in performance due to two main types of display, one spatial, like a PPI, the other tabular, like a list. The displays used were symbolic, and the factors varied in the course of the experiments were constructed on principles not directly relevant to air traffic control. Their conclusion was that the performance of observers could be described by two methods of information storage within the observer. The first was a temporary peripheral storage, which was particularly adapted to accessibility, the second was a central associative memory, which was more retentive, but less accessible. In the experiments relevant to these findings some 40 observers were employed.

The second research study reported was by Moss, Kraft and Howell (1961) on the effect of overlay configurations on estimations of speed and heading. Four overlays were studied, using every combination of range rings and angle marks. They found that the range errors approached 4% as the interval between range rings was decreased, (going down in error). Angle marks reduced error in heading estimation by about .5 degrees, but increased errors in range. Range rings seemed to have little effect on either judgement. Tracks were coded either by providing a lead line, or by providing a trail line. The former produced quicker, the latter more accurate judgements.

5. Studies of radar collision avoidance using dynamic simulations.

There have been relatively few studies of the dynamic type, probably on account of the difficulties of devising simple but adequate equipment, and of recording and analysing responses.

The earliest study of this type was that of Gottsdanker and Edwards (1957) which arose naturally from the previous work of Gottsdanker (1952, 1955).

In this work, two slits were used, and two moving point targets were shown. The slits were angled at 90 degrees, and the moving points were seen to move towards each other. The apparent speed of one target was held constant, at about 15.5mm/sec., while the speed of the other varied. In two cases the other target appeared to accelerate, having been drawn as a parabolic line. Ten observers (mostly college students) were employed, six of whom appeared to judge the events from the final relative position, rather than the relative speed. The smoothing reported in other experiments where accelerating targets were employed did not seem to happen here. Subjects tended to decide that the variable target would not reach the cross-over point first. This type of experiment appears to suffer rather from lack of realism.

Gerhard (1958) describes a series of experiments undertaken at Reading University on the judgement of velocities, and motion prediction using two back projected point targets approaching at right angles. Gerhard used an interception situation, varying the amount of time for which the oberserver could see the target to be intercepted. Gerhard first blocked off the descending target for different parts of its travel, and found that subjects tended to use only the first and last parts of the trail, taking little account of intermediate sightings.

In another experiment, in which the velocity of the target was also varied, as well as the proportion of track obscured, the variability of miss distances rose with speed, and with the proportion of the track which was obscured.

It appears that Gerhard's subjects acquired a rather different type of skilled behaviour than intended, so that very little can be deduced from his observations. Gerhard used a track motion of 190mm, and a velocity of approximately 36mm/sec. This would be the equivalent of some 10,000m.p.h. on a standard 10" PPI at a scale of 20 miles per inch.

Brown and Brown (1955) reported that there were apparently three types of motion perception. These were - in ascending order of speed:

1. For very low speeds, subject used changes in position to deduce the existence of motion, which was not perceived directly, (e.g. Clock Hands).
2. Medium speeds - which were directly sensed - (Birds flying, cars passing).
3. Very fast motion - object seen as blur - other clues used to estimate speeds - (Fan blades, propellor blades).

It seems possible that Gerhard was getting a mixture of types 1 and 2, whereas in radar surveillance type 1 is probably predominant. The type of simulation used by Gerhard was continuous, so that the intermittent advance characteristic of the Radar PPI did not occur.

Alexander and Cooperband (1965) describe an experiment which was designed to test the hypothesis that the rate of rotation of the line of sight was a sufficient clue for collision prediction. Subjects used were four male senior or graduate students from an American university. Stimuli presented were presented on a P.P.I. type display screen, which had no remanence, so that the observer saw only points of light 3/16th inch in diameter. One point moved steadily at 1 inch/sec. for a distance of 1.2 inches, while the other target rotated about it at a constant angular velocity. The subjects employed showed a threshold of about .5 to .7 degrees per second. The authors demonstrate that the effect observed must be primarily due to the rotational component, by eliminating the effect of the relative motion in the direction of of translation. It should be noted however, that the situation employed was an abstraction - deliberately made - and that the two points of light used did not behave like radar "blips", having no "tails" and being continuously visible. The absolute speed, considered in terms of a ten-inch P.P.I. at 20 miles per inch, would be of the order of 70,000 miles per hour. If allowance is made for the distance at which the situation was viewed, this might be reduced by a factor of 10, but the speed of travel would still be large compared with that normally to be expected in radar surveillance.

6. Other studies.

Four studies closely related to the actual radar situation will be discussed, in view of the incidental information relevant to the conflict situation contained therein.

Bassett, Kahn, La May, Levy, and Page (1965), discuss the evaluation of a three dimensional display. They found, using the display that the errors in superposition were increased when there were targets in the line of sight, and that location errors were of the order of one half to one inch, they were correlated to the position on the scope, but differed significantly from person to person. The threshold for perception of motion was affected by ambient illumination, and the assessment of relative motion was most accurate in the middle ranges. The method of rate estimation had little effect on the results, whether it was by active control, method of adjustment, or the method of constant stimuli. The speeds used were around .1 to .7 inches per second, corresponding to 15-90 minutes of arc.

These results cannot be transferred to the two-dimensional screen but they do furnish some general corroborative ideas.

LaForge and Kennedy (1959) studied the effect of different glide path display configurations on the accuracy of control, measured in terms of path deviations. They found that a display presenting both azimuth and elevation was much more efficient than one presenting azimuth and elevation separately.

Paul and Buckley (1967) describe an assessment of a proposed large common screen for radar air traffic controllers, to replace the present individual screens. Their results include the finding that the percentage of conflicts correctly detected (Now called HAWK - not BLOODHOUND) was about 70%, while the number of WOLF reports was about 3%. The sixteen observers were skilled, practicing, controllers, so that these results may be compared with those observed in the present investigations. It is also interesting to note that error scores were found to be independent of the type of display employed.

Finally, Morin, Grant and Nystrom (1956) used a specially devised apparatus employing a series of lamps illuminated in succession to simulate the pips on a radar screen. They used twentytwo students as observers, with ten lights at 16 feet away from the observer. The observer recorded his response by pushing a button when he thought the target had reached an 'object' lamp.

By cleverly selecting the number and order of bulbs to be lit up by a pre-set timer, the apparent velocity of the object could be varied, the speed of the sweep line could be increased, the number of sweeps could be altered, and the distance from the last point to the target could be changed. The results observed were that times taken were much underestimated especially when the speed of movement was slow, so that the planned time was large. The longer the distance of travel, the greater was the error. In general the errors were proportional to time, and were reduced if more sweeps were given, or at larger intervals. The results observed are consistent with the general expectation, and the technique employed is remarkably ingenious. It is not clear however why a standard PPI with some simple electrical control circuit could not have been used.

This concludes the survey of methods employed and results obtained by previous investigators. In spite of considerable effort, it has not been possible to find any record of a fully organised simulation using skilled observers and adequate measurement techniques for the assessment of conflict detection.

Exactly why this gap should exist is not really clear. It may be that the few simulators available are in general too urgently employed, in the training of air traffic controllers and the assessment of modified techniques, to be available for such experiments. The continuation of paper and pencil simulation inclines one to this opinion. The setting up of radar simulation experiments is a major operation, so that such experiments cannot be undertaken lightly.

In order, therefore, to obtain quantitative measurements of the ability of the Air Traffic Controller to predict quickly and accurately whether aircraft were likely to pass dangerously close to each other the present investigations were undertaken. There were other, subsidiary, aims - which are described in detail in the next section.

III. PURPOSE OF PRESENT INVESTIGATIONS

This research had three objectives. These were:-

1. To describe in quantitative terms the ability of observers to form judgements of the future relative positions of aircraft presented on a Plan Position Indicator type display.

2. To investigate the effects of reducing the degree of verisimilitude of the simulation technique employed.

3. To investigate the differences in performance occurring between skilled and unskilled observers.

The first of these objectives is justified by the observation that there exists at present no quantitative information of this type. Such information as is available is derived from simplified simulations, often employing individuals far different from those who carry out the task in practice.

There are a number of possible approaches to the problem of gathering such quantitative information. Chapanis (1959) presents an excellent review of these approaches.

The most direct way of gathering information is by observation. An experimenter might record the performance of air traffic controllers in an actual air traffic control centre. He might do this by sitting behind a controller and noting the behaviour of the controller. This method has a number of drawbacks. Some of these are that it would require many hours of observation to accumulate sufficient data, incidents being rare on the whole and that it would require the experimenter to be an infinitely better and more patient observer than the controller. What may be more important is that it would require the experimenter, having seen a potential collision in the course of developing, to remain silent and wait to see if the controller noticed it. This would amount to risking the lives of aircrew and passengers and would be unethical.

Alternatively, the experimenter might have access to records of aircraft movement - such as are now obtained as a routine precaution in some areas, and of corresponding recordings of radio traffic. Although such methods might be less distracting for the controller, the sheer volume of analysis required to isolate potentially dangerous situations, particularly those not noticed by the controller would be prohibitive. (At the initiation of this study, air traffic control data was not recorded as a routine in the United Kingdom, so that this alternative was not then available).

The next most direct method would be that of direct experimentation in an actual Air Traffic Control Centre. This would involve the setting up of situations in which aircraft approached others dangerously closely in accordance with pre-arranged plans while observers judged what was about to happen. This would be expensive, difficult to arrange and dangerous. It would require the taking of unnecessary risks and would therefore be unethical.

A third approach would be to carry out a critical incidents survey. In this type of survey persons skilled in the field are asked to relate incidents in which dangerous situations have come about (Chapanis, 1959, Fitts and Jones, 1947, reprinted in Siniako 1961). -

This type of survey is particularly useful for determining what are the most common types of mistake or error, but is not suitable for the production of precise quantitative information. It is subject to subjective distortion of several types. People may forget episodes of which they are ashamed, or they may form their own ideas of the types of errors and mistakes which would not interest the observer and fail to report these. (Signal noise in radio equipment may not be reported because it may be considered unavoidable by the user.)

A fourth approach is to use simulation (Meister and Rabideau 1965, Chapanis 1959). This method is often expensive, may not represent adequately the true situation, and may provide misleading results owing to the knowledge that it is not the real thing distorting the performance of experimental subjects. In this case, it was possible to use elaborate simulation equipment operated by the Air Traffic Control Evaluation unit at Bournemouth (Hurn) Airport. The Ministry of Transport and Civil Aviation made available a number of civil air traffic controllers to act as observers, and arranged for service air traffic controllers to be made available. It was therefore possible to use a relatively realistic simulation situation, with subjects of an appropriate background.

A final approach, often adopted 'faute de mieux' by the experimental psychologist is to abstract the relevant features of a situation and present these in a diagrammatic form. This approach requires that the relevant features of the situation are known and are removeable from their normal context without perceptual distortion. It is by no means obvious that this is always the case, and an act of faith in the judgement of the experimenter is often required if the results are to be applied in the real world. This is always undesirable and may on occasion be dangerous. The method has certain advantages. It is usually cheap, flexible and easy to arrange. It allows preliminary trials to be carried out quickly and large or qualitative differences to be detected. These virtues must be balanced against their occasionally dangerous unreliability in absolute terms.

With these alternatives in mind, it was decided to investigate the problem by setting up a large number of situations for close simulation on a radar simulator, which provided the closest possible resemblance to the real situation. The situations selected for study were chosen to allow as many features of the real situation as possible to be isolated for statistical analysis, so that the first aim of the investigation might be achieved.

A selection of these simulations was then abstracted into the form of a simpler paper simulation model. The performance of observers on these simpler simulations was then compared with the performance of observers on the more elaborate simulation, so that the second aim of the research might be achieved. The third aim of the research was met by having groups of unskilled observers complementing the groups of skilled observers. (The difficulty of obtaining sufficient skilled observers led to the employment of two groups of skilled observers, one drawn from civilian sources, the other being composed of service air traffic controllers.)

Considerations of fatigue, learning and subject availability made it advisable to limit the number of possible simulations to between fo rty and seventy, each consisting of about four minutes running time, providing four sessions of approximately one and a half hours, resembling a normal radar air traffic controller's operational shift. (A normal shift would not consist entirely of collision avoidance operations.)

In fact, the choice of the exact number of simulations was determined by the experimental design used. This was a 'Hyper-greco-latin Cube'. This enables six factors to be tested at each of four levels in sixty four simulations in such a way that the effects of any factor can be isolated and assessed separately for significance. In practice, sixty four simulations each lasting two hundred seconds were used. The length of each experimental session was therefore about seventy minutes, including starting, ending and delays between simulations.

In order to reduce the number of possible factors to as few as six, the situation chosen for experimental study was that in which two aircraft approach each other on straight courses at steady speeds. The height levels of the two aircraft were not displayed, but were assumed to be the same. In practice, such conflicts are much the most common, although Hopkin and Ledwith (1953), mention that multiple conflicts are particularly difficult to resolve. Conflicts involving more than two aircraft give rise to so many possibilities that many more than sixty-four simulations would be required to cover the possibilities adequately.

The factors chosen, in consultation with experienced controllers, to be varied in this experiment were the following:-

1. The heading of the controlled aircraft.
2. The angle at which the aircraft approached each other.
3. The speed at which the aircraft approached each other.
4. The direction of rotation of the line joining the aircraft (the 'line of sight') together with the passing of the rogue aircraft in front of or behind the controlled aircraft.
5. The distance by which the rogue aircraft missed the control, measured along the tracks of the aircraft.
6. The position on the Plan Position Indicator at which the encounter took place.

The parameters measured were the speed with which the judgement could be made, together with the accuracy of the judgement in terms of a number of possibly important criteria. The speed was measured in terms of the time which elapsed between the observer making a judgement and the aircraft reaching their closest point.

In the paper simulation experiment, the sixteen simulations selected formed a 'latin square', so that the effects of the first four variables could be measured independently.

In the following chapters the experimental design, apparatus and methods employed in the electronic simulation are discussed in more detail. The choice of an appropriate variate is discussed, and performance is described in detail. The paper simulation experiment is then treated similarly, and finally the information obtained from the two experiments is used to satisfy the original aims of this investigation.

IV. THE ELECTRONIC SIMULATION EXPERIMENT. DESIGN, APPARATUS AND METHOD.

1. Experimental design.

The factors selected for testing in this experiment were:-

1. The direction in which the controlled aircraft was flying.
2. The angle at which the aircraft approached each other.
3. The speed at which the two aircraft approached each other.
4. The direction of rotation of the line joining the two aircraft, with the passage of the rogue aircraft ahead of, or behind the controlled aircraft.
5. The distance separating the two aircraft when the tracks intersect.
6. The position of the encounter on the radar screen.

These factors were chosen, in consultation with experienced air traffic control personnel, as representing the possible factors that might influence the behaviour of observers, and providing as great a variety of possible conditions as was feasible. Certain modifications to the situations were made so that the decisions made should be realistic, neither too easy nor to hard. Some practical difficulties were encountered in filming some of the simulations, which had to be moved from areas of the radar screen which could not be reproduced by the simulator. (The nature of the film recording is described in detail later in this chapter.)

The experimental design adopted is what is known as a "Hyper-greco-latin cube". This is a design similar to the well-known "Latin Square", and is analysed in a similar manner. Sixty-four simulations were designed in such a way that each of four levels of the six factors selected occurred sixteen times in all, accompanied in each case by four examples of each of the four levels of the other five factors. The design may be represented by a cube, using three factors as the three axes, and representing the other three factors by numbers, latin letters and greek letters. The design is sometimes known as a "Sino-greco-latin cube" in which case the levels of one of the factors are represented by Chinese letters. This procedure has not been adopted here. The nature of the design is such that it is not possible to analyse the data for the significance of interactions between the main factors.

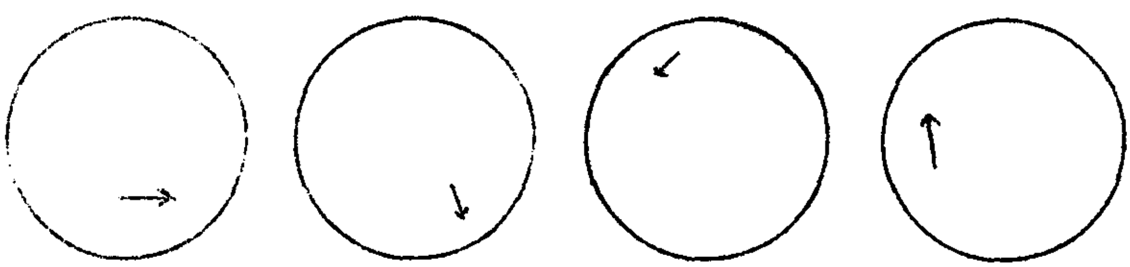
For the reasons mentioned in the previous chapter, it was considered necessary that each observer should be exposed to all the sixty-four experimental conditions. In order to obtain results suitable for generalisation to the population of air traffic controllers, a sufficiently large number of observers must be employed. Considerations of cost and the availability of equipment and skilled observers require that this number should be kept small. In the event, it was found possible to obtain twenty skilled Air Traffic Controllers, ten being civil air traffic controllers from the London Air Traffic Control Centre, and ten being Royal Navy and Royal Air Force air traffic controllers. In addition twenty-one unskilled observers were employed, selected as representative of the type of experimental subject used in experimental psychology - students and technicians.

For various reasons, the responses of certain subjects were not decipherable from the tape recordings made, and in certain experimental runs the simulator suffered from technical malfunctions which made the recorded simulations indecipherable. In these cases, the experimental observers were completely discarded. Analyses were finally based on the performance of eight civil air traffic controllers, five service air traffic controllers and fourteen unskilled subjects.

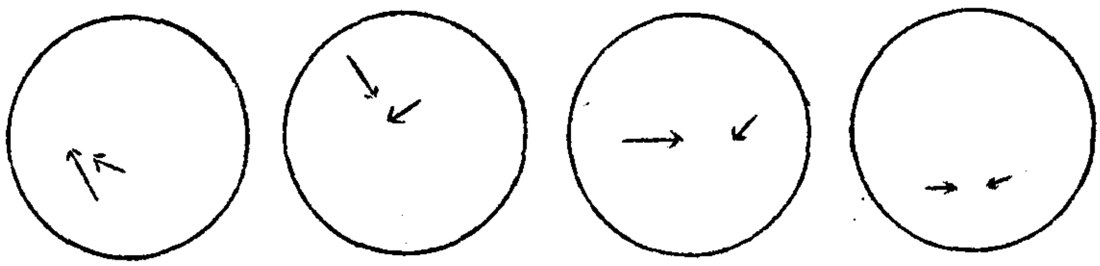
Factors varied between simulations.

Four levels were chosen of the six factors varied which it was hoped would cover the normal range of air traffic control operation.

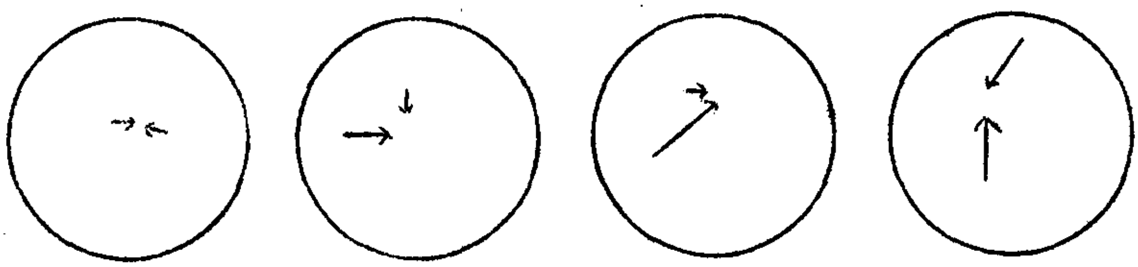
(1) The first factor varied was the heading of the Control Aircraft, and the four levels employed were 090 degrees, 150 degrees, 225 degrees, and 350 degrees (standard compass degrees).



(2) The second factor was the type of conflict, or, in other words, the angle between the tracks of the two aircraft. The levels employed were 45 degrees, 90 degrees, 135 degrees and 170 degrees.

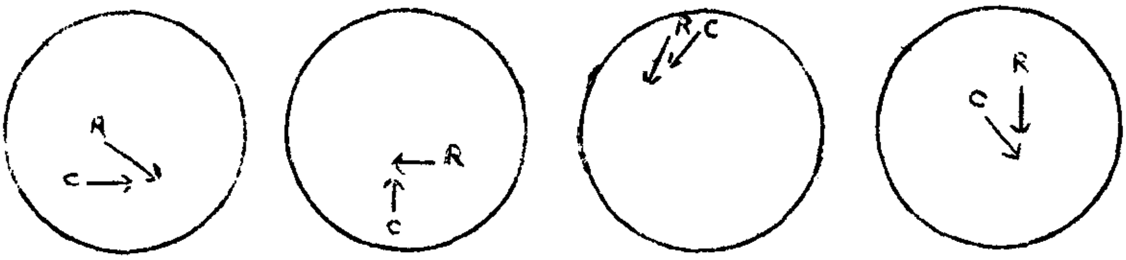


(3) The third factor employed was the speed of closing. This factor was employed at 240, 360, 480 and 600 knots. This speed is the vector difference of the aircraft speeds. In fact, it is assumed that the aircraft are at infinite distance when this closing speed is measured, so that the component of $\dot{\theta}$ velocity is nil.

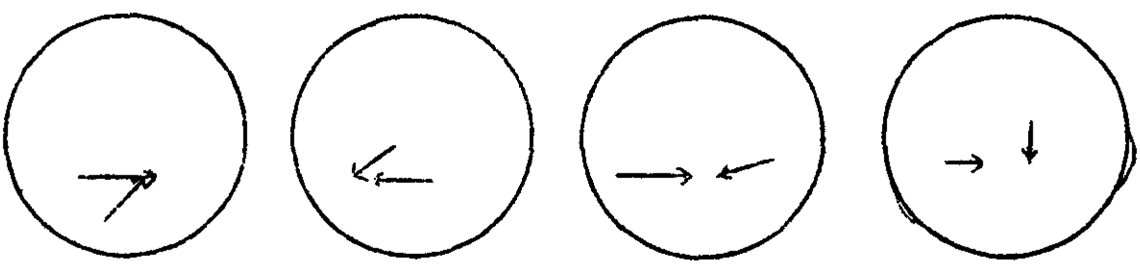


(4) The fourth factor employed was the nature of the miss of the two aircraft. Because there were no cases in which the two aircraft collided, it was possible to classify the situations into those in which the Rogue Aircraft passed ahead of the Control, and those in which it passed behind the Control. In

each of these cases it was possible to arrange the aircraft so that the line of sight rotated clockwise or anticlockwise. In doing so we ensure that the Rogue is initially on the right or left of the Control, as shown in the accompanying diagram.



(5) The fifth factor was the <u>track intersection distance</u>, measured as the distance of the Rogue from the point of cross-over when the Control reaches that point. This definition was chosen in preference to the distance at the point of closest approach for ease of the initial calculation. Distances chosen were 2, 4, 6, and 8 miles.



(6) The sixth and final factor varied was the <u>position on the PPI</u> at which the incident occurred. Four levels were used, defined according to the position with respect to the centre of the PPI. These levels were outer edge of PPI, with the control

heading inwards, outer edge of PPI, with control heading outwards, median, (which is to say not on the edge and not at the centre), and central. These levels relate only to radial distance, and do not contain any restraint on angular positions.

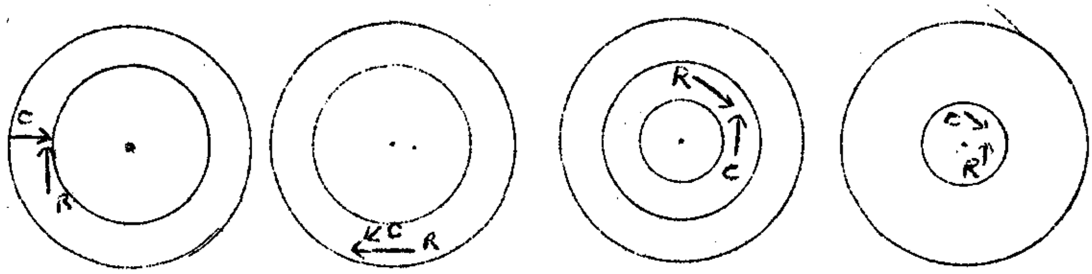


Table 1 provides a summary of these levels, and Table 2 states which levels were applied in each simulation. Figures 1 - 4 show the 64 simulations employed. Full tracks are shown, although only about a quarter of the trail shown would be visible at any given time, and only one simulation would be visible at any time.

TABLE 1

Levels Used of Factors Examined (Summary)

	Factor	Level	Value	Unit
1.	Track of Control	1	090	Degrees (Compass)
		2	150	
		3	225	
		4	350	
2.	Type of Conflict	1	45	Degrees (Angular)
		2	90	
		3	135	
		4	170	
3.	Speed of Closing	1	240	Knots (Nautical Miles per hour)
		2	360	
		3	480	
		4	600	
4.	Nature of Miss	1	Rogue Ahead/Clockwise/ Rogue on Right	
		2	Rogue Behind/Clockwise/ Rogue on Left	
		3	Rogue Ahead/Anti-clockwise/Rogue on Left	
		4	Rogue Behind/Anti-clockwise/Rogue on Right	
5.	Track Intersection	1	2	Miles
		2	4	
		3	6	
		4	8	
6.	Position on P.P.I.	1	Outer, control heading inward	
		2	Outer, control heading outward	
		3	Median	
		4	Central	

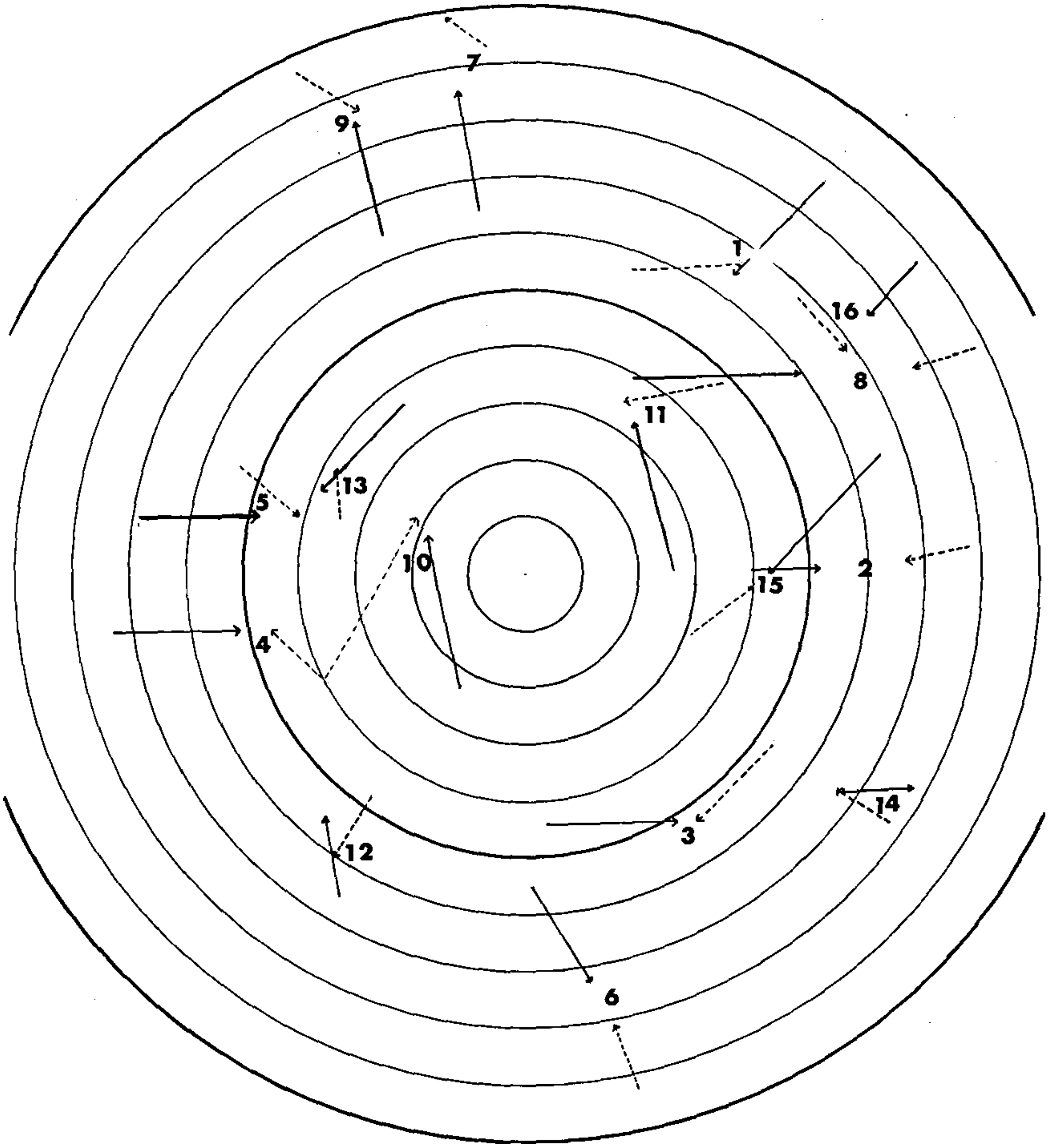
TABLE 2

Levels of Factors Employed in Each Simulation

Simulation	Factor 1	2	3	4	5	6	Simulation	Factor 1	2	3	4	5	6
1	3	3	4	2	1	1	33	4	4	2	3	1	1
2	1	4	2	1	3	2	34	1	2	3	1	4	3
3	1	3	4	1	2	4	35	3	3	1	1	3	3
4	1	3	3	3	3	1	36	2	1	4	3	2	1
5	1	1	1	1	1	1	37	3	1	2	4	3	1
6	2	4	3	3	4	2	38	3	3	2	3	2	2
7	4	1	1	3	3	2	39	1	2	1	4	3	4
8	1	4	4	4	4	1	40	2	2	1	1	2	2
9	4	3	3	1	1	2	41	3	3	3	4	4	4
10	4	1	2	1	2	3	42	4	1	4	4	1	4
11	4	2	3	3	2	4	43	1	4	1	3	2	3
12	4	3	2	2	3	4	44	4	2	2	4	4	2
13	3	1	1	2	2	4	45	3	4	1	4	1	2
14	1	3	1	2	4	2	46	4	1	3	2	4	1
15	3	4	4	3	3	4	47	4	3	4	3	4	3
16	3	2	1	3	4	1	48	2	1	2	2	1	2
17	2	1	3	1	3	4	49	2	3	2	1	4	1
18	1	4	3	2	1	4	50	1	2	4	3	1	2
19	4	4	4	2	2	2	51	2	4	2	4	2	4
20	2	2	3	4	1	1	52	4	3	1	4	2	1
21	3	1	4	1	4	2	53	1	1	4	2	3	3
22	1	2	2	2	2	1	54	4	4	1	1	4	4
23	3	1	3	3	1	3	55	3	2	2	1	1	4
24	2	2	4	2	4	4	56	2	3	4	4	3	2
25	2	3	3	2	2	3	57	3	4	3	1	2	1
26	4	2	1	2	1	3	58	1	1	2	3	4	4
27	2	2	2	3	3	3	59	2	4	4	1	1	3
28	2	4	1	2	3	1	60	4	2	4	1	3	1
29	3	2	4	4	2	3	61	1	3	2	4	1	3
30	2	1	1	4	4	3	62	3	2	3	2	3	2
31	3	4	2	2	4	3	63	2	3	1	3	1	4
32	1	1	3	4	2	2	64	4	4	3	4	3	3

Figure 1

Simulations 1 - 16



Controlled aircraft indicated by solid lines
Rogue aircraft are indicated by dotted lines

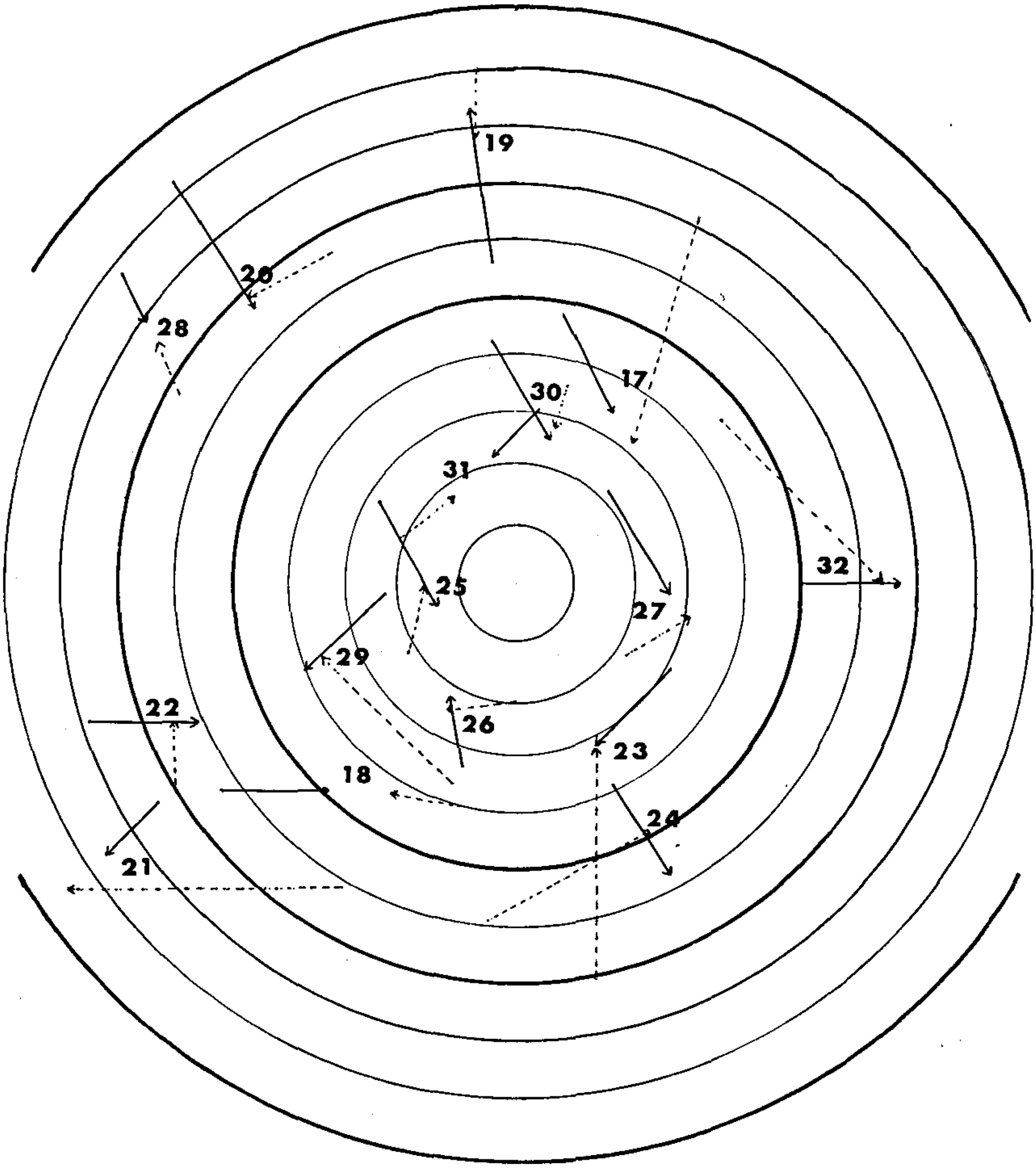
Tracks indicate the entire flight path of the aircraft, of which only 25% would be visible at any one time.

SCALE

20 miles (simulated)
= 1 inch on display
= 17 mm in this figure

Figure 2

Simulations 17 - 32



Controlled aircraft indicated by solid lines
Rogue aircraft are indicated by dotted lines

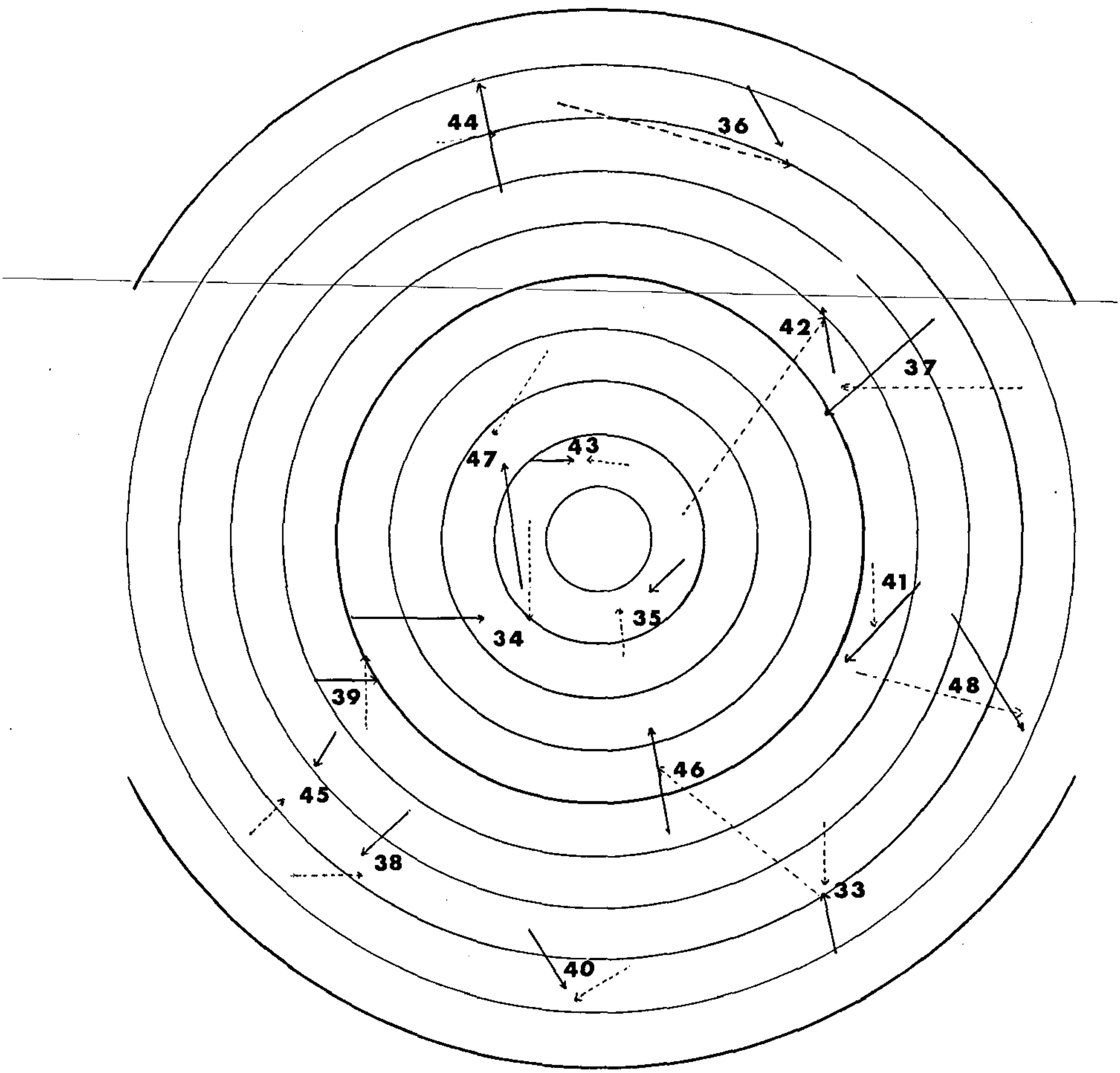
Tracks indicate the entire flight path of the aircraft, of which only 25% would be visible at any one time.

SCALE

20 miles (simulated)
= 1 inch on display
= 37 mm in this figure

Figure 3

Simulations 33 - 48



Controlled aircraft indicated by solid lines
Rogue aircraft are indicated by dotted lines

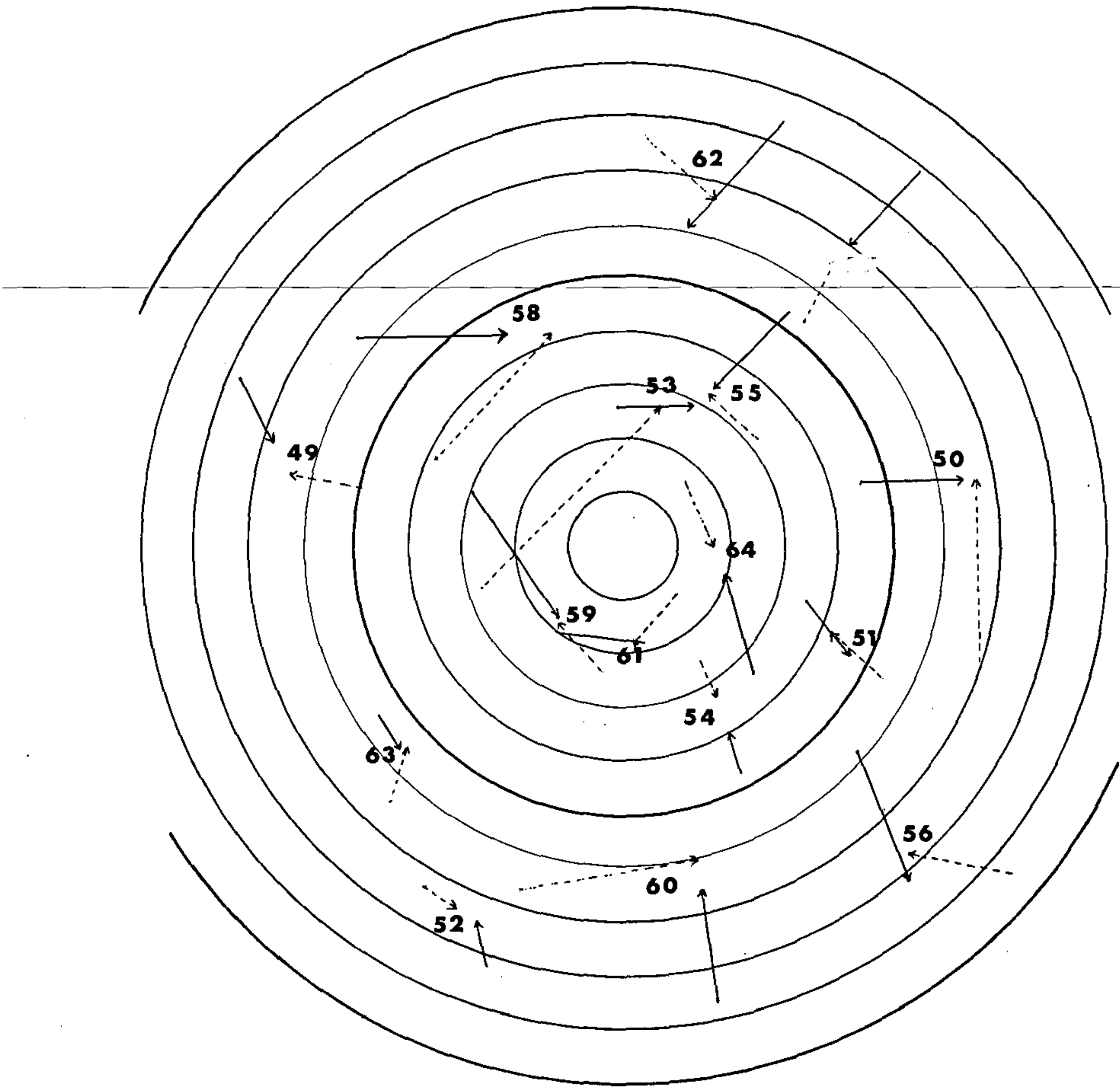
Tracks indicate the entire flight path of the aircraft, of which only 25% would be visible at any one time.

SCALE

20 miles (simulated)
= 1 inch on display
= 17 mm in this figure

Figure 4

Simulations 49 - 64



Controlled aircraft indicated by solid lines
Rogue aircraft are indicated by dotted lines

Tracks indicate the entire flight path of the aircraft, of which only 25% would be visible at any one time.

SCALE

20 miles (simulated)
= 1 inch on display
= 17 mm in this figure

2. <u>Preparation of experimental material and apparatus.</u>

The preparation of the experimental material for the electronic simulation experiment was performed by the A.T.C.E.U. at Hurn, using the Simulator, and the Metrovick film recorder.

The A.T.C.E.U. simulator, now being replaced by a more precise machine, is an electro-mechanical analogue computer type of radar simulator. The blips simulating aircraft are controlled by separate individual control ~~units, which are run by separate operators, called~~ "Blip-drivers". While a simulation is being carried out, it may be recorded on film, which is then processed, and may be re-run using the Metrovick film recorder, to provide a picture simulating the running of a radar on one or more standard consoles.

The sixty-four experimental combinations of factors were made up into film scripts, each simulation being equivalent to an elapsed time of 200 seconds, during which the aircraft passed from fairly distant positions to somewhere in the region of the point of closest approach, and occasionally beyond this point. No effort was made to begin the films at exactly the same point for each shot, since this might have caused spurious learning of times.

Four "scripts", each consisting of sixteen "shots" were compiled. Each "shot" consisted of a simulation run of about four minutes duration. Allowing for blank frames and starting, each script took about 70 minutes to run.

The production of the film called for considerable expertise and patience on the part of the A.T.C.E.U.'s staff. The limiting factor was the accuracy of the simulator, which was old, and suffered from a certain degree of mechanical "play". The film was recorded in reverse, to ensure that the blips would finish in the right place as closely as possible. During recording. the operational sequence was as follows. First the blip drivers positioned their blips in accordance with the instructions of the supervisor, the blips were then started on reversed courses, while the film was recorded. After about twenty sweeps the rogue was turned off, and the control alone ran for a few (2 - 4) more sweeps. A few blank sweeps were left, the recorder was stopped, and the blips positioned for the end of the previous shot. In order to make it possible to join the film without losing the orientation, a North Marker was incorporated in all shots. This served as a reference point in the subsequent joining of film, the Metrovick film being continuous - not by frame.

The degree to which the images of aircraft jumped varied considerably, and there was not necessarily a close correspondence between the jumping of blips observed on the monitor during the filming of shots and the jumping of blips observed on the film after processing.

Where it was judged that a shot was not satisfactory, the shot was repeated again, and if necessary, a third time. Certain shots were found to cause the blips to vanish, either close to the centre or near the edge, and these shots were re-positioned before the repeat filming. A total of about one-third of the shots had to be repeated. When satisfactory shots had been produced, they were spliced into the original film in their correct positions.

The splicing of film was carried out by the technical staff of the A.T.C.E.U. so that the resultant shifts of orientation rarely reached 10 degrees. (This was easily remedied by manual corrections during running).

It should be noted that to record a film backwards, not only must the shots be filmed in reverse order, but the aircraft must be placed in the mirror images of their final positions, and "flown" in the reverse of the mirror image of their courses. When in addition a film recorder must be started and stopped at precise times at short intervals, the operation is difficult.

In order to check that the final scripts were correctly assembled, photographs were taken of the final stages of each shot. These were then compared with the initial positions specified. Figure 5 shows the end of a typical "shot".

Figure 5

End of a typical simulation

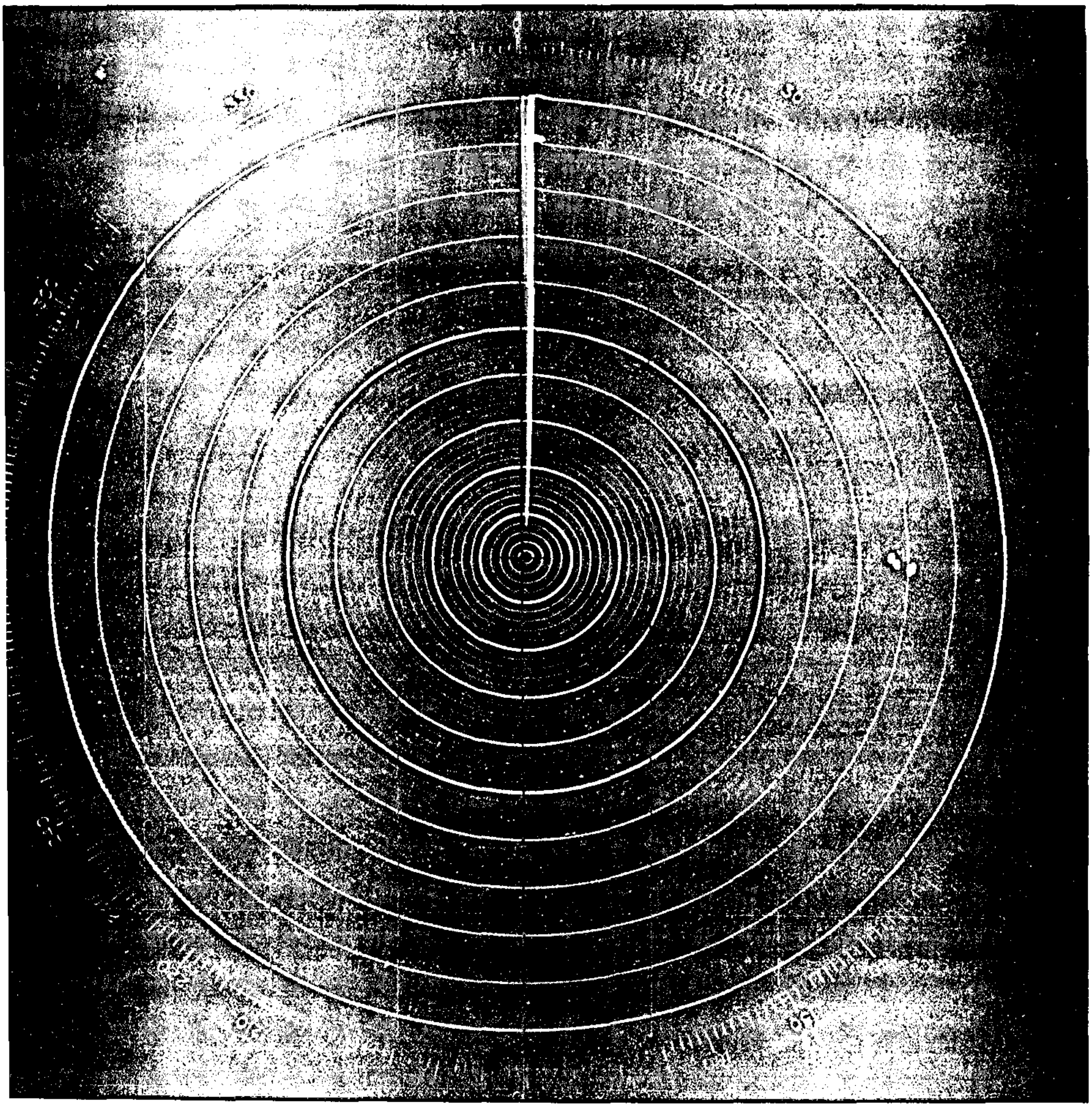


Figure 6 shows the general layout of the experimental area, and the apparatus used during the running of the experiment. The experimental area was divided into two parts, the Equipment Room, and the Simulated Control Room.

The Equipment Room contained the Metrovick film recorder, now used only to display the previously recorded film, the tape recorders used for the recording of the observer's responses, and the special apparatus designed to inject a $\frac{1}{2}$ second audio-frequency "pip" onto the tape recordings as the sweep of the radar passed through the North Marker position.

The Metrovick Film Radar Recorder has the peculiarity that the information recorded on the film is given by the position of dark points across the film, which runs continuously over a sensing head, and is used to control the brightness of the radar sweep. This has the consequence that the size of the blip, and the accuracy with which its position can be determined will be proportional to its distance from the centre of the display. Thus an error of, say, one degree in the bearing of a blip from the centre, could cause a positioning error of about one-sixtieth of an inch at one inch from the centre, or of about one-twelfth of an inch at the periphery of the screen, five inches from the centre. This corresponds to the type of errors observed on radar Plan Position Indicators of the vintage here simulated. The presence of a certain amount of 'play' in the film transport system can lead to an irritating tendency to raggedness in the resultant 'trails'. The Metrovick recorder operator was provided with a monitor screen, on which he could observe the picture produced, and - where necessary - check that the manual corrections to display orientation had produced the desired results. A telephone link was provided between the experimenter and the Metrovick recorder operator. (Figure 7).

The Simulated Control Room (Figure 8) was equipped to allow five observers (S1-S5) to view the experimental film at the same time on separate consoles. In addition, a sixth console was provided for the experimenter (X). In order to provide a fair compromise between the requirements of experimental efficiency and of maintaining an approximation to the normal environment, observers were not completely isolated. The consoles were arranged around the experimental area in such a way that no observer was in the normal field of vision of another.

Observers wore standard headsets, which tended to reduce their awareness of extraneous stimuli. In general, observers did not, when questioned, express awareness of the comments given by other observers. When both skilled and unskilled subjects were employed at the same time, they were allocated consoles in such a way that there was no grouping of skilled or unskilled observers.

The lighting of the area was maintained at a low level, to simulate the lighting of a normal air traffic control room - it was in fact rather dim for this purpose. This provided the maximum persistence of the traces on the PPI's and had the advantage of reducing visual communication between observers.

The consoles used are shown in Figures 8 and 9. (The two closed circuit TV display screens mounted above the displays, and the construction observable to the far right in Figure 8 were used in another experiment, and were not involved in the present experiment. The TV displays were not illuminated.)

The PPI display is mounted at an angle of twenty degrees to the vertical, so that it is approximately normal to the line of sight of the observer. The horizontal ledge in front of the observer contains a trans-illuminated map, not used in this experiment. The controls for the radar display are grouped around the screen. Most of these controls were inoperative for this experiment.

Looking more closely at the screen itself, we note that the actual diameter of the radar tube is ten inches, and that this is surrounded by a dark ring marked in degrees from 0 to 360 in the standard navigational manner. A good idea of the picture presented can be obtained from Figure 5. In this photograph, the degree markings appear brighter in some areas than in others. This is solely due to the difficulty of photographing luminous objects. In practice the scale was clearly visible and evenly illuminated. The concentric circles visible on the screen are the range rings. These consist of a fairly heavy ring at a distance of 2½ inches (50 miles) from the centre, and lighter rings at ½ inch intervals, corresponding to ten mile intervals. There are fainter rings at two mile intervals, although these do not appear on the photograph. The brightness with which these rings are shown can be adjusted by the observer, who can remove them completely if he so desires. In practice almost all observers chose to employ range rings at approximately the level of this photograph.

The cursor is a sheet of perspex, mounted in front of the radar display tube. It is ruled with parallel lines $1\frac{1}{2}$ inch (25 miles) distance. This sheet may be rotated by hand to provide a reference for direction. It can be seen faintly in Figure 5, and is clearly visible in Figure 9 running in a diagonal direction on the left-hand, and nearly vertically on the right-hand console. The perspex sheet is edge-illuminated, and the brightness of the illumination is adjustable by the operator. It can be adjusted to be nearly invisible, or to be very marked. In practice most observers used this cursor to remind themselves of the heading of the controlled aircraft. Only on two occasions did any observer attempt to use the cursor to register the rotation of the line of sight - on both occasions the observer abandoned the attempt after two or three simulations.

Chinagraph pencil is designed to allow the user to write on glass or perspex materials. The observers sometimes attempted to plot the positions of the aircraft by marking in each point as it occurred, but could not achieve sufficient precision, owing to the coarseness of the resultant marks, and the parallax between the front surface of the perspex and the rear surface of the PPI tube. On other occasions observers contented themselves with identifying which trace was which by chinagraph notes.

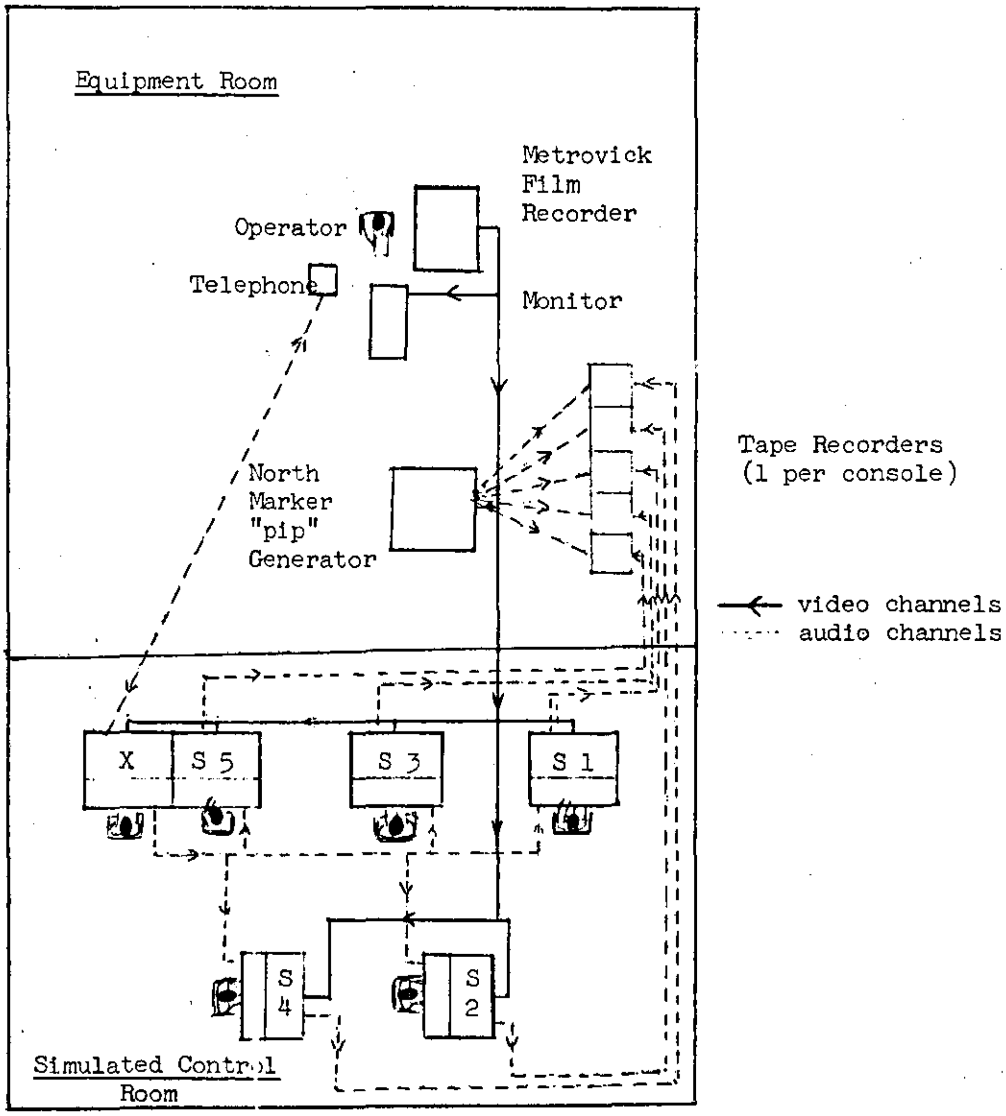
The "press-to-talk" switch was necessary in order to provide electronic balance within the circuits. A similar switch, mounted in the same place, is used in the normal operation of the equipment simulated in this experiment. In practice, the skilled observers experienced no difficulty with this switch, although some inexperienced observers had to be reminded repeatedly to use it.

The headsets used were of the standard pattern. This has two earphones, and a microphone mounted on a wire boom extending from the left earpiece, to which goes the connecting cable. The microphone can be moved to a comfortable position by hand and is held in position by a friction clamp.

The chairs used are of the type provided in Radar Air Traffic Control centres, and are adjustable in height, although the back-rest is fixed. They are mounted on castors, and can be moved forwards or swivelled with ease. No complaints or evidence of seating discomfort was encountered at any time.

Figure 6

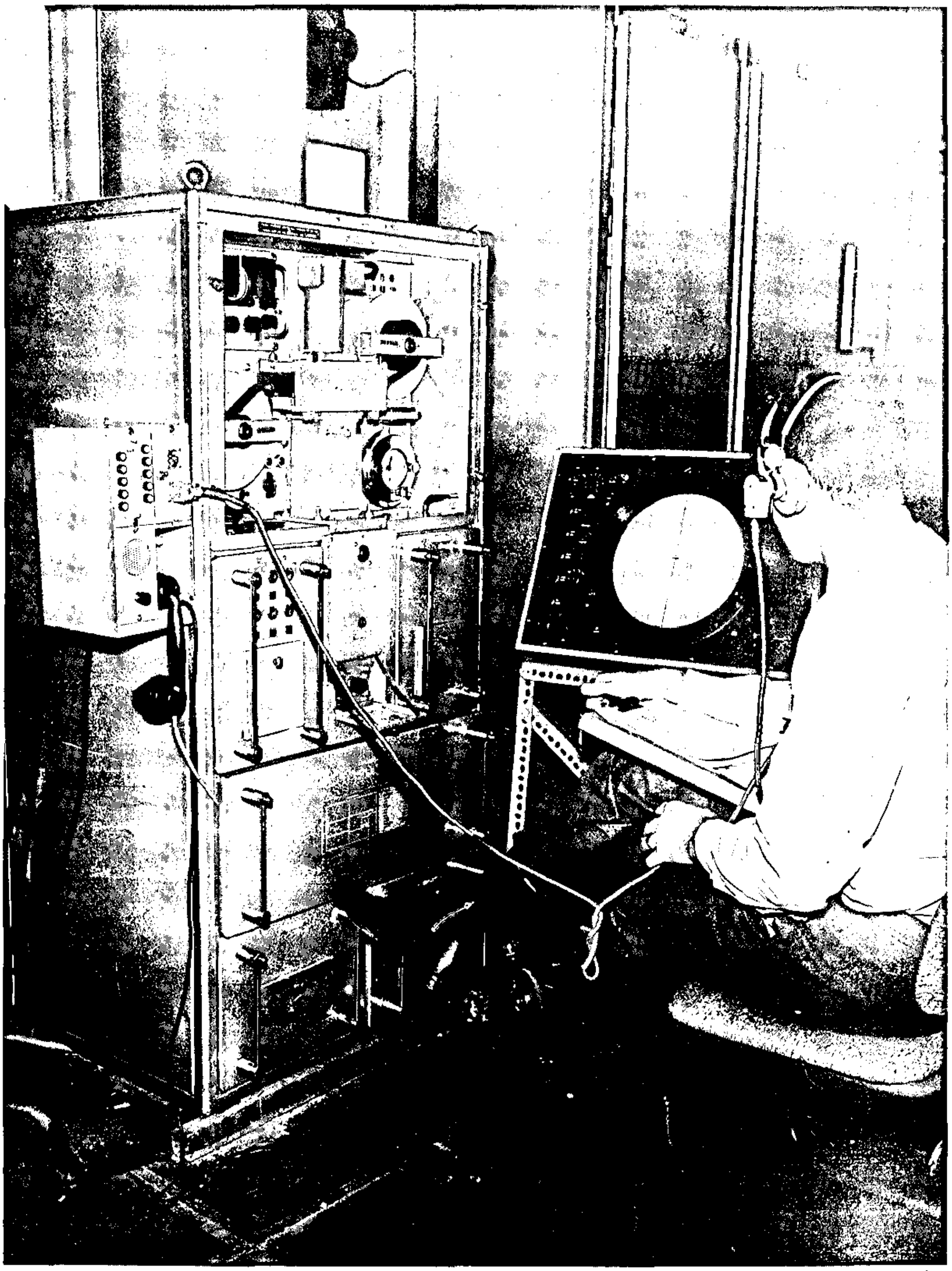
Experimental area and apparatus



NOT TO SCALE

Figure 7

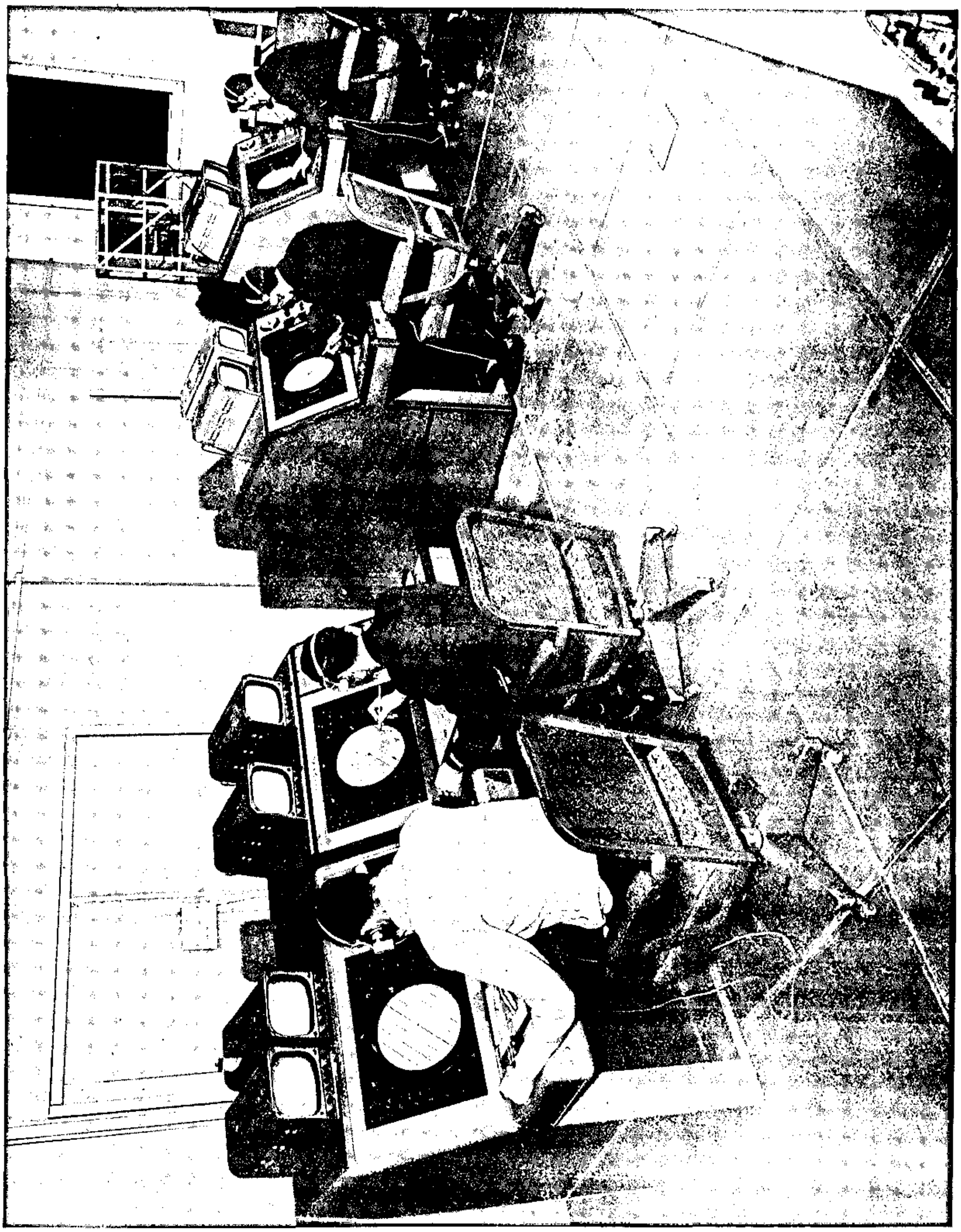
Metrovick Film Recorder



Note:- Telephone to Experimenter,
Monitor Console
Check list of Orientation Errors.

Figure 8

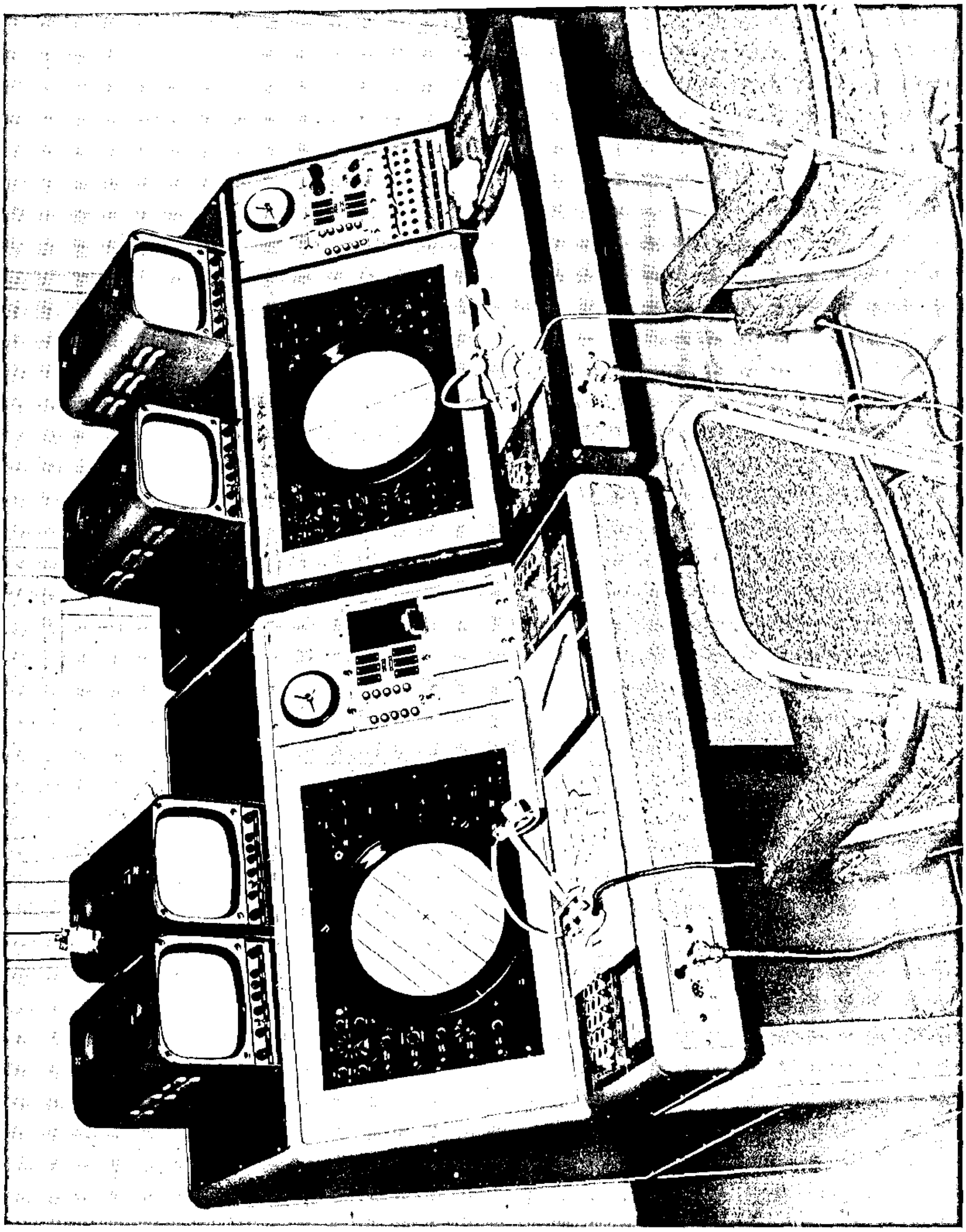
Simulated Control Room



Experimenter's console is at extreme left.
(The level of illumination has been raised for photographic reasons.)

Figure 9

Experimenter's and observer's consoles



3. Experimental procedure.

Observers were used in groups of five. Each observer took part in four experimental sessions, during each of which he saw a complete "script" consisting of 16 "simulations".

Subjects usually arrived at mid-day. A prepared brief was read to them (Appendix 4) and they were allowed to ask questions about it before starting. The forms of briefing differed slightly between skilled and unskilled observers, the latter form containing more elementary explanation of how the radar operated. When the experimenter was satisfied that the observers had grasped what was expected of them, the observers were seated at the radar consoles and the working of the brightness control, the range rings control, and the cursor explained. They were also shown the operation of the "press to talk" switch. They were given a sheet showing the meaning of the clock face code used for indicating control aircraft position, the four possible headings of the control aircraft, and the size of a 5-mile circle drawn to scale. In addition they were provided with the initial information about the controlled aircraft in duplicated form for each script.

At the start of each script, observers were asked to record verbally their names, the number of the console at which they were sitting, and the date. At the start of script one, a short additional sequence - showing two simulations - was added, to serve as a practice session. From then on, the procedure shown in Table 3 was followed. Table 3 shows not only what responses the observers were expected to make, but also the additional information provided by the North Marker pip, and by the experimenter. The items underlined in Table 3 are these which were transcribed and timed when the tape recordings were analysed. At the end of each script the observers again recorded their names, the date, and the number of the console at which they were sitting.

It was usual for observers to view two scripts in the first afternoon, with a fifteen minute break between them, and to view a further two on the following morning, again with a fifteen minute break between them. It was necessary in some cases to vary this procedure slightly, so that observers saw scripts 3 and 4 in the morning, then scripts 1 and 2 in the afternoon.

A few observers, mostly unskilled, complained of eyestrain, and one was overcome by nausea. This was attributed by his fellows to factors other than the radar observation situation. Some subjects became slightly bored during the later stages, and some skilled subjects complained of the "jumping" of the blips on the screen.

At the time of the experiment the responses of each observer were tape recorded individually in the manner described in this section. The analysis of the data is described in the next chapter, chapter 5, which also describes the findings of this experiment.

TABLE 3

Recording Sequence Followed For Each Shot by Each Observer

Time (Secs)	Simulated Event	North Marker	Observer's Comment	Experimenter's Comment
	Not directly recorded		*Items recorded by observer's tape*	
10	2 - 4 blank sweeps	pip		"Shot 16- Controlled Air-craft is COMET, SPEED 400 kts. HEADING 090 deg. Initial Position 10 O'CLOCK CENTRAL"
20		pip		
30		pip		
40	Control appears	pip	"CONTROL ON"	
50	Control alone on screen for 2-3 sweeps	pip		
60		pip		
70	Rogue appears	pip	"ROGUE ON"	
80		pip		
90		pip		
100	Control and Rogue now fly on steady courses at constant speed	pip	"CONFLICT"	
110		pip		
120		pip	"Rogue passing AHEAD-3 miles"	
130		pip		
140		pip		
150		pip	"Turn LEFT 30 degrees*	
160		pip		
170		pip		
180		pip	"Correction-rogue passing ASTERN - 1 mile"	
190		pip		
200		pip		
210		pip		
220	Both A/C did not appear	pip		
230		pip		"END OF SHOT 16"

---

* This comment is not required for unskilled observers.

Items underlined are transcribed and timed.

V. THE ELECTRONIC SIMULATION EXPERIMENT FINDINGS

1. Transcription of data.

The experimental data left the Air Traffic Control Evaluation Unit in the form of one seven-inch reel of double-play magnetic tape for each observer. This reel carried four tracks of 90 minutes duration, each recording in full the traffic to and from the head-set of the observer.

These reels were played through and timed by a technician at Loughborough University, a small sample being independently checked by the experimenter. In fact, no significant errors or omissions by the technician were found. The comments of the observer were recorded on separate forms, and the relevant comments and times were transcribed into a standard form. The data initially recorded included a considerable amount of redundant information, as shown in Table 3. (Previous chapter page 66.)

The following items, underlined in Table 3, were transcribed and timed.

1. 'Control ON' comment.
2. Pip following.
3. 'Rogue ON' comment.
4. Pip following.
5. 'Conflict'.
6. 'Rogue passing ahead - 3 miles'.
7. 'Turn left 30 degrees'
8. 'Correction - Rogue passing astern - 1 mile'.
9. 'End of shot 16'.

Of these comments, only 5, 6, 7 and 8 contain information unique to the observer, the other elements being substantially the same for all observers.

Items 1, 2, 3, 4 and 9 were used to standardise the time-scale of the tape, using a detailed record of the number of sweeps occurring in each simulation, together with the number of blank sweeps between simulations.

It was thus possible to eliminate the effects of different starting times for the tape recorders, and of tape stretching and slipping. (All tapes were new when used to record.) In the process a considerable number of transcription errors were found and rectified. These errors were for the most part transcription errors, or blunders - such as the transposition of digits.

After all necessary checks and adjustments were made, the times within the sessions were converted to times from the time of closest approach, times before this being considered positive, times after this negative.

In addition to this coding of times, the comments themselves were coded as Safe or Conflict, and according to the separation predicted, to the nearest mile, with a positive sign if the rogue was predicted to pass ahead of the control and a negative sign if the rogue was predicted to pass behind the controlled aircraft. (The advice given about manoeuvres was also coded, but is not relevant to this thesis.)

2. Classification of decisions.

If an assessment is to be made of the accuracy of a decision made by an observer, some criterion of accuracy must be established, and operational rules must be stated so that decisions can be classified.

For the purposes of this experiment,an observer was considered to make a decision when he made a recognisable verbal comment on what he observed.

Four main types of decision were recorded in this experiment, and analyses of variance have been carried out to separate the effects of the six factors varied within the experiment.

The four types of decision were:-

(a) The 'first decision' is simply the first recognisable verbal decision made by the observer, regardless of whether or not it is correct.

(b) The 'first correct Conflict/Safe decision' is the first decision which states correctly whether the situation is safe or a conflict. The definition of safety employed was that:- "A situation is safe if at no time the two aircraft pass each other closer than five miles".

(c) The 'first correct Ahead/Behind decision' is the first decision which states correctly which aircraft will pass ahead of the other. The observers were instructed to state this as 'Rogue passing ahead of control' or 'Rogue passing behind control'. In many cases the observer stated this in terms of the passing of the control behind the rogue. This was accepted as a valid comment, mutatis mutandis. In some cases the observer was not able to make any comment other than 'collision', implying that the observer could not detect any rotation of the line of sight under these circumstances. (The idea of the 'rotation of the line of sight' was not mentioned to the subject at any time.)

(d) The first correct judgement of separation is the first decision which states correctly what the separation of the aircraft will be when they are at their closest (the time of closest approach). This judgement is considered to be positive if the rogue is predicted to pass ahead of the controlled aircraft, negative if it is predicted to pass behind the control. If the judgement was 'collision' this is considered as an estimated separation of zero at closest approach.

A judgement is considered to be correct if it is within three miles of the planned value. (This definition of correctness had no operational significance. It was chosen to provide a suitable division into correct and incorrect judgements.)

For the last three of these judgements we may define a 'correct' judgement as a judgement that satisfies the criterion of accuracy relevant to the decision. For the first decision we can construct three measures of accuracy, in terms of the three criteria. Each simulation watched by each observer can be scored as accurate or not accurate in terms of the accuracy of the first decision in terms of the three separate criteria, and in terms of the presence of the three possible types of correct decisions. There are thus six possible measures of accuracy present, as against the four possible time measures, making a total of ten analyses of variance based on 64 readings for each of 27 observers, 17,280 readings in all.

It may help to consider an example, made up to show how the ten readings are obtained. We will consider a situation in which the rogue aircraft will in fact pass three miles ahead of the controlled aircraft, so that the situation is a conflict. Let us suppose we have the following comments made by one observer.

Time of comment seconds before closest approach.	Literal Transcription from tape.	Coded as:-
320	Um-er	Not coded
305	Safe - Rogue ahead, 7 miles apart	305/S/+7
281	Safe - Rogue ahead, 5 miles	281/S/+5
207	Correction-Conflict 3 miles	207/C/+3
180	Rogue passing ahead 4 miles	180/C/+4

These would produce the following scores for use in the separate analyses of variance,

1.	Time of first decision	305
2.	Accuracy of first decision (Conflict/Safe)	0
3.	Accuracy of first decision (Ahead/Behind)	100
4.	Accuracy of first decision (Separation)	0
5.	Time of first correct conflict/safe decision	207
6.	Accuracy of conflict/safe decision	100
7.	Time of first correct Ahead/Behind decision	320
8.	Accuracy of Ahead/Behind decision	100
9.	Time of first correct judgement of separation	281
10.	Accuracy of judgement of separation	100

The 'accuracy' measures given as 6, 8 and 10 are in fact the percentages of trials in which a correct decision is ultimately achieved. If one of these had been 0 in this example, there would have been a missing value in the corresponding time of first correct decision.

In addition to these analyses based on the performance of individuals, we may consider the performances of the groups of skilled and unskilled observers for each simulation. (The groups of civil and service observers were too small to provide meaningful statistics in individual simulations.)

For each simulation we may calculate the 5th and 95th percentiles of the time to go to Tca, these being the times when an estimated 5 percent and 95 percent of the observers will have made their decisions. We may, in addition, calculate a measure of performance for each type of decision by multiplying the time before Tca of the first decision by the percentage of correct first decisions for each simulation. We may calculate such a performance measure for each of the three types of decision.

In an attempt to measure the effects of early errors in assessment, a measure of bias was obtained by subtracting the mean time of the first decisions that were correct from the mean time of all first decisions in each situation. It was hoped that this would provide an index of situations which were particularly liable to error in their early stages, or in their later stages. Unfortunately, any such systematic effects were not large enough to be separable from differences between individuals and from random error.

Table 4 lists the analyses of variance used in the investigation of the four types of decision.

The remainder of this chapter describes the findings of this experiment in terms of the four types of decision. The first decision is treated in considerable detail, the other types of decision with more brevity. Analysis of variance tables are given for the first decision but not for the remaining decisions, in order to avoid unnecessary repetition of similar tables. For similar reasons, tables of mean values are provided only where means are significantly different. (Each analysis of variance involves the calculation of 294 mean values, mostly not significantly different.)

TABLE 4.

Analyses of Variance Employed

First Decision

Individual Data

Time to go to Time of Closest Approach
Percentage of Correct (Conflict/Safe) First Decisions
Percentage of Correct (Ahead/Behind) First Decisions
Percentage of Correct Judgements of Separations at First Decision

Group Data

95th Percentile of Time to Tca
5th Percentile of Time to Tca

First Correct Conflict/Safe Decision

Individual Data

Time to go to Time of Closest Approach
Accuracy

Group Data

95th Percentile of Time to Tca
5th Percentile of Time to Tca
Performance
Bias

First Correct Ahead/Behind Decision

Individual Data

Time to go to Time of Closest Approach
Accuracy

Group Data

95th Percentile of Time to Tca
5th Percentile of Time to Tca
Performance
Bias

First Correct Judgement of Separation

Individual Data

Time to go to Time of Closest Approach
Accuracy

Group Data

95th Percentile of Time to Tca
5th Percentile of Time to Tca
Performance
Bias

3. First decision.

The first decision is the first recognisable decision made by the controller, regardless of whether it is correct or not. The three measures of accuracy refer to the percentages of these decisions which are correct in terms of the definitions of correctness given above.

Table 13 is an analysis of variance for the time at which the first decision is made. Tables 14, 15 and 16 are analyses of variance for the accuracy of this decision in terms of the three criteria of whether the decision is correct. These were whether the observer correctly stated that the situation was safe or a conflict, whether the observer judged correctly which aircraft was passing ahead, and whether the observer correctly judged what the separation will be at the closest. The significant effects observable are summarised in Table 5.

Considering the differences between group means (Table 6, Figure 10), we note that the mean time to go to Tca for skilled observers is 17 seconds more than that for unskilled observers, while the mean 95th percentile is 27 seconds earlier for skilled observers than for unskilled observers. The 5th percentile is only six seconds earlier - a non-significant difference. These results mean that skilled observers make their first decisions earlier than unskilled observers, on the whole, although some unskilled observers make their decisions just as early as the skilled observers. Unskilled observers start making their decisions at about the same time before Tca, but are more spread out, so that their mean and 5th percentiles are correspondingly later than those of skilled observers.

It is also noticeable that the mean time to Tca for Service observers is earlier than that for Civil observers by 15 seconds. No corresponding figures for percentiles are available owing to the smaller size of these groups.

The within group variability of unskilled observers is significantly greater than that of skilled observers for the mean time to Tca at which the first decision is made. The difference is reflected in the larger difference between 5th and 95th percentiles for unskilled observers (109 sec.) than for skilled observers (88 sec.) This difference is masked in part by the large difference now existing between individual simulations. Because there is a statistically significant difference between the variabilities of these two groups of observers, it is necessary to use a t* test in place of a t or F test to assess the significance of the difference between group means for skilled and unskilled observers. The test is rather less sensitive than a t test, so that the larger difference between skilled and unskilled observers is not significant, while the smaller difference between Civil and Service observers, which may be tested with an F test, is considered significant.

The first significant factor is the angle of approach. Table 7 and Figure 11 show the effects of this factor on the 95th, 50th and 5th percentiles of the time to go to the time of closest approach, and Table 8 and Figure 12 show the effects of the angle of approach on the accuracy of the first decision in terms of the decision which aircraft is passing ahead of the other. Because there are significant differences between the mean times for different groups of observers, means for each level of each factor have been plotted for skilled and unskilled observers, as well as for the combined group of all observers.

Examination of these tables and diagrams will show that the first three levels of the angle of approach are more or less similar, but that the fourth level, 170 degrees, is decided earlier by about 42 seconds, and has a much lower initial accuracy. Differences in the final accuracy of this decision, including later corrections, are significant, although less so. It appears that observers realise that the situation is a dangerous one, and make a comment to that effect well before they can determine which aircraft will pass ahead of the other.

The second significant factor is the speed of closing. This affects only the 50th and 5th percentiles of the time to go to Tca, but all three measures of time to Tca are included in Figure 13 and Table 9. These show that for the slowest speed of closing (240 knots) the mean overall time to go to Tca is 2 minutes 54 seconds, while for all situations it is 2 minutes 28 seconds. The spread of values is again greater for unskilled observers, resulting in a non-significant difference at the 5th percentile.

The third and final significant effect is that of the passage of the rogue ahead of or behind the controlled aircraft on the 5th percentile of the time to Tca. Overall, the difference is 32 seconds, the decision being made earlier when the rogue is passing ahead of the controlled aircraft. This may be because the other decisions required were also easier to take in this case.

Although this argument could well apply to skilled observers, who would find it easier to decide what manoeuvre to adopt to rectify the situation, it would not explain the similar though less marked effect observable for unskilled observers.

Table 11 lists the mean time to Tca and accuracy in terms of the three criteria for the first decision for each simulation, averaging over all observers. Figure 15 plots time to Tca versus the accuracy of the first decision, in terms of the Conflict/Safe criterion for all 64 situations.

Table 12 presents the mean times to Tca and accuracies for all 27 observers. Figure 16 plots time to Tca versus the accuracy of the Conflict/Safe decision for all 27 observers, skilled observers being represented by black stars, unskilled observers by white ones.

TABLE 5

First Decision -Significant Effects

Type of Effect	TIME			ACCURACY		
	95th.%ile	Time to Tca Mean (50%)	5th.%ile	Conflict/ Safe	Accuracy Ahead/Behind	Within 3 Miles
Differences between groups						
1. Group Means	Skilled/ Unskilled	Service/ Civil	-	-	-	-
2. Within Group Variability	-	Skilled/ Unskilled	-	-	-	-
Effects of factors varied						
1. Overall	Angle of Approach	Angle of Approach	Angle of Approach	-	Angle of Approach	-
	-	Speed of Closing	Speed of Closing	-	-	-
	-	-	Rogue Ahead/ Behind	-	-	-
2. Between Groups	-	-	-	-	-	-

TABLE 6.

First Decision - Mean Overall Performance within Groups

	Time to Tca			Accuracy		
	95th %ile	Mean	5th %ile	Conflict/ Safe	Ahead/ Behind	Within 3 miles
All Observers	102 sec	148 sec	200 sec	73 %	59%	57%
Skilled Observers	116 sec	157 sec	204 sec	75%	60%	61%
Unskilled Observers	89 sec	140 sec	198 sec	72%	58%	54%
Civil Controllers	-	151 sec	-	76%	65%	58%
Service Controllers	-	166 sec	-	73%	53%	50%

TABLE 7.

First Decision - Effects of Angle of Approach and Time to Tca

Time to Tca (percentiles)	Level 1 (45 deg)			Level 2 (90 deg)			Level 3 (135 deg)			Level 4 (170 deg)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	92	137	189	99	141	190	90	136	188	129	180	236
Skilled Observers	106	143	186	110	149	194	101	146	196	146	190	239
Unskilled Observers	77	132	192	89	134	187	79	126	180	112	170	232

TABLE 8

First Decision - Effects of Angle of Approach on Accuracy of Initial Ahead/Behind Decision

Accuracy	Level 1 (45 deg)	Level 2 (90 deg)	Level 3 (135 deg)	Level 4 (170 deg)
Overall	74%	65%	59%	39%
Skilled Observers	77%	68%	60%	37%
Unskilled Observers	71%	63%	58%	40%

TABLE 9.

First Decision - Effects of Speed of Closing on Time to Tca

Time to Tca (percentiles)	Level 1 (240 kt)			Level 2 (360 kt)			Level 3 (430 kt)			Level 4 (600 kt)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	126	174	228	102	147	200	95	140	195	87	132	179
Skilled Observers	136	184	237	117	156	198	106	148	199	103	140	180
Unskilled Observers	115	165	219	87	140	202	84	133	191	71	124	179

TABLE 10.

First Decision - Effects of Rogue passing Ahead/Behind on Time to Tca

Time to Tca (percentiles)	Rogue Ahead 95th	Rogue Ahead 50th	Rogue Ahead 5th	Rogue Behind 95th	Rogue Behind 50th	Rogue Behind 5th
Overall	112	159	217	92	137	185
Skilled Observers	126	170	221	105	145	187
Unskilled Observers	98	150	213	80	130	183

TABLE 11.

Mean Time of First Decision, and Accuracy of Initital Decisions for Individual Simulations

Simulation Number	Time to Tca	Conflict /Safe	Ahead /Behind	Separation	Simulation Number	Time to Tca	Conflict /Safe	Ahead /Behind	Separation
1	112.0	96.3	22.2	55.6	33	141.5	88.9	25.9	55.6
2	232.2	85.2	29.6	44.4	34	168.3	66.7	63.0	48.1
3	127.0	74.0	81.4	44.4	35	206.3	92.6	37.0	51.9
4	164.6	85.2	66.7	51.9	36	95.9	74.0	70.4	66.7
5	199.2	77.8	85.2	70.4	37	119.4	55.6	66.7	59.3
6	179.5	63.0	88.9	29.6	38	163.4	25.9	63.0	18.5
7	204.2	66.7	88.9	63.0	39	137.0	48.1	85.2	74.0
8	179.0	85.2	11.1	51.9	40	193.6	96.3	48.1	48.2
9	116.7	96.3	59.3	70.4	41	114.5	96.3	44.4	59.3
10	129.1	66.7	92.6	85.2	42	142.8	22.2	85.2	18.5
11	103.0	92.6	88.8	70.4	43	187.8	96.3	44.4	74.1
12	87.4	77.8	81.4	66.7	44	104.7	85.2	55.6	40.8
13	112.5	92.6	40.7	70.4	45	240.1	63.0	37.0	48.2
14	17.1	70.4	66.7	63.0	46	168.2	66.6	88.9	74.1
15	146.7	81.5	59.3	40.7	47	176.2	37.0	77.8	37.0
16	228.6	55.6	85.2	81.5	48	131.1	77.8	74.1	63.0
17	110.4	22.9	85.2	66.7	49	203.7	66.7	81.5	66.7
18	193.6	100.0	37.0	66.7	50	141.3	85.2	33.3	44.4
19	84.1	100.0	18.5	77.8	51	131.1	96.3	25.9	70.4
20	114.8	77.7	18.5	33.3	52	178.2	77.8	77.8	77.8
21	120.5	37.0	74.1	29.7	53	132.5	63.0	88.9	81.5
22	122.7	88.9	44.4	44.4	54	256.2	96.3	37.0	81.5
23	127.7	85.2	44.4	55.6	55	143.4	85.2	77.8	74.1
24	138.3	81.5	81.5	62.9	56	105.1	100.0	40.8	59.3
25	126.5	81.5	44.4	55.5	57	181.7	96.3	40.8	77.8
26	136.7	77.8	85.2	74.1	58	151.1	55.6	81.5	51.9
27	186.4	7.4	74.0	29.6	59	142.3	96.3	55.6	70.4
28	199.4	85.2	18.5	70.4	60	138.3	18.5	70.4	40.7
29	142.8	14.8	85.2	40.7	61	133.9	100.0	25.9	85.2
30	145.1	88.9	29.6	59.3	62	112.4	85.2	44.4	44.4
31	233.0	48.1	77.8	22.2	63	183.6	88.9	74.1	40.8
32	154.5	29.6	81.5	48.2	64	179.5	96.3	11.1	77.8

TABLE 12.

Time Before Tca of First Decision and Initial Accuracies for Individual Observers

Observer	Group	Time to Tca	Accuracy of First Decisions		
			Conflict /Safe	Ahead /Behind	Separation
1	Civil	148.0	71.9	68.7	67.2
2	Civil	149.3	75.0	64.1	70.3
3	Civil	142.7	76.6	70.3	70.3
4	Civil	152.3	70.3	60.9	54.7
5	Civil	156.3	73.4	71.9	59.4
6	Civil	150.0	75.0	64.1	59.4
7	Civil	163.1	81.3	65.6	84.4
8	Civil	156.1	85.9	56.3	75.0
9	Service	165.5	82.8	59.4	81.3
10	Service	154.0	46.9	48.4	31.3
11	Service	174.6	84.4	32.8	32.8
12	Service	170.2	71.9	54.7	54.7
13	Service	164.5	78.1	67.2	50.0
14	Unskilled	158.4	68.8	59.4	54.7
15	Unskilled	158.5	79.8	68.8	57.8
16	Unskilled	142.4	73.4	75.0	65.6
17	Unskilled	118.0	84.4	71.9	75.0
18	Unskilled	139.6	75.0	68.8	64.1
19	Unskilled	153.0	73.4	67.2	57.8
20	Unskilled	149.8	53.1	51.6	51.6
21	Unskilled	131.0	67.2	59.4	56.3
22	Unskilled	147.4	76.6	46.8	57.8
23	Unskilled	150.7	81.3	28.1	32.8
24	Unskilled	129.0	59.4	51.6	46.8
25	Unskilled	133.4	70.3	48.4	39.1
26	Unskilled	124.9	60.9	34.4	26.6
27	Unskilled	129.5	82.8	79.7	75.0

Figure 10

First decision - Group means

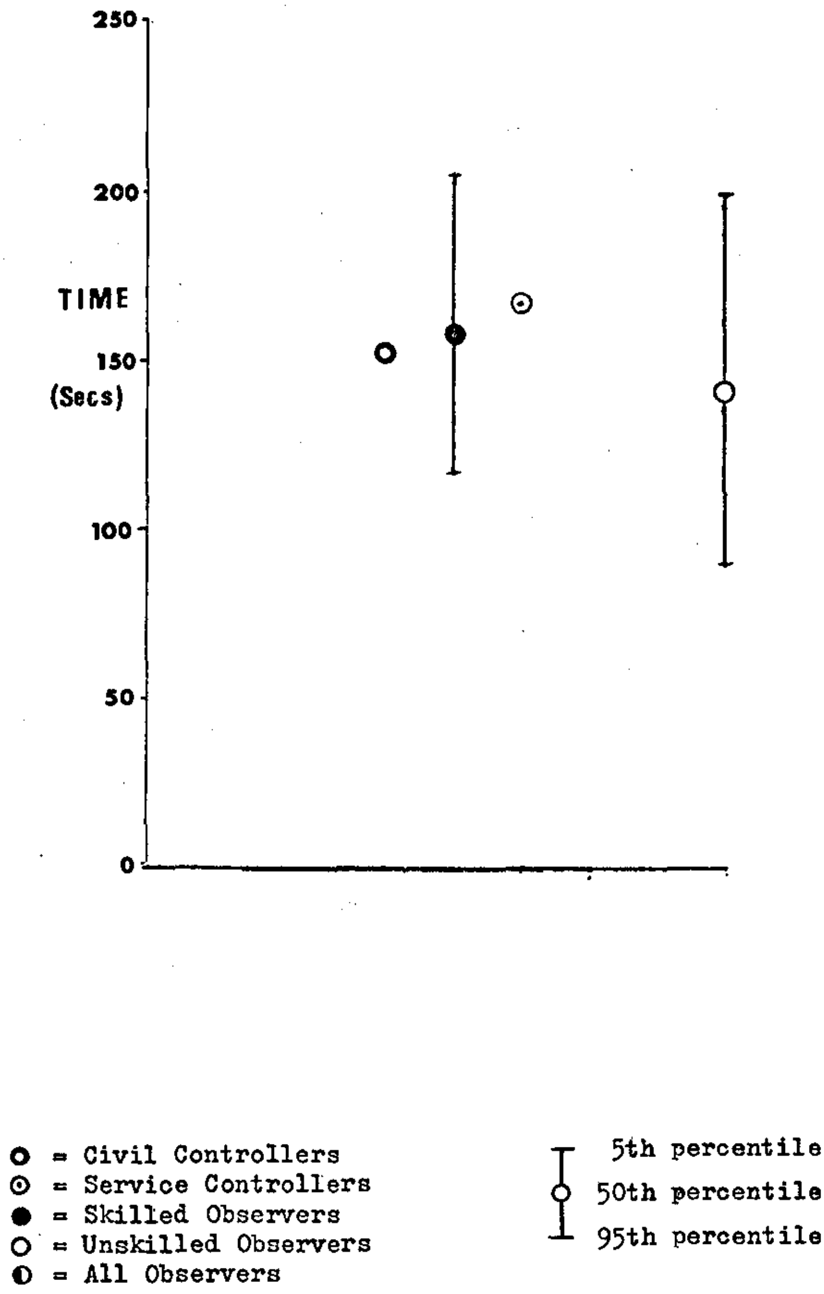
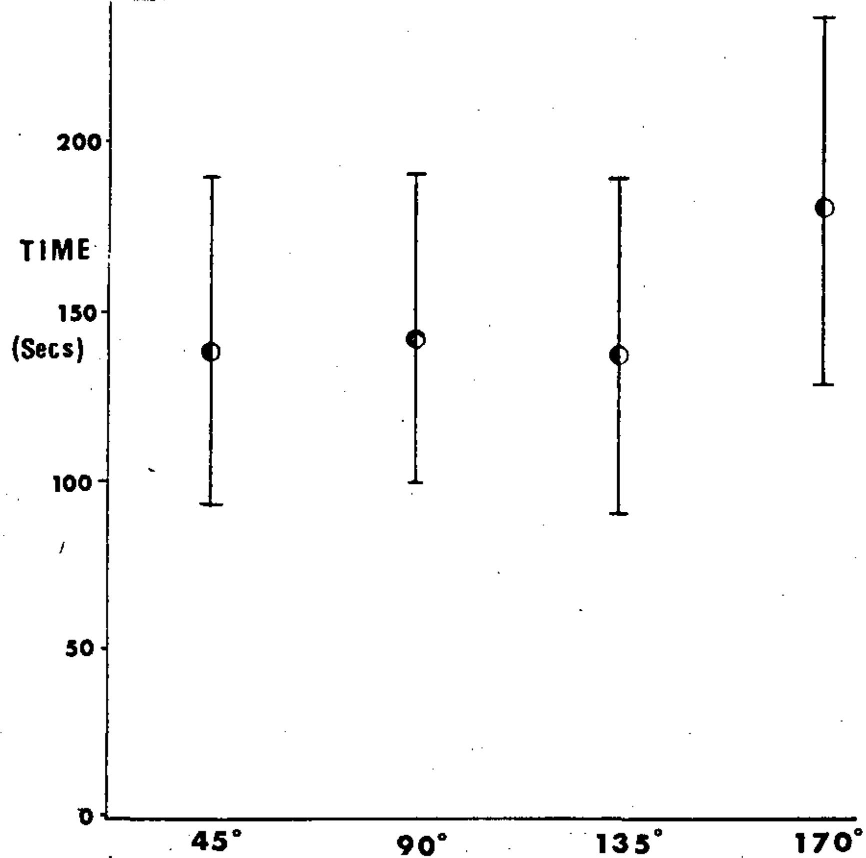
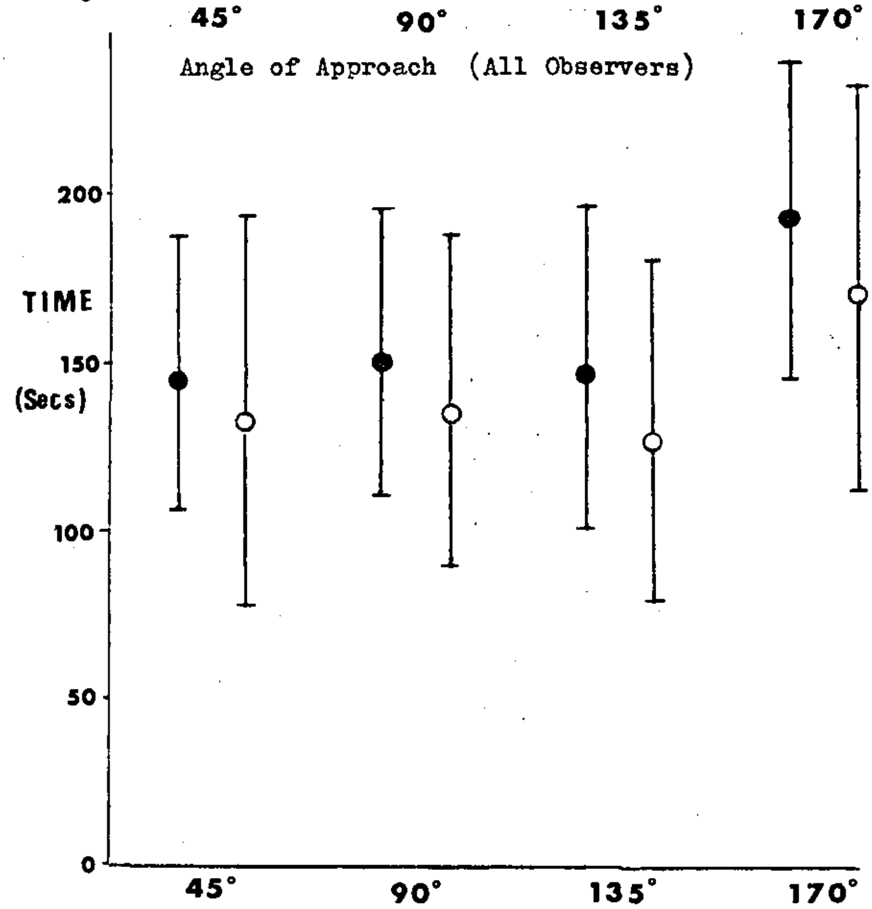


Figure 11

First decision - Angle of approach - Time to Tca



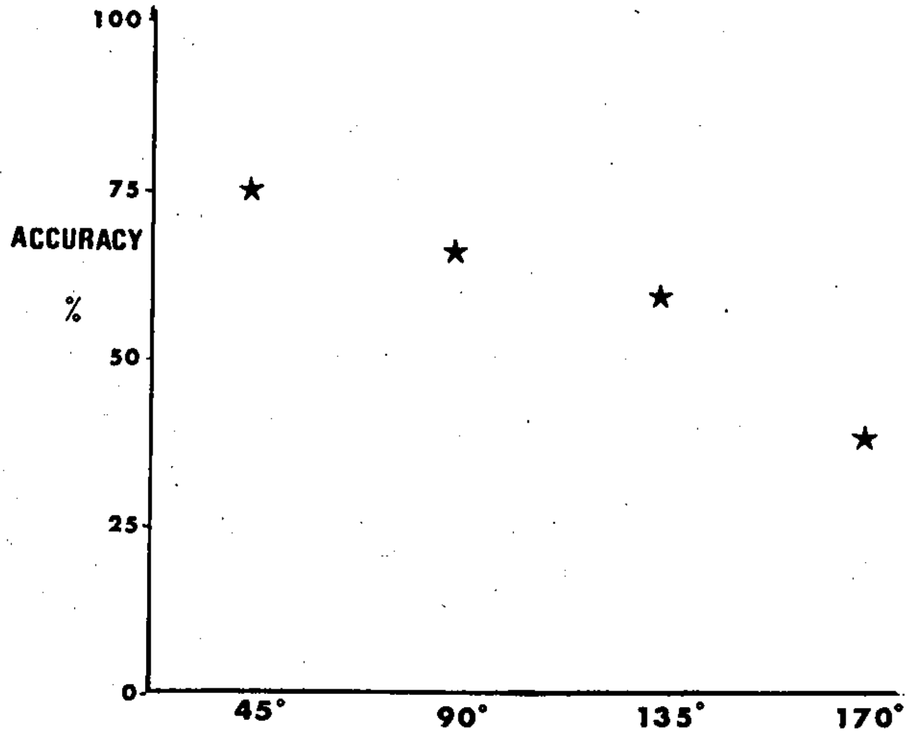
Angle of Approach (All Observers)



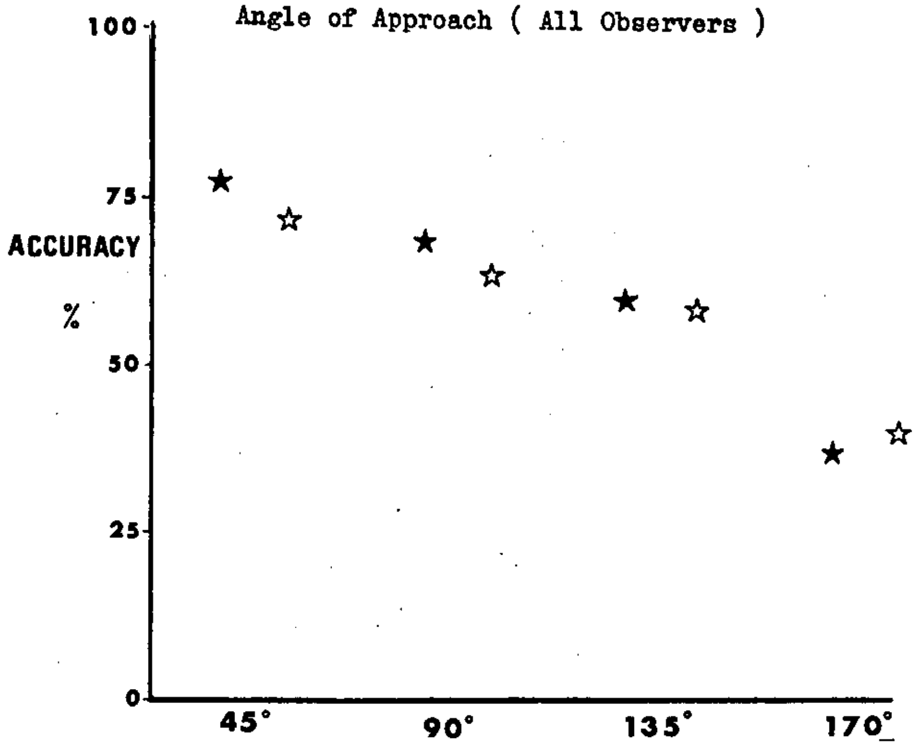
Angle of Approach (Skilled / Unskilled Observers)

Figure 12

First decision - Angle of approach - Accuracy



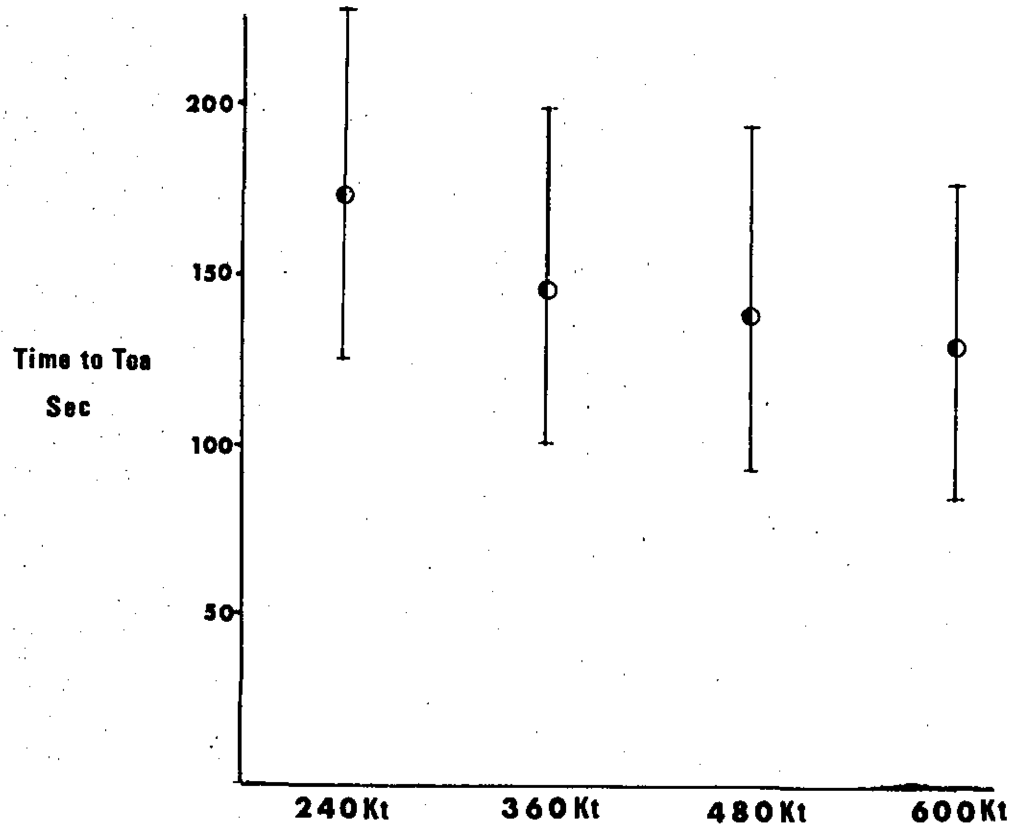
Angle of Approach (All Observers)



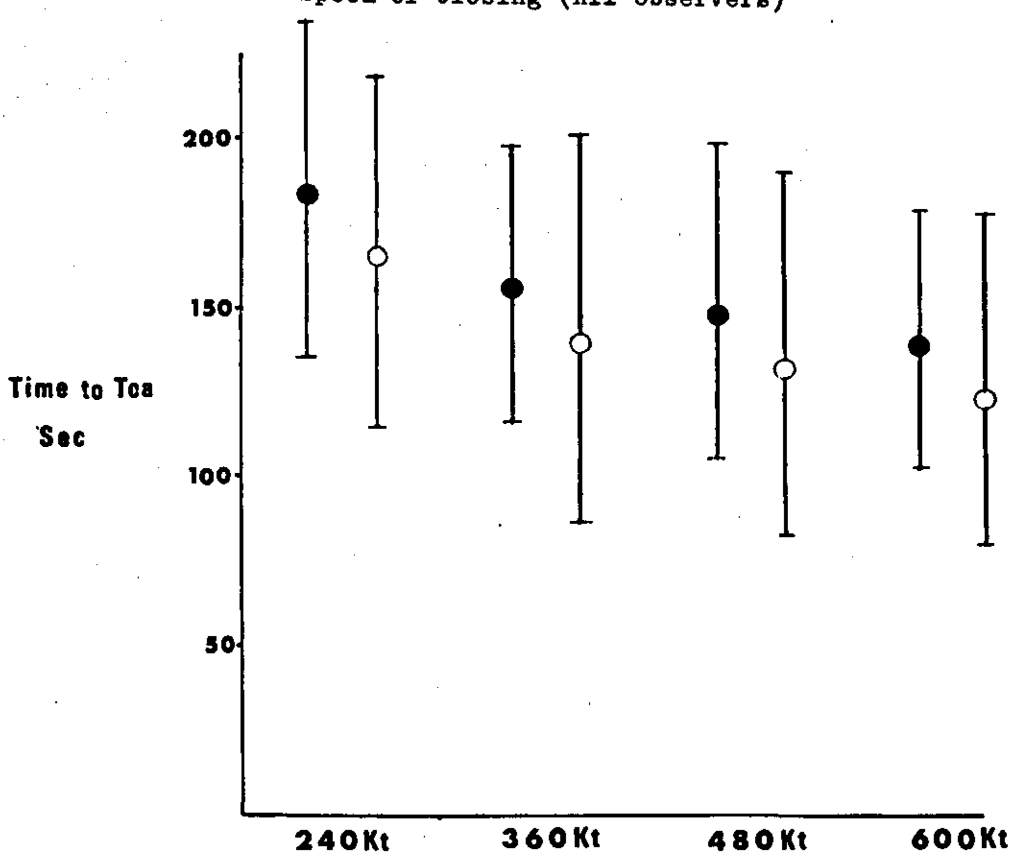
Angle of Approach (Skilled / Unskilled Observers)

Figure 13

First decision - Speed of closing - Time to Tca



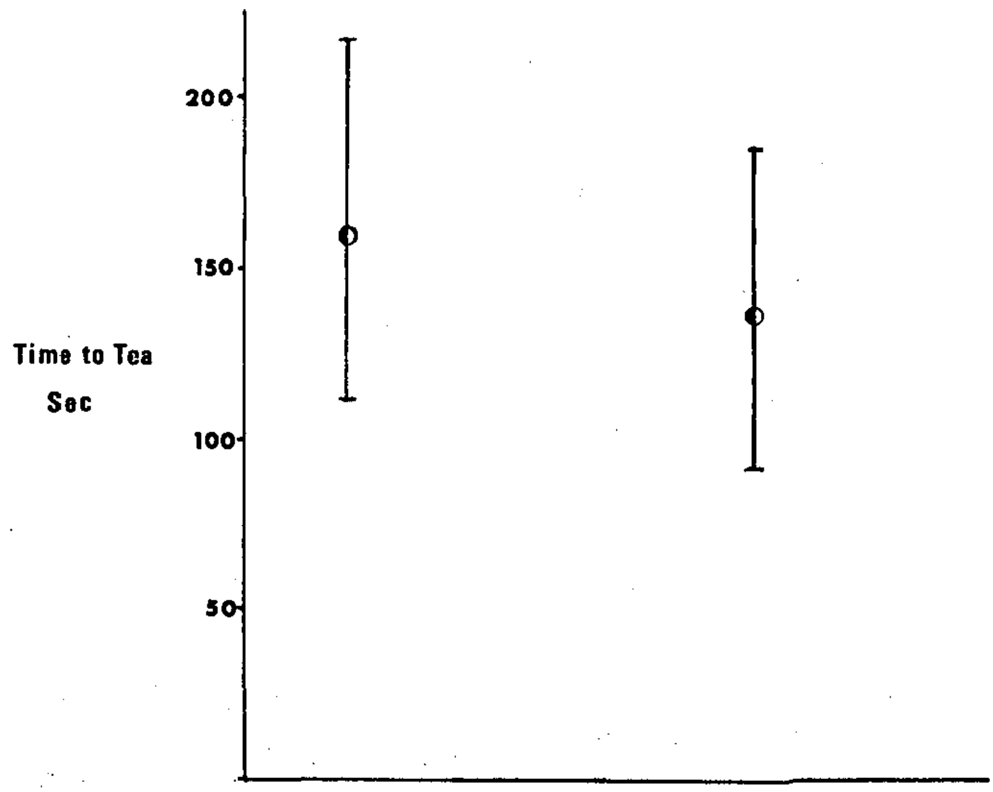
Speed of Closing (All Observers)



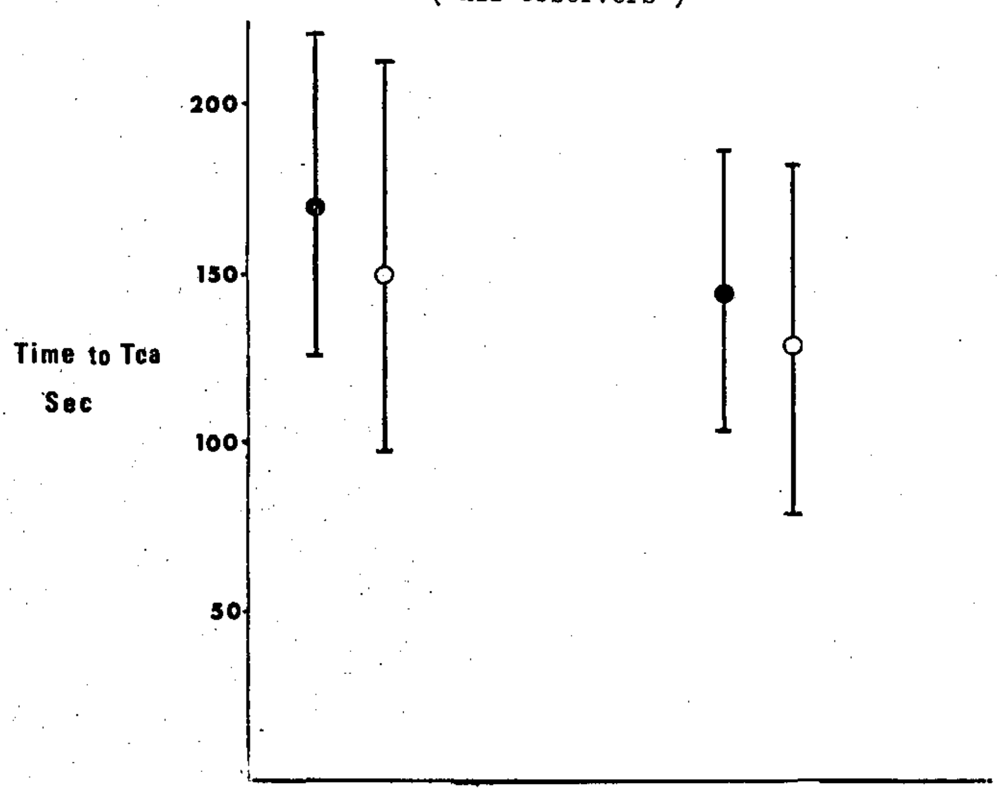
Speed of Closing (Skilled / Unskilled Observers)

Figure 14

First decision - Passage of rogue - Time to Tca



AHEAD - Rogue passing - BEHIND
(All Observers)



AHEAD - Rogue passing - BEHIND
(Skilled / Unskilled Observers)

Figure 15

First decision - Time to Tca/Accuracy - Simulations

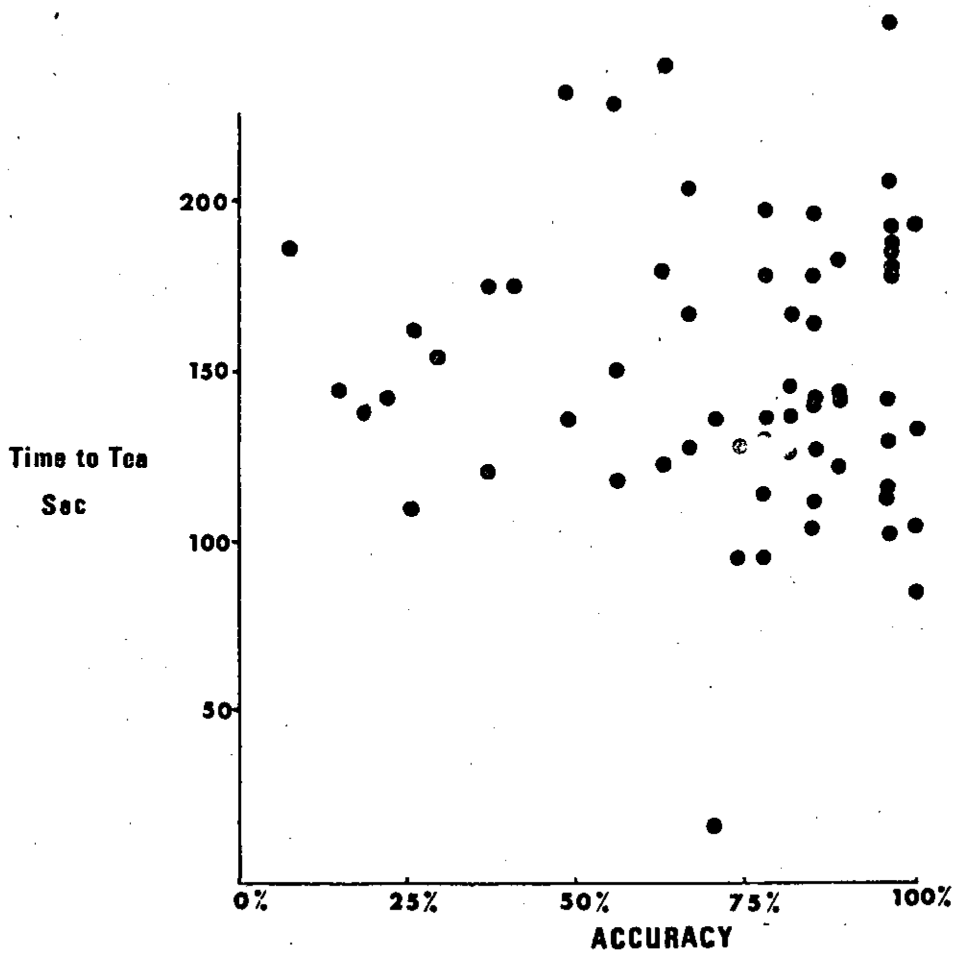


Figure 16

First decision - Time to Tca/Accuracy - Individuals

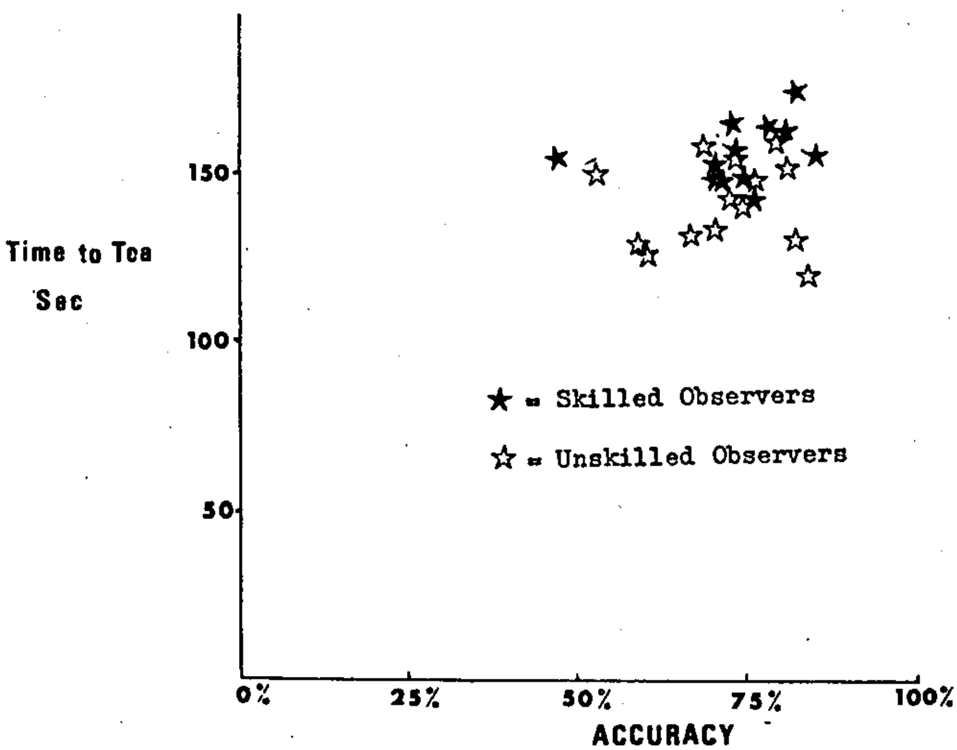


TABLE 13

Analysis of Variance for

First Decision Time to go to TCA

Source of Variation	Total Sum of Squares	dF	Mean Sum of Squares	Var.Ratio		w.r.t.
Overall Performance Levels						
1 Heading of control	28 015.7	3	9 338.6	-	NS	UV
2 Angle of approach	570 972.0	3	190 324.0	5.7	**	UV
3 Speed of closing	428 742.0	3	142 914.0	4.3	**	UV
4 Nature of miss	252 791.5	3	84 263.8	2.5	NS	UV
5 Distance of miss	35 806.2	3	11 935.4	-	NS	UV
6 Position on PPI	82 586.7	3	27 528.9	-	NS	UV
Unassigned variation	1513 965.1	45	33 643.7	36.2	***	Res.
Service v Civil Controllers						
Difference in Performance	38 625.8	1	38 625.8	41.6	***	Res.
1 Heading of control	6 429.2	3	2 143.1	2.1	NS	UV
2 Angle of aproach	5 728.8	3	1 909.6	1.8	NS	UV
3 Speed of closing	1 111.5	3	370.5	-	NS	UV
4 Nature of miss	86.7	3	28.9	-	NS	UV
5 Distance of miss	1 755.9	3	585.3	-	NS	UV
6 Position of miss	8 687.0	3	2 895.7	2.8	NS	UV
Unassigned variation	46 580.5	45	1 035.1	1.11	NS	Res.
Skilled v Unskilled Observers						
Difference in Performance	120 365.3	1	120 365.3	129.5	***	Res.
1 Heading of control	4 731.2	3	1 577.1	-	NS	UV
2 Angle of approach	6 692.7	3	2 230.9	1.1	NS	UV
3 Speed of closing	1 434.4	3	478.1	-	NS	UV
4 Nature of miss	3 586.0	3	1 195.3	-	NS	UV
5 Distance of miss	3 747.0	3	1 249.0	-	NS	UV
6 Position on PPI	4 472.5	3	1 490.8	-	NS	UV
Unassigned variation	94 885.1	45	2 108.6			Sub
Within Groups Variation						
Civil controllers	19 458.5	7	2 779.8	3.0	***	Res.
Service controllers	15 218.4	4	3 804.6	4.1	***	Res.
Unskilled controllers	139 887.2	13	10 760.5	11.6	***	Res.
Residual	1 356 707.1	1460	929.3			
TOTAL SUM OF SQUARES	4 793 070.0	1675				

Notes: NS = Not Significant
* = Significant at 95% level
** = Significant at 99% level
*** = Significant at 99.9% level
UV = Unassigned variation for the relevant set of factors
Res.= Residual Sum of squares

TABLE 14

Analysis of Variance for

First Decision — Accuracy of Conflict/Safe Judgement

Source of Variation	Total sum of squares	dF	Mean Sum of Squares	Var.Ratio	w.r.t.
Overall Performance Levels					
1. Heading of control	10 572.9	3	3 524.31	- NS	UV
2 Angle of approach	161 637.7	3	53 879.24	3.672 *	UV
3 Speed of closing	52 748.8	3	17 582.95	1.198 NS	UV
4 Nature of miss	38 258.1	3	12 752.70	0.869 NS	UV
5 Distance of miss	61 035.9	3	20 345.29	1.387 NS	UV
6Position on PPI	9 647.0	3	3 215.66	0.219 NS	UV
Unassigned variation	660 306.7	45	14 677.48		
Service v Civil Controllers					
Difference in Performance	2 222.4	1	2 222.36	-	Sk sub
1 Heading of control	13 520.4	3	1 173.48	0.832 NS	UV
2 Angle of approach	455.5	3	151.84	0.108 NS	UV
3 Speed of closing	5 530.0	3	1 843.35	1.306 NS	UV
4 Nature of miss	6 832.6	3	2 277.53	1.614 NS	UV
5 Distance of miss	1 756.0	3	585.34	0.414 NS	UV
6 Position on PPI	6 167.1	3	2 055.69	1.457 NS	UV
Unassigned variation	63 496.4	45	1 411.03		
Skilled v Unskilled Observers					
Difference in Performance	3 895.1	1	3 895.1	- NS	All sub
1 Heading of control	5 150.0	3	1 716.65	- NS	UV
2Angle of approach	877.7	3	292.57	- NS	UV
3 Speed of closing	4 553.7	3	1 517.90	- NS	UV
4 Nature of miss	11 798.6	3	3 932.85	2.063 NS	UV
5 Distance of miss	888.9	3	296.30	- NS	UV
6 Position on PPI	4 942.6	3	1 647.55	- NS	UV
Unassigned variation	85 797.3	45	1 906.61		
Within Groups Variation					
Civil controllers	11 852.8	7	1 693.2	- NS	
Service controllers	59 875.0	4	14 968.7	8.840 *	Civ con
Unskilled observers	71 819.0	13	5.524.5	1.001 NS	All ski
Residual	2 024 494.7	1512	1 338.9		
TOTAL SUM OF SQUARES	3 380 133.1	1727			

TABLE 15.

Analysis of Variance for

First Decision — Accuracy of Ahead/Behind Judgement

Source of Variation	Total sum of Squares	dF	Mean Sum of Squares	Var.Ratio		w.r.t.
Overall Performance Levels						
1 Heading of control	22 656.2	3	7 552.1	-	NS	UV
2 Angle of approach	286 776.6	3	95 592.2	8.04	***	UV
3 Speed of closing	4 415.5	3	1 471.8	-	NS	UV
4 Nature of miss	80 758.1	3	26.919.4	2.265	NS	UV
5 Distance of miss	35 063.7	3	11 687.9	-	NS	UV
6 Position on PPI	36 452.5	3	12 150.9	1.022	NS	UV
Unassigned variation	534 936.3	45	11 887.5			
Service v Civil Controllers						
Difference in Performance	933.9	1	31 933.9	6.515	*	ski obs
1 Heading of control	2 058.9	3	686.3	-	NS	UV
2 Angle of approach	7 419.5	3	2 473.2	1.118	NS	UV
3 Speed of closing	6 544.5	3	2 181.5	-	NS	UV
4 Nature of miss	3 517.9	3	1 172.6	-	NS	UV
5 Distance of miss	14 522.8	3	4 841.0	2.188	NS	UV
6 Position on PPI	12 020.4	3	4 006.8	1.811	NS	UV
Unassigned variation	99 573.3	45	2 212.7			
Skilled v Unskilled Observers						
Difference in Performance	2 510.7	1	2 510.7	-	NS	All obs
1 Heading of control	8 771.5	3	2 923.8	1.112	NS	UV
2 Angle of approach	6 120.9	3	2 040.3	-	NS	UV
3 Speed of closing	5 089.1	3	1 696.4	-	NS	UV
4 Nature of miss	8 849.6	3	2 949.9	1.122	NS	UV
5 Distance of miss	4 949.2	3	1 649.7	-	NS	UV
6 Position on PPI	8 745.8	3	2 915.3	1.108	NS	UV
Unassigned variation	118 347.5	45	2 629.9			
Within Groups Variation						
Civil observers	11 801.9	7	1 685.9			
Service observers	43 000.0	4	10 750.0	6.376		Civ con
Unskilled observers	193 265.1	13	14 866.5	2.984		Ski obs
Residual	2 587 253.9	1512	1 711.1			
TOTAL SUM OF SQUARES	4 177 355.3	1727				

TABLE 16.

Analysis of Variance for
First Decision — Accuracy of Judgement of Separation

Source of Variation	Total sum of Squares	dF	Mean Sum of Squares	Var.Ratio		w.r.t.
Overall Performance Levels						
1 Heading of control	30 063.7	3	10 021.2	1.395	NS	UV
2 Angle of approach	13 998.8	3	4 666.3	-	NS	UV
3 Speed of closing	47 008.1	3	15 669.3	2.181	NS	UV
4 Nature of miss	33 628.5	3	11 209.5	1.560	NS	UV
5 Distance of miss	10 572.9	3	3 524.3	-	NS	UV
6 Position on PPI	36 961.8	3	12 320.6	1.715	NS	UV
Unassigned variation	323 316.0	45	7 184.8			
Service v Civil Controllers						
Difference in Performance	60 847.4	1	60 847.4	4.550		Ski obs
1 Heading of control	2 203.1	3	734.4	-	NS	UV
2 Angle of approach	17 256.0	3	5 752.0	2.519	NS	UV
3 Speed of closing	3 732.0	3	1 244.0	-	NS	UV
4 Nature of miss	246.4	3	821.3	-	NS	UV
5 Distance of miss	7 780.0	3	2 593.4	1.136	NS	UV
6 Position on PPI	8 332.9	3	2 777.6	1.216	NS	UV
Unassigned variation	756.0	45	2 283.5			
Skilled v Unskilled Observers						
Difference in Performance	18 029.1	1	18 029.1			
1 Heading of control	3 094.8	3	1 031.6	-	NS	UV
2 Angle of approach	1 955.0	3	651.7	-	NS	UV
3 Speed of closing	264.4	3	88.1	-	NS	UV
4 Nature of miss	8 692.1	3	2 897.4	-	NS	UV
5 Distance of miss	8 437.2	3	2 812.4	-	NS	UV
6 Position on PPI	130 695.9	45	2 904.4			
Within Groups Variation						
Civil Observers	41 798.6	7	5 971.2			
Service Observers	105 312.5	4	26 328.1	4.409		Civ con
Unskilled Observers	169 429.0	13	13 033.0	-		Ski obs
Residual	3 018 602.8	1512	1 996.4			
TOTAL SUM OF SQUARES	4 223 697.9	1727				

4. First correct Conflict/Safe decision.

The first correct conflict/safe decision is the first decision which states correctly whether the situation will be safe or a conflict. The standard of safety employed is the rule that:

"A situation is a conflict if at any time the two aircraft will be within five miles of each other"

The measure of accuracy here employed is the number of occasions on which a correct judgement was expressed at some time during the trial, compared with the total number of occasions, as described above.

Estimates of performance and bias were obtained as described in that section. The performance index is obtained by multiplying time to Tca by accuracy, and the bias index by subtracting the mean of the timd of the first correct conflict/safe decision from the mean of the time of first decisions in each situation. (The bias index may be neglected, since it never exhibited any significant differences.)

In general the effects present (Table 17) resemble those for the first decision. The differences between groups are primarily evident in time to Tca, accuracy being affected only (rather oddly) by the position of the simulation on the PPI. There are significant differences between groups in the performance index, but these may be attributed to the effects of differences in timing.

Considering differences between group means (Table 18) we observe the mean time before Tca at which skilled observers make their first correct conflict/safe decision is 16 seconds more than that for unskilled observers, the mean time of the 95th percentile being 25 seconds earlier, and the mean time for the 5th percentile being, again, only six seconds earlier. Skilled observers tend to start making their correct decisions earlier than unskilled observers, but are more spread out, so that the finishing 5th percentiles are about the same. The mean time to Tca for Service controllers is about 9 seconds greater than that for Civil oontrollers, although this difference is not significant.

There are no significant differences in variability within groups, although the pattern of variability is as before. For this type of decision the range from 5th to 95th percentiles is 112 seconds for skilled observers, and 131 seconds for unskilled observers. By simple proportion, considering the times and percentage accuracies for the first decision and the first correct conflict/safe decision, one may calculate that the delay in correcting an initially wrong decision is 114 seconds for skilled observers and 80 seconds for unskilled observers. There is a mean difference in performance between skilled and unskilled observers, but this merely reflects the difference in timing.

The first significant factor is the angle of approach, as before (Table 19). This affects the mean, 95th and 5th percentiles of the time to Tca at which the first correct conflict/safe decision is made. It should be noticed that the percentiles are more widely spaced for the more acute angles, implying that there is much greater agreement as to when decisions ought to be made for aircraft approaching at obtuse (wide) angles than for aircraft approaching at acute angles. Mean levels have been plotted for each level of this factor, for all observers, for skilled and unskilled observers, and for Civil (C) and Service (M) controllers. The difference between skilled and unskilled observers is purely one of overall mean, both groups showing the same pattern of behaviour. The difference between Civil and Service controllers is more interesting. There is a significant difference between these groups in the way in which they are affected by alteration in the angle of approach of the aircraft, and it appears to lie in the greater urgency attached by service controllers to nearly head-on approaches. Civil controllers appear to be more willing to wait and see.

The performance measure again differs significantly (Table 20) as a consequence of the difference in time, showing that the greater speed shown in dealing with head-on cases is not accompanied by a decrease in accuracy to any significant extent.

The only other factor having a significant overall effect is speed of closing of the two aircraft (Table 21). This affects the 5th and 50th percentiles but not the 95th. What happens may be expressed by saying that as the aircraft speeds get faster, so mean time at which the decision is taken decreases from 2 min. 49 seconds to 1 min. 56 seconds. The spread of readings in time remains more or less constant, however, and there are no differences between groups of observers in the way in which they are affected. The performance index also shows a significant drop; (Table 22) although the effect does not appear to be simply linear, since mean times to Tca are shorter for skilled observers where the aircraft are closing at 360 knots than when they are closing at 480 knots. This is emphasised by the performance index, since the accuracy for 360 knots is also less than that for 480 knots, reversing the general trend.

In addition to the overall effects of these two factors, two other factors exhibit significant interactions with groups of observers. This is to say that, while the overall average effects of different levels of these factors are not significantly different, skilled observers are affected significantly differently from unskilled observers. The first of these minor factors is the passage of the Rogue, ahead of, or behind the Control (Table 23). This has a significant effect on the time at which the first (5th percentile) skilled observers make their decisions, but appears to affect unskilled observers not at all. This difference does not appear to be significant for the mean values of Tca, but is significant in terms of performance index (Table 24) situations where the rogue passes ahead being judged earlier and more accurately, although the difference in accuracy is not marked enough to be significant.

Lastly, there appears to be an effect on the accuracy of judgements made by skilled or unskilled observers of the position on the PPI at which a particular simulation took place, (Table 25). For some reason, unskilled observers performed particularly poorly on targets in the median range of the screen, from about 1.5 to 3.5 inches from the centre. This result is significant only at the 5% level (1 chance of 20) and may be a statistical artefact.

TABLE 17.

First Correct Conflict/Safe Decision

Significant Effects	95th.%ile	Time to Tca Mean (50%)	5th.%ile	Accuracy	Performance	Bias
Differences between groups						
1. Group Means	Skilled/ Unskilled	Skilled/ Unskilled	-	-	Skilled/ Unskilled	-
2. Within Group Variabilities	-	-	-	-	-	-
Effects of Factors Varied						
1. Overall	Angle of Approach	Angle of Approach	Angle of Approach	-	Angle of Approach	-
	-	Speed of Closing	Speed of Closing	-	Speed of Closing	-
2. Between Groups Service v. Civil Controllers	-	Angle of Approach	-	-	-	-
Skilled v. Unskilled Observers	-	-	Rogue Ahead /Behind	Position on PPI	Rogue Ahead /Behind	-

TABLE 18.

First Correct Conflict/Safe Decision

Mean Overall Performance within Groups

	95th %ile	Mean	5th %ile	Accuracy	Performance	Bias
All Observers	80 sec.	138 sec.	200 sec.	82%	112	-.1
Skilled Observers	92 sec.	146 sec.	204 sec.	83%	119	0.0
Unskilled Observers	67 sec.	130 sec.	198 sec.	81%	105	-.3
Civil Controllers	-	142 sec.	-	83%	-	-
Service Controllers	-	153 sec.	-	83%	-	-

TABLE 19.

First Correct Conflict/Safe Decision

Effects of Angle of Approach on Time to Tca

Time to Tca (percentiles)	Level 1 (45 deg)			Level 2 (90 deg)			Level 3 (135 deg)			Level 4 (170 deg)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	48	115	189	72	133	190	78	129	183	122	175	236
Skilled Observers	59	122	190	81	137	195	91	141	199	139	185	243
Unskilled Observers	37	109	185	62	129	175	65	118	174	105	165	233
Service Controllers	-	123	-	-	141	-	-	147	-	-	203	-
Civil Controllers	-	121	-	-	134	-	-	137	-	-	174	-

TABLE 20

First Correct Conflict/Safe Decision

Effects of Angle of Approach on Performance Index

Performance	Level 1 (45 deg)	Level 2 (90 deg)	Level 3 (135 deg)	Level 4 (170 deg)
Overall	87	95	108	159
Skilled Observers	92	99	118	167
Unskilled Observers	82	91	99	149

TABLE 21

First Correct Conflict/Safe Decision

Effects of Speed of Closing on Time to Tca

Time to Tca (percentiles)	Level 1 (240 kt) 95th	Level 1 (240 kt) 50th	Level 1 (240 kt) 5th	Level 2 (360 kt) 95th	Level 2 (360 kt) 50th	Level 2 (360 kt) 5th	Level 3 (480 kt) 95th	Level 3 (480 kt) 50th	Level 3 (480 kt) 5th	Level 4 (600 kt) 95th	Level 4 (600 kt) 50th	Level 4 (600 kt) 5th
Overall	115	169	230	71	135	196	78	132	197	57	116	175
Skilled Observers	127	180	240	86	140	205	91	142	201	66	123	181
Unskilled Observers	103	160	220	55	130	186	64	123	193	47	110	168

TABLE 22.

First Correct Conflict/Safe Decision

Effects of Speed of Closing on Performance Index

Performance Index	Level 1 (240 kt)	Level 2 (360 kt)	Level 3 (480 kt)	Level 4 (600 kt)
Overall	144	103	113	89
Skilled Observers	151	106	124	95
Unskilled Observers	138	99	102	82

TABLE 23.

First Correct Conflict/Safe Decision

Effects of Passage of Rogue Ahead/Behind Control on Time to Tca.

	Rogue Passing Ahead			Rogue Passing Ahead		
Time to Tca (percentiles)	95th	50th	5th	95th	50th	5th
Overall	86	148	213	74	128	185
Skilled Observers	103	159	224	82	133	189
Unskilled Observers	69	138	201	65	122	181

TABLE 24.

First Correct Conflict/Safe Decision

Effects of Passage of Rogue Ahead/Behind Control on Performance Index

	Rogue Passing Ahead	Rogue Passing Astern
Overall	118	107
Skilled Observers	130	109
Unskilled Observers	106	105

TABLE 25.

First Correct Conflict/Safe Decision

Effect of Position on PPI on Accuracy

	Level 1 (Outer	Level 2 Outer)	Level 3 (Median)	Level 4 (Central)
	Rogue Heading (inward	Outward)		
Overall	82	85	75	85
Skilled Observers	81	84	81	85
Unskilled Observers	84	86	70	85

5. First correct Ahead/Behind decision.

The first correct ahead/behind decision is defined as the first decision indicating correctly which aircraft is about to pass ahead of the other. In practice, this decision was states as "Rogue passing ahead", or "Rogue passing behind". In a considerable number of trials the observer was not able to make any comment other than "Collision", implying that he was not able to judge which aircraft was passing in front of the other. (This is equivalent to saying that he could not perceive any rotation of the line of sight). Accuracy is defined in the manner laid down above.

The time to go to Tca and the accuracy were measured for each observer for each simulation, and in addition the 5th and 95th percentiles, performance index and bias index were calculated for skilled and unskilled groups of observers for each simulation.

In general the effects present (Table 26) resemble the effects observed for the first decision, although in this case the confidence limits are considerably wider. Timing differences account for most of the observe d variation, although there are some effects of factors on accuracy. There are no significant differences in terms of performance or bias indices.

Considering first the differences between group means (Table 27) we observe that the group mean for skilled observers is in all cases significantly earlier than that for unskilled observers. The difference is of the order of 25 seconds for the 95th percentiles, and of 14 seconds for the 5th percentiles. This indicates that although the skilled subjects start to make this judgement rather earlier than the unskilled, they finish considerably earlier, an effect similar to that observed for conflict/safe decisions. There are no significant differences in accuracy, performance index, or bias index.

There are no significant differences between groups in the variability of individuals within groups.

The first significant factor is the angle of approach. This affects the mean and the 5th percentile of the time to Tca, and the accuracy. Table 28 shows that the nature of the effects on the time to Tca is to increase the time where the angle of approach is 170 degrees by about 36 seconds. The effect is more marked for skilled observers, but not to a significant extent.

The effect of angle of approach on accuracy (Table 29) is simply described by saying that the accuracy of judgements of precendence for angles of approach of 170 degrees is about 50%. In fact, a greater accuracy would be obtained by random guessing. This is in part accounted for by the reluctance of observers to make this type of judgement in this type of conflict. They tended to call the situation a "collision", order a course alteration and leave it at that.

The second significant factor is the speed of closing. This affects the mean and 5th percentile of the time to Tca. (Table 30). The general effect is that the slower the aircraft are closing, the longer time there is to Tca. The difference between the 5th and 95th percentiles is remarkably constant, both for skilled and unskilled observers.

The third significant effect is that of the passage of the rogue ahead of or behind the controlled aircraft. This has a significant effect on the 5th percentile (the time people start making judgements), (Table 31) and on the accuracy, (Table 32). First correct judgements are made 26 seconds earlier when the rogue is passing ahead, a difference which exactly parallels that observed for the first decision. In addition to being earlier, judgements of situations in which the rogue passes ahead are significantly more accurate, (78%) compared with those in which the rogue passes behind (65%). This can in part be accounted for by the greater difficulty of deciding what to do about the latter type of situation, but this explanation does not account for the similar magnitude of differences in speed and accuracy shown by unskilled observers, who were not required to make such decisions.

There are no significant differences in the effects of factors between groups for the first correct decision whether the rogue is passing ahead or behind the control.

TABLE 26.

First Correct Ahead/Behind Decision

Significant Effects	95th %ile	Time to Tca Mean (=50%)	5th %ile	Accuracy	Performance	Bias
Difference between groups						
1. Group means	Skilled/ Unskilled	Skilled/ Unskilled	Skilled/ Unskilled	-	-	-
2. Within Group Variabilities	-	-	-	-	-	-
Effects of Factors Varied						
1. Overall	-	Angle of Approach	Angle of Approach	Angle of Approach	-	-
	-	Speed of Closing	Speed of Closing	-	-	-
	-	-	Rogue Ahead /Behind	Rogue Ahead /Behind	-	-
2. Between Groups	-	-	-	-	-	-

TABLE 27.

First Correct Ahead/Behind Decision

Mean Overall Performance with Groups.

	95th %ile	Time to Tca Mean(=50%)	5th %ile	Accuracy	Performance	Bias
All Observers	72 sec.	133 sec.	194 sec...	71%	90	-1.7
Skilled Observers	85 sec.	142 sec.	201 sec.	70%	94	-2.0
Unskilled Observers	60 sec.	123 sec.	187 sec.	72%	87	-1.4
Civil Controllers	-	139 sec.	-	74%	-	-
Service Controllers	-	147 sec.	-	64%	-	-

TABLE 28.

First Correct Ahead/Behind Decision

Effects of Angle of Approach on Time to Tca.

Time to Tca (percentiles)	Level 1 (45 deg)			Level 2 (90 deg)			Level 3 (135 deg)			Level 4 (170 deg)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	60	122	186	69	126	186	60	121	183	101	159	221
Skilled Observers	76	129	185	71	132	194	78	135	189	114	172	237
Unskilled Observers	44	116	186	67	120	178	42	107	178	87	148	204

TABLE 29.

First Correct Ahead/Behind Decision

Effects of Angle of Approach on Accuracy.

	Level 1 (45 deg)	Level 2 (90 deg)	Level 3 (135 deg)	Level 4 (170 deg)
Overall	88%	78%	71%	47%
Skilled Observers	88%	79%	68%	46%
Unskilled Observers	88%	78%	74%	47%

TABLE 30.

First Correct Ahead/Behind Decision

Effects of Speed of Closing on Time to Tca.

Time to Tca (percentiles)	Level 1 (240 kt)			Level 2 (360 kt)			Level 3 (480 kt)			Level 4 (600 kt)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	96	156	221	77	136	199	59	123	184	57	114	172
Skilled Observers	104	162	229	96	146	196	69	133	199	70	128	180
Unskilled Observers	88	151	213	59	127	201	50	113	169	44	101	163

TABLE 31.

First Correct Ahead/Behind Decision

Effects of Rogue Passing Ahead or Behind on Time to Tca.

Time to Tca (percentile)	Rogue Ahead 95th	Rogue Ahead 50th	Rogue Ahead 5th	Rogue Behind 95th	Rogue Behind 50th	Rogue Behind 5th
Overall	88	145	211	62	119	177
Skilled Observers	94	154	217	75	129	185
Unskilled Observers	71	136	204	49	110	168

TABLE 32.

First Correct Ahead/Behind Decision

Effects of Rogue Passing Ahead or Behind on Accuracy.

Accuracy	Rogue Ahead	Rogue Behind
Overall	78%	65%
Skilled Observers	76%	64%
Unskilled Observers	79%	65%

6. <u>First 6orrect judgement of separation</u>.

The first correct judgement of separation is defined as the first correct judgement of what the separation of the two aircraft will be at their closest (the time of closest approach). The judgement is considered to be positive if the rogue is predicted to pass in front of the control, negative if it is predicted to pass behind the control, and is considered to be zero if the judgement is "Collision".

A judgement is considered to be correct if it is within three miles of the true value. (There is nothing special about this distance, it was chosen to provide a reasonable distribution of correct and incorrect judgements).

Measures analysed for individuals were the time to go to Tca at which this judgement was made, and the accuracy of the judgement, as defined above.

Measures defined for each simulation for each group of observers (skilled and unskilled) were the 5th and 95th percentiles of the time to Tca, and the performance and bias indices.

In general, the effects present resemble those for the first decision, although the range of values is greater, and there appear to be no significant effects of any of the factors on accuracy. The major factors are the angle of approach, and the speed of closing, although the performance index appears to be affected by the position of the conflict on the PPI. (Table 33).

Considering differences between group means, (Table 34) we observe that the mean time for skilled observers is 24 seconds before that for unskilled observers, and that the 95th percentile is 31 seconds before that for unskilled observers. The 5th percentile however is only eight seconds earlier. Thus we may observe that skilled observers start to make this judgement at the same time as unskilled observers, but finish earlier. This may be connected with the observation that 22% of unskilled observers make a subsequent correction to an initially wrong estimate, as against only 9% of skilled observers.

There are no significant differences in individual variability between groups, although unskilled observers tend to exhibit more variation than skilled ones. The range from 5th to 95th percentile is 125 seconds for skilled observers, and 154 seconds for unskilled.

The first significant factor is the angle of approach which is significant for all measures of time (Table 35) and for performance (Table 36). This can be ascribed to the difference between the 170 degree approaches and the rest, the nearly head-on cases being recognised about 48 seconds earlier than the rest. Skilled observers appear to show an increase in the speed with which they recognise the separation which is almost linearly proportional to the angle. Unskilled observers, however, do not appear to be affected by differences in angle between 45 degrees and 135 degrees. This difference between groups is not statistically significant. Performance follows closely the pattern for time.

The second factor affecting the overall performance is the speed of closing (Table 37). Again we find that the slower the speed of closing, the longer there is to go to Tca. The effect is more marked for unskilled than for skilled observers. The difference between 5th and 95th percentile is more or less constant throughout.

The performance index (Table 38) tends to follow much the same lines as before, except that level 2 (360 kts) tends to overtake level 3 (480 kts), contrary to expectation, but in agreement with its previous behaviour.

The only other significant effect is that of the position in the PPI on the performance index. This appears to be due to a relatively low level of performance for unskilled observers for level 2 - conflicts taking place in the outer part of the screen, in which the controlled aircraft is heading outwards. The level of significance is not high, and the reason for this effect is obscure. It may be a statistical artefact. (Table 39).

TABLE 33.

First Correct Judgement of Separation.

Significant Effects	95th %ile	Mean (=50%)	5th %ile	Accuracy	Performance	Bias
Differences between Groups						
1. Group Means	Skilled/ Unskilled	Skilled/ Unskilled	-	-	-	-
2. Within Group Variabilities	-	-	-	-	-	-
Effect of Factors						
1. Overall	Angle of Approach	Angle of Approach	Angle of Approach	-	Angle of Approach	-
	Speed of Closing	Speed of Closing	Speed of Closing	-	Speed of Closing	-
	-	-	-	-	Position on PPI	-
2. Between Groups	-	-	-	-	-	-

TABLE 34.

First Correct Judgement of Separation.

Mean Overall Performance within Groups.

	95th %ile	Time to Tca Mean (=50%)	5th %ile	Accuracy	Performance	Bias
All Observers	65 sec	130 sec	199 sec	74%	88	-1.4
Skilled Observers	80 sec	142 sec	205 sec	72%	96	-1.7
Unskilled Observers	49 sec	118 sec	193 sec	76%	80	-1.2
Civil Controllers	-	138 sec	-	78%	-	-
Service Controllers	-	148 sec	-	62%	-	-

TABLE 35.

First Correct Judgement of Separation at Tca.

Effects of Angle on Approach to Tca.

Time to Tca (percentiles)	Level 1 (45 deg)			Level 2 (90 deg)			Level 3 (135 deg)			Level 4 (170 deg)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	47	114	184	56	120	186	52	121	192	103	166	234
Skilled Observers	61	120	187	68	131	192	68	139	205	125	178	234
Unskilled Observers	32	107	181	44	110	180	37	104	178	82	152	235

TABLE 36.

First Correct Judgement of Separation at Tca.

Effects of Angle of Approach on Performance Index.

	Level 1 (45 deg)	Level 2 (90 deg)	Level 3 (135 deg)	Level 4 (170 deg)
Overall	85	80	77	111
Skilled Observers	89	89	87	122
Unskilled Observers	81	72	67	101

TABLE 37.

First Correct Judgement of Separation at Tca

Time to Tca (percentiles)	Level 1 (240 kt)			Level 2 (360 kt)			Level 3 (480 kt)			Level 4 (600 kt)		
	95th	50th	5th	95th	50th	5th	95th	50th	5th	95th	50th	5th
Overall	99	162	231	67	128	196	58	122	193	35	106	176
Skilled Observers	113	176	242	84	137	197	73	134	195	52	120	185
Unskilled Observers	86	150	220	49	119	196	43	110	192	17	93	167

TABLE 38.

First Correct Judgement of Separation at Tca

Effects of Speed of Closing on Performance Index.

Performance Index	Level 1 (240 kt)	Level 2 (360 kt)	Level 3 (480 kt)	Level 4 (600 kt)
Overall	119	81	85	69
Skilled Observers	128	89	94	76
Unskilled Observers	110	73	77	62

TABLE 39.

First Correct Judgement of Separation.

Effects of Position on P.P.I. on Performance Index.

Performance Index	Level 1	Level 2	Level 3	Level 4
Control	(Hdg in)	(Hdg out)	-	-
Position of Conflict	Outer	Outer	Median	Central
Overall	101	71	95	87
Skilled Observers	102	81	105	98
Unskilled Observers	101	61	85	75

VI. THE PAPER SIMULATION EXPERIMENT. DESIGN, APPARATUS AND METHOD

1. Experimental design.

The factors selected for testing in this experiment were:-

1. The heading of the controlled aircraft.
2. The angle of approach of the two aircraft.
3. The speed of closing of the two aircraft.
4. The nature of the miss.

These four factors are the first four used in the electronic simulation experiment. In view of the relatively simple techniques of this experiment, and the necessity of working with single subjects, the number of simulations was reduced from sixty-four to sixteen. This was done by selecting the sixteen situations for which the miss distance (factor 5 in the previous experiment) was at its greatest level. These sixteen situations formed a greco-latin square with respect to the four levels of each factor employed. Table 40 lists the four levels of each factor employed.

Table 41 lists (for each of the sixteen situations employed) its number in the original electronic simulation experiment, the levels of the four factors employed, the separation of the two aircraft at their point of closest approach, and whether the rogue passed ahead of or behind the controlled aircraft.

Figure 17 represents the sixteen situations employed, solid lines representing controlled aircraft, dotted lines representing rogues. It should be remembered that these lines represent the entire tracks of the aircraft in question, only one quarter of which would be visible at any given time.

It will be remembered that it had originally been intended to use two groups of twenty observers in the electronic simulation experiment, although the groups were ultimately reduced to thirteen and fourteen subjects. Two similar groups were used for the paper simulation experiment. One was of unskilled experimental observers, such as might normally be used in experimental psychological research, consisting of junior technicians and undergraduates, twenty in all. The other group - of skilled observers - was composed of two sub-groups, each of ten observers. The first sub-group consisted of ten military observers, all practiciig air traffic controllers at R.A.F. Sopley, and the second of ten civil air traffic controllers all practicing at London (Heathrow) Air Traffic Control Centre. It was not found necessary to discard any of these subjects, so that all forty appear in the analyses described in Chapter VII.

TABLE 40.

Levels of Factors Employed.

		Level 1	Level 2	Level 3	Level 4	
1.	Heading of controlled aircraft	090	150	225	350	degrees (Compass)
2.	Angle of approach	45	90	135	170	degrees (Angular)
3.	Speed of closing	240	360	480	600	knots (Nautical miles per hour)
4.	Nature of Miss					
	a) Rogue passing	Ahead	Behind	Ahead	Behind	
	b) Line of sight rotating	C-wise	C-wise	Anti-Cw	Anti-Cw	
	c) Rogue initially on	Right	Left	Left	Right	

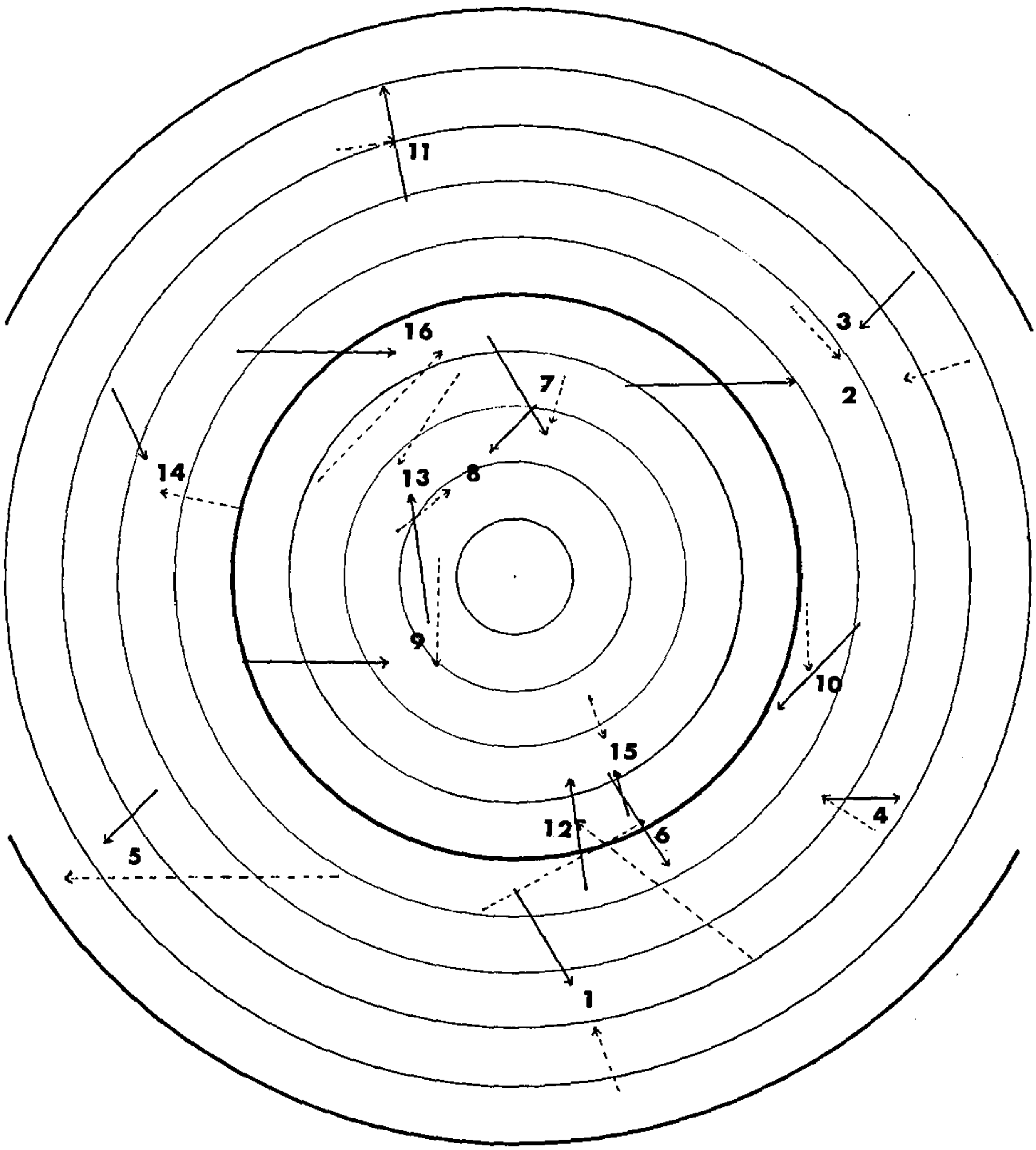
TABLE 41.

Combinations of Factors Employed

Simn. No.	No. in Elect. Simn.	Levels of Factors 1	2	3	4	Separation at Tca (miles)	Safe/ Conflict	Rogue Ahead/ Behind
1	6	2	4	3	3	+0.52	Conflict	Ahead
2	8	1	4	4	4	-0.35	Conflict	Behind
3	16	3	2	1	3	+5.56	Safe	Ahead
4	19	1	3	1	2	-3.27	Conflict	Behind
5	21	3	1	4	1	+6.79	Safe	Ahead
6	24	2	2	4	2	-7.02	Safe	Behind
7	30	2	1	1	4	-1.89	Conflict	Behind
8	31	3	4	2	2	-0.93	Conflict	Behind
9	34	1	2	3	1	+4.50	Conflict	Ahead
10	41	3	3	3	4	-2.26	Conflict	Behind
11	44	4	2	2	4	-4.15	Conflict	Behind
12	46	4	1	3	2	-7.49	Safe	Behind
13	47	4	3	4	3	+2.72	Conflict	Ahead
14	49	2	3	2	1	+3.01	Conflict	Ahead
15	54	4	4	1	1	+0.69	Conflict	Ahead
16	58	1	1	2	3	+7.59	Safe	Ahead

Figure 17

Simulations employed for Paper Simulation experiment



Controlled aircraft indicated by solid lines
Rogue aircraft are indicated by dotted lines

Tracks indicate the entire flight path of the aircraft, of which only 25% would be visible at any one time.

SCALE

20 miles (simulated)
= 1 inch on display
= 17 mm in this figure

2. Experimental apparatus and material.

a) Preparation of experimental material.

The preparation of the experimental material for this experiment was undertaken at Loughborough University of Technology. The aim was to produce a radar simulation which would be reasonably similar to the electronic simulation methods available, but which would be within the reach of any experimenter equipped only with normal officeequipment. The aim was to avoid any unnecessary complications, such as unorthodox electronic equipment, or automatic recording devices, while maintaining an adequate record of events.

Simple presentation methods, such as those employed by Hopkin (1963, 1965), Manglesdorf (1955a) and Schipper and Versace (1956), were considered. These methods however have certain basic limitations. They represent the situation in a static form, so that the judgement is one of implied motion, rather than actual motion. They produce data in a "Yes/No" form (Hopkin), or by adjusting the situation to provide a conflict (Manglesdorf). The former, although valid as a data measurement method, provides too little information. The latter type of measurement is subject to so many possible disturbing influences that results so obtained must be treated with a certain reserve.

It was decided (on 'a priori' grounds) to develop a method of paper simulation that would permit the presentation of events to the observer on a "Real Time" basis.. This is to say a method of simulation in which the events occur at the rate in which they occur in practice.

Some method had therefore to be found to present a changing picture to the observer. In the conventional radar simulator, a motion picture camera records a detailed picture, either in the conventional frame-by-frame method used in normal cine-cameras, or by recording the signals delivered to the "sweep" of the radar display, and using special apparatus to interpret this to a radar console when display is required. In either case, all the elaborate and costly equipment involved in photography, with its consequent faults, delays and planning requirements is introduced into the simulation system.

A number of possible methods for the simulation of a radar sweep were considered, involving such expedients as automatic slide changers equipped with rotating filters to simulate a radar sweep, or cathode ray oscilloscope controlled by pinholes in paper tape. Such devices can be constructed, with a little ingenuity, from the normal range of equipment to be found in ergonomic laboratories.

Expensive and careful preparations are required for even the shortest simulation runs using such techniques, because the positions of pinholes or other position indications must be calculated precisely and transferred exactly to the recording medium. The resultant simulation materials are delicate, and liable to substantial damage if used repeatedly.

A close study of the requirements of radar surveillance shows that radar observers are usually concerned with aircraft in one particular area of the screen. The radar sweep updates these trails at approximately the same time. It is therefore reasonable to dispense with the rotary sweep, and to present a complete new picture at an interval corresponding to the sweep rate.

To present these successive pictures, one possible method is to use a slide projector equipped to change slides at fixed intervals. These are commercially available and can hold up to 200 slides, which would be sufficient for about half an hour of simulation at a sweep rate of ten seconds per sweep (6 rpm). The problems of photography can be avoided by the use of opaque film, or smoked glass slides, inscribed with pin-holes to indicate positions and trails of aircraft. The labour of constructing such slides to any degree of accuracy is considerable, because very slight errors in locating points on the slide are greatly magnified by the process of projection. A further defect is that it is not easy to ensure that the slides appear in exactly the same place on the screen when projected, or when mounted. Possibly permanent features such as range rings and north markers could be incorporated in an initial slide, drawn on a large scale, then photographed. The cost of construction of many copies of one negative would be nearly the same as that of a film.

There seems however to be no real objection to presenting the radar trails as black marks on a white background. It is in this manner that previous experimenters have approached the problem, where cathode ray tubes were not used.

In this event there is no need to use slide projection. The required images may be drawn full size on sheets of paper of appropriate size. These may be pre-printed with the necessary background details, which may be used as reference points when the variable features are added. At a time corresponding to the sweep interval a new sheet may be placed over the previous one, showing the moving points in their new positions.

An initial approach was made using sheets of translucent paper, successive positions being marked on these, and a common background. It was hoped that the adding of extra layers would provide an effect analogous to the fading of the successive points of a radar trail.

Unfortunately it was found that when a sheet of tracing paper is placed on top of another sheet, small pockets of air become trapped between the sheets, and hold the sheets apart in places. The degree to which a point is visible through a sheet of tracing paper is critically dependent on its closeness to the paper. In consequence, where the sheets touched, the previous points were nearly as visible as the most recent; where they did not, the previous points were invisible.

A further disadvantage was that it was not possible to present successive sheets in exactly the same registration. Trails therefore appeared unacceptably "jumpy". In this particular study, such error was not acceptable.

The idea of using transparent paper was therefore abandoned. The effect of a trail was obtained by marking a small circle at the point where the aircraft was, and leading a triangular tail back to the point at which the aircraft had been five sweeps before. This corresponded to a time of fifty seconds at 6 rpm. Since opaque paper was now being used, the accuracy of placing of successive sheeta was of no great importance, provided that the points were correctly positioned with respect to the background and to each other. The successive sheets could then be stapled together, with the first to be shown at the bottom of the stack. The stack was slightly out of the vertical when stapled together, so that individual sheets could be released in succession without the risk of releasing two at one time.

A simple expedient was adopted to ensure that accurate directions and positions were produced for each aircraft, without putting any sort of construction lines on the final sheet. A common background was carefully drawn, and reproduced by offset lithography, enough copies being made to provide one for each sweep of the radar screen.

The standard sheet was 10 inches by fifteen inches in size, this being the largest sheet which could be reproduced by offset lithography with the resources available. On the sheet were reproduced a diagrammatic Plan Position Indicator. This took the form of a heavy ten-inch circle marked with degrees at ten-degree intervals. On the screen were range rings at half inch intervals, with a heavier ring at 2½ inches. A north marker line ran from the centre to the upper edge. The upper and lower ends of the north marker area were used as reference points.

The initial and final positions of the two aircraft were plotted on a transparent sheet, on which the two reference points were marked. The trails were then divided into twenty equal sections, using a nomogram. (Figure 18). Two springbow dividers were set to intervals of five sections, one corresponding to the rogue, the other to the controlled aircraft.

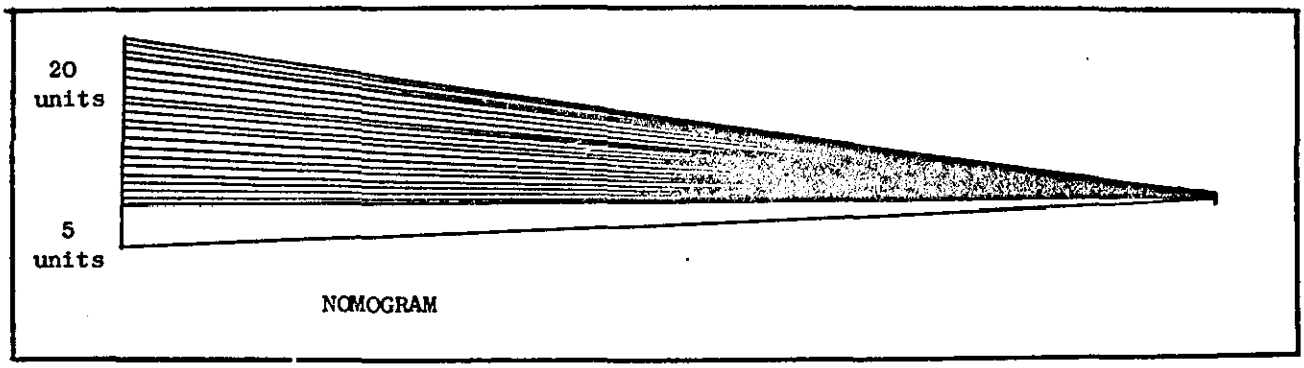
The transparent overlay was then placed on one of the opaque sheets obtained by offset lithography. It was carefully lined up by means of the reference points. The dividers were used to prick through the transparent overlay, the initial positions and the ends of the trails. The circle surrounding the present position was then drawn. The trails were then shaded in freehand using red coloured pencil for the rogue, and blue for the controlled aircraft.

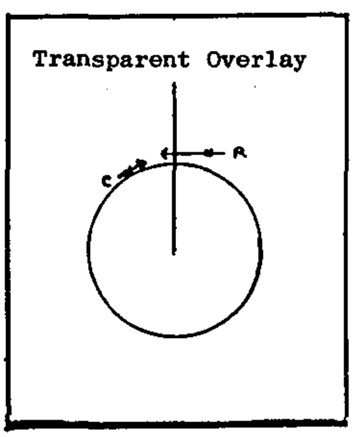
This process was repeated for each of the 20 sheets of the simulation. The sheets were then stacked, with the initial position at the bottom. The stack was carefully aligned, then repeatedly flexed so that successive sheets overlapped by about one-tenth of an inch. They were then stapled together in three places at the top. The number of the simulation was marked clearly on the back. (Figure 19 shows a typical simulation set).

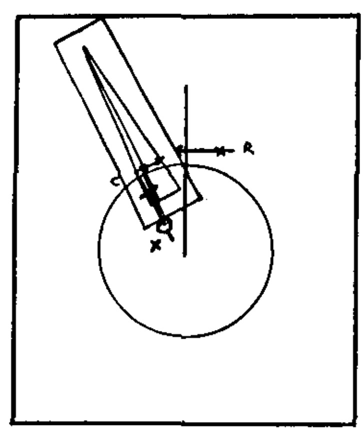
It was found in practice that these sets of sheets could be handled easily after a little practice, and that other tasks could be carried out at the same time. Figure 20 shows the experimental material in use.

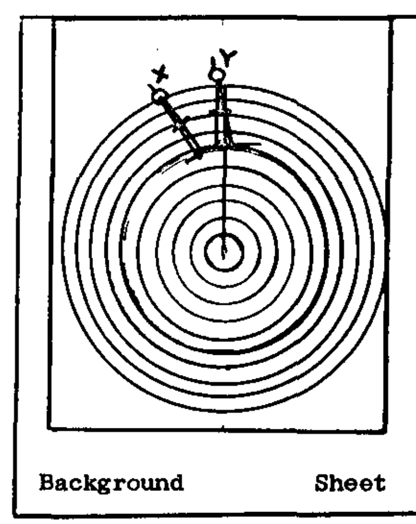
Figure 18

Method employed for the production of
accurate paper simulations





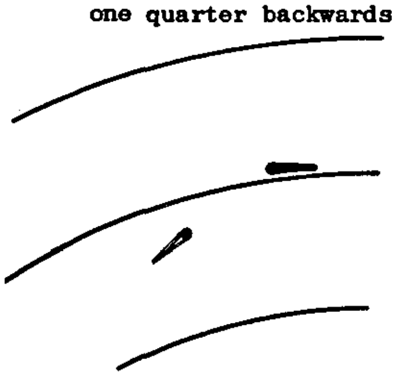




1. Draw initial and final positions of both aircraft on overlay. Join these and extend one quarter backwards

2. Position nomogram under each trail. Prick through with fine point at each of 20 points on trail. Set spring-bow dividers to 5 unit length. (Set X for control, Y for rogue aircraft)

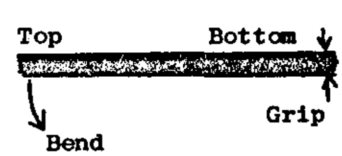
3. Position overlay exactly over stencilled background sheet, using North Marker line. Prick through with dividers, to give pin-point marks at start and end of trail.



4. Remove overlay. Draw small circles around heads of trails. Draw tangents from tail. Colour appropriately.

5. Repeat steps 3 and 4 for remaining nineteen background sheets.

6. Stack background sheets in order, face up, last position on top.

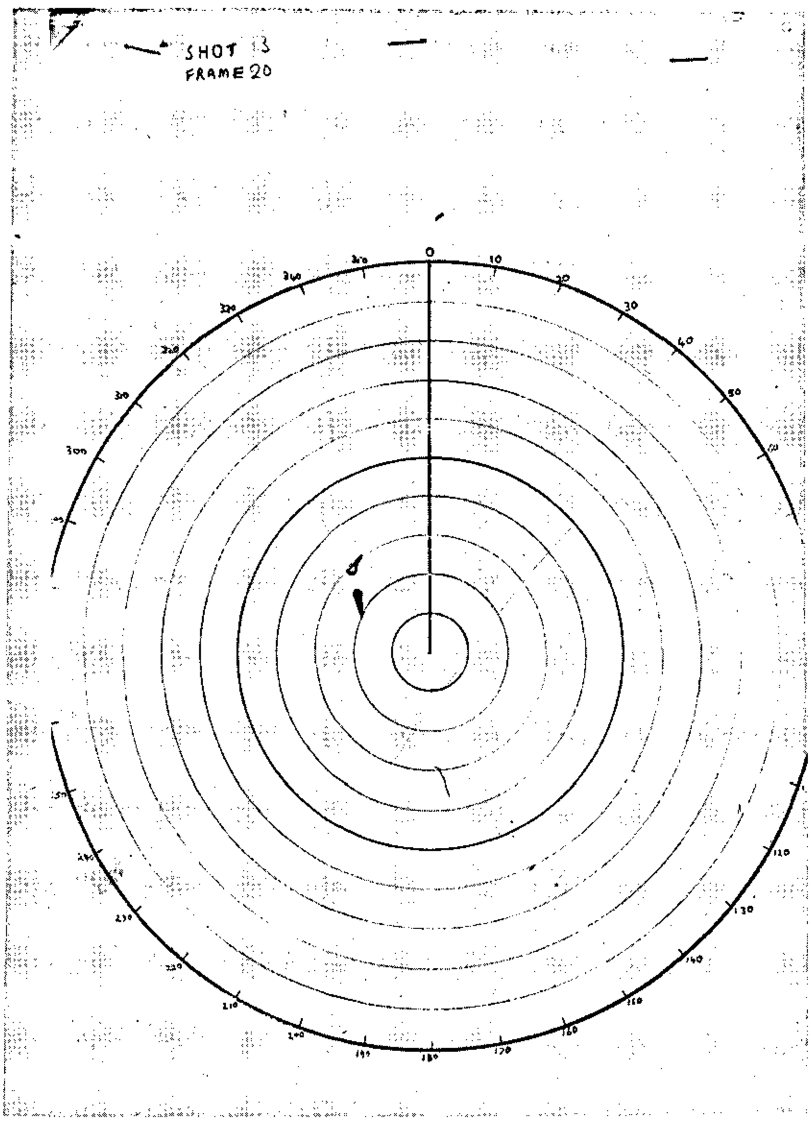


7. Bend pack, holding bottom firmly, to spread upper edge. (repeat if necessary)

8. Staple top edge. Release pack. Check order of sheets. Store pack in flat position. Do not fold or roll.

Figure 19

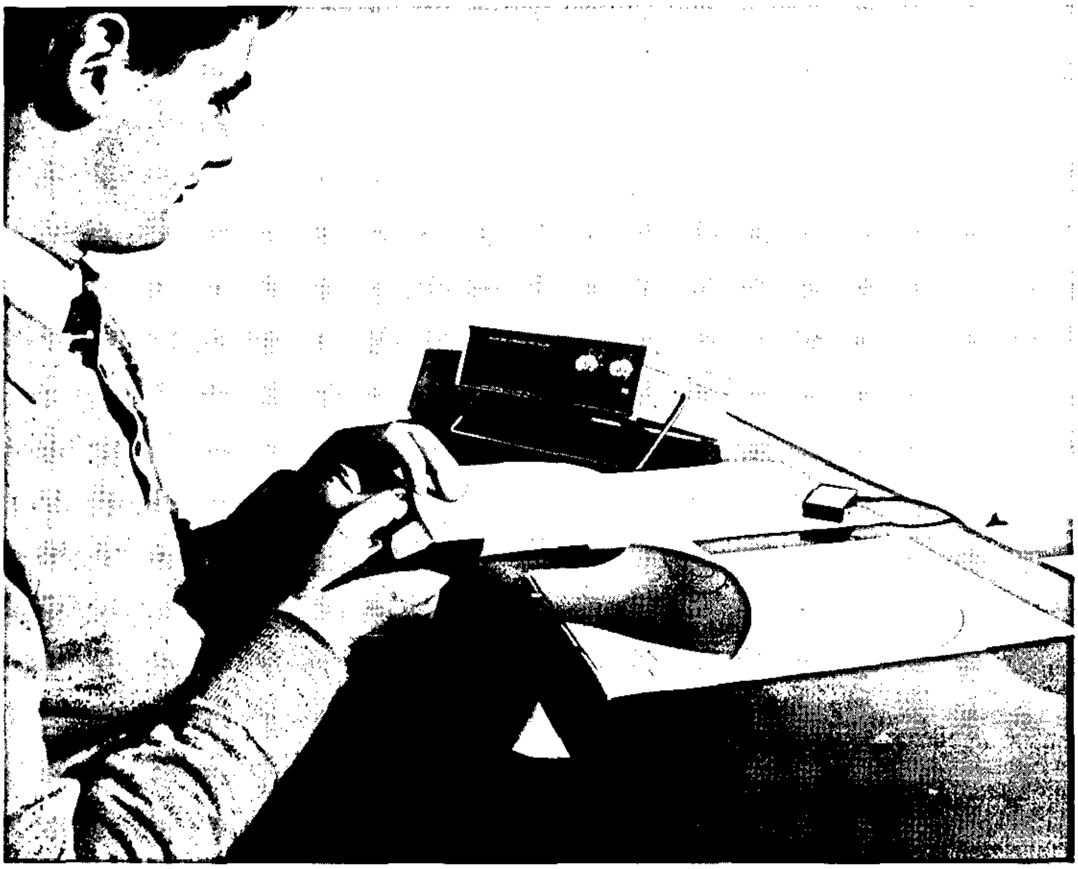
A typical simulation set



(as seen from above with last sheet released)

Figure 20

Experimental simulation in use



b) Experimental area and apparatus.

The equipment used in this experiment was designed to be simple and portable, and the experimental area was specified as any room having space for two chairs, a table and a power socket, being adequately lit, and free from distracting interruptions.

Three experimental rooms were employed. At the London Air Traffic Control Centre, a small experimental room was provided in the Training Section. This room had one window, which provided light from behind the experimenter, but had no view to distract the observer. At R.A.F. Station Sopley, the station commander, Wing Commander R.D.S. Orchard, M.B.E., very kindly allowed the use of his office, which had no natural lighting, but was provided with suitable artificial lighting. At Loughborough University a small experimental sound-proofed room was used. This room had a window, which was behind the experimenter, but provided a view of the sky only.

In each case, the layout of the experimental equipment was maintained constant as far as possible. The subject was seated at one side of a desk or table, with the experimenter seated opposite him. Within the field of view of the experimenter was a Venner Digital Stopclock, set to count seconds. This provided the experimenter with a cue on which to release the next sheet of the simulation, and provided a check on the timing of observers' comments.

The responses of the observer were recorded by means of a specially modified tape recorder, with which was combined a timing device which was intended to print out the time at which each comment was made.

In future experiments, it is recommended that a simple tape recorder without interrupt facilities should be used for any recording required, and that timing should be by any quiet running clock equipped to indicate seconds. The Venner stop-clock is particularly well suited to the situation, being completely silent, and having a digital display. It is on the other hand, rather heavy, and requires mains supply. If a battery-operated tape recorder were employed, in conjunction with a self contained clock, the entire apparatus could be made independent of power requirements.

Figure 21 shows the experimental arrangement used at Loughborough University of Technology. In order to provide a clear view for photography, the equipment has been moved into an open laboratory from the cubicle normally used. Note the Venner stop-clock to the left of the experimenter, and the tape recorder (extreme right).

Figure 21

Experimental arrangement employed at Loughborough University

3. Experimental procedure.

Observers were tested singly, each observer viewing sixteen simulations lasting 200 seconds each, with an initial practice run lasting approximately one hour including briefing.

Observers were briefed by the experimenter on arrival, and were allowed to ask any questions about the simulation. During this briefing the simulation method was explained to the observer, who was asked to report the various decisions later analysed. The observer was told how to report that the situation was safe or a conflict, that the rogue was passing ahead of or behind the control and so on. Forms of briefing were slightly different for skilled observers and unskilled observers, the latter not being asked to report any manoeuvres recommended, but being told more about how the radar that was simulated was used. When the experimenter was satisfied that the observer was able to operate the equipment and understood what was required of him, the observer was seated opposite the experimenter, and an initial practice simulation was run. Observers were told at the start of each simulation what the simulated velocity and heading of the control aircraft were, and were given the name of the type of aircraft it represented.

Observers recorded their comments by pressing a small button which started the tape recorder motor running, and speaking into a hand-held microphone. After speaking they released the button, and the tape recorder stopped. The experimenter noted the time at which each comment was made, and a verbal record was made by the observer of the start of each simulation. It was therefore easily possible to link up the comments made with the successive times recorded.

VII. PAPER SIMULATION EXPERIMENT - FINDINGS

1. Transcription of experimental data.

The use of a tape recorder which ran only when the observer made a comment enabled considerable economies to be made in stocks of recording tape and in subsequent transcription times. The times at which comments were noted on a prepared form during the experimental run, and the comments made by the observer were coded and filled in by subsequent reference to the tapes. In the later stages of the experiment, it was found possible to code comments as they were made. This was particularly the case for unskilled observers, who held more closely to the reporting procedure than did skilled observers. (It is worth remarking that the difference was primarily due to the lack of other ways of reporting situations on the part of unskilled observers. Skilled observers tended to use terms such as "port" and "starboard", and to report positions by clock-face methods - "Rogue passing at three miles, ten o'clock").

The timed responses were coded and transcribed onto I.B.M. cards. The responses were then classified in the manner described in the next section and analysed statistically.

2. Classification of decisions.

As in the electronic simulation experiment, four main types of decision were produced (see page 68 Chapter V, Electronic Simulation Experiment, 2. Classification of Decisions.)

These were:-

a) The first decision.

b) The first correct conflict/safe decision.

c) The first correct ahead/behind decision.

d) The first correct judgement of separation.

The same definitions of correctness were applied as were used in the electronic simulation experiment.

For the first decision, three measures of correctness could be obtained by evaluating the decision in terms of the three criteria of correctness. These were:-

a) Is the situation a conflict or is it safe?

b) Is the rogue aircraft passing ahead of or behind the controlled aircraft?

c) Is the separation estimated to within three miles?

For decisions b, c, and d listed above, the number of correct decisions was used as a measure of the overall performance of the observer. (The reader is referred to the example in Chapter V, Section 2 page 71).

It was thus possible to carry out ten separate analyses of variance, each based on sixteen readings from each of forty subjects who observed the paper simulations.

The primary purpose of the paper simulation was to provide data which could be compared directly with the appropriate portion of the electronic simulation experiment. Accordingly the corresponding readings for the electronic simulation experiment were extracted for the same sixteen simulations. These were analysed simultaneously with the readings from the paper simulation, so that the analyses were based on the performances of sixty-seven observers who each watched sixteen simulations. These observers may be divided into four groups, not of equal size.

a) Thirteen skilled observers saw electronic simulations.

b) Fourteen unskilled observers saw electronic simulations.

c) Twenty skilled observers saw paper simulations.

d) Twenty unskilled observers saw paper simulations.

The total number of readings for each analysis could therefore be as many as 1024.

It is statistically inconvenient that the groups are of different sizes, since this makes it impossible to carry out an orthogonal partition of the analysis of variance. It is possible to cope with this situation either by carrying out a least-squares fitting, which is laborious, and gives greater emphasis to the larger groups, or by carrying out an analysis on the unweighted means for each group in each simulation, for each type of simulation. This method gives an estimate of the significance of interactions which is not biased in favour of larger groups, and corresponds more to what we require in this case. Winer (1962) gives an adequate discussion of the methods available, although in this experiment, the analysis applied to unweighted means is more elaborate than that described by Winer.

In the experiments here described, we are interested in the effects observed as samples of population behaviour, rather than as effects in their own right, so that the differences observed between simulations and between groups of observers overall are more properly compared with the differences between subjects within groups than with the overall residual term. (In addition, this is preferable for measures of accuracy since in fact the measures employed are two-valued rather than continuous, so that the overall residual term is not a true estimate of error.)

Where a term (such as S - the difference between simulations) is not significant compared with the residual, then the term should not be further subdivided, since the variations present are explained in terms of the estimated variation between subjects. Where a term is significant, it may be subdivided in the appropriate way to produce the effects of the specific factors varied in this experiment. Table 40 in Section 1 of Chapter VI showed the four factors employed, with the sub-division of the last of these factors into three two-way contrasts. These contrasts are 'a priori' - determined before the experiment was carried out, and representing items of interest in themselves - rather than members of a population. (The passage of the rogue ahead or behind the control is a choice between exactly two alternatives, rather than a choice of two of a number of alternatives). They may therefore be compared directly with the residual term of the sub-division, and are shown in the appropriate partitioned form. In order to calculate the size of higher order terms, if these are to be partitioned, the earlier terms must also be partitioned, and the corresponding sums of squares are shown in the accompanying analyses. Where the main term is not significant no conclusions are drawn from the variance ratios observed.

Figure 22 shows how the readings obtained for a single decision are divided up, and what proportion of the readings are common to the analyses of chapter V and this chapter.

3. First decision

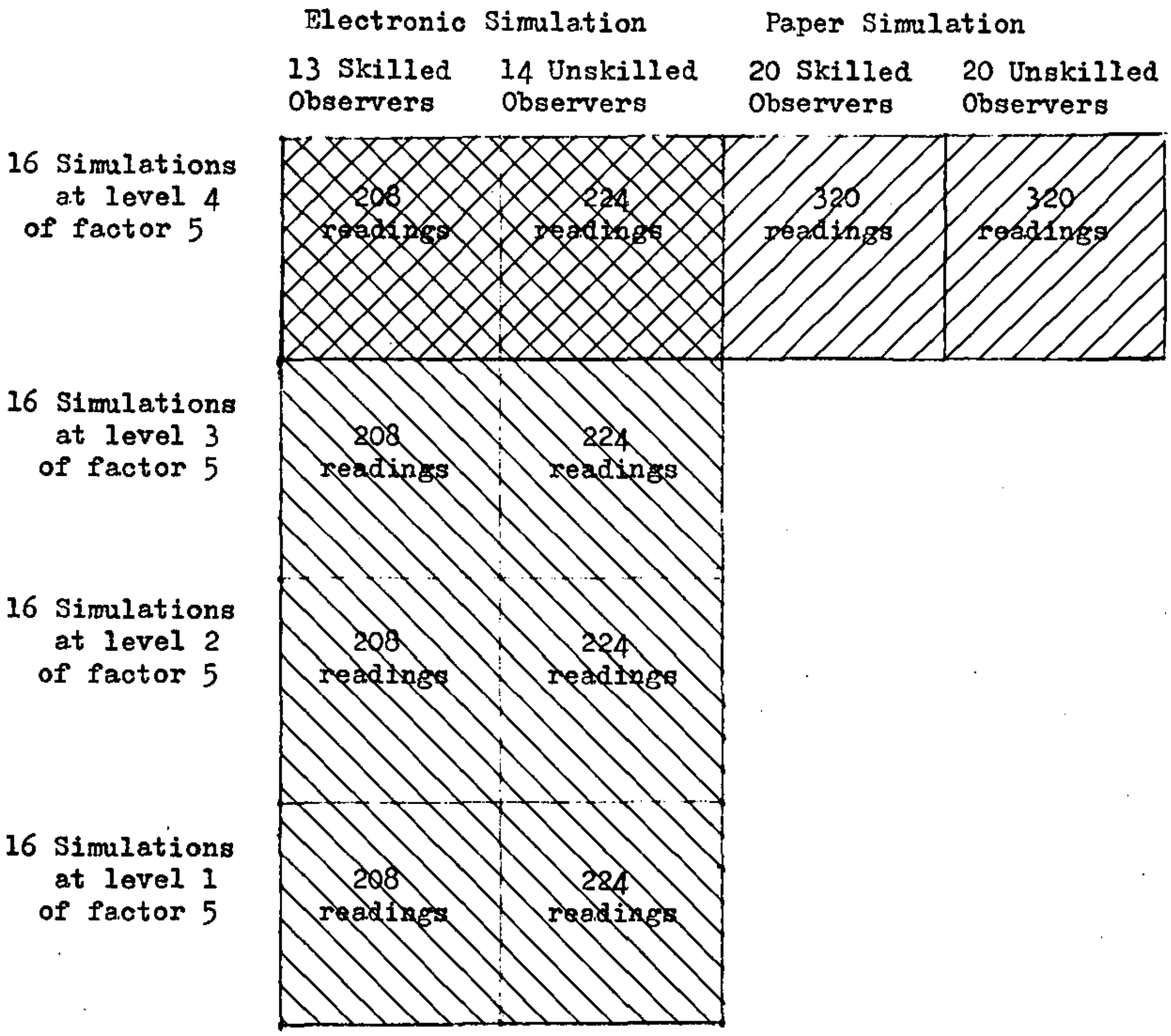
The first decision is the first recognisable decision made by the controller, regardless of whether it is or is not correct. The three measures of accuracy employed refer to the percentage of these decisions which are correct in terms of the definitions given in the previous section.

Table 49 is an analysis of variance for the time at which the first decision is made, and Tables 50, 51 and 52 are analyses of the accuracy of this decision in terms of the three criteria of accuracy. The significant effects derived from these analyses are summarised in Table 42.

Considering the differences between group means (Table 43, Figure 23), we observe that skilled observers make their first decisions earlier than

Figure 22

Meshing of Paper and Electronic Simulation experiments



Readings used in "Electronic Simulation" analyses : 

64 simulations form a Hyper-Greco-Latin Cube (6 factors at 4 levels)

27 observers provide 1728 readings

Readings used in "Paper Simulation" analyses : 

16 simulations form a Greco-Latin Square (4 factors at 4 levels)

67 observers provide 1072 readings

Readings common to both sets of analyses : 

16 simulations at level 4 of factor 5 of "Electronic Simulation"

27 observers provide 432 readings

unskilled observers, the difference being about 17 seconds on the average. (An aircraft travelling at 600 m.p.h. travels about three miles in this time.) Similarly simulations presented on paper simulations are resolved some 23 seconds earlier than corresponding simulations presented by the electronic simulator here employed (corresponding to 2 to 3 scans of the radar beam, or sheets of paper simulation).

Considering the accuracy effects reported in the same table, we observe that there are no significant differences in the accuracy with which the situations are judged to be conflicts or safe, which was the main purpose of the experiment. There is a significantly poorer performance in the judgement of which aircraft will pass in front of the other on paper simulations, both for skilled and unskilled observers, In addition, skilled observers are worse at judging separation on the first decision on paper simulation than they are using electronic simulations. These latter results are probably ascribable to the emphasis placed on reporting whether the situation was a conflict or safe, and the greater willingness of skilled observers to report operationally important information in the more operationally relevant situation. These differential effects are considerably reduced when the overall accuracies are considered, and can be ascribed primarily to failure to make reports rather than to failure to judge the situation or misjudgements of the situation.

Considering next the overall effects of different simulations, it should be first emphasised that our interest lies primarily in the nature of significant interactions and their causes, rather than in simulations themselves. The effects of the factors varied in this experiment must be large to be significant at all, and represent only a small proportion of the information available about the two aircraft conflict situations. Table 44 presents the mean time of first decision for each simulation for all observers, and Figure 24 presents these times on the vertical axis, with the separation of the aircraft at the time of closest approach on the horizontal axis, this being the most important other parameter influencing performance. A study of Figure 24 suggests that the time to Tca is inversely proportional to the difference of the separation from the critical 5 miles between conflicts and safe situations, marked as a pair of vertical lines. A linear regression of the observed means on that separation has been carried out, and yields a correlation of 0.37 for a regression equation of $Y = 127 + 14.5x$ where Y is the difference of the separation from 5 miles. We may transform this equation to obtain the W-shaped line shown in Figure 24. The correlation is not quite significant, which is only to be expected in view of the small number of available readings, and the existence of certain exceptional situations - such as no 4.

Considering next the differences between simulations in the proportion of correct conflict/safe decisions, we note that there are significant effects both of simulation type and of skill of observer (Table 45, Figures 25 and 26). In addition there is a significant overall effect of the passage of the rogue ahead of or behind the controlled aircraft, the accuracy being considerably greater when the rogue is passing behind the control.

Considering the effects in terms of the separation at closest approach, we observe that there appears to be a certain asymmetry of the data; situations where the rogue passes ahead of the controlled aircraft being particularly poorly assessed. There seems to be a general tendency for the accuracy to fall off with increasing separation, and for unskilled observers to be better at assessing safe situations than conflict situations. This presumably reflects the skilled observers reluctance to make a decision having possibly disastrous consequences rather than one causing only a minor diversion of traffic.

Considering the differences between paper and electronic simulations, shown in Figure 26, we observe a tendency for paper simulations to be more accurate where the separation is low, while electronic simulations are more accurate at higher separations.

Considering next the accuracy of the first decision in terms of the judgement of which aircraft is passing ahead of the other, we observe no significant interaction terms, only the overall effect of differences between simulations. These differences seem to represent a decrease in accuracy as the separation decreases, as might be expected. (Table 47, Figure 27).

Finally considering the accuracy in terms of judgement of separation we observe a significant effect of simulations, and a significant difference between paper and electronic simulations. (Table 48, Figure 28). The significance of the difference between simulations is considerably less than that observed for the previous two measures of accuracy, and appears to correspond to a slight trend for the accuracy to be less in proportion to the extent that the rogue is passing ahead of the control. The differences between paper and electronic simulation are very marked, so much so that the difference for simulation no. 3 suggested that the data might have been accidentally inverted. A direct check on the original transcriptions of data verified that the majority of observers viewing this simulation on the radar screen considered it to be safe at first sight, while the majority of subjects viewing it on the paper simulation considered it a potential conflict. It is worth noting that the situations in which the rogue passes well ahead of the control are more often judged correctly for separation when seen on an electronic simulation, while those in which the rogue passes very close to the control seem to be better judged on a paper simulation.

Considering differences between subjects within groups, we observe that unskilled observers viewing paper simulations are significantly more variable than any other group of observers, including skilled observers watching the same simulations. We also observe that there are significant differences between individual observers compared with the overall residual, except for the accuracy of the conflict/safe judgement. The non-significant level here is probably due to the drift of the overall mean accuracy away from the central 50% level to the 71% level (Table 43 - top line) leading to a lack of homogeneity and increased residual variance.

TABLE 42.

First Decision - Significant Effects.

Type of Effect	Time to Tca	Conflict/Safe	Accuracy Ahead/Behind	Separation
Differences Between Groups	Skilled/ Unskilled Paper/ Electronic	-	Paper/ Electronic	Skill/Simulation Interaction
Within Groups Variability	Unskilled Paper Vs All others	-	-	-
Differences between Observers Compared with Residual Variation	Significant	-	Significant	Significant
Differences between Simulations	Overall	Overall	Overall	Overall
Factors within Simulations	-	Rogue Ahead/ Behind	-	-
Interactions with Simulations	-	Skilled/ Unskilled Paper/ Electronic	-	Paper/Electronic
Factors within Interactions	-	-	-	-

TABLE 43.

First Decision - Mean Performance Within Groups

Group of Observers	Time to Tca	Conflict/Safe	Accuracy Ahead/Behind	Separation
All Observers	164 sec	71%	48%	49%
Skilled Observers	172 sec	72%	49%	44%
Unskilled Observers	155 sec	69%	47%	54%
Electronic Simulation	150 sec	69%	65%	54%
Paper Simulation	173 sec	73%	36%	46%
Skilled/Electronic	160 sec	71%	69%	59%
Unskilled/Electronic	140 sec	67%	62%	49%
Skilled /Paper	181 sec	73%	36%	34%
Unskilled Paper	165 sec	72%	36%	58%

TABLE 44.

First Decision - Time to go to Tca.

Mean performance for each simulation for skilled/ unskilled and paper/electronic simulation.

Simulation	Mean
1	180
2	180
3	229
4	48
5	121
6	139
7	146
8	234
9	168
10	114
11	105
12	168
13	177
14	204
15	256
16	152

TABLE 45.

First Decision - Accuracy in Terms of Conflict/Safe Decision

Simulation	Mean	Skilled	Unskilled	Electronic	Paper
1	79	91	68	63	90
2	90	91	88	85	93
3	48	42	53	56	43
4	73	70	76	70	75
5	31	42	21	37	28
6	72	73	71	81	65
7	88	91	85	89	88
8	78	76	79	48	98
9	73	76	71	67	78
10	99	97	100	96	100
11	84	91	76	85	83
12	72	55	88	67	75
13	63	79	47	37	80
14	54	61	47	67	45
15	99	97	100	96	100
16	36	30	41	56	23

TABLE 46.

First Decision - Effect of Rogue Passing Ahead/Behind on Conflict/Safe Accuracy

Observers	Rogue Passing Ahead	Rogue Passing Behind	Mean	Difference
All Observers	60%	82%	71%	22%
Skilled Observers	65%	80%	72%	15%
Unskilled Observers	56%	83%	69%	27%
Electronic Simulation	60%	77%	69%	17%
Paper Simulation	61%	84%	73%	23%
Skilled/Electronic	65%	77%	71%	22%
Unskilled/Electronic	54%	79%	67%	25%
Skilled/Paper	64%	83%	73%	19%
Unskilled/Paper	57%	86%	72%	29%

TABLE 47.

First Decision - Accuracy in Terms of Ahead/Behind Decision

Simulation	Mean Accuracy
1	49%
2	10%
3	37%
4	69%
5	60%
6	73%
7	21%
8	37%
9	45%
10	28%
11	55%
12	78%
13	54%
14	72%
15	22%
16	57%

TABLE 48.

First Decision - Accuracy in Terms of Judgement of Separation

Simulation	Mean	Electronic Simulation	Paper Simulation	Difference
1	46%	30%	58%	+28%
2	57%	52%	60%	+ 8%
3	36%	81%	5%	-76%
4	66%	63%	68%	+ 5%
5	31%	30%	33%	+ 3%
6	54%	63%	48%	-15%
7	49%	59%	43%	-16%
8	51%	22%	70%	+48%
9	31%	48%	20%	-28%
10	60%	59%	60%	+ 1%
11	40%	41%	40%	- 1%
12	61%	74%	53%	-21%
13	43%	37%	48%	+11%
14	58%	67%	53%	-14%
15	75%	81%	70%	-11%
16	31%	52%	18%	-34%
ALL	49%	54%	46%	- 8%

TABLE 49.

Analysis of Variance - Time of First Decision

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig
1 G=Skilled/ Unskilled	75,799.3	1	75,799.3	13.356	36	***
2 T=Paper/ Electronic	134,050.9	1	134,050.9	23.620	36	***
3 GT= Skill/ Type IA	1,046.8	1	1,046.8	0.184	36	NS
4 S=Simulations (1 - 16)	2,682,416.2	15	178,827.7	31.510	36	***
5 H=Heading of Control	270,157.4	3	90,052.5	0.276	11	NS
6 A=Angle of Approach	882,294.8	3	293,804.2	0.902	11	NS
7 V=Speed of Closing	65,144.4	3	21,712.6	0.067	111	NS
8 B=Rogue Ahead/ Behind	471,426.1	1	471,426.1	1.447	11	NS
9L=Rotn.of Line of Sight	13,646.0	1	13,646.0	0.042	11	NS
10 I=Initial Posn. of Rogue	2,084.3	1	2,084.3	0.006	11	NS
11 Residual Between Simns.	977,663.2	3	325,855.1	-	-	
12 GS=Skill/Simn.IA	21,995.7	15	1,467.1	0.259	36	NS
13 GH=Ski/Hdg. IA	872.4	3	290.8	0.220	19	NS
14 GA=Ski/Ang. IA	882.7	3	294.2	0.222	19	NS
15 GV=Ski/Spd. IA	11,855.6	3	3,951.5	2.987	19	NS
16 GB=Ski/Psg. IA	184.9	1	184.9	0.140	19	NS
17 GL=Ski/Rot. IA	625.4	1	625.5	0.473	19	NS
18 GI=Ski/Pos. IA	3,605.5	1	3,605.5	2.725	19	NS
19 Residual of GS	3,969.0	3	1,322.9	-	-	
20 TS= Type/Simn. IA	57.191.3	15	3,814.7	0.672	36	NS
21 TH=Typ/Hdg. IA	14,812.2	3	4,936.9	0.895	27	NS
22 TA=Typ/Ang. IA	4,868.8	3	1,622.8	0.294	27	NS
23TV=Typ/Spd. IA	7,891.3	3	2,630.2	0.477	27	NS
24 TB=Typ/Psg. IA	7,319.2	1	7,319.2	1.327	27	NS
25 TL=Typ/Rot. IA	121.4	1	121.4	0.022	27	NS
26 TI=Typ/Pos. IA	5,629.8	1	5,629.8	1.021	27	NS
27 Residual of TS	16,548.6	3	5,515.6	-	-	
28 GTS=Ski/Type/Simn.IA	24,552.5	15	1,637.6	0.289	36	NS
29 GTH=Ski/Typ/Hdg.IA	1,689.9	3	563.2	0.625	35	NS
30 GTA=Ski/Typ/Ang.IA	3,036.0	3	1,012.0	1.123	35	NS
31 GTV=Ski/Typ/Spd.IA	7,299.0	3	2,433.0	2.699	35	NS
32 GTB=Ski/Typ/Psg.IA	1,269.5	1	1,269.5	1.408	35	NS
33 GTL=Ski/Typ/Rot.IA	7,421.5	1	7,421.5	8.232	35	NS
34 GTI=Ski/Typ/Pos.IA	1,132.0	1	1,132.0	1.256	35	NS
35 Residual of GTS	2,704.6	3	901.4			
36 Between Subjects	357,543.9	63	5,675.3	7.991	37	***
37 Within GTS Res.	660,472.6	930	710.2			
38 TOTAL SUM OF SQUARES	4,015,269.2	1056				

TABLE 50.

Analysis of Variance
No.of Correct Initial Conflict/Safe Decisions.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	2,721.9	1	2,721.9	1.53	36	NS
2 T=Paper/ Electronic	3,468.5	1	3,468.5	1.95	36	NS
3 GT=Skill/Type IA	487.0	1	487.0	0.27	36	NS
4 S=Simns. (1-16)	364,278.5	15	24,318.6	13.70	36	***
5 H=Heading of Control	31,783.3	3	10,594.4	1.43		
6 A=Angle of Approach	90,480.3	3	30,160.1	4.07		
7 V=Speed of Closing	59,187.6	3	19,729.2	2.67		
8 B=Rogue Ahead/ Behind	111,355.6	1	111,355.6	15.04		*
9 L=Rotn. of Line of Sight	4,778.6	1	4,778.6	0.64		
10 I=Initial posn. of Rogue	44,986.0	1	44,986.0	6.08		
11 Residual Between Simns.	22,207.0	3	7,402.3	-		
12 GS=Skill/Simn. IA	60,813.9	15	4,054.3	2.28	36	**
13 GH=Ski/Hdg IA	7,449.3	3	2,483.1	0.42		
14 GA=Ski/Ang IA	2,732.2	3	910.8	0.15		
15 GV=Ski/Spd IA	15,537.1	3	5,179.0	0.88		
16 GB=Ski/Psg IA	9,142.3	1	9,142.3	1.55		
17 GL=Ski/Rot IA	2,764.0	1	2,764.0	0.47		
18 GI=Ski/Pos IA	5,438.0	1	5,438.0	0.91		
19 Residual of GS	17,751.0	3	17,751.0			
20 TS=Type/Simn IA	115,824.6	15	7,721.6	4.35	36	***
21 TH=Typ/Hdg IA	12,608.1	3	4,202.7	0.27		
22 TA=Typ/Ang IA	37,887.5	3	12,629.1	0.80		
23 TV=Typ/Spd IA	8,868.6	3	2,956.2	0.19		
24 TB=Typ/Psg IA	2,262.1	1	2,262.1	0.14		
25 TL=Typ/Rot IA	1.2	1	1.2	0.00		
26 TI=Typ/Pos IA	6,671.5	1	6,671.5	0.42		
27 Residual of TS	47,525.3	3	15,841.7			
28 GTS=Skill/Type/Simn. IA	30,457.6	15	2,030.5	1.14	36	NS
29 GTH=Ski/Typ/Hdg IA	5,099.0	3	1,699.8	14.46	35	*
30 GTA=Ski/Typ/Ang IA	12,910.4	3	4,303.4	36.62	35	**
31 GTV=Ski/Typ/Spd IA	8,881.5	3	2,960.5	25.19	35	*
32 GTB=Ski/Typ/Psg IA	228.2	1	228.2	0.24	35	
33 GTL=Ski/Typ/Rot IA	766.9	1	766.9	6.52	35	
34 GTI=Ski/Typ/Pos IA	1,129.9	1	1,129.9	9.61	35	
35 Residual of GTS	352.5	3	117.5			
36 Between Subjects IA	111,869.5	63	1,775.7	1.141	37	NS
37 Within GTS RES.	1,470,218.4	945	1,555.8			
38 TOTAL SUM OF SQUARES	2,160,639.9					

TABLE 51.

Analysis of Variance
No.of Correct Initial Ahead/Behind Decisions.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	2,880.7	1	2,880.7	0.41	36	NS
2 T=Paper/ Electronic	218,927.2	1	218,927.2	30.94	36	***
3 GT=Skill/Type IA	2,880.7	1	2,880.7	0.41	36	NS
4 S=Simns. (1-16)	395,529.5	15	26,381.8	3.73	36	***
5 H=Heading of Control	21,820.7	3	7,272.8	0.499	11	NS
6A=Angle of Approach	101,728.9	3	33,906.2	2.328	11	NS
7 V=Speed of Closing	46,401.4	3	15,465.6	1.062	11	NS
8B=Rogue Ahead/ Behind	6,793.5	1	6,793.5	0.466	11	NS
9 L=Rotn. of Line of Sight	74,722.2	1	74,722.2	5.129	11	NS
10 I=Initial posn. of Rogue	100,360.4	1	100,360.4	6.889	11	NS
11 Residual Between Simns.	43,702.5	3	14,566.0	-		
12 GS=Skill/Simn. IA	39,699.0	15	2,647.9	0.37	36	NS
13 GH=Ski/Hdg IA	15,450.1	3	5,149.5	2.70	19	NS
14 GA=Ski/Ang IA	3,484.8	3	1,161.5	0.61	19	NS
15 GV=Ski/Spd IA	9,803.1	3	3,267.4	1.71	19	NS
16 GB=Ski/Psg IA	4.6	1	4.6	0.00	19	NS
17 GL=Ski/Rot IA	4,702.8	1	4,702.8	2.46	19	NS
18 GI=Ski/Pos IA	521.0	1	521.0	0.27	19	NS
19 Residual of GS	5,732.5	3	1,910.6			
20 TS=Type/Simn IA	145,700.7	15	9,718.2	1.37	36	NS
21 TH=Typ/Hdg IA	40,554.4	3	13,516.8	4.75	27	NS
22 TA=Typ/Ang IA	13,909.3	3	4,636.0	1.63	27	NS
23 TV=Typ/Spd IA	8,507.3	3	2,835.5	1.00	27	NS
24 TB=Typ/Psg. IA	33,394.2	1	33,394.2	11.73	27	*
25 TL=Typ/Rot IA	6,054.0	1	6.054.0	2.12	27	NS
26 TI=Typ/Pos IA	34,735.5	1	34,735.5	12.20	27	*
27 Residual of TS	8,544.4	3	2,848.1	-		
28 GTS=Skill/Type Simn IA	58,994.3	15	3,933.0	0.55	36	NS
29 GTH=Ski/Typ/Hdg IA	4,620.7	3	1,540.1	0.47	35	
30 GTA=Ski/Typ/Ang IA	31,006.4	3	10,334.4	3.13	35	
31 GTV=Ski/Typ/Spd IA	8,514.6	3	2,837.9	0.86	35	
32 GTB=Ski/Typ/Psg IA	3,888.3	1	3,888.3	1.18	35	
33 GTL=Ski/Typ/Rot IA	2.7	1	2.7	0.00	35	
34 GTI=Ski/Typ/Pos IA	1,079.7	1	1,079.7	0.33	35	
35 Residual of GTS	9,881.9	3	3,293.7			
36 Between Subjects	445.830.4	63	7,076.7	4.96	37	***
37 Within GTS Res.	1,347,037.8	945	1,425.4			
38 TOTAL SUM OF SQUARES	2,657,480.3	1071				

TABLE 52.

Analysis of Variance
No.of Correct Initial Judgements of Separation.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	11,905.1	1	11,905.1	2.36	36	
2 T=Paper/ Electronic	14,435.3	1	14,435.3	2.86	36	
3 GT = Skill/Type IA	76,821.1	1	76,821.1	15,21	36	***
4 S=Simns. (1-16)	154,895.8	15	10,331.6	2.05	36	*
5 H=Heading of Control	16,922.1	3	5,640.2	0.48	11	NS
6 A=Angle of Approach	37,143.1	3	12,379.8	1.06	11	NS
7 V=Speed of Closing	29,464.3	3	9,820.4	0.84	11	NS
8 B=Rogue Ahead/ Behind	20,801.4	1	20,801.4	1.78	11	NS
9 L=Rotn of Line of Sight	14,507.7	1	14,507.7	1.24	11	NS
10 I=Initial posn. of Rogue	890.9	1	890.9	0.08	11	NS
11 Residual Between Simns.	35,166.3	3	11,722.1	-		
12 GS=Skill/Simn. IA	79,145.2	15	5,276.4	1.04	36	NS
13 GH=Ski/Hdg IA	8,836.2	3	2,945.4	0.97	19	NS
14 GA=Ski/Ang IA	37,158.8	3	12,386.3	4.08	19	NS
15 GV=Ski/Spd IA	5,364.1	3	1,788.0	0.59	19	NS
16 GB=Ski/Psg IA	7,610.5	1	7,610.5	2.50	19	NS
17 GL=Ski/Rot IA	10,835.6	1	10,835.6	3.57	19	NS
18 GI=Ski/Pos IA	222.0	1	222.0	0.08	19	NS
19 Residual of GS	9,117.9	3	3,039.3	-		
20 TS=Type/Simn. IA	185,516.5	15	12,368.4	2.45	36	**
21 TH=Typ/Hdg IA	2,529.7	3	843.1	0.05	27	NS
22 TA=Typ/Ang IA	86,312.1	3	28,767.8	1.77	27	NS
23 TV=Typ/Spd IA	28,287.6	3	9,461.6	0.58	27	NS
24 TB=Typ/Psg IA	17,341.0	1	17,341.0	0.12	27	NS
25 TL=Typ/Rot IA	2,033.9	1	2,033.9	0.00	27	NS
26 TI=Typ/Pos IA	22.7	1	22.7	-		
27 Residual of TS	48,889.4	3	16,296.4	-		
28 GTS=Skill/Type/Simn IA	63,208.5	15	4,213.9	0.83	36	NS
29 GTH=Ski/Typ/Hdg IA	4,419.6	3	1.473.1	0.33	35	NS
30 GTA=Ski/Typ/Ang IA	22,802.6	3	7,600.1	1.70	35	NS
31 GTV=Ski/Typ/Spd IA	2,195.7	3	731.8	0.16	35	NS
32 GTB=Ski/Typ/Psg IA	792.0	1	792.0	0.18	35	NS
33 GTL=Ski/Typ/Rot IA	5,110.3	1	5,110.3	1.14	35	NS
34 GTI=Ski/Typ/Pos IA	14,459.4	1	14,459.4	3.23	35	NS
35 Residual of GTS	13,428.9	3	4,476.3	-		
36 Between Subjects	318,211.2	63	5,051.0	2.77	37	***
37 Within GTS RES.	1,724,563.5	945	1,824.9			
38 TOTAL SUM OF SQUARES	2,628,702.2	1071				

Figure 23

First decision - Group means

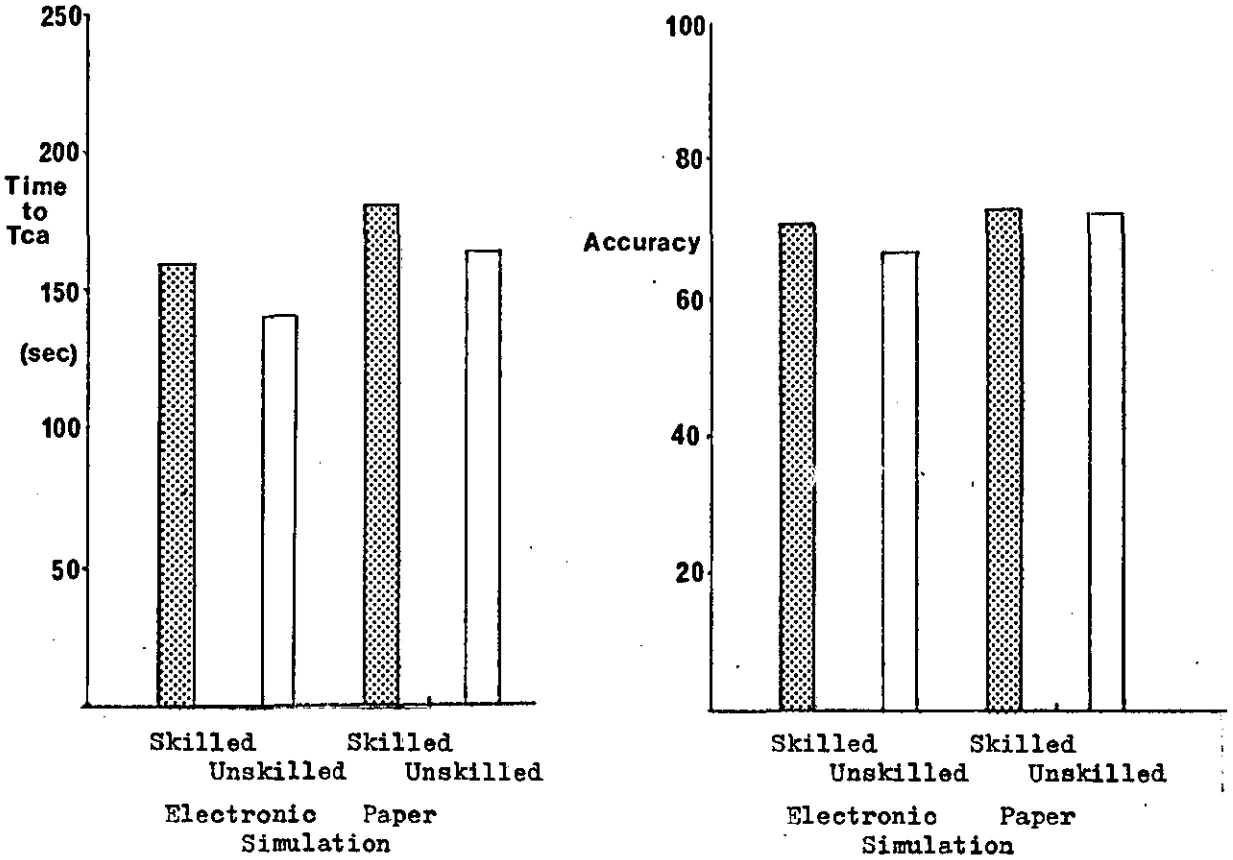


Figure 24

First decision - Time to Tca

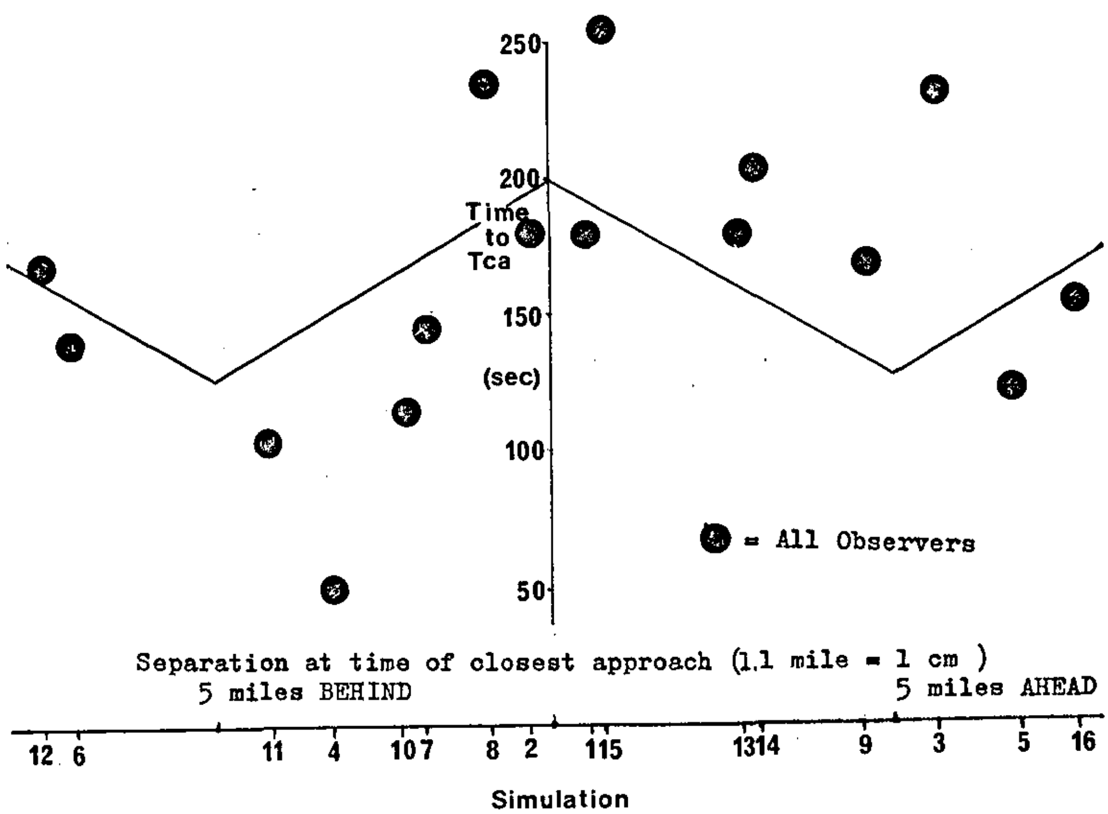


Figure 25

First decision - Accuracy(conflict/safe) - Skill

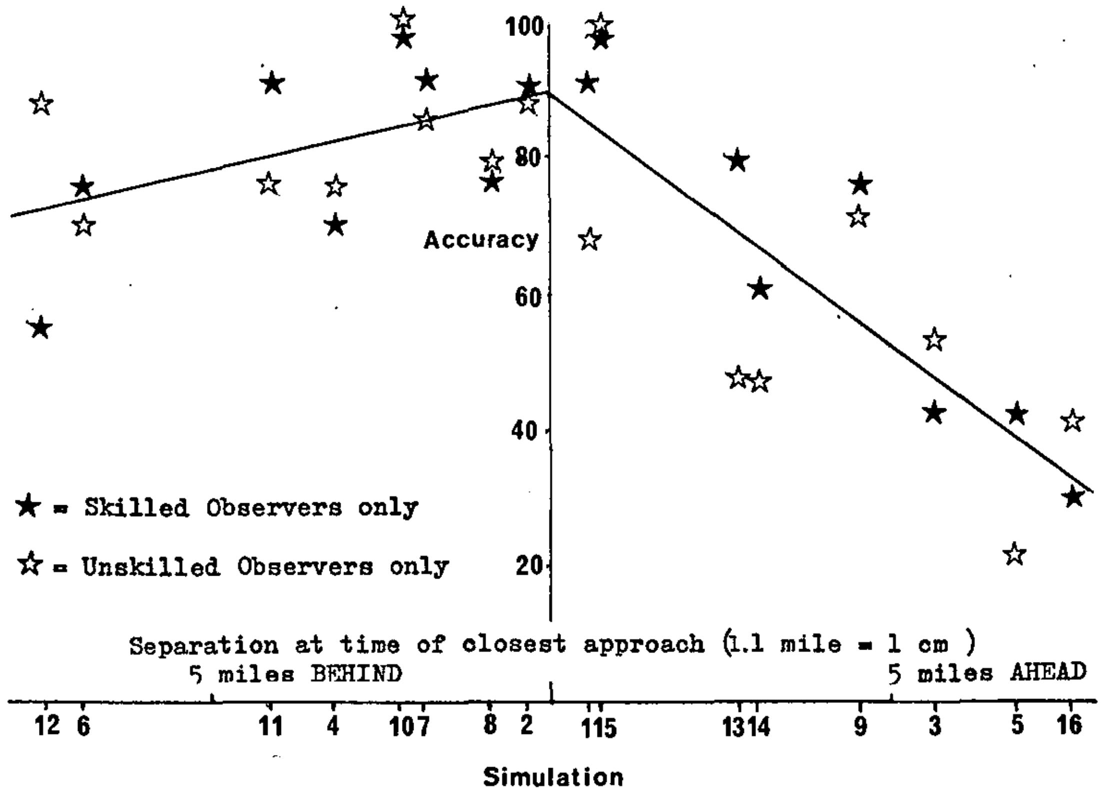


Figure 26

First decision - Accuracy(conflict/safe) - Simulation type

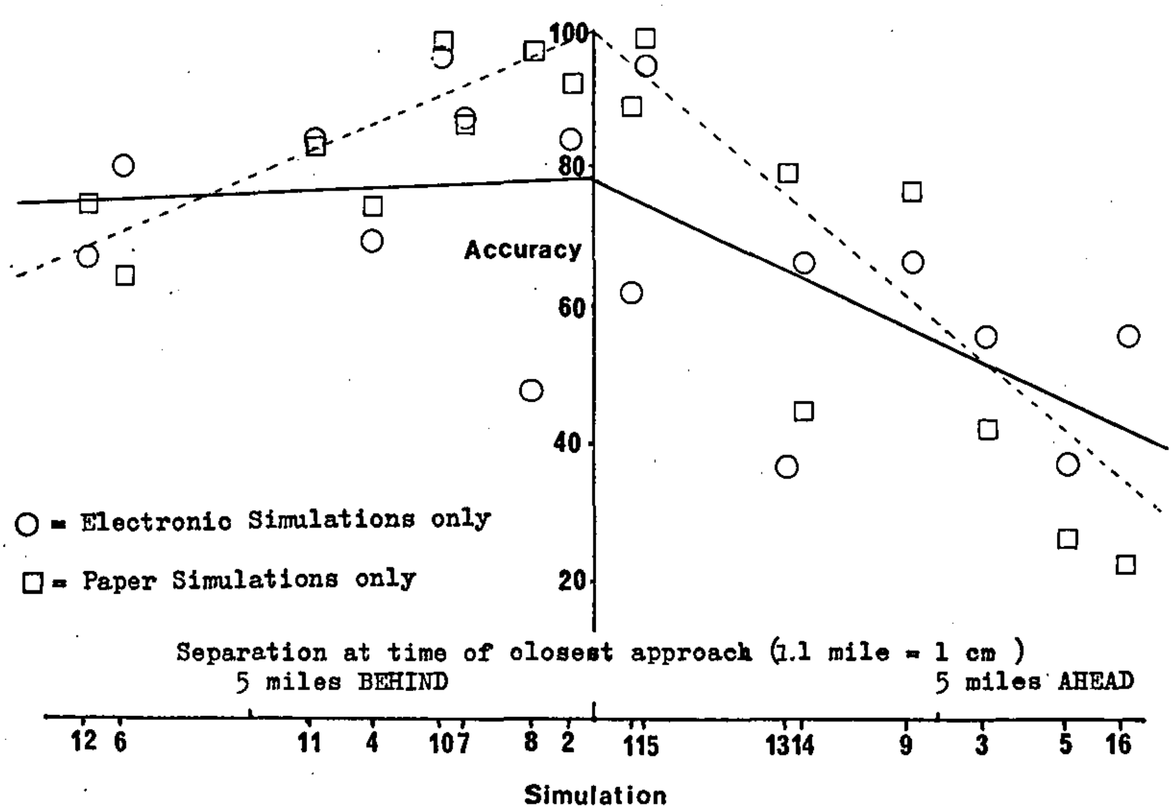


Figure 27

First decision - Accuracy (ahead/behind)

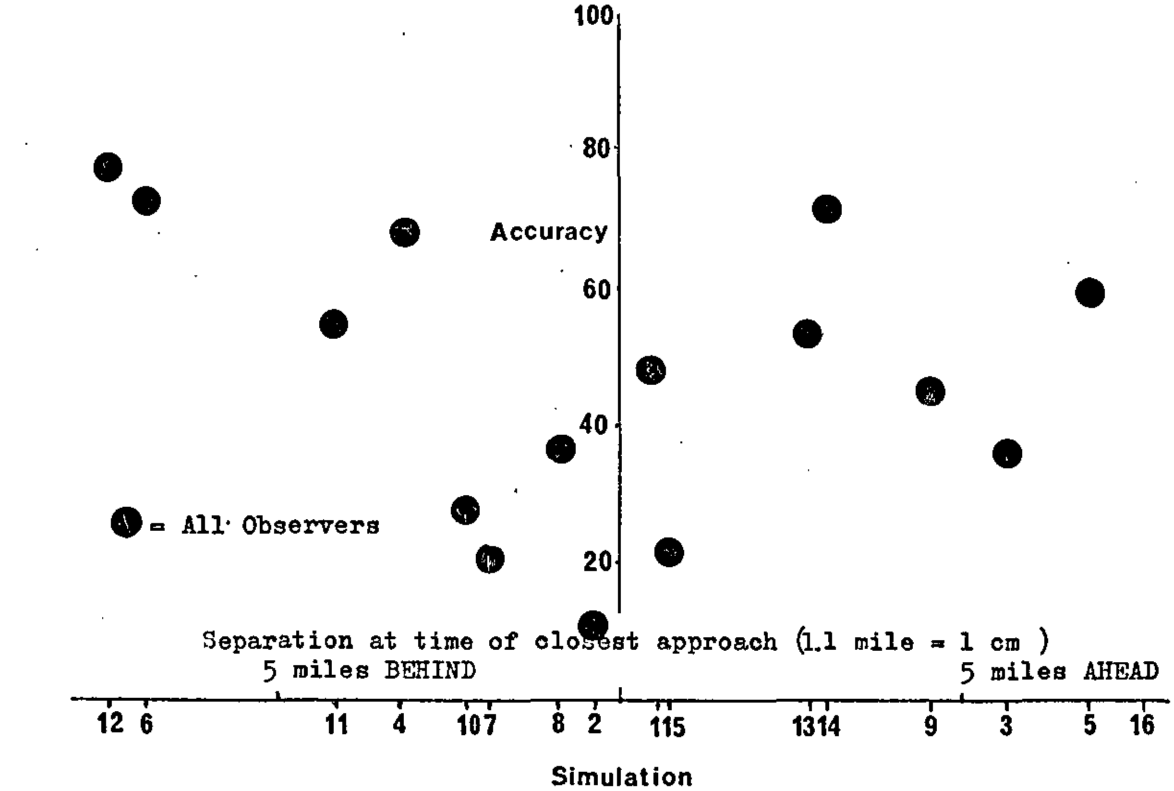
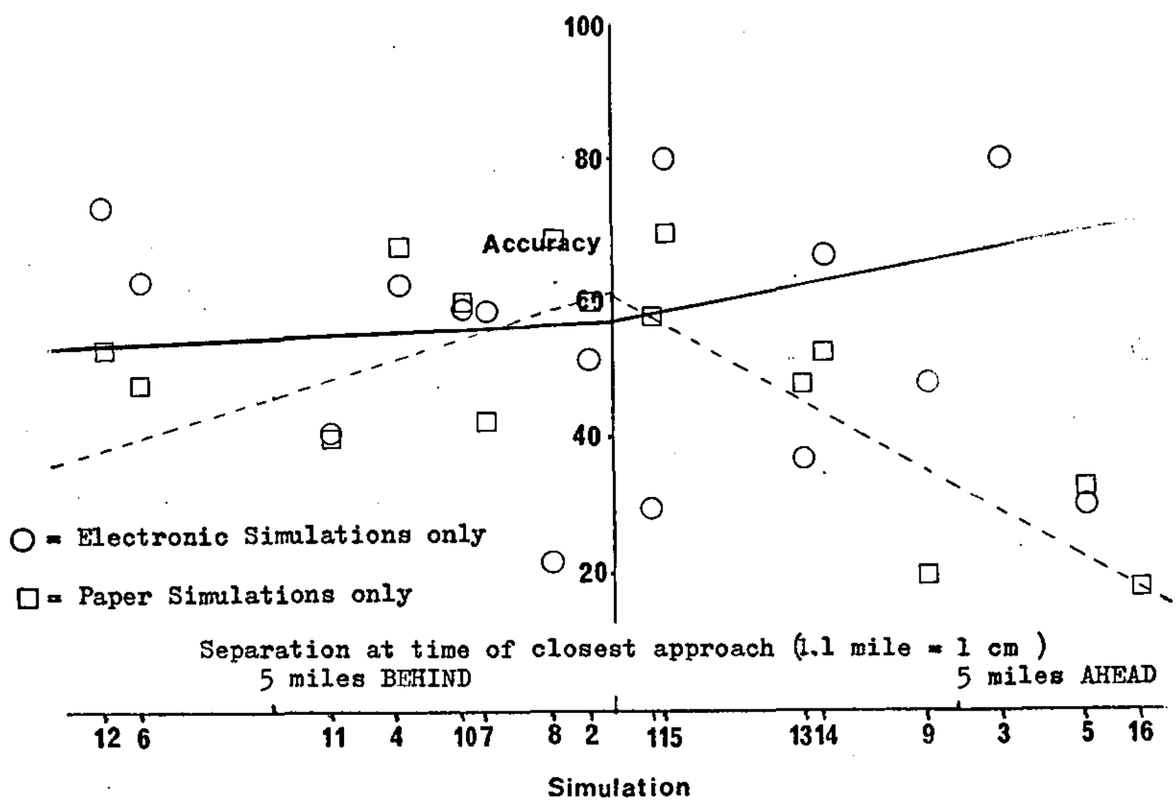


Figure 28

First decision - Accuracy (separation) - Simulation type



4. First correct conflict/safe decision.

The first correct conflict/safe deaision is the first decision which states correctly whether the situation will be safe or a conflict. The standard of safety employed is the rule that:-

"A situation is a conflict if at any time the two aircraft will be within five miles of each other."

The measure of accuracy here employed is the number of occasions on which a correct decision was made during the course of a trial, compared with the total number of occasions as described in chapter V, section 2.

Table 58 is an analysis of variance for the first correct conflict/safe decision in terms of the time to go to the time of closest approach, and Table 59 is an analysis of variance for the number of decisions made, expressed as a percentage.

Table 53 is a summary of the significant effects deduced from these two analyses of variance.

Considering the differences between group means (Table 54) we observe that skilled observers make their first correct conflict/safe decision earlier than unskilled observers by some 22 seconds, equivalent to two sweeps of the radar scan. In addition, paper simulations are decided earlier than electronic simulations by exactly the same amount. There is no significant interaction between skill and simulation type, as far as time to Tca is concerned. There is only one significant accuracy effect - paper simulation is more accurate than electronic simulation by about 6%. This difference is significant only at the 5% level, all other differences so far being significant at the .1% level.

Considering next the overall differences between simulations, and remembering that the differences we observe in this experiment are based on only sixteen simulations, we observe that the time at which the first correct conflict/safe decision is made appears to depend on the direction of rotation of the line of sight, and the initial position of the rogue (Table 56). If these mean times are plotted against separation, (Figure 29), it will be observed that there are four simulations, Nos. 4, 7, 10 and 11 which are reported particularly late. These are all, except no.4, situations with level 4 of the original fourth factor, (rogue passing behind, line of sight rotating anti-clockwise and rogue initially on right). Situation no. 4 was an exceptional situation in which the aircraft started very close to the point of closest approach. It is not, however, possible to obtain a significant regression effect for the time to Tca in terms of the aircraft separation. The percentage of correct decisions for each simulation is given in Table 57, and observation suggests that the accuracy of this judgement can be expressed in terms of the number of miles separation at Tca, (Figure 30), a different constant being required for rogues passing ahead or astern. A regression analysis confirms this suggestion, providing a formula of the form

$$\text{Accuracy } (\%) = 91.4 - 4.8\, S_{min} \text{ (Rogue ahead)}$$
$$= 91.4 - 1.0\, S_{min} \text{ (Rogue astern)}$$

In other words, the accuracy of judgement of whether or not the situation would be conflict was between 80 and 100 percent when the rogue passed astern, but dropped off to about 68% when the rogue passed well ahead of the control. There are plausible reasons why this should be so. These are covered in more detail in chapter 9 - Conclusions.

There are certain significant differences between skilled and unskilled observers in terms of time to go to Tca (Figure 31). These are apparently of the form that skilled observers make their correct judgements earlier than unskilled observers to a significantly greater extent when the rogue is passing ahead of the control - that is to say, in just the situations when the percentage of correct judgements falls off most.

There are significant differences between simulations in the times to go to Tca, according to whether the situations are presented on paper or electronic simulations (Figure 32). These differences appear to be greater for the cases where the rogue is passing ahead of the control, and suggest that the difference in the means remarked earlier is primarily due to these situations.

There are no significant differences between simulations in the accuracy with which situations are judged between groups of observers or between simulation types.

TABLE 53.

First Correct Conflict/Safe Decision.

Type of Effect	Time to Tca	Accuracy
Differences between groups.	Skilled/ Unskilled Paper/ Electronic	Paper/ Electronic
Within groups variability.	-	-
Observers/Residual.	Significant	Significant
Differences between simulations.	Significant	Significant
Factors within simulations.	Rotation of line of sight Initial position of rogue	-
Interactions within simulations.	Skilled/ Unskilled Paper/ Electronic	-
Factors within interactions.	-	-

TABLE 54.

First Correct Conflict/Safe Decision -
Mean Performance within Groups

Group of Observers	Time to Tca	Accuracy
All Observers	150 sec.	80%
Skilled Observers	161 sec.	80%
Unskilled Observers	139 sec.	81%
Electronic Simulations	139 sec.	78%
Paper Simulations	161 sec.	83%
Skilled/Electronic	150 sec.	79%
Unskilled/Electronic	129 sec.	77%
Skilled/Paper	172 sec.	82%
Unskilled/Paper	150 sec.	85%

TABLE 55.

First Correct Conflict/Safe Decision - Time to Tca.

Mean Performance for each Simulation

Simulation	Mean (sec.)	Skilled (sec.)	Unskilled (sec.)	Electronic (sec.)	Paper (sec.)
1	168	179	157	139	196
2	173	184	163	168	179
3	202	198	207	192	213
4	41	57	25	15	67
5	73	103	44	76	71
6	129	133	125	141	118
7	141	151	130	135	146
8	209	214	204	183	233
9	171	183	160	156	187
10	113	119	107	111	115
11	102	112	91	96	107
12	149	144	154	134	165
13	164	173	155	149	179
14	191	217	166	184	198
15	254	262	246	245	263
16	123	151	95	108	138

TABLE 56.

Effects of Nature of Miss on Time to Tca.

	Mean (sec.)	Skilled (sec.)	Unskilled (sec.)	Electronic (sec.)	Paper (sec.)
Rogue passing ahead.	168	183	154	156	180
Rogue passing behind.	132	139	125	123	142
Rotation of L.o.S.					
Clockwise	152	164	141	142	163
A/Clockwise	148	158	138	137	159
Rogue initially on:					
Left	152	166	138	146	159
Right	148	156	140	133	164

TABLE 57.

First Correct Conflict/Safe Decision -

Percentage of Correct Decisions.

Mean performance for each simulation.

Simulation	Mean
1	86
2	96
3	62
4	77
5	68
6	85
7	95
8	84
9	76
10	100
11	85
12	86
13	67
14	66
15	100
16	53

TABLE 58.

Analysis of Variance
First Correct Conflict/Safe Decision Time to Tca.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	89,057.2	1	89,057.23	19.643	36	***
2 T=Paper/ Electronic	89,057.2	1	89,057.23	19.643	36	***
3 GT=Skill/Type IA	75.0	1	75.00	0.01	36	NS
4 S=Simns. (1-16)	2,002,562.9	15	133,504.1	29.447	36	***
5 H=Heading of Control	161,217.2	3	53,739,0	0.204	11	NS
6 A=Angle of Approach	732,643.8	3	244,214.6	0.927	11	NS
7 V=Speed of Closing	66,456.9	3	22,152.2	0.084	11	NS
8 B=Rogue Ahead/ Behind	245,038.5	1	245,038.5	0.930	11	NS
9 L=Rotn of Line of Sight	3,253.5	1	3,253.5	0.012	11	NS
10 I=Initial posn. of Rogue	3,234.1	1	3,234.1	0.012	11	NS
11 Residual Between Simns.	790,718.8	3	263,572.9			
12 GS=Skill/Simn. IA	67,839.4	15	4,522.6	0.9975	11	NS
13 GH=Ski/Hdg IA	12,133.4	3	4,044.4	1.198	19	NS
14 GA=Ski/Ang IA	12,341.9	3	4,113.9	1.219	19	NS
15 GV=Ski/Spd IA	14,735.0	3	4,911.6	1.455	19	NS
16 GB=Ski/Psg IA	11,005.5	1	11,005.5	3.260	19	NS
17 GL=Ski/Rot IA	581.0	1	581.0	0.172	19	NS
18 GI=Ski/Pos IA	6,913.8	1	6,913.8	2.048	19	NS
19 Residual of GS	10,128.7	3	3,376.2			
20 TS=Type/Simn IA	78,910.6	15	5,260.7	1.1603	36	NS
21 TH=Typ/Hdg IA	7,466.3	3	2,488.7	0.454	27	NS
22 TA=Typ/Ang IA	15,250.2	3	5,083.4	0.927	27	NS
23 TV=Typ/Spd IA	20,835.8	3	6,945.2	1.267	27	NS
24 TB=Typ/Psg IA	1,845.7	1	1,845.7	0.337	27	NS
25 TL=Typ/Rot IA	33.2	1	33.2	0.006	27	NS
26 TI=Typ/Pos IA	17,031.5	1	17,031.5	3.106	27	NS
27 Residual of TS	16,448.0	3	5,482.6			
28 GTS=Skill/Type/Simn. IA	37,609.7	15	2,507.3	0.533	36	NS
29 GTH=Ski/Typ/Hdg IA	7,276.7	3	2,425.5	1.536	35	NS
30 GTA=Ski/Typ/Ang IA	3,273.6	3	1,091.1	0.691	35	NS
31 GTV=Ski/Typ/Spd IA	2,595.5	3	865.1	0.548	35	NS
32 GTB=Ski/Typ/Psg IA	951.4	1	951.4	0.602	35	NS
33 GTL=Ski/Typ/Rot IA	14,259.3	1	14,259.3	9.028	35	NS
34 GTI=Ski/Typ/Pos IA	4,515.0	1	4,515.0	2.859	35	NS
35 Residual of GTS	4,738.2	3	4,738.2			
36 Between Subjects	285,622.6	63	4,533.69	3.74549	37	***
37 Overall Residual	894,682.4	741	1,207.40			
38 TOTAL SUM OF SQUARES	3,545,417.0	867				

TABLE 59

Analysis of Variance

First Conflict/Safe Decision - Number of Decisions.

	Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1	G=Skilled/ Unskilled	78.0	1	78.0	0.060	36	
2	T=Paper/ Electronic	7,446.6	1	7,446.6	5.733	36	*
3	GT=Skill/Type IA	1,709.1	1	1,709.1	1,316	36	
4	S=Simns. (1-16)	190,123.3	15	12,681.2	9.763	36	***
5	H=Heading of Control	12,677.2	3	4,225.3	1.837	11	
6	A=Angle of Approach	42,662.2	3	14,219.3	6.182	11	
7	V=Speed of Closing	32,193.6	3	10,730.1	4.665	11	
8	B=Rogue Ahead/ Between	65,778.5	1	65,778.5	28.596	11	*
9	L=Rotn of Line of Sight	20.4	1	20.4	0.009	11	
10	I=Initial posn. of Rogue	29,890,5	1	29,890.5	12.994	11	*
11	Residual Between Simns.	6,900.8	3	2,300.0			
12	GS=Skill/Simn. IA	41,428.4	15	2,763.3	2.127	36	*
13	GH=Ski/Hdg IA	5,470.1	3	1,823.2	0.302	19	
14	GA=Ski/Ang IA	12,739.2	3	4,246.0	0.702	19	
15	GV=Ski/Spd IA	888.4	3	296.1	0.049	19	
16	GB=Ski/Psg IA	7.9	1	7.9	0.001	19	
17	GL=Ski/Rot IA	924.4	1	924.4	0.153	19	
18	GI=Ski/Pos IA	3,259.8	1	3,259.8	0.539	19	
19	Residual of GS	18,138.7	3	6,046.2			
20	TS=Type/Simn IA	98,927.4	15	6,598.5	5.080	36	***
21	TH=Typ/Hdg IA	11,452.9	3	3,817.3	0.217	27	
22	TA=Typ/Ang IA	15,280.1	3	5,092.9	0.289	27	
23	TV=Typ/Spd IA	17,012.5	3	5,670.3	0.322	27	
24	TB=Typ/Psg IA	1,191.5	1	1,191.5	0.068	27	
25	TL=Typ/Rot IA	604.4	1	604.4	0.034	27	
26	TI=Typ/Pos IA	500.7	1	500.7	0.028		
27	Residual of TS	52,885.4	3	17,626.7			
28	GTS=Skill/Type/Simn IA	25,604.9	15	1,707.8	1.315	36	NS
29	GTH=Ski/Typ/Hdg IA	5,458.0	3	1,819.1	1.066	35	
30	GTA=Ski/Typ/Ang IA	8,949.4	3	2,982.8	1.749	35	
31	GTV=Ski/Typ/Spd IA	4,676.2	3	1,558.6	0.914	35	
32	GTB=Ski/Typ/Psg IA	1,393.3	1	1,393.3	0.817	35	
33	GTL=Ski/Typ/Rot IA	0.1	1	0.1	0.000	35	
34	GTI=Ski/Typ/Pos IA	9.7	1	9.7	0.006	35	
35	Residual of GTS	5,118.2	3	1,705.9			
36	Between Subjects	83,129.4	64	1,298.9	1.937	37	*
37	Within GTS. Res.	630,900.4	941	670.5			
38	TOTAL SUM OF SQUARES	1,079,347.5	1071				

Figure 29

First correct conflict/safe decision - Time to Tca

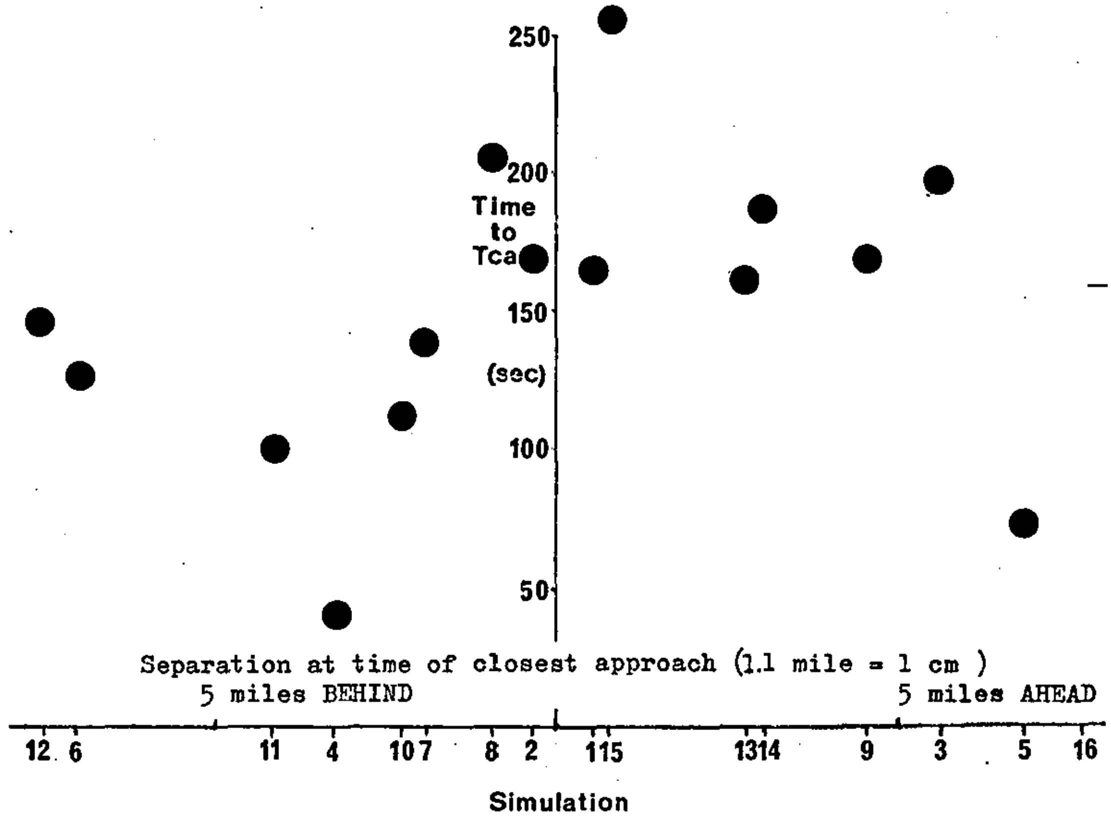


Figure 30

First correct conflict/safe decision - Accuracy

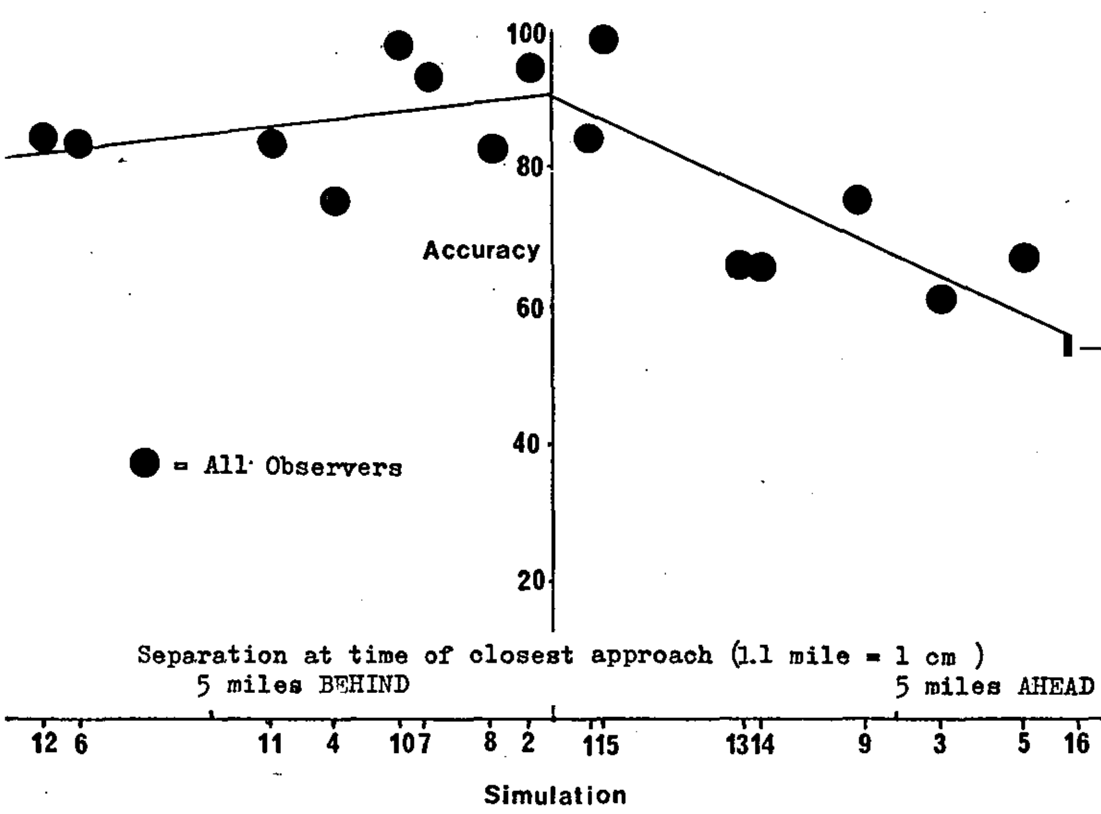


Figure 31

First correct conflict/safe decn - Time to Tca - Skill

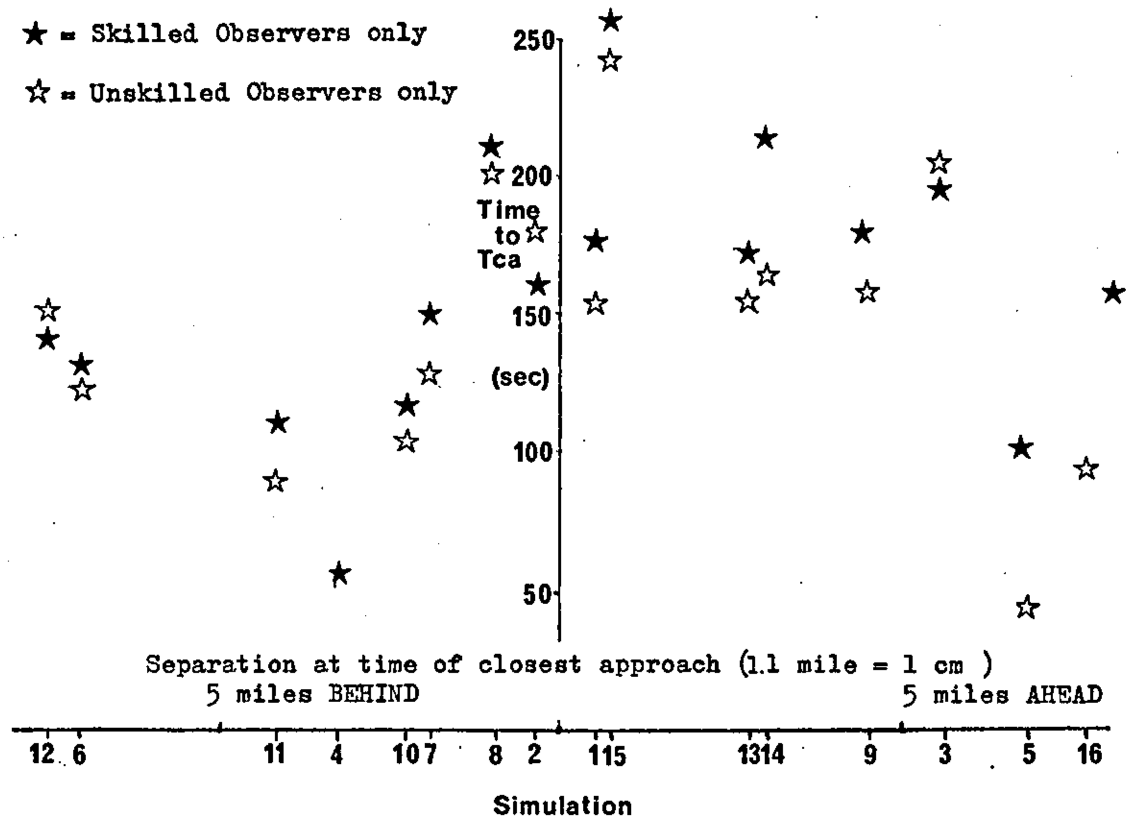
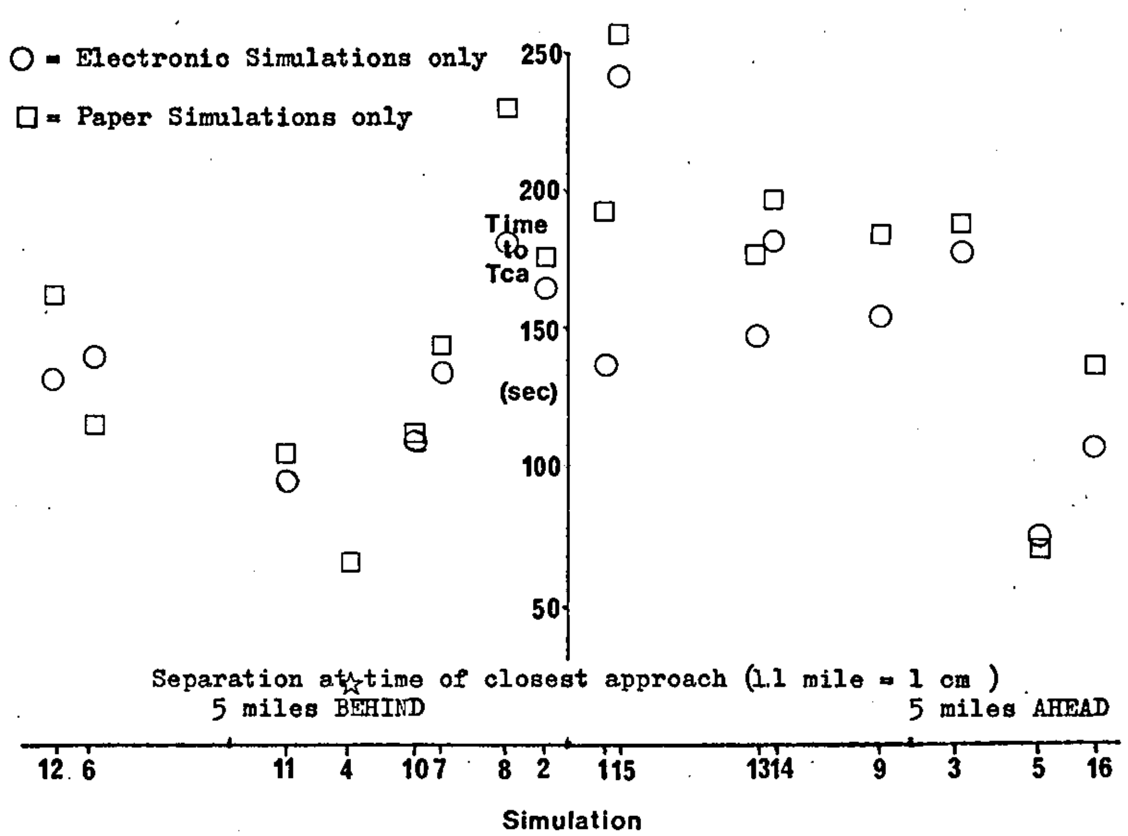


Figure 32

First correct c/s decn - Time to Tca - Simulation type



5. First correct ahead/behind decision.

The first correct ahead/behind decision is the first decision indicating correctly which aircraft is passing ahead of the other. In practice this decision was often not made, or given in the form of 'collision', where the observer could not distinguish between the possibilities, although he was able to judge that the situation was not safe.

Table 64 is an analysis of variance for the time to Tca at which the decision was made, and Table 65 is an analysis of variance for the percentage of occasions on which the decision was made. Table 60 summarises the significant effects present in these two tables.

Considering first the significant differences between group means, presented in Table 61, we observe that skilled observers make this decision some 24 seconds before unskilled observers, a figure corresponding closely to that observed for the previous type of correct decision, and to that for the first decision. We observe also that there is a significantly higher percentage of decisions made if the simulation is seen on an electronic simulator, than if it is seen on a paper simulation, the difference being some 11%.

We observe that there are significant differences between simulations in terms of time to go to Tca, (Table 62, Figure 33), although these differences cannot be linked to any of the factors varied within the experiment. The differences appear to resemble those observed for the first decision, with the situations in which the rogue passes relatively close behind the control being decided rather later. The differences between simulations in time to Tca are not affected by the skill of the observers or by the simulation type.

The accuracy measure is significantly different between simulations - as might be expected, (Table 63, Figure 34) - and correlates strongly with the absolute value of the separation ($r = 0.7$). The prediction equation for the mean accuracy is

$$\text{Accuracy}_{a/b} = 49.4 + 6|S_{min.}|$$

This expression would require that the accuracy should reach 100% at a separation of about eight miles. (The general form of the data suggests an asymptotic relationship, the accuracy tending exponentially to 100%). There are significant differences between paper and electronic simulations in the accuracy of this decision. In general these tend to be greatest in the region of minimum separation less than three miles, although there is one anomalous situation (No. 3 - separation 5.6 miles) which was correctly estimated on electronic simulation nine times out of ten, and incorrectly estimated on paper simulation nine times out of ten. The differences do not yield any systematic regression expression.

There appear to be no further significant effects for the first correct ahead/behind decision.

TABLE 60.

First Correct Ahead/Behind Decision.

Type of Effect	Time to Tca	Percentage of Correct Decisions
Difference between groups.	Skilled/ Unskilled	Paper/ Electronic
Within groups variability.	-	-
Observers/ Residual.	Significant	Significant
Differences between simulations.	Significant	Significant
Factors within simulations.	-	-
Interactions within simulations.	-	Paper/ Electronic
Factors within interactions.	-	-

TABLE 61.

First Correct Ahead/Behind Decision - Mean Performance Within Groups.

Group of Observers	Time to Tca	Accuracy
All Observers	137 sec.	72%
Skilled Observers	149 sec.	72%
Unskilled Observers	125 sec.	72%
Electronic Simulation	136 sec.	77%
Paper Simulation	139 Sec.	66%
Skilled/Electronic	145 sec.	78%
Unskilled/Electronic	127 sec.	76%
Skilled/Paper	153 sec.	65%
Unskilled/Paper	124 sec.	67%

TABLE 62.

First Correct Ahead/Behind Decision - Time to Tca.

Mean Performance for Each Simulation.

Simulation	Mean (sec.)
1	158
2	145
3	218
4	35
5	96
6	132
7	65
8	209
9	141
10	78
11	89
12	156
13	149
14	189
15	211
16	124

TABLE 63.

First Correct Ahead/Behind Decision - Percentage of Correct Decisions

Mean Performance for Each Simulation

Simulation	Mean	Electronic	Paper
1	69%	92%	45%
2	20%	12%	28%
3	50%	89%	10%
4	88%	78%	98%
5	94%	93%	95%
6	90%	85%	95%
7	59%	66%	53%
8	50%	77%	25%
9	81%	74%	88%
10	65%	59%	70%
11	84%	81%	88%
12	94%	93%	95%
13	77%	82%	73%
14	90%	89%	90%
15	43%	63%	23%
16	92%	96%	88%

TABLE 64.

Analysis of Variance
Time to Tca Ahead/Behind Decision.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	83,753.8	1	83,753.8	13.079	36	***
2 T= Paper/ Electronic	1,234.0	1	1,234.0	0.193	36	
3 GT=Skill/Type IA	5,049.6	1	5,049.6	0.789	36	
4 S=Simns. (1-16)	1,660,749.8	15	110,772.0	17.290	36	***
5 H=Heading of Control	159,589.7	3	53,191.2	0.310	11	
6 A=Angle of Approach	489,197.2	3	163,049.4	0.951	11	
7 V=Speed of Closing	49,568.2	3	16,521.1	0.096	11	
8 B=Rogue Ahead/ Behind	334,794.0	1	334,794.0	1,952	11	
9 L=Rotn of Line of Sight	47,423.2	1	47,423.2	0.276	11	
10 I=Initial posn. of Rogue	65,611.1	1	65,611.1	0.383	11	
11 Residual Between Simns.	514,566.5	3	171,505.0			
12 Gs=Skill/Simn. IA	45,466.7	15	3,032.6	0.474	36	NS
13 GH=Ski/Hdg IA	14,337.0	3	4,778.0	3.317	19	
14 GA=Ski/Ang IA	4,407.9	3	1,469.1	1.020	19	
15 GV=Ski/Spd IA	17,777.0	3	5,925.1	4.113	19	
16 GB=Ski/Psg IA	479.7	1	479.7	0.333	19	
17 GL=Ski/Rot IA	3,469.8	1	3,469.8	2.409	19	
18 GI=Ski/Pos IA	673.7	1	673.7	0.468	19	
19 Residual of GS	4,321.6	3	1,440.4			
20 TS=Type/Simn IA	62,313.0	15	4,156.3	0.649	36	NS
21 TH=Type/Hdg IA	15,858.6	3	5,285.7	0.524	27	
22 TA=Typ/Ang IA	7,467.8	3	2,489.0	0.247	27	
23 TV=Typ/Spd IA	6,503.4	3	2,167.8	0.215	27	
24 TB=Typ/psg IA	2.0	1	2.0	0.000	27	
25 TL=Typ/Rot IA	28.2	1	28.2	0.003	27	
26 TI=Typ/Pos IA	2,207.0	1	2,207.0	0.219	27	
27 Residual of TS	30,245.9	3	10,080.9			
28 GTS=Skill/Type/ Simn IA	86,540.1	15	5,769.3	0.901	36	NS
29 GTH=Ski/Typ/Hdg IA	20,822.0	3	6,940.0	3.095	35	
30 GTA=Ski/Typ/Ang IA	30,712.2	3	10,236.4	4.566	35	
31 GTV=Ski/Typ/Spd IA	27,410.5	3	9,135.9	4.075	35	
32 GTB=Ski/Typ/Psg IA	726.2	1	726.2	0.324	35	
33 GTL=Ski/Typ/Rot IA	141.3	1	141.3	0.063	35	
34 GTI=Ski/Typ/Pos IA	0.9	1	0.9	0.000	35	
35 Residual of GTS	6,727.0	3	2,242.1			
36 Between Subjects	403,434.5	63	6,403.7	5.184	37	***
37 Within GTS RES.	789,273.0	639	1,235.2			
38 TOTAL SUM OF SQUARES	3,137,814.5	765				

TABLE 65.

Analysis of Variance
Percentage Accuracy - First Ahead/Behind Decision

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	.67	1	7.67	0.018	36	NS
2 T=Paper/ Electronic	30,324.9	1	30,324.95	8.09	36	**
3 GT=Skill/Type IA	995.4	1	995.41	0.26	36	NS
4 S=Simns. (1-16)	487,554.2	15	32,519.86	8.680	36	***
5 H=Heading of Control	22,961.0	3	7,652.90	0.357	11	NS
6 A=Angle of Approach	252,125.7	3	84,303.49	3.921	11	NS
7 V=Speed of Closing	61,039.0	3	20,344.31	0.949	11	NS
8 B=Rogue Ahead/ Behind	7,833.0	1	7,833.02	0.365	11	NS
9 L=Rotn of Line of Sight	55,653.2	1	55,653.20	2.597	11	NS
10 I=Initial posn. of Rogue	23,640.8	1	23,640.88	1.103	11	NS
11 Residual Between Simns.	64,301.3	3	21,431.65			
12 GS=Skill/Simn. IA	47,180.7	15	3,146.95	0.840	36	NS
13 GH=Ski/Hdg IA	4,120.0	3	1,373.22	0.323	19	NS
14 GA=Ski/Ang IA	17,918.0	3	5,972.08	1.406	19	NS
15 GV=Ski/Spd IA	8,154.1	3	2,717.76	0.640	19	NS
16 GB=Ski/Psg IA	776.3	1	776.31	0.183	19	NS
17 GL=Ski/Rot IA	2,892.1	1	2,892.15	0.681	19	NS
18 GI=Ski/Pos IA	579.4	1	579.48	0.136	19	NS
19 Residual of GS	12,740.5	3	4,246.43			
20 TS=Type/Simn IA	209,706.3	15	13,987.41	3.733	36	***
21 TH=Typ/Hdg IA	53,285.9	3	17,760.21	9.193	27	NS
22 TA=Typ/Ang IA	48,459.5	3	16,151.57	8.360	27	NS
23 TV=Typ/Spd IA	39,549.2	3	13,181.76	6.823	27	NS
24 TB=Typ/Psg IA	29,054.1	1	29,054.19	15.038	27	*
25 TL=Typ/Rot IA	6,665.2	1	6,665.29	3.450	27	NS
26 TI=Typ/Pos IA	26,895.8	1	26,895.83	13.921	27	*
27 Residual of TS	5,796.2	3	1,931.89			
28 GTS=Skill/Type/ Simn. IA	38,085.3	15	2,539.02	0.677	36	NS
29 GTH=Ski/Typ/Hdg IA	1,505.2	3	501.69	1.060	35	NS
30 GTA=Ski/Typ/Ang IA	27,391.1	3	9,129.47	19.281	35	*
31 GTV=Ski/Typ/Spd IA	4,246.4	3	1,415.35	2.989	35	NS
32 GTB=Ski/Typ/Psg IA	8.2	1	8.22	0.017	35	NS
33 GTL=Ski/Typ/Rot IA	163.9	1	163.96	0.346	35	NS
34 GTI=Ski/Typ/Pos IA	3,349.6	1	3,349.65	7.073	35	NS
35 Residual of GTS	1,420.6	3	473.50			
36 Between Subjects	2,361,028.3	63	3,746.5	3.158	37	***
37 Within Cells	1,121,015.8	945	1,186.3			
38 TOTAL SUM OF SQUARES	2,170,892.1	1071				

Figure 33

First correct ahead/behind decision - Time to Tca

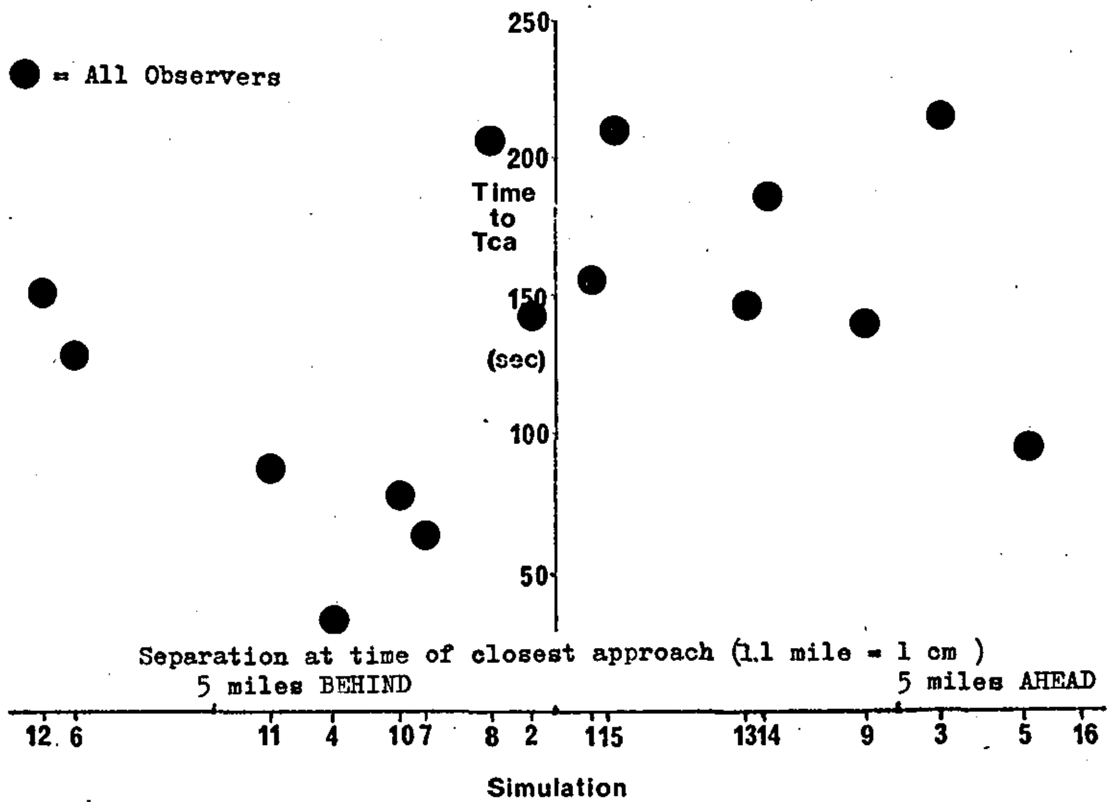
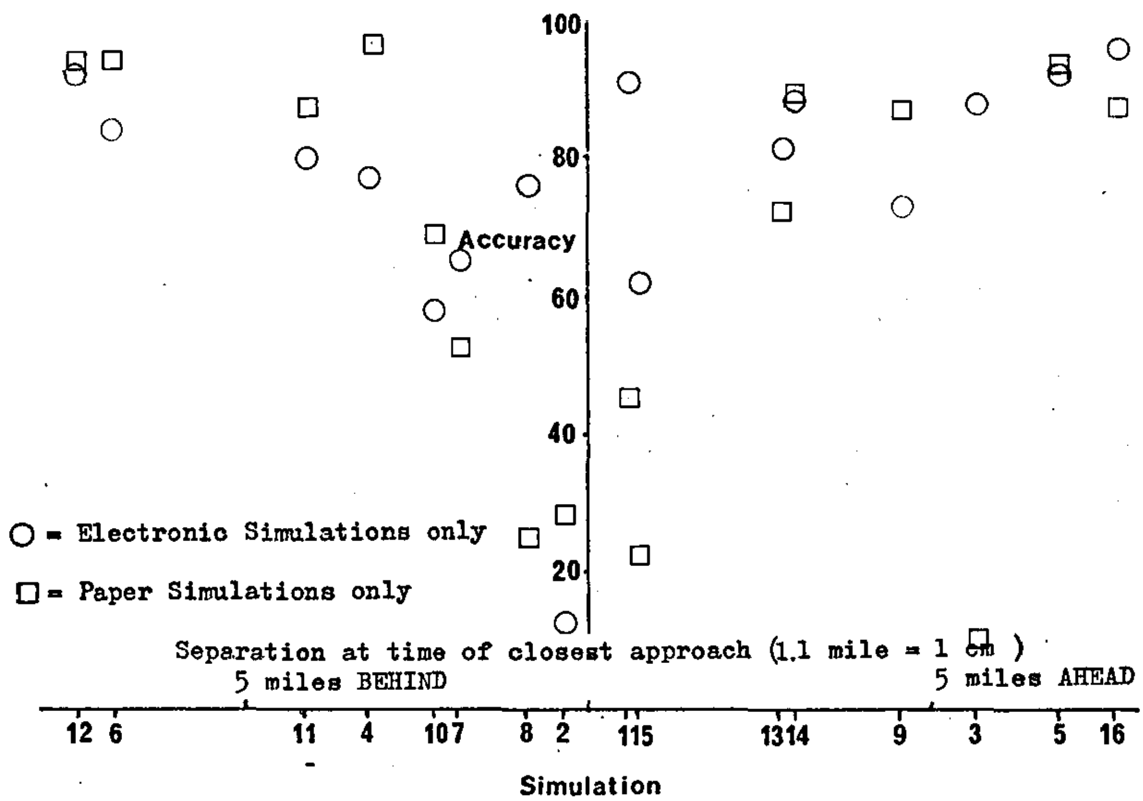


Figure 34

First correct a/b decn - Accuracy - Simulation type



6. First correct judgement of separation.

The first correct judgement of separation is defined as the first correct judgement of what the separation of the aircraft will be at their closest (the time of closest approach). A judgement is considered correct if it is within three miles of the correct judgement, counting the rogue passing ahead as positive, the rogue passing astern as negative, and 'collision' as zero. The three mile criterion was chosen to provide a reasonable accuracy distribution - it has no operational significance.

Table 71 is an analysis of variance for the time to go to Tca at which the first correct judgement of separation is made, Table 72 is an analysis of variance for the average percentage of these judgements made. Table 66 is a summary of the significant effects observed within these two tables.

Considering first the differences between group means, we observe that both the Time to Tca, and the Accuracy are affected by the skill of the observer and the type of simulation. Table 67 shows that the mean time for skilled observers is 12 seconds before that for unskilled observers. Similarly the mean time is 14 seconds earlier for paper simulation than for electronic simulation and paper simulation is 8% more accurate. The significance levels for these effects are not high, and in addition, the interaction between skill and simulation type is just significant. A look at the group means shows that unskilled observers watching paper simulations produce an accuracy 10% greater than any group, and this abnormality results in a significantly greater level for unskilled subjects overall.

Considering now the differences between simulations, which are significant for time to go to Tca, (Table 68, Figure 35), we observe the usual pattern of late decisions where the rogue passes just behind the controlled aircraft. There are significant effects of skill on these differences in timing, the situations just mentioned and those where the rogue passes well in front of the Control being judged earlier by skilled observers.

Accuracy also differs significantly from simulation to simulation, in a manner roughly proportional to the separation, (Table 69, Figure 36), (with the sign allotted). The correlation of accuracy of judgement of separation with separation is 0.54, which is significant. The regression equation corresponding is

$$\text{Accuracy}_{\text{sep}} = 74.3 - 1.5 \text{ Sep.}$$

In other words the accuracy with which the separation at Tca would be judged for a rogue flying behind the control at 5 miles distance would be about 82%, and for a rogue flying five miles ahead about 67%.

The accuracy is significantly affected by the type of simulation, and regression on the difference between skilled observers and unskilled suggests that the difference is proportional to the absolute separation.

Combining the regression equation for the mean accuracy with that for the difference between paper and electronic simulation we obtain the following results.

For electronic simulation

$$\text{Accuracy}_{\text{sep}} = 91.4 - 5.04 \text{ Sep (rogue ahead)}$$

$$= 91.4 - 2.08 \text{ Sep (rogue behind)}$$

For paper simulation

$$\text{Accuracy}_{\text{sep}} = 57.4 + 2.08 \text{ Sep (rogue ahead)}$$

$$= 57.4 + 5.04 \text{ Sep (rogue behind)}$$

Tabulation of these values at the extremes may be helpful.

Separation	-5 miles	0	+5 miles
Electronic	81.4%	91.4%	66.2%
Paper	82.6%	57.4%	67.6%

In other words this seems to suggest that electronic simulations are judged fairly well for accuracy, except when the rogue is passing well ahead, and that paper simulations are judged fairly badly for accuracy, except when the rogue is passing well astern. This generalisation holds for judgements of separation, which are the judgements required last in the original procedure, and most frequently omitted.

TABLE 66.

First Correct Judgement of Separation -

Significant Effects.

Type of Effect	Time to Tca	Accuracy
Differences between groups.	Skilled/ Unskilled	Skilled/ Unskilled
	Paper/ Electronic	Paper/ Electronic
Within groups variability.	-	-
Observers/ Residual	Significant	Significant
Differences between simulations.	Significant	Significant
Factors within simulations.	-	Rogue initially left/right
Interactions within simulations.	Skilled/ Unskilled	Paper/ Electronic
Factors within interactions.	-	-

TABLE 67.

First Correct Judgement of Separation - Mean Performance

Group of Observers	Time to Tca	Accuracy
All Observers	138 sec	74 %
Skilled Observers	140 sec	72 %
Unskilled Observers	128 sec	76 %
Electronic Simulation	130 sec	70 %
Paper Simulation	144 sec	78 %
Skilled/Electronic	143 sec	71 %
Unskilled/Electronic	152 sec	70 %
Skilled/Paper	118 sec	73 %
Unskilled/Paper	135 sec	83 %

TABLE 68.

First correct Judgement of Separation

Mean Time to Tca

Simulation	Mean (sec)	Skilled (sec)	Unskilled (sec)
1	155	160	150
2	159	160	157
3	189	176	202
4	34	47	22
5	67	94	40
6	119	122	117
7	107	110	104
8	210	199	202
9	133	146	120
10	96	105	87
11	78	101	56
12	149	149	149
13	148	141	155
14	182	205	159
15	243	250	237
16	118	142	95

TABLE 69.

First Correct Judgement of Separation -

Percentage of Correct Decisions.

Simulation	Mean	Paper	Electronic
1	66%	44%	88%
2	77%	66%	88%
3	46%	85%	8%
4	85%	74%	95%
5	79%	77%	80%
6	80%	78%	83%
7	88%	85%	90%
8	66%	37%	95%
9	67%	60%	75%
10	80%	74%	85%
11	77%	74%	80%
12	79%	81%	78%
13	69%	45%	93%
14	78%	78%	78%
15	94%	93%	95%
16	53%	70%	35%

TABLE 70.

Effect of Initial Position of Rogue

on Percentage of Correct Decisions

	Mean	Paper	Electronic
Rogue initially on left	78%	76%	84%
Rogue initially on right	69%	64%	71%

TABLE 71

Analysis of Variance
First Correct Judgement of Separation - Time to Tca.

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	42,187.7	1	42,187.7	6.896	36	*
2 T=Paper/ Electronic	32,439.8	1	32,439.8	5.303	36	*
3 GT=Skill/Type IA	9,421.1	1	9,421.3	1.540	36	
4 S=Simns. (1-16)	1,812,520.8	15	120,895.1	19.761	36	***
5 H=Heading of Control	167,112.1	3	55,698.5	0.246	11	NS
6 A=Angle of Approach	670,291.3	3	223,408.1	0.987	11	NS
7 V=Speed of Closing	51,538.9	3	17,177.9	0.076	11	NS
8 B=Rogue Ahead/ Behind	222,010.3	1	222,010.3	0.981	11	NS
9 L=Rotn of Line of Sight	16,343.7	1	16,343.7	0.072	11	NS
10 I=Initial posn. of Rogue	5,995.8	1	5,995.8	0.026	11	NS
11 Residual Between Simns.	679,228.6	3	226,386.9			
12 GS=Skill/Simn. IA	83,495.3	15	5,569.1	0.910	36	***
13 GH=Ski/Hdg IA	5,768.9	3	1,922.8	0.235	19	NS
14 GA=Ski/Ang IA	9,754.9	3	3,251.3	0.398	19	NS
15 GV=Ski/Spd IA	19,617.7	3	6,538.6	0.800	19	NS
16 GB=Ski/Psg IA	2,043.0	1	2,043.0	0.250	19	NS
17 GL=Ski/Rot IA	3,569.0	1	3,569.0	0.436	19	NS
18 GI=Ski/Pos IA	18,212.0	1	18,212.0	2.227	19	NS
19 Residual of GS	24,529.8	3	8,175.8			
20 TS=Type/Simn. IA	88,348.1	15	5,892.8	0.963	36	NS
21 TH=Typ/Hdg IA	2,157.8	3	719.2	0.075	27	
22 TA=Typ/Ang IA	31,839.0	3	10,611.9	1.107	27	
23 TV=Typ/Spd IA	15,252.2	3	5,038.5	0.530	27	
24 TB=Typ/Psg IA	4,255.5	1	4,255.5	0.444	27	
25 TL=Typ/Rot IA	5,945.9	1	5,945.9	0.620	27	
26 TI=Typ/Pos IA	142.0	1	142.0	0.015	27	
27 Residual of TS	28,755.8	3	9,584.3			
28 GTS=Skill/Type/ Simn. IA	54,895.3	15	3,661.5	0.598	36	NS
29 GTH=Ski/Typ/Hdg IA	1,710.1	3	570.0	0.737	35	
30 GTA=Ski/Typ/Ang IA	30,889.5	3	10,295.5	13.306	35	
31 GTV=Ski/Typ/Spd IA	14,060.8	3	4,686.5	6.057	35	
32 GTB=Ski/Typ/Psg IA	1,519.4	1	1,519.4	1.963	35	
33 GTL=Ski/Typ/Rot IA	32.4	1	32.4	0.042	35	
34 GTI=Ski/Typ/Pos IA	4,361.5	1	4,361.5	5.636	35	
35 Residual of GTS	2,321.5	3	773.8			
36 Within Subjects IA	389,204.3	63	6,117.8	3.308	37	***
37 Within GTS Res.	1,120,832.0	606	1,849.6			
38 TOTAL SUM OF SQUARES	3,633,344.4	732				

TABLE 72.

Analysis of Variance
First Correct Judgement of Separation -
Number of Correct Decisions

Source of Variation	Sum of Squares	dF	Mean Sum of Sq.	Var.Rat.	w.r.t.	Sig.
1 G=Skilled/ Unskilled	5,564.6	1	5,564.6	3.002	36	NS
2 T=Paper/ Electronic	14,531.9	1	14,531.9	7.841	36	**
3 GT=Skill/Type IA	8,272.0	1	8,272.0	4.463	36	*
4 S=Simns. (1-16)	146,088.0	15	9,739.2	5.254	36	***
5 H=Heading of Control	25,810.2	3	8,602.6	3.241	11	
6 A=Angle of Approach	14,283.7	3	4,760	1.793	11	
7 V=Speed of Closing	14,120.3	3	4,706.3	1.773	11	
8 B=Rogue Ahead/ Behind	25,786.2	1	25,786.2	9.713	11	
9 L=Rotn of Line of Sight	21,649.1	1	21,649.1	8.154	11	
10 I=Initial posn. of Rogue	36,473.8	1	36,473.8	13.738	11	*
11 Residual Between Simns.	7,964.6	3	2,654.6			
12 GS=Skill/Simn. IA	35,734.4	15	2,383.5	1.286	36	NS
13 GH=Ski/Hdg IA	3,917.8	3	1,305.8	0.352	19	
14 GA=Ski/Ang IA	11,776.6	3	3,925.1	1.057	19	
15 GV=Ski/Spd IA	4,603.8	3	1,534.4	0.413	19	
16 GB=Ski/Psg IA	1,434.5	1	1,434.5	0.386	19	
17 GL=Ski/Rot IA	299.5	1	299.5	0.081	19	
18 GI=Ski/Pos IA	2,562.1	1	2,562.1	0.690	19	
19 Residual of GS	11,140.0	3	3,713.0			
20 TS=Type/Simn. IA	244,851.3	15	16,323.4	8.807	36	***
21 TH=Typ/Hdg IA	9,639.0	3	3,212.7	0.112	27	NS
22 TA=Typ/Ang IA	87,947.4	3	29,312.9	1.021	27	NS
23 TV=Typ/Spd IA	39,209.3	3	13,068.5	0.455	27	NS
24 TB=Typ/Psg IA	15,716.2	1	15,716.2	0.547	27	NS
25 TL=Typ/Rot IA	6,179.5	1	6,179.5	0.215	27	NS
26 TI=Typ/Pos IA	21.8	1	21.8	0.001	27	NS
27 Residual of TS	86,138.1	3	28,709.8			
28 GTS=Skill/Type/ Simn. IA	19,546.1	15	1,303.7	0.703	36	NS
29 GTH=Ski/Typ/Hdg IA	91.0	3	30.3	0.009	36	
30 GTA=Ski/Typ/Ang IA	3,599.1	3	1,199.6	0.355	36	
31 GTV=Ski/Typ/Spd IA	873.7	3	291.2	0.086	35	
32 GTB=Ski/Typ/Psg IA	163.6	1	163.6	0.048	35	
33 GTL=Ski/Typ/Rot IA	498.3	1	498.3	0.148	35	
34GTI = Ski/Typ/Pos IA	4,194.4	1	4,194.4	1.243	35	
35 Residual of GTS	10,125.9	3	3,374.9			
36 Within Subjects Res.	116,767.1	63	1,853.4	1.352	37	*
37 Residual Overall	1,294,343.2	944	1,371.1			
38 TOTAL SUM OF SQUARES	1,885.698.6	1070				

Figure 35

First correct judgement of separation - Time to Tca - Skill

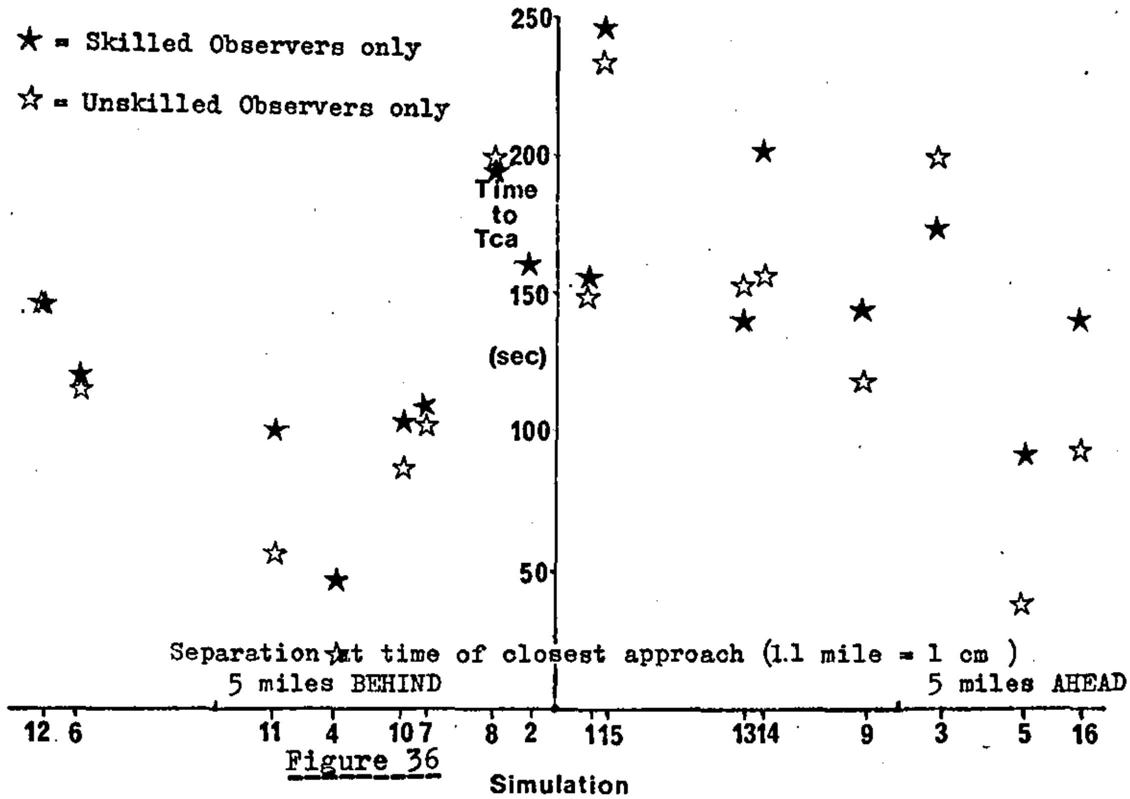
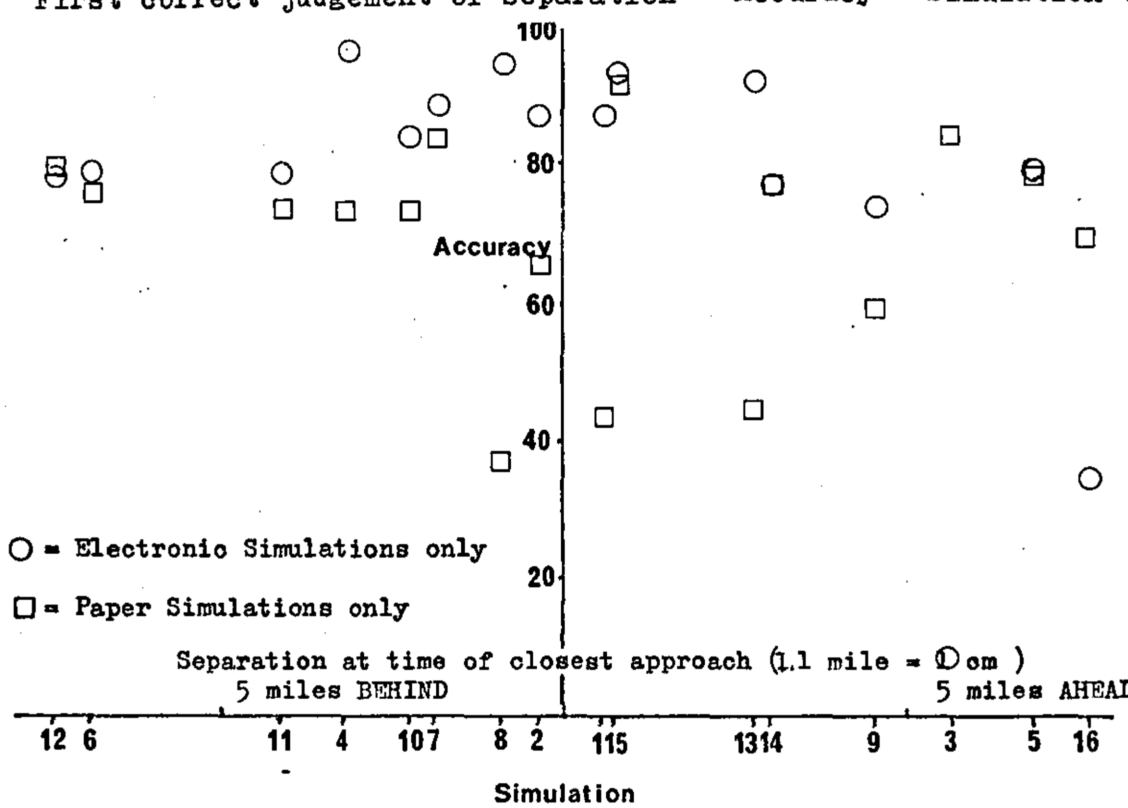


Figure 36

First correct judgement of separation Accuracy - Simulation type



VIII. DATA REDUCTION

The previous chapters have provided certain items of information, with assessments of their significance. In this chapter a process of data reduction is undertaken in order to provide more concise answers to the original problems.

In order to establish a consistent terminology, a first section defines twenty-two possible parameters relating to a situation of the type studied, and discusses their mathematical relationships.

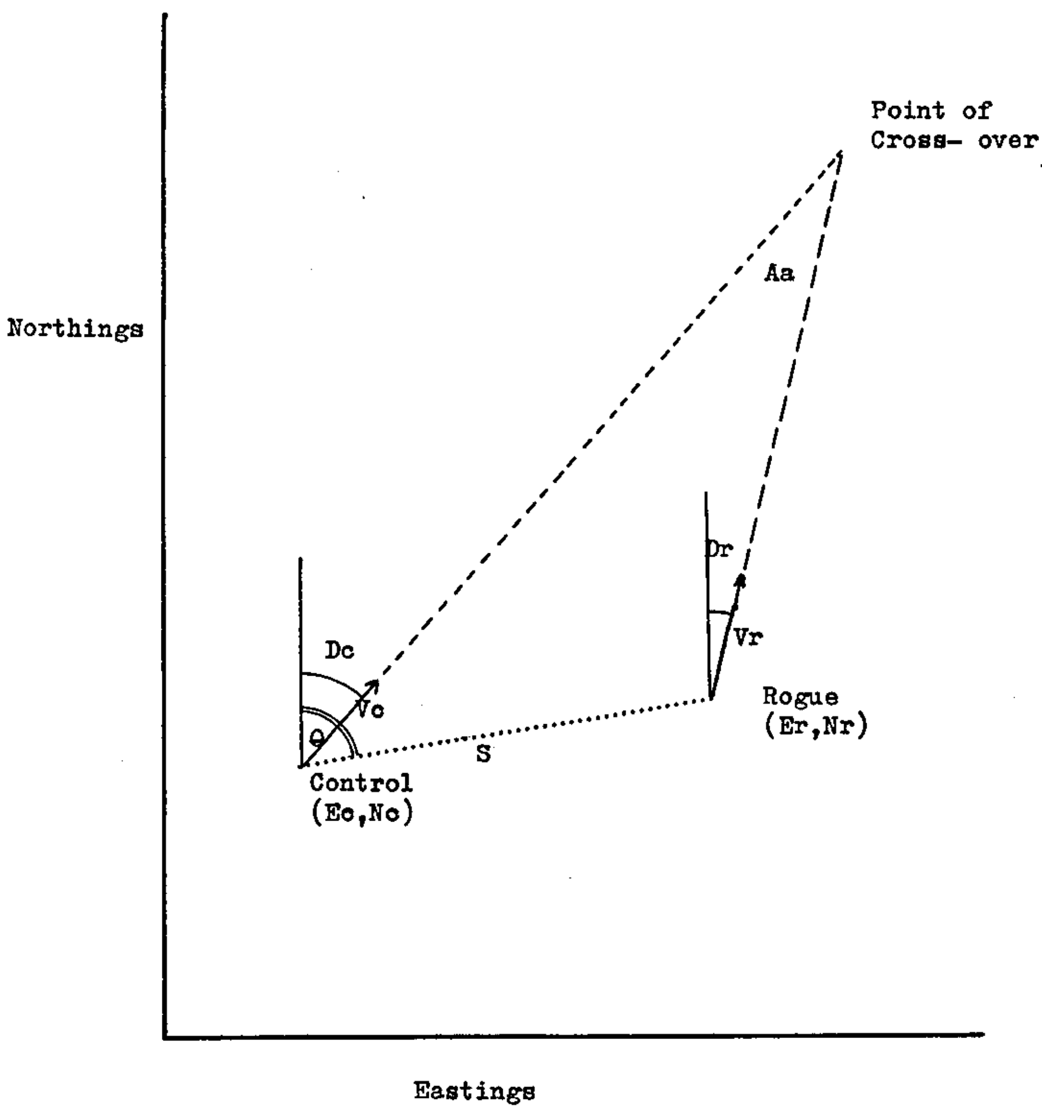
The second section discusses the statistical relationships existing between these parameters in the sixty-four situations employed in the electronic simulation. This is necessary to avoid the use of irrelevant but highly correlated variables to describe behaviour.

The third section discusses measures of performance, and establishes that the time to go to the time of closest approach is the most consistent measure of the situation.

The fourth section derives a series of multiple linear correlations to describe the performance of observers. This section uses the mean times to go to Tca and mean accuracies as the predicted variables for the sixty-four simulations for skilled observers.

Figure 37

Conflict situation - Mathematical parameters



1. Mathematical relationships between situation parameters.

Any situation in which two aircraft, one considered to be controlled, the other a rogue aircraft, take part, may be defined at any time by specifying the following independent parameters, four for each aircraft.

Parameter	Controlled Aircraft	Rogue Aircraft
Easting (X co-ordinate)	Ec	Er
Northing (Y co-ordinate)	Nc	Nr
Heading	Dc	Dr
Speed	Vc	Vr

In the general situation, all of these values may change for any aircraft. In the situations with which this report is concerned, the aircraft are known to maintain steady Heading and Speed.

If we decide that we will measure time with respect to the time at which the aircraft are at their closest, the time of closest approach (Tca), we may write the above formulae in the form

Parameter	Controlled Aircraft	Rogue Aircraft
Easting	Ec + Vc.sinDc.t	Er + Vr.sinDr.t
Northing	Nc + Vc.cosDc.t	Nr + Vr.cosDr.t

The position of the controlled aircraft relative to the rogue aircraft can be expressed in cartesian co-ordinates as

Ec-Er+(Vc.sinDc-Vr.sinDr).t, Nc-Nr+(Vc.cosDc-Vr.cosDr).t

This expression may be broken down into horizontal and vertical components of the relative position at time $t = 0$, and the horizontal and vertical components of velocity, which are formulated as below, and will be assigned symbols as shown for ease of manipulation.

Parameter	Horizontal Component	Vertical Component
Position at t=0	De = Ec - Er	Dn = Ne - Nr
Relative velocity	Re = Vc.sinDc-Vr.sinDr	Rn = Vc.cosDc-vr.cosDr

In terms of these relative initial position and velocity parameters, the co-ordinates of the control relative to the rogue are

$$(De + Re.t, \quad Dn + Rn.t)$$

For mathematical convenience we now assume that the relative velocity is not zero ($Re^2 + Rn^2 \neq 0$) and that the separation of the two aircraft is not actually zero at any time, although it may become as small as necessary.

Under these conditions we may work out the following basic formulae, which apply at any time t. At any time t the separation of the two aircraft is

$$S = ((De + Re.t)^2 + (Dn + Rn.t)^2)^{\frac{1}{2}}$$

Differentiating with respect to time

$$dS/dt = \dot{S} = \frac{(De.Re + Dn.Rn + (Re^2 + Rn^2).t)}{S}$$

and

$$d^2S/dt^2 = \ddot{S} = \frac{(Re^2 + Rn^2).-\dot{S}}{S}$$

The angle of the line of sight is

$$\theta = \tan^{-1} \frac{De + Re.t}{Dn + Rn.t}$$

Again, differentiating with respect to time

$$d\Theta/dt = \dot{\Theta} = \frac{Dn.Re - De.Rn}{S^2}$$

$$d^2\Theta/dt^2 = \ddot{\Theta} = \frac{-2.\dot{\Theta}.\dot{S}}{S}$$

$$d^3\Theta/dt^3 = \dddot{\Theta} = 2.\dot{\Theta}.(\frac{3.\dot{S}^2 - S.\ddot{S}}{S^2})$$

At time t = 0, which we have now made the time of closest approach

$$S = Smin = (De^2 + Dn^2)^{\frac{1}{2}}$$

$\dot{S} = 0$ (which is consistent with S being a minimum)

$\ddot{S} = \frac{(Re^2 + Rn^2)}{(De^2 + Dn^2)^{\frac{1}{2}}}$ (which is a positive quantity, and, in fact, a maximum)

Similarly $\dot{\Theta}$ = is a maximum, since its upper term is independent of t, and the lower is a minimum. It has the value

$$\dot{\Theta}max = \frac{Dn.Re - De.Rn}{De^2 + Dn^2}$$

$\ddot{\Theta} = 0$ (because $\dot{S}$ is zero)

By equating $\dddot{\Theta}$ to zero we can determine that Θx $\ddot{\Theta}$ has zero slope at times

$$\pm ((De^2 + Dn^2)/3.(Re^2 + Rn^2))^{\frac{1}{2}}$$

the maximum, and minimum values of $\ddot{\Theta}$ then being

$$(Dn.Re - De.Rn)(Re^2 + Rn^2)^{\frac{1}{2}}(\frac{3}{4(De^2+Dn^2)})^{3/2}$$

We will now derive 22 parameters which do not vary for a given situation, but which vary from situation to situation. We will derive these parameters, as far as possible, from the relative velocities, speeds, headings and relative positions at Tca of the two aircraft.

Each parameter is allotted a number, and a mnemonic symbol for convenience, and the type of variable will be noted. For the purpose of this exposition, the types of variables are distances, angles, speeds, times, angular velocities, angular accelerations, and choices. A choice is a "dummy variable" which can have only a few possible values, such as the passage of the rogue ahead of or behind the Controlor the direction of rotation of the line of sight.

Parameter 1 is the heading of the controlled aircraft. Symbol=Dc, Type=Angle, Units= Compass Degrees. (The convention used by navigators is that degrees are counted in a clockwise direction from North, which is 0 up to 360 degrees, which is again North. Non significant zeros are usually written thus: 005,090)

Parameter 2 is the heading of the rogue aircraft. Symbol=Dr, Type+Angle, Unit=Compass Degrees.

Parameter 3 is the Angle of Approach. This is the angle between the trails of the two aircraft, expressed in conventional angular terms, with a possible range from 0 to 180 degrees. (In fact, only 45, 90, 135 and 170 degrees were used) Symbol=Aa, Type=Angle, Unit=Degrees.

Parameter 4 is the Speed of Closing. This is the vector difference of the velocities of the aircraft involved. Symbol=Sc, Type of measurement=velocity, Units employed=Miles per Hour. (In caclulation miles per second are used, but these are less familiar to most observers)

$$Sc = (Re^2 + Rn^2)^{\frac{1}{2}}$$

Parameter 5 is the passage of the rogue ahead of, or behind the controlled aircraft,. This parameter is a choice, passage of the rogue ahead of the control being coded as +1, passage of the rogue behind being coded -1. The value of this may be determined as the sign of the difference between two subsequently defined parameters (21 and 22). Symbol used Prb.

$$Prb = \text{sign}\ (dTcx - dTrx) = \frac{dTcx-dTrx}{|dTcx-dTrx|}$$

Parameter 6 is the direction of rotation of the line of sight. This is a choice, coded +1 for clockwise rotation, -1 for anti-clockwise rotation. The symbol employed is Rls.

$$Rls = \text{sign}\ (\dot{\Theta})$$

Parameter 7 is the position of the rogue initially on the right or left of the controlled aircraft. This is determined by the combination of the previous two choices. The symbol used is Prl.

$$Prl = prb.Rls$$

Parameter 8 is the track intersection distance, defined as the distance of the rogue from the point of cross-over when the controlled aircraft reaches it. Symbol = Tid, Type = Distance, Unit = Miles.

$$Tid = |dTcx - dTrx| . Vr$$

Parameter 9 is the position on the PPI. This parameter is not dependent on the relative positions, but on the absolute positions on the PPI. It is considered as a choice parameter, having four levels corresponding to distance from the centre. These are coded as:

1. Outer ring, control heading inwards.

2. Outer ring, control heading outwards.

3. Median.

4. Central.

Symbol = Pppi, Type = Choice, Units = 1,2,3,4.

Parameter 10 is the separation of the aircraft, measured directly, at the time when they are at their closest. Symbol = Smin , Type = Distance, Units = Miles.

$|Smin| = (De^2 + Dn^2)^{\frac{1}{2}}$

Parameter 11 is the separation at closest approach, with the sign of the passage of the rogue added. Symbol = Smin, Type = Distance, Units = Miles.

$Smin = |Smin| . Prb$

Parameter 12 is the difference of the separation from 5 miles, using the absolute value of separation, but retaining the sign of the difference. Symbol = dSep, Type = Distance, Unit= Miles.

$dSep = |Smin| - 5.$

Parameter 13 is the absolute value of the preceding item. Symbol = dSep, Type = Distance, Unit = Miles.

$|dSep| = ||Smin| - 5|$

Parameter 14 is again not truly a parameter dependent on the initial positions, velocities and headings. This is the time between the start of the simulation and the time of closest approach. This is not constant, for obvious technical reasons, and is systematically related to some of the factors, for technical reasons. (For example, if one were to film only the two hundred seconds before Tca, situations in which a slow rogue passes well astern would be obviously resolvable as soon as seen. Such situations were therefore moved backward in time by from two to four minutes.) Symbol = Dt, Type = Time, Unit = Seconds.

Parameter 15 is the speed of the controlled aircraft, one of the basic parameters. Symbol = Vc, Type = Speed, Units = Miles per Hour.

Parameter 16 is the speed of the rogue aircraft, another basic parameter. Symbol = Vr, Type = Speed, Units = Miles per Hour.

Parameter 17 is the scalar difference between the speed of the control and that of the rogue. Symbol = Vd, Type = Speed, Units = Miles per Hour

$$Vd = Vc - Vr$$

Parameter 18 is the peak angular velocity. Symbol = $\dot{\theta}max$, Type = Angular Velocity, Units = Degrees/Sec.

$$\dot{\theta}max = \frac{Dn.Re - De.Rn}{De^2 + Dn^2}$$

Parameter 19 is the peak angular acceleration. Symbol = $\ddot{\theta}max$, Type = Angular Acceleration, Units = Degrees/Sec/Sec.

Parameter 20 is the indirect distance at the time of closest approach, measured via the point at which the aircraft tracks intersect (Pxo). Symbol = IDD_{tca}, Type = Distance, Unit = Miles.

$$IDD_{tca} = dTcx.Vc + dTrx.Vr$$

Parameter 21 is the time between the time of closest approach and the time at which the controlled aircraft reaches the cross-over point. Symbol = dTxc, Type = Time, Unit = Seconds.

$$dTcx = \frac{Rn.\sin Dr - Re.\cos Dr}{Vc(\sin Dc.\cos Dr - \cos Dc.\sin Dr)}$$

Parameter 22 is the time between the time of closest approach and the time at which the rogue aircraft reaches the point of cross-over.
Symbol = dTrx, Type = Time, Unit = Seconds.

$$dTrx = \frac{Rn.\sin Dc - Re.\cos Dc}{Vr(\sin Dc.\cos Dr - \cos Dc.\sin Dr)}$$

Summary Table of Situation Parameters, derived from relative positions and velocities of aircraft on steady courses.

No.	Parameter	Symbol	Type	Unit
1.	Heading of Controlled Aircraft	Dc	Angle	Degrees
2.	Heading of Rogue Aircraft	Dr	Angle	Degrees
3.	Angle of Approach	Aa	Angle	Degrees
4.	Speed of Closing	Sc	Speed	m.p.s.
5.	Passage of Rogue Ahead or Behind Control	Prb	Choice	+/-1
6.	Rotation of Line of Sight Clockwise/ Anti-Clockwise	Rls	Choice	+/-1
7.	Position of Rogue Initially on Left/ Right of Control	Prl	Choice	+/-1
8.	Track intersection distance	Tid	Distance	Miles
9.	*Position on PPI Outer,cont. in or out, Median,Central	Pppi	Choice	1/2/3/4
10.	Separation at Tca	$\lvert Smin \rvert$	Distance	Miles

No.	Parameter	Symbol	Type	Unit
11.	Separation at Tca (with sign of passage of Rogue)	Smin	Distance	Miles
12.	Difference of Separation from five miles	$\lvert Smin \rvert -5$	Distance	Miles
13.	Absolute value of item 12	$\lvert \lvert Smin \rvert -5 \rvert$	Distance	Miles
14.	*Time from closest approach to start of simulation	Dt	Time	Seconds
15.	Speed of controlled aircraft	Vc	Speed	M.p.h.
16.	Speed of rogue aircraft	Vr	Speed	M.p.h.
17.	Difference of speeds	Vd	Speed	M.p.h.
18.	Peak angular velocity	$\dot{\theta}max$	Ang.Vel.	deg/sec
19.	Peak angular acceleration	$\ddot{\theta}max$	Ang.Acn.	deg/sec^2
20.	Indirect distance at Tca	IDD_{tca}	Distance	Miles
21.	Time between Tca and control reaching Cross-over	∂Txc	Time	Seconds
22.	Time between Tca and rogue reaching Cross-over	∂Txr	Time	Seconds

*These items do not depend on the relative positions and velocities of the aircraft simulated, but can be determined for any simulation, and may be relevant to subject's performance.

2. <u>Statistical relationships between simulation parameters.</u>

The twenty-two parameters of the experimental situation defined and discussed in mathematical terms in section 1 of this chapter are not statistically independent.

It is therefore necessary to investigate how they vary with or against each other, in the sample of sixty-four simulations used in this experiment. Table 73 shows the correlation coefficients between the twenty-two parameters for the sample of sixty-four simulations. It is worth noting that if a different set of simulations were taken, forming a sample with different bias (for example, one in which all the conflicts were either overtaking or head-on conflicts) differing values of these correlation coefficients would be appropriate.

The upper triangle of Table 73 gives the correlation coefficients to two decimal places, the lower triangle gives the significance of their difference from zero.

Notice that parameters 1 and 2, (the headings of the aircraft), 6, (the direction of rotation of the line of sight), 7, (the initial position of the rogue) and 9, (the position of the conflict on the PPI) do not show any significant correlations with any parameters. In addition, parameter 12 differs from parameter 10 by a constant only, so that the correlation of parameters 10 and 12 is 1. Notice also that those parameters which are based on the levels of the Hyper-greco-latin cube design used are, apart from minor rounding errors, independent of each other. (The parameters in question are numbers 3 to 9 inclusive).

The correlation matrix so produced is not particularly informative in itself. Accordingly

Table 74 has been prepared. In this table, parameters have been arranged so that large correlations are grouped as closely as possible to the diagonal of the matrix. The direction in which the correlations are measured is not important in these circumstances, so certain of the parameters have been inverted in sign to provide the maximum number of significant positive correlations.

Examination of this table shows that there appear to be two groups of parameters (Clusters). The first, the largest contains eight of the sixteen significantly related parameters. These are, in numerical order

Parameter 3 - the angle of approach

Parameter 8 - the track intersection distance

Parameter 10 - the absolute distance of minimum separation

Parameter 13 - the difference of this from 5 miles (unsigned)

Parameter 16 - the speed of the rogue aircraft

Parameter 17 - the difference of velocities

Parameter 18 - the peak angular velocity of the line of sight

Parameter 19 - the peak angular acceleration of this line

Parameter 20 - the indirect distance at Tca.

These may be considered as measures of the closeness of the aircraft in relation to their speed, although the attaching of 'a posteriori' labels to empirical groupings is not really advisable.

The second group of variables contains five parameters, these being

Parameter 5 - the passage of the rogue ahead of or behind the controlled aircraft.

Parameter 11 - the separation at Tca, with the sign of the previous term (parameter 5)

Parameter 14 - the time before Tca at which the simulation starts

Parameter 21 - the time for the control to reach the point of cross-over from the time of closest approach

Parameter 22 - the time for the rogue to reach the point of cross-over from the time of closest approach.

This group of variables is concenred primarily with the precedence of the aircraft, although the presence of variable 14 is interesting. This variable is mathematically urelated to any of the other parameters, but was in practice related to the expected time at which decisions would be made, which in turn is determined by some of the other parameters in the group.

Finally, there are two variables forming an intermediate group:-

Parameter 4 - the speed of closing

Parameter 15 - the velocity of the controlled aircraft.

These two parameters appear to be intermediate between the two main groups, and are related to both.

So much is observable by examination of the matrix of correlation coefficients. It is now appropriate to use more elaborate mathematical methods to formalise our conclusions so far.

If we carry out a factor analysis of the data matrix consisting of the twenty-two parameter values obtained for the sixty-four simulations - remembering that these are not really independent data sets, so that any 'factors' resulting are primarily of illustrative value, we find that nine eigenvalues exceed the normal unit cut-off value. These account for 24.8, 14.5, 8.4, 8.1, 6.8, 5.6, 5.1, 4.8 and 4.6 per cent of the variation present, a total of 82.5% in all. The principal components matrix is not very informative, for so many significant factors. Rotation of the nine factors to give a simple structure produces roots which group together parameters 3, 10, 12 and 13, parameters 5, 11, 14, 21 and 22, parameters 4 and 15, parameters 9, 18. and 19, parameters 8 and 20, parameters 1 and 2, with parameters 4, 6, and 7 appearing as single independent factors.

Clearly, this distribution of roots is too detailed in the circumstances, and depends to too great an extent on the intial experimental design - parameters 3,4, 5, 6, 7, 8 and 9, the original factors varied, appear in separate factors derived in this form.

In order to get a better idea of the general statistical relations obtaining the two largest factors were considered. (These account for 24.8% and 14.5% of the variation present - the remaining roots may be neglected for simplicity). For this sample of sixty-four simulations, the first two factors are almost exactly at the varimax rotation position for simple structure, the rotation required being less than half a degree.

The factor matrix for the first two factors is given in the acommpanying Table 75, and illustrated in Figure 38. Note that the points representing parameters are spread out in the form of a cross, with only a few points (14, 8, 20) considerably away from the arms. Axis I, which represents the principal component making up the observed correlations, is heavily represented by parameters 10 (and 12, which is identical, except for a difference in the mean of five units) and 16, which are positively weighted and by parameters 3, 13, 17, 18 and 19 which are negatively weighted. This axis, in fact, corresponds to the group of variables previously called the first main group.

Axis II, the second largest component of variance, shows up particularly in parameters 5, 11 and 21 positively, and 22 negatively. This corresponds to our second main group of parameters. Notice that variables 4 and 15, which were not assigned to either group, and the other variables showing no significant correlation appear in the region of the zero point. Notice also that parameter 14, included on inspection in the second group, is much further off axis II than any other member, and has less significant correlations with the other members of the group. Parameters 8 and 20, which are more or less on the fringes of the first main group of parameters, also appear to be further off axis I than the other members of that group.

To sum up, statistically the parameters describing a simulation can be divided as a first approximation into two groups: one corresponding to the closeness which the aircraft get to, (and their speed), the other corresponding to the order in which they arrive at the cross-over point. These account for about half the differences between simulations.

TABLE 73.

Correlations between Situation Variables.

Parameter No.	Parameter Symbol	1	2	3	4	5	6	7	8	9	10	11
1	Dc	*	-.18	.00	.00	.00	.00	.00	.00	.00	-.02	-.04
2	Dr	.	*	.15	-.05	.00	.00	.08	.10	-.10	-.14	-.04
3	Aa	.	.	*	.00	.00	.00	.00	.00	.00	-.69	-.04
4	Sc	.	.	.	*	-.01	.00	-.01	.01	.00	.10	-.03
5	Prb	.	.	.	.	*	.00	.00	.00	.00	.04	.77
6	Rls	.	.	.	.	.	*	.00	.00	.00	.10	.01
7	Prl	.	.	.	.	.	.	*	.00	.00	.02	.06
8	Tid	.	.	.	.	.	.	.	*	.00	.47	.00
9	Pppi	.	.	.	.	.	.	.	.	*	-.04	.00
10	|Smin|	.	.	---	.	.	.	.	+++	.	*	.06
11	Smin	.	.	.	.	+++	.	.	.	.	.	*
12	|Smin| -5	.	.	---	.	.	.	.	+++	.	+++	.
13	||Smin| -5|	.	.	+++	.	.	.	.	--	.	---	.
14	Dt	.	.	++	-	++	.	.	. .	.	.	+
15	Vc	.	.	.	+++	.	.	.	.	.	.	.
16	Vr	.	.	---	+++	.	.	.	.	.	+++	.
17	$\dot{V}$d	.	.	+++	-	.	.	.	.	.	---	.
18	$\ddot{\theta}$max	.	.	+++	.	.	.	.	.	.	---	.
19	θmax	.	.	+	.	.	.	.	.	.	--	.
20	IDDtca	.	.	.	.	.	.	.	+++	.	+++	.
21	dTcx	.	.	.	.	+++	.	.	.	.	.	+++
22	dTrx	.	.	.	.	---	.	.	.	.	.	--

TABLE 73 (Cont.)

Correlations between Situation Variables

Parameter No.	Parameter Symbol	12	13	14	15	16	17	18	19	20	21	22
1	Dc	-.02	.03	-.04	.00	-.01	.00	.03	.00	-.01	.01	-.01
2	Dr	-.14	.14	-.05	-.03	-.19	.16	.12	.15	-.07	.02	-.02
3	Aa	-.69	.69	.33	-.19	-.66	.54	.51	.33	-.13	.07	-.11
4	Sc	.10	-.03	-.25	.54	.54	-.26	.06	-.05	.12	.00	.01
5	Prb	.04	-.05	.38	-.01	.00	-.01	-.14	-.15	.03	.62	-.59
6	Rls	.10	-.07	-.03	-.01	.01	.01	.07	.11	.18	.12	-.15
7	Prl	.02	-.13	.10	-.01	.00	-.01	-.11	-.13	.04	.02	.10
8	Tid	.47	-.36	.05	.01	-.01	.01	-.06	-.05	.52	.16	-.10
9	Pppi	-.04	.08	-.14	-.01	-.01	.01	-.15	-.18	.02	.04	.02
10	|Smin|	1.00	-.82	-.22	.09	.61	-.54	-.48	-.34	.58	-.02	.03
11	Smin	.06	-.06	.30	.03	.00	.01	-.01	-.01	.00	.70	-.37
12	|Smin| -5	*	-.82	-.22	.09	.61	-.53	-.48	-.34	.58	-.02	.03
13	||Smin| -5|	---	*	.23	-.05	-.49	.44	.55	.39	-.44	-.04	-.02
14	Dt	.	.	*	-.27	-.27	.13	.22	.16	.08	.25	-.51
15	Vc	.	.	-	*	.15	.34	-.03	-.12	-.17	-.04	.00
16	Vr	+++	---	-	.	*	-.88	-.25	-.18	.33	-.02	.06
17	.Vd	---	+++	.	++	---	*	.23	.12	-.39	.00	-.06
18	..θmax	---	+++	.	.	.	.	*	.92	-.37	.00	.22
19	θmax	--	++	.	.	.	.	+++	*	-.34	-.01	.03
20	IDDtca	+++	---	.	.	++	--	--	--	*	.18	-.24
21	dTcx	.	.	.	.	.	.	.	.	.	*	-.62
22	dTrx	.	.	---	.	.	.	.	.	.	---	*

TABLE 74 - Clustering of Coefficients.

Parameter number (with sign inversion, if any)

No.	Symbol	Inverted?	-19	-18	-3	10	-13	16	-17	20	8	-15	-4	14	-22	21	5	11
19	$\ddot{\theta}max$	Yes		+++	+	++	++			++								
18	$\dot{\theta}max$	Yes	+++		+++	+++	+++			++								
3	Aa	Yes	+	+++		+++	+++	+++	+++									
10	|Smin|	No	++	+++	+++		+++	+++	+++	+++	+++							
13	||Smin| -5|	Yes	++	+++	+++	+++		+++	+++	+++	++							
16	Vr	No			+++	+++	+++		+++	++			---					
17	Vd	Yes			+++	+++	+++	+++		++		++	-					
20	IDD_{tca}	No	++	++		+++	+++	++	++		+++							
8	Tid	No				+++	++			+++								
15	Vc	Yes							++				+++					
4	Sc	Yes						---	--			+++		+				
14	Dt	No											+		+++		++	+
22	dTrx	Yes												+++		+++	+++	+++
21	dTcx	No													+++		+++	+++
5	Prb	No												++	+++	+++		+++
11	Smin	No												+	+++	+++	+++	

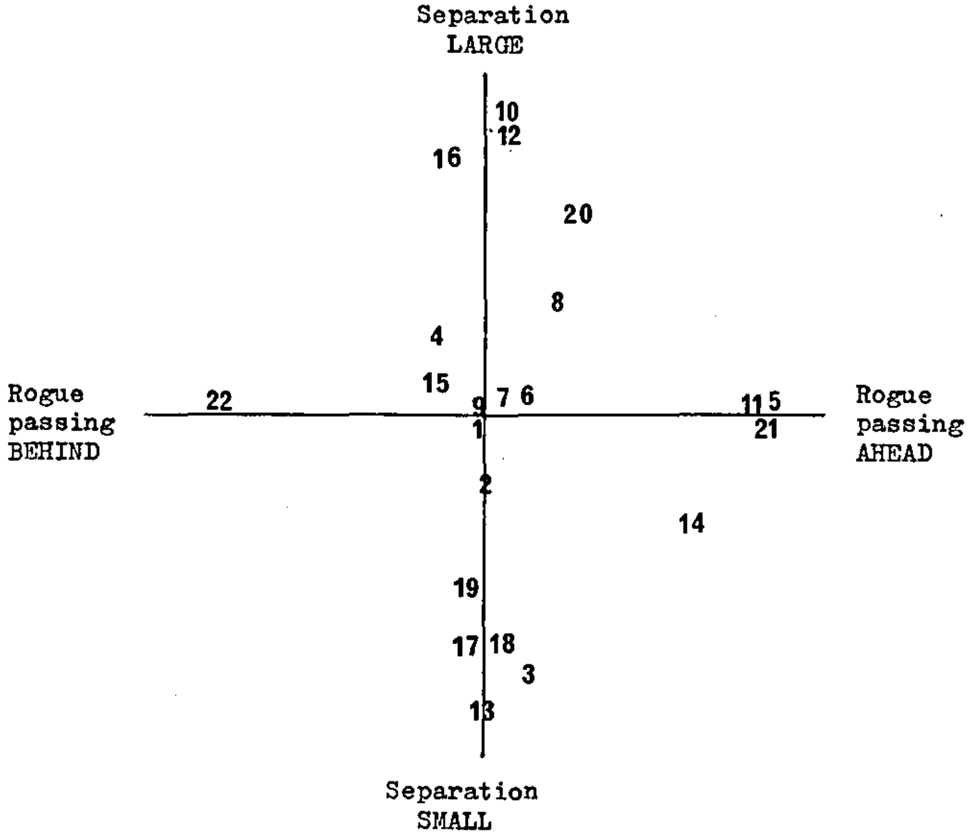
Parameter 12 (|Smin| -5) is identical with parameter 10 as far as variation is concerned.

Parameters 1 Dc
2 Dr
6 Rls
7 Prl
9 Pppi

are not significantly related to any other parameters.

Figure 38

Two-component Factor Analysis of situation parameters



Axis I - Separation

Positive	10	Separation at time of closest approach (modulus)
	12	Difference of separation from five miles
	16	Speed of Rogue aircraft
Negative	3	Angle of Approach
	13	Difference of separation from 5 miles (modulus)
	17	Difference of speeds
	18	Peak angular velocity of line of sight
	19	Peak angular acceleration of line of sight

Axis II - Precedence

Positive	5	Passage of Rogue Ahead or Behind Control
	11	Separation at time of closest approach (with sign)
	21	Time from Tca that Control reaches cross-over
Negative	22	Time from Tca that Rogue reaches cross-over

3. Choice between Possible Variates for description of performance.

a) Possible variates for description of performance.

We have described twenty-two parameters of the conflict situation, which vary from simulation to simulation, but which are fixed for any simulation in which two aircraft approach one another on constant courses at constant speeds. If we wish to describe the performance of an observer, or a group of observers in useful terms, we must have measures of the situation which do vary with the development of the situation, and we must define events which we will measure in these terms.

If we consider first the choice of measures of the situation, five possible variates which are not linearly related suggest themselves. These are:-

1. The time to go to the time of closest approach. This we will call t. This possible variate is of the type Time, the unit used will be seconds.

2. The separation of the aircraft, measured directly between the two aircraft. This will be called S, is of the type Distance, and the unit used will be Miles. This is related to the first possible variate by the formula:

   $S = (De^2 + Dn^2 = (Re^2 + Rn^2).t^2)^{\frac{1}{2}}$

3. The indirect distance between the aircraft, measured via the point of cross-over.

   Symbol = IDD, Type = Distance, Units = Miles.

   $IDD = Vc.|t - dTcx| + Vr.|t - dTrx|$

4. The rate of rotation of the line of sight between the aircraft. The sign of the variate is taken as positive throughout.
   Symbol = $\dot{\theta}$, Type = Angular Velocity,
   Unit = Degrees/Second.

$$\dot{\theta} = \frac{|Dn.Re - De.Rn|}{S^2} = \frac{|Dn.Re - De.Rn|}{(De^2 + Dn^2 + (Re^2 + Rn^2).t^2)}$$

5. The rate of change of the rate of rotation of the line of sight. (Again the sign is discarded). Symbol = $\ddot{\theta}$, Type = Angular Acceleration, Unit = Degrees/Second/Second.

$$\ddot{\theta} = -2.\frac{\dot{\theta}.\dot{S}}{S}$$

In addition to these five non-linearly related possible variates, there are four other possible measures in terms of time, measured from different zero-points. These are:-

6. The time before the controlled aircraft reaches the point of cross-over.
   Symbol = tcx, Type = Time, Unit = Seconds.

$$tcx = t - dTcx$$

7. Time before rogue aircraft reaches the point of cross-over.
   Symbol = trx, Type = Time, Unit = Seconds.

$$trx = t - dTrx$$

8. Time before first aircraft reaches point of cross-over.
   Symbol = txl, Type = Time, Units = Seconds

$$txl = t - \max(dTcx, dTrx)$$

9. Time before second aircraft reaches point of cross-over.

Symbol = tx2, Type = Time, Unit = Seconds.

$$tx2 = t - \min(dTcx, dTrx)$$

Table of Possible Variates

No.	Possible Variate	Symbol	Type	Unit
1	Time to go to time of closest approach	t	Time	Seconds
2	Separation of aircraft - measured directly	S	Distance	Miles
3	Separation of aircraft - via cross-over point	IDD	Distance	Miles
4	Angular Velocity of Line of Sight	$\dot{\theta}$	Ang.Vel.	Deg/sec
5	Angular Acceleration of Line of Sight	$\ddot{\theta}$	Ang.Accn.	Deg/sec^2
6	Time before control reaches cross-over point	tcx	Time	Seconds
7	Time before rogue reaches cross-over point	trx	Time	Seconds
8	Time before first aircraft reaches cross-over point	tx1	Time	Seconds
9	Time before second aircraft reaches cross-over point	tx2	Time	Seconds

Let us now consider the events we wish to measure. An observer watches the simulation, and at some point he reaches conclusions as to what is going on in the situation.

The types of decisions that he is required to make and the definitions of these decisions are described in detail in Chapter V, Section 2. For the convenience of the reader the three questions that the observer was required to answer were:-

A) Is the situation a conflict or is it safe? (i.e. will the aircraft ever be within five miles of each other?)

B) Is the rogue passing ahead of, or behind the control?

C) How far apart will the aircraft be at their closest?

At this point he will make a decision, stating the answers to some of these questions, as they appear to him at that stage. He will continue to observe the situation, and may make further decisions later, in which he may answer the other questions, or correct his earlier answers. These decisions can be scored as correct or incorrect in terms of each of the three questions, and his performance over any one trial can be quantified in terms of the following ten measures.

No.	Measure	Symbol	Type	Unit
1	First Decision (State of Situation)	FD	qualitative	
2	Accuracy of Initial Decision (Conflict/Safe)		choice	0/100
3	Accuracy of Initial Decision (Ahead/Behind)		choice	0/100
4	Accuracy of Initial Decision (within 3 miles)		choice	0/100

No.	Measure	Symbol	Type	Unit
5	First Correct C/S Decision (State of situation)	FC/SD	qualitative	
6	Final accuracy of C/S Decision		choice	0/100
7	First Correct A/B Decision (State of situation)	FA/BD	qualitative	
8	Final accuracy of A/B Decision		choice	0/100
9	First Correct estimate of separation (State of situation)	F=/-3D	qualitative	
10	Final accuracy of +/-3 Decision		choice	0/100

If we consider a single observer watching a single simulation, then we will be unable to make any estimate of the state of the situation for the first correct conflict/safe decision unless he did in fact make a correct decision of this type. Similarly, for a single observer the scores for accuracy will be limited to 0 or 100 for a single simulation. If we take averages for groups of observers, or over groups of simulations, however, we can obtain qualitative estimates of the accuracy of the different decisions at the initial decision (Measures 2, 3 and 4) and over the whole simulation (Measures 6, 7 and 10).

b) Choice between possible variates.

We have described nine possible variates in the first sub-section of this section. Five of these variates are measures of time, using differently defined starting points. These measures will differ systematically from simulation to simulation, so that, for example, if the mean time to go to Tca is known for a particular simulation it is possible to calculate the mean time to go before the rogue aircraft reaches the point of cross-over.

The remaining four measures are not so simply related as the first five. For example, when the aircraft are close together a small increment in the time to go to Tca may lead to a very large change in the rate of rotation of the line of sight. Figure 39 shows how the rate of rotation of the line of sight, the separation, and the rate of change of the rate of rotation of the line of sight vary with time to go to Tca for a typical simulation. This simulation is in fact number 21 in the electronic simulation - number 5 in the paper simulation series. Note that at the time of closest approach the rate of rotation of the line of sight is a maximum, the separation is a minimum and the rate of change of the rate of rotation of the line of sight is zero. If one were to calculate the mean of a number of times in the region of the point of closest approach and convert this to angular acceleration, one would not get the same value as one would by converting each reading to angular acceleration and taking the mean of the resultant set of values.

In an ideal world one would be able to take one of these variables, and specify a 'threshold value' at which it became possible to make the judgements investigated in this thesis. Unfortunately this does not appear to be the case. All the possible measures are affected to a greater or lesser extent by the factors varied between simulations, and by individual judgement bias, and by experimental error. It is therefore necessary to formulate the decision in some more indirect way.

Proceeding by elimination, certain measures are not unique. For example, the linear separation of the aircraft reaches a minimum and increases, so that to say 'This judgement was made when the aircraft were separated by ten miles' may mean that they were approaching each other, or that they were already diverging, after having passed close to each other. Similar objections apply to the indirect distance between aircraft, which shows different rates of change depending on whether the aircraft have neither, one or both reached the point of cross-over. The rate of rotation of the line of sight, and the rate of change of the rate of rotation of the line of sight suffer from the same ambiguity, and are therefore discarded.

The time to go to the time of closest approach, and the other four measures linearly related to it are left. We wish to choose the variate which is most nearly constant, so that deviations will be more nearly linear, and residual error will be reduced to a minimum. For this purpose, the Coefficient of Variation may be employed. (This is simply defined as the sample s.d. divided by the sample mean, expressed as a percentage). This statistic has the advantage of being a dimensionless ratio, so that variates employing different units may be compared.

For each of the sixty-four simulations, for each type of decision, for each observer, the values of the nine parameters were derived. From these the Arithmetic mean, standard deviation and coefficient of variation for skilled and unskilled observers were found. In general the values for unskilled observers resembled those for skilled workers, except that the means tended to be smaller in proportion, and coefficients of variance were consequently larger. Because we are now primarily concerned with the performance of skilled observers we will not discuss further the performance of unskilled observers.

Table 75 gives for each type of decision, for each parameter, the arithmetic mean, standard deviation and Coefficient of Variation for skilled observers only. A low coefficient of variation implies that the variate is more nearly constant.

The coefficient of variation tends to be lower for the first decision than for others, the coefficient of variation for the first correct conflict/safe decision running it close.

The lowest coefficient is that for the time to go to closest approach, which has also the lowest standard deviation of the 'time' measures. If this measure is not suitable, since it is not always easy to find the time to go to Tca quickly, then the time before the rogue aircraft reaches the point of cross-over provides nearly as good a measure. If a time measure is not suitable, then the direct linear separation is the most suitable measure.

It could be argued that these coefficients ought to be adjusted to eliminate known significant effects from the analysis of variance in terms of each parameter. This has been done, and it appears that the pooled non-significant terms and residual terms for each measure - which form an estimate of the standard deviation, with some mathematical manipulation - provide exactly the same conclusions as reached above.

To sum up:-

The progress of the situation may be described in terms of nine variates, described in this section. None of these provides a 'Threshold Value'. We choose the time to go to Tca as our variate because it is nearest to that ideal, is unambiguous and because we are not limited in computational facilities.

Figure 39

Variation with time of possible variates

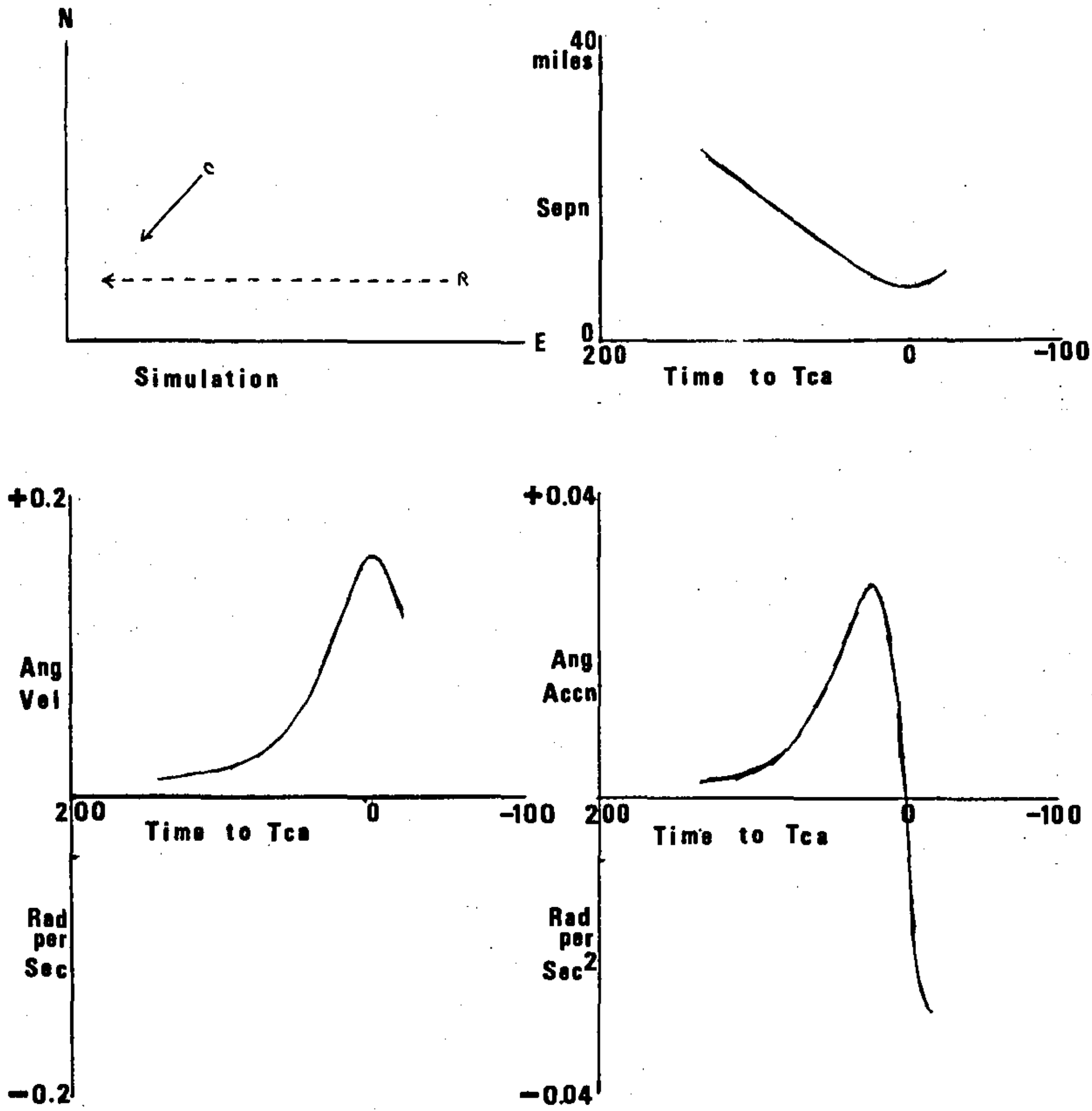


TABLE 75

Performance Measures for Skilled Observers.

Parameter	Measure	First Decn.	First C/S Decn.	First A/B Decn.	First +/-3 Decn.
Time to Tca	A.M.	157.1	146.1	142.1	142.0
	S.D.	42.7	44.7	46.1	46.6
	C of Vn	27.2	30.6	32.4	32.8
Separ-ation	A.M.	20.7	19.1	18.8	18.5
	S.D	6.4	6.2	6.8	6.3
	C of Vn	30.9	32.4	36.2	33.9
Indirect Distance	A.M.	27.0	24.6	24.6	24.0
	S.D.	10.2	8.4	11.1	9.5
	C of Vn	37.8	34.4	45.0	39.6
$\dot{\theta}$	A.M.	0.96	1.07	1.07	1.11
	S.D.	0.87	0.97	0.90	1.01
	C of Vn	90.1	90.1	84.8	91.0
$\ddot{\theta}$	A.M.	0.014	0.017	0.017	0.019
	S.D.	0.014	0.081	0.081	0.021
	C of Vn	104.4	106.4	100.6	109.0
tcx	A.M.	161.3	150.4	146.4	146.3
	S.D.	78.4	78.0	78.4	77.4
	C of Vn	48.6	51.9	53.6	52.9
trx	A.M.	151.7	140.8	136.8	136.6
	S.D.	44.4	51.4	45.9	50.7
	C of Vn	29.3	36.5	33.6	37.1
txl	A.M.	120.7	109.7	105.7	105.6
	S.D.	43.7	48.7	43.6	46.9
	C of Vn	36.3	44.5	41.2	44.4
tx2	A.M.	192.5	181.5	177.5	177.4
	S.D.	60.3	61.6	61.5	61.7
	C of Vn	31.4	33.9	34.6	34.8

4. Regression equations describing performance of observers.

The formal analyses given in Chapter V on the electronic simulation experiment show how the six factors varied affect the performance of observers in terms of the time before Tca and the accuracy of their decisions. A brief study of Sections 3 to 6 of Chapter V of this thesis will show that there is a good deal in common between the various measures employed. Because the overall accuracy of the first decision is high (75% for conflict/safe decisions, 60% for other decisions), the mean time and accuracy of the first decision play a decisive role in determining the mean time and accuracy of correct decisions.

It is therefore worth going into the structure of the First Decision in some detail. In order to simplify the discussion we will take only the values of time and accuracy for skilled observers watching electronic simulations into consideration, since the results for unskilled observers are generally similar, but more erratic and of less intrinsic interest.

Let us first consider the development of a situation from the point of view of the controller, bearing in mind the briefing given to him (Appendix 4) and the experience of controllers in general.

The controller was told to say "Conflict" if he was sure the situation was a conflict, or "Safe" if he was sure it was safe. He was then to say what action he would advise, and finally to estimate what was going to happen. (The lesser emphasis placed on the last part of this instruction is reflected in the lower final accuracy of the second and third types of correct decision).

As a matter of observation, the controllers showed signs of tension until they made their first report. (The signs of stress observed were a tendency to hunch over the radar screen, to follow aircraft movements with the point of a pencil, or to play with the press-to-talk switch.) Once the first "conflict" or "safe" report had been delivered, the observers would lean back, stretch or adjust their headphones. The period of about a minute following a decision would usually be free from additions or corrections.

The time at which the decision was made depended on the urgency and difficulty of the situation. (Two aircraft heading straight for each other at high speed present an urgent but not difficult situation. Two aircraft, where the control will pass behind the rogue by about four and a half miles present a difficult but not urgent situation).

The correlation between speed and accuracy is not significant, suggesting that there is no "selling accuracy for speed" or vice-versa.

Section 3 of Chapter V lists the significant effects on the timing and accuracy of the first decision of the six factors varied in the latin cube experimental design. These factors are independent, so that effects which cause a significant difference in terms of one factor will be independent of those causing variation in another. Table 5 presents all the significant effects observed.

a) Time of first decision.

There are three factors affecting the time of first decision of skilled observers. These are:

The angle of approach (Aa)

The speed of closing (Sc)

The passage of the rogue ahead of, or behind the controlled aircraft (Prb)

The first of these, the angle of approach, affects both time and the initial accuracy of the decision which aircraft passes ahead of the other. Table 7 and Figure 11 show the effect of this factor on the time of the decision, and Table 8 and Figure 12 show the effects on the accuracy of the first ahead/behind decision. The nature of the difference in timing is that head-on cases are resolved rapidly, while other types of situation are resolved about 42 seconds later, on the average. The accuracy with which it is decided which aircraft is passing ahead of the other is also considerably worse for head-on cases than for other angles of approach. The difference in accuracy is considerably less for the final decision, indicating that observers often become aware of the situation as a conflict, and find it advisable to take action before they can determine which aircraft is passing ahaad of the other.

The second significant factor is the speed of closing. This affects only the time before Tca at which the decision is made, in fact only the 5th and 50th percentiles of the time. All three times are included in Figure 13 and Table 9. As might be expected, the time to Tca is greater for slow speeds of closing, and smaller for high speeds, although it remains nearly constant at intermediate speeds.

The final significant effect, shown in Table 10 and Figure 14 is that of the passage of the rogue ahead of, or behind the controlled aircraft. This affects only the 5th percentile of the time to Tca, in other words the time at which observers start to make decisions. The nature of the difference is that skilled observers tend to start making decisions about 34 seconds earlier when the rogue aircraft is passing ahead of the control than when it is passing behind. This could be attributed to the need for less thought on what to do in those circumstances, except that unskilled observers, who do not have to decide what action ought to be taken, exhibit the same pattern of timing. An alternative is that the urgency of the situation appears greater when the rogue is passing ahead, the "centre of gravity" being somewhere between the times at which the two aircraft pass the cross-over point.

To sum up the deductions we can make from the analysis of variance:-

As the angle of approach increases the time to Tca remains steady until the nearly head-on position is reached. At that point it increases sharply. The accuracy with which the skilled observer can judge which aircraft will pass ahead drops steadily as the angle increases, being almost random in the head-on case.

As the speed of closing increases, the time to Tca decreases, but the accuracy is not affected.

Decisions are made earlier when the rogue is passing ahead of the control.

These effects are, by the nature of the design of the experiment, mutually independent. There are other possible measures of the situation, and it may well be profitable to study their effect on the situation. To this end, a series of multiple linear correlations has been carried out with a view to finding the most useful predictor sets. We start with the 22 parameters defined in Section 1 of this chapter.

Some of these parameters are redundant, being linear combinations of other variables within the set. If these are included in the analysis, the matrix which is inverted to solve the necessary simultaneous equations becomes "ill-conditioned", and rounding-off errors combine to produce nonsensical results. Variables 10, 12, 15, 16 and 17 are eliminated for this reason. Variable 14, the time between the start of the simulation and the time of closest approach is a parameter which cannot be generalised to other situations. It is also not really independent of the measured variable, since the time was chosen so that most subjects would find themselves becoming certain towards the middle of the run.

If we carry out a multiple linear correlation of the remaining sixteen variables against the mean time to go to Tca, we obtain a regression equation having sixteen variables, of which only four appear to be significant. The correlation of the observed and predicted times is 0.807. This is significant, and accounts for about three-quarters of the variation present in terms of sums of squares. The equation would be impossibly clumsy in use, and contains redundant, non-significant terms.

We therefore proceed in the opposite direction, first choosing the single variable most closely correlated with the time to Tca, and adding other terms to find the best pair, triplet etc. of variables. (In order not to construct too elaborate a structure we are constrained to stop when no new variable has a significant regression coefficient, and to test each variable at each stage to see if it can be eliminated).

The best single parameter turns out to be number twenty-two, the time required for the rogue to reach the point of cross-over from the time of closest approach. The resultant prediction equation is $T=154.6-.47T_{rxo}$. The predicted and observed times have a correlation of 0.527, which is significant, but the decrement in the standard deviation of the time to Tca is only from 43 seconds to 36 seconds.

Parameter 4, the speed of closing, turns out to be almost as good a predictor, having a correlation of .368 with the observed time to Tca. For this variable, which in this experiment has four standard values, 240, 360, 480 and 600 knots, the prediction equation is

$t = 205.7 - 0.1\ Sc$ where Sc is the speed of closing.

Using this equation one obtains the following values for the mean time of first decision before Tca.

Time to Tca (seconds)	Speed of Closing			
	240 knots	360 knots	480 knots	600 knots
Observed	184	156	148	140
Predicted	178	164	150	137

(The prediction equation is linear).

Parameter 3, the angle of approach, is nearly as good a predictor as parameter 4, having a correlation of 0.351 with the observed time to Tca. The equation for parameter 3 as predictor is:

$$t = 122.4 + 35\ Aa$$

Using this equation one obtains the following values for the mean times of first decision before Tca.

Time to Tca (Seconds)	Angle of Approach			
	45 degrees	90 degrees	135 degrees	170 degrees
Observed	143	149	146	190
Predicted	138	154	170	182

Referring back to Section 2, it will be noticed that we have here one parameter from each group (3 and 22) and one in neither (4). We have also one parameter with a heavy factor I weighting (3), one with a heavy factor II weighting (22) and one with no heavy weighting for either factor (4).

Considering parameters in pairs, the most effective pair of predictors appears to consist of parameter 22, the time for the rogue to reach the point of cross-over from the point of closest approach, and parameter 4, the speed of closing. The combination of these two produces a prediction equation of the form

$$t = 202.9 - .1\ Sc - .47\ dTrx$$

The correlation of the predicted with the observed value is .641, accounting for about half the observed variation.

Considering triplets of parameters, we find that the most effective combination of three predictors is the angle of approach (3), the speed of closing (4) and the time for the rogue to reach the point of cross-over from the point of closest approach (22). The prediction equation is of the form

$$T = 173.6 - 0.44\ dTrx - 0.1\ Sc + 0.27\ Aa$$

The predicted value produced by this equation has a correlation of 0.707 with the observed value, compared with the correlation of 0.807 obtained by using all sixteen parameters. Notice that the coefficients of the variables are almost the same as those employed when they are used by themselves, indicating that they are virtually independent.

No significant fourth term can be found, so that no further elaboration of the prediction equation for the time before Tca at which the first decision is made from the parameters of the situation is possible.

b) Accuracy of first decision.

Just as it is possible to derive equations predicting the time at which the first decision is taken, so is it possible to derive equations predicting the percentage of occasions on which these decisions will be correct in terms of the three criteria of "accuracy" defined in Chapter 5.

The three types of judgements were:-

Are the aircraft passing within five miles of each other?

Is the rogue passing ahead of the control?

How close will they be at their closest? (within 3 miles accuracy).

For briefness these will be referred to as the C/S criterion, the A/B criterion and the +/-3 m criterion.

For the first decision the best predictor of the percentage accuracy of the decision in terms of the Conflict/Safe criterion is Parameter 13, the absolute difference of the separation from 5 miles. The predicition equation is

$$A_{cs} = 45.4 + 9.89\,||Sep| - 5|$$

This equation would predict that the accuracy of decision for aircraft passing at exactly the limit would be about 50%, while the accuracy for aircraft which are actually about to collide would be about 95%. Similarly for aircraft passing at more than 10 miles the accuracy of judgement should be about 95%.

If two prediction terms are used, the second should be Parameter 6, the direction of rotation of the line of sight, Rls. It appears that the accuracy is slightly greater when the line of sight is rotating clockwise, so that the equation should then be

$$A_{cs} = 44.4 + 10.2\,||Sep| - 5| + 6.0\,Rls$$

The improvement in the fit caused by the addition of the second term is not great, the standard error of estimates falling only from 20.6 to 19.8, and the correlation of predicted and observed values rising only from .56 to .61. Under the circumstances the second term should be treated with some reserve, as a possible statistical artefact. No significant third term can be added.

The second type of accuracy decision is on whether the rogue passes ahead of the control. For this again the best single predictor is the difference of the absolute separation from 5 miles, although the relationship is now reversed, the effect of increasing the difference being negative instead of positive. The equation is:-

$$A_{ab} = 98.7 - 12.9 \,\big| |Sep| - 5 \big|$$

This equation predicts that the accuracy of judgement for separations in the region from -1.2 to +1.2 miles will be less than 50%, and when the aircraft will actually collide it will be about 34%. In fact, this is to say that where the aircraft are passing extremely close, in only one case in three will it be apparent which is passing ahead of the other, and it will be an even chance when they are passing within about a mile. The implications of this for collision avoidance rules based on determining which aircraft passes ahead of the other are considerable.

If a second predicting term is added, this should be Parameter 9, which describes the position of the encounter on the radar screen. This variable has hovered on the edge of significance in some of the formal analyses, but is not significant considered in isolation.

It appears to allow the equation to be more affected by the separation term, but compensates for this effect in the centre of the screen. The equation takes the form

$$A_{ab} = 86.1 - 13.3 \,\big|\,|Sep| - 5\big| + 5.4\ P_{ppi}$$

Or, substituting for the four possible levels of P_{ppi},

$A_{ab} = 91.5 - 13.3 \,\big|\,|Sep| - 5\big|$	at the outer edge; control heading in
$A_{ab} = 96.9 - 13.3 \,\big|\,|Sep| - 5\big|$	at the outer edge, control heading out
$A_{ab} = 102.3 - 13.3 \,\big|\,|Sep| - 5\big|$	in the median region
$A_{ab} = 107.7 - 13.3 \,\big|\,|Sep| - 5\big|$	in the centre of the screen.

Thus the region in which only 50% of judgements are correct is about +/-½ mile at the centre of the screen and about +/-2 miles towards the centre. This effect can be ascribed to the nature of the simulation technique, and the differential accuracy of positioning of points between the centre and the periphery.

There is no significant third term.

The third decision, the judgement of how far apart the aircraft will be at their closest, to within three miles, is the most vague of the three judgements, and appears to be affected by 'a multiplicity of factors'. The only factor significant on its own is the speed of closing, producing a prediction equation of the form

$A_{3m} = 75.5 - 0.03$ Sc, which for the three levels of speed of closing predicts accuracies of 67, 63, 59 and 55 percent compared with observed mean accuracies of 69, 58, 61 and 54 percent. The nature of the predicting formula employed is such that it cannot predict non-linear relations, but as a linear prediction the agreement is close. The speed of closing did not affect the accuracy significantly in the analysis of variance, being just non-significant.

If a second term is introduced, the peak angular velocity is the best addition to the speed of closing, providing a combination which is significant considered as a pair, but in which the second term is not significant in itself. There exists no combination of two variables both of which are significant in themselves, nor is there one of three variables of which all three are significant, although the combination of Parameters 4, speed of closing, 13, difference of separation from 3 miles and 18, peak angular velocity is nearly adequate.

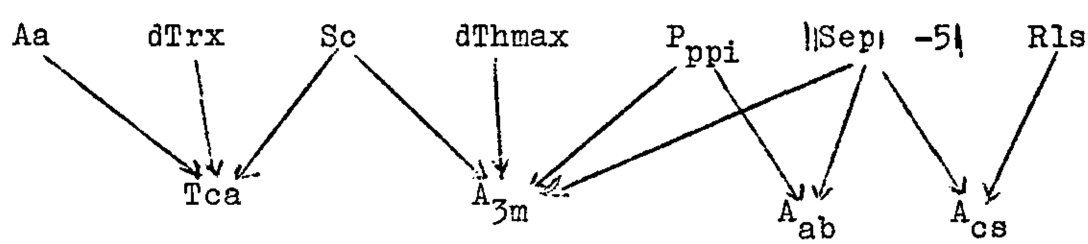
If however the four Parameters 4, 13 and 18 are taken together, they are individually significant and therefore worth employing as separate terms. The prediction formula is then:-

$$A_{3m} = 77.0 - .034Sc + 4.1P_{ppi} - 4.77\left|\,|Sep| - 5\right| + 0.4\ dThmax$$

The effect of applying this formula is to reduce the standard error of the estimate of percentage accuracy from 19 to 17.5, and the correlation of the estimated accuracy with the actual is 0.45, not a very impressive prediction performance using four predictors. In practice it would be better to stick to a single predictor, the speed of closing.

We may summarise our predictions of the four variables by the following table and diagram.

Predicted item:	Time to Tca	A_{cs}	A_{ab}	A_{3m}
Predictor No.				
3 Aa	+0.27	-	-	-
4 Sc	-0.10	-	-	-0.034
6 Rls	-	+6.0	-	-
9 P_{ppi}	-	-	+5.4	+4.1
13 $\lvert\lvert Sep\rvert -5\rvert$	-	+10.2	-13.3	-4.77
18 dThmax	-	-	-	+0.4
22 dTrx	-0.44	-	-	-
Constant	173.6	44.4	86.1	77.0
Correlation	0.71	0.61	0.58	0.45



c) First correct decisions from first decisions.

Let us now consider the first correct decisions of the various types defined in Chapter V.

In the previous sub-section we noted that the first decision was in fact correct in terms of whether the situation was a conflict or safe in 75% of trials, in terms of whether the rogue was passing ahead or behind in 60% of trials and in 61% of trials the separation was given accurately to within 3 miles.

In these cases, the first decision was the first correct decision of that type. The final accuracies of these judgements were 83%, 72% and 72%, so that a first correct decision other than the first decision occurred in only 8%, 12% and 11% of trials. In addition, no correct decisions were made in 17%, 28%, and 28% of trials respectively. These figures may be summarised as a table (below).

Correct Decision Made:	First Time	Later	Not at all
Type of Decision			
Conflict/Safe	75%	8%	17%
Ahead/Behind	60%	12%	28%
Within 3 miles	61%	11%	28%

In view of these figures, it is not unexpected that there should exist large correlations between the speed and accuracy figures for the first decision, and those for the first correct decisions of all three types.

Considering first the first correct decision that the situation is a conflict or is safe, we find that there is a correlation of .90 between the time of the first decision and the time of the first correct conflict/ safe decision. The prediction equation is of the form

$$T_{cs} = -1.8 + .94\ T_{fd}$$

Since this is measured in terms of the time before the time of closest approach, this implies that the mean time for the first correct conflict/safe decision is later than the time of the first decision, and that although the difference in times is roughly proportional to the time available, the delay becomes a larger proportion of the time to go as the latter gets less.

If we include a term corresponding to the accuracy of the first decision, we obtain a correlation of 0.96, which is sufficiently large for most of the remaining error to be accounted for by the inherent inaccuracy of data recording and quantification techniques. The prediction equation is

$$T_{cs} = - 48.6 + 0.62\ A_{csi} + 0.94\ T_{fd}$$

This equation suggests that the effect of an accurate initial decision is to decrease the delay between the first decision and the first correct conflict/safe decision.

No third significant term can be found which provides a significant addition to these two terms, and the residual error is of so small an order that these two terms virtually determine the values of the time of the first correct conflict/safe decision.

Similarly we may predict the accuracy of the first correct conflict/safe decision, that is to say, to predict the percentage of trials for which the decision that the situation is a conflict or safe is made either initially or subsequently, The best predictor is the accuracy of the first decision in terms of this decision, the correlation being 0.93. The prediction equation is

$$A_{csf} = 27.9 + .73\ A_{csi}$$

This equation can be transformed into a prediction equation of the percentage of cases in which a correct decision is not eventually made, in terms of the percentage of cases in which it is not made initially. It then becomes

$\bar{A}_{csf} = .73\ \bar{A}_{csi} - 1.02$ where $\bar{A}_{csi}$ and $\bar{A}_{csf}$ represent the percentage of situations not correctly judged. This is to say that the percentage decrease in inaccuracy is a constant proportion of the percentage of inaccurate first decisions, with a very small modifying factor.

The time at which the first decision is made has no predictive value for the accuracy of the first correct conflict/safe decision, nor does any other variable add significantly to the prediction equation.

If we now consider the first correct decision which aircraft is passing ahead of the other, for which predictions of mean time and mean accuracy may be made on the basis of the time and accuracy of the first decision, we find that the best predictor of the mean time of the first correct decision which aircraft is passing ahead of the other is the time of the first decision, the prediction equation being of the form

$$T_{ab} = 0.98\ T_{fd} - 11.8$$

where T_{fd} is the time of the first decision. The fact that the constant term is negative implies that the time of the first correct decision is not merely a simple fraction of the time of the first decision, but that an additional constant delay should be added.

The best pair of predictors is the time and the accuracy of the first decision in terms of the relevant criterion. The prediction equation is then

$$T_{ab} = 1.03\ T_{fd} + 0.47\ A_{abi} - 48.6$$

Comparing this with the prediction equation for the first correct conflict/safe decision, which was

$$T_{cs} = 0.94\ T_{fd} + 0.62\ A_{csi} - 48.6$$

we observe that the effect of the time of the first decision appears more important, and the accuracy of the first decision less important, while the constant delay term is virtually identical.

Considering the accuracy of this decision, we find that the accuracy of the first decision is the best predictor of the accuracy of the decision overall, the prediction equation being:-

$$A_{abf} = 21.5 + 0.81\ A_{abi}$$

This equation may also be transformed to become a prediction of the percentage of cases not resolved, in which case it becomes

$$\bar{A}_{abf} = 0.81\ \bar{A}_{abi} - 2.14$$

This equation which considerably resembles that for the accuracy of conflict/safe decisions suggests that a constant proportion of incorrect judgements is rectified.

The table given earlier shows that 12% out of a possible 40% of possible errors are corrected, compared with 8% out of a possible 25% for conflict/safe decisions.

For the first correct decision of how close the two aircraft will pass, closely similar equations can be obtained, although they do not account for so much of the variation.

The best single predictor of the time of the first correct judgement of separation is the time of the first decision, the prediction equation being

$$T_{3mf} = 0.98\ T_{fd} - 11.9$$

and the best pair of predictions, which is the best significant prediction includes also the accuracy of this decision. The consequent prediction equation is

$$T_{3mf} = 0.98\ T_{fd} + 0.74\ A_{3mi} - 57.2$$

The resemblance of this equation to that for the first correct conflict/safe decision is considerable.

The best prediction for accuracy of the judgement of which aircraft will pass within three miles of each other is the accuracy of the first decision in this respect, the prediction equation being :-

$$A_{3mf} = 26.4 + 0.75\ A_{3mi}$$

This equation again bears a considerable resemblance to the previous equation, and can be transformed into a prediction equation for the percentage of errors in the final equation in terms of those in the initial equation, in the form:-

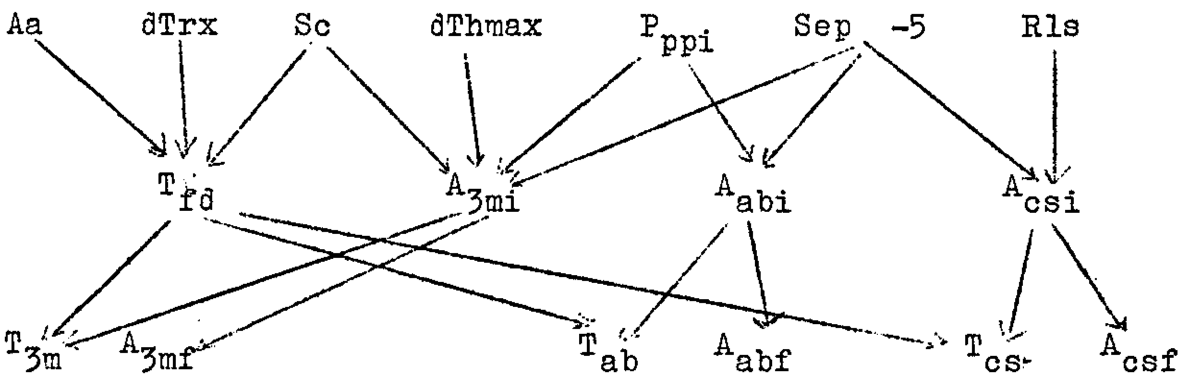
$$\bar{A}_{3mf} = 0.75\ \ddot{A}_{3mi} - 1.14$$

We therefore observe that for each type of correct decision a sufficient prediction of accuracy can be made from the initial accuracy, and a sufficient prediction of the mean time of the correct decision can be made from the time of the initial decision and its accuracy, and that these equations bear strong mutual resemblances.

The table below summarises these equations for comparison.

Predicted item:	Time to Tca			Overall Accuracy		
Decision Type:	C/S	A/B	+/-3m	C/S	A/B	+/-3m
Predictor						
Time of First Decision	0.94	11.003	0.98	-	-	-
Accuracy of First Decision by relevant criterion	0.62	0.47	0.74	0.73	0.81	0.75
Constant Term	-48.6	-48.6	-57.2	27.9	21.5	26.4

The diagram below summarises the system of prediction equations from the situation parameters to the times and accuracies of correct decisions via the first decision.



IX. CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS.

In chapter III three main objectives were defined for this investigation. These were:-

1. To describe in quantitative terms the ability of observers to form judgements of the future relative positions of aircraft presented on a Plan Position Indicator type display.

2. To investigate the effects of reducing the degree of detail by changing the simulation technique employed.

3. To investigate the difference in performance occurring between skilled and unskilled observers.

On the basis of the experimental work and statistical evaluation described in chapters IV to VIII, these objectives can now be reached.

1. Ability of observers to form judgements.

The time to go to the time of closest approach (Time to Tca) is the most consistent measure of when the observer can form judgements. The linear distance between the aircraft is nearly as good, and may be easier to obtain in practical situations (for example, by post-analysis of filmed records) (Chapter VIII, Section 3).

The performance of skilled observers is described in terms of this variate, and in terms of the correctness of decisions made, considered in terms of three criteria. Measures employed are the time before Tca at which the first decision is made, the times before Tca at which the first correct decisions are made, the accuracy of the first decision made, and the number of correct decisions made in terms of the three criteria. The results obtained show considerable variation, and certain marked resemblances from measure to measure. (Chapter V).

The experimental results described so far are reduced to more practical form in chapter VIII, which includes a detailed discussion of the situation parameters. The times and numbers of correct decisions are shown to be derivable from the time and accuracy of the first decision made, which are themselves derivable from the parameters of the situation - to a certain extent, not absolutely. (Chapter VIII).

For most practical purposes, only the first decision made will be of importance, since action will usually be taken on the basis of that decision. The available regression equations involve parameters of the situation which may not always be available. The spread of values to be expected should be comparable with those observed in this experiment - from about 3½ minutes to 2 minutes before Tca. (Chapter V, Section 3).

This range of values is based on the empirical data derived from the simulations studied in this thesis. It has been shown that the time of the first decision is significantly affected by three factors which together account for half the variation observed. To recapitulate, the formula for prediction of the time at which this decision is made is of the form

$$T = 173.6 - 0.44\ dTrx - 0.1\ Sc + 0.27\ Aa$$

where:

T is the time at which the first decision is made, dTrx is the time for the rogue to reach the point of cross-over from the time of closest approach (this will be positive if the rogue is passing behind the control - for most normal circumstances) expressed in seconds.

Sc is the speed of closing - the vector difference of velocities (expressed in miles per hour, not knots).

Aa is the Angle of Approach of the two aircraft, expressed in degrees.

Where it is desired to predict the mean time at which decisions will be given, the appropriate values of the parameters described should be substituted in this equation. If any of the parameters are not available, it is probably best to substitute the mean values used in the derivation of this equation, which are -5.4 seconds, 482 miles per hour, and 110 degrees respectively.

It is possible to use the above equation to predict mean values where the relative frequencies of the predicting parameters differ from those employed in this experiment, by substituting mean values for each parameter weighted according to the frequency desired. Such a process, however, is not recommended if any alternative can be found, since the real relationships of some these parameters must be non-linear, and such predictions may give a false impression of accuracy.

Similar equations, to which similar restrictions apply, may be obtained for the accuracy of the first decision. (Chapter VIII, Section 4(b)). The predictions so obtained are as follows:-

$$A_{cs} = 44.4 + 10.2 \,\big| |Sep| - 5 \big| + 6.0\ Rls$$

$$A_{ab} = 86.1 - 13.3 \,\big| |Sep| - 5 \big| + 5.4 P_{ppi}$$

$$A_{3m} = 77.0 - 0.034\ Sc + 4.1 P_{ppi} - 4.77 \,\big| |Sep| - 5 \big| + 0.4\ dThmax$$

where the parameters not already defined are as follows

Rls - direction of rotation of line of sight

(1 = clockwise, -1 = diesel)

P_{ppi} - position on PPI

$\big| |Sep| - 5 \big|$ - difference of separation at time closest from 5 miles

dThmax - peak velocity of rotation of line of sight.

Should it be necessary to work in terms of the total number of correct decisions and the mean time of correct decisions, these may be derived with considerable confidence from the times of first decisions and the accuracies in terms of the relevant criterion. The relevant equations are:

First correct conflict/safe decision

Time = 0.94 T = 0.62 A - 48.6

Accuracy = 0.73 A + 27.9

First correct Ahead/Behind Decision

Time = 1.03 T + 0.47 A - 48.6

Accuracy = 0.81 A + 21.5

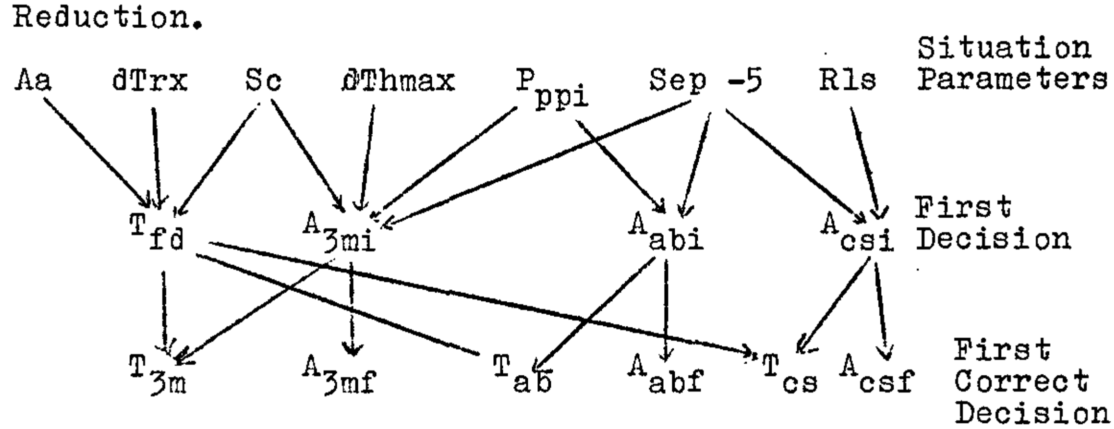
First Correct Judgement of Separation

$$\text{Time} = 0.98\ T + 0.74\ A - 57.2$$

$$\text{Accuracy} = 0.75\ A + 26.4$$

Where in each case T is the time of first decision, and A is the accuracy of the first decision in terms of the relevant criterion.

The relations observed can be summed up descriptively in the final diagram of Chapter VIII - Data Reduction.



2. <u>Effect of reducing simulation accuracy</u>.

Chapter VII - Paper Simulations (Findings) - contains detailed analyses and comparisons of the performances of skilled and unskilled observers using the two different types of simulation method. There is not sufficient material in these sixteen simulations to allow for comparisons to be made with any great accuracy. It should be noted that this constraint is inherent in the different nature of the question now being asked. In the previous section we were concerned with differences between simulations primarily, differences between individuals being mainly an irrelevant variation to be 'filtered out' during analysis.

We are now concerned with differences between groups of individuals, which must be shown to be significant in terms of the variation between the individuals.

Although the results are not entirely unambiguous, it seems to be the case that decisions are made some twenty seconds earlier in paper simulations, and that there are significant, unsystematic differences between paper and electronic simulations in accuracy.

There are differences between individual simulations in the way in which they are affected by the way in which they are presented. These differences are not related to any of the factors varied, but are statistically significant.

The differences in timing are particularly marked where the rogue is passing ahead of the control. This may be because these situations are relatively easy to solve in terms of 'what is to be done', so that in the more realistic situations, more urgency was attached to ordering avoidance manoeuvres than where the simulation is obviously unreal.

The differences in accuracy appear to be very marked in a few situations. This tends to suggest that these situations may have in fact appeared incorrectly on the electronic simulation. The 'jumping' observed may well have given the impression that some of these simulations involved closer passage than was in fact the case. It is noticeable also that in viewing paper simulations observers were more accurate in their judgements of whether situations were conflicts or safe, both initially and overall, while the other two types of decision were much less often reported correctly (or at all) initially.

The precise causes and descriptions of these differences are of less importance than the fact that they do occur. In every case, there is less variation between paper and electronic simulations than there is between simulations themselves. It must, however, be concluded that attempts to use simple simulations in cases where precise answers are required are unjustifiable.

3. Differences between skilled and unskilled observers.

Differences between skilled and unskilled observers appear in Chapter V - Electronic Simulation - Findings, and in Chapter VII - Paper Simulation - Findings.

The differences appearing in Chapter VII represent differences between the averages for paper and electronic simulation, and are of value only as part of the analysis of variance. The analyses show that there are no significant interactions between skill and simulation type, although there appears to be a just significant interaction ($5\% > p > 1\%$) between the mean accuracies of judgement of separation for skill and simulation. This is because the mean accuracy for unskilled observers is 83%, while for all other conditions the accuracy is about 70-73%. This can reasonably considered to be a statistical artefact, rather than evidence of a genuine interaction.

In order to examine the differences between groups of observers in their own right, it is better to turn to chapter V, in which the differences observed are based on 64 simulations, rather than sixteen.

From this data it appears that there is a significant difference between skilled and unskilled observers in the mean time that they make decisions. Skilled observers make their first decisions seventeen seconds earlier, their first correct decisions about twenty seconds earlier. There are no significant differences between groups of observers for different simulations, and there are no significant differences between groups in accuracy.

There is a significant difference in within-group variability between skilled and unskilled observers in the mean time at which they make their first decisions. The nature of the difference is well illustrated in Figure 10, which shows that although skilled and unskilled groups of observers start making decisions at about the same time, the skilled observers have virtually completed the task at two minutes before Tca, while about 20% of unskilled observers have still to make a decision. Although the differences between groups in variability reflect this differences in other analyses, they do not again reach significance.

There seems to be no objection, on the basis of the data here analysed, to the use of a sufficient number of unskilled observers in place of skilled observers, where estimates of difference between situations are required, or where timing is not important. It would, however, be unwise to make assumptions about the distribution of mean times for skilled observers from unskilled observers. Unskilled observers start to make decisions at about the same time as skilled, but finish later. Estimates based on 5th percentiles for unskilled observers would therefore be unduly pessimistic.

4. Discussion.

This section contains a discussion of the practical implications of this research and allied points of general interest. It should be emphasised that this discussion is partly speculative and entirely individual. It does not necessarily reflect the opinion of any official body or of anyone other than the writer. (The writer is however indebted to his colleagues and the air traffic controllers and others with whom he has come into contact in the course of this research for many illuminating and informative discussions.)

The major part of the training of air traffic controllers is in procedures. These are for the most part stereotyped patterns of verbal and other communication, using standard formulae. Emphasis is put on the correct and punctilious performance of procedures. While this is of course an essential feature of air traffic control, it is by no means sufficient in itself. An analogous situation has occurred in naval situations (personal communication of Dr. N.S.Kirk), where radar operators were required to report targets approaching their ships. The operation was performed correctly, ranges and bearings being found rapidly, accurately and in the correct manner.

However, observers studying the performance of the operators found that they were not reporting many of the targets until long after the observers had seen them. It was found that the radar operators had been trained extensively on simulators which presented very large and definite echoes, far larger than those observed in practice. It was found that the objective performance of radar operators could be greatly improved by instruction in recognising faint and fleeting targets of the type that occurred in practice.

Perhaps the main reason why this aspect of radar training was neglected is that very little was known about how or why targets were not detected. There have now been extensive studies of target detection, and much is now known. General theories of some predictive value have been developed to explain why certain targets were not detected, and training includes instruction in the detection of targets.

Although a formal theory of conflict assessment has not been developed, certain practical inferences can be made on the basis of this study, which do not require formal theoretical justification. There are certain types of situation in which it is particularly difficult to assess what is going to happen. These are in general situations in which a fast'rogue' aircraft overtakes a slow controlled aircraft, and those in which aircraft approach each other 'head-on', or nearly so. These tend to be situations where the angle between the aircraft tracks is either very acute, or very obtuse, so that slight errors in directional accuracy have major effects on the point at which the tracks cross. In addition to this, it seems that when a decision has been taken, it takes at least a minute to alter it, and the probability that a wrong decision will be corrected is small compared with the probability that a correct decision will be made initially. In general, it appears that controllers are able to cope with deceptive situations once these have been identified, so that it should suffice for the deceptive situations to be drawn to their attention. General experience of such situations suggests that this would require practical demonstration, in view of the reluctance of many observers to believe that they themselves are liable to error, however willing they may be to admit the possibility of such errors in the abstract.

The reasons why some situations seem particularly difficult are not always clear. One possible cause may be a form of perceptual distortion attributable to the background structure displayed on the radar. It appears that radar trails may be liable to a number of possible optical illusions, the Hering and Ponzo illusions being the most important. The former of these is the illusion that causes a rectangle drawn on a background of circles to appear 'cushion-shaped'. Under certain circumstances, the trail of an aircraft may be just touching a range ring. The observer will tend to extrapolate this line at a slight angle to the true course, in the direction of the centre of the display. The Ponzo illusion occurs where a trail approaches two parallel lines diagonal to its course.

In this case the trail is displaced rather than distorted, and will often be judged to cross the second line at a point closer to the first crossing than in fact it does. These illusions can usually be eliminated by making sure that the background is relatively dull compared with the relevant radar trails.

It may be argued that the increasing use of automatic systems renders this discussion academic, as the task will not in future be performed by human operators but will be taken over by automated conflict avoidance systems.

While this is to a certain extent a valid point, it is by no means a decisive argument. Automation is costly, complex and liable to errors of a different type to those of human operated systems. Social, political and economic considerations limit the extent to which it is possible to rely absolutely on automation. Filtered radar displays may well reduce 'noise' in a technical electronic sense, but may induce other perceptual distortions of unknown or unsuspected types. The work of J.F. Brown suggests that the size and shape of symbols may influence subjective perception of speed, to name only one possible cause of difficulty. Although the electronic equipment may not be subject to these perceptual errors, it will be checked and supervised by operators who are. If, for example, aircraft moving down a radar screen appear to move in towards the centre, then out again as they pass it, the electronic engineer will be expected to rectify this. The more elaborate the equipment involved, the more willing the operator will be to attribute such malfunctions to the system.

Another point of importance is that it is often usual to maintain the original unautomated system as a stand-by in the event of technical failure of the automatic system. If the original system relies on human skills, particularly human perceptual skills, it may well be of critical importance that these perceptual skills be maintained at an adequate level. If this is to be done by training, the training should concentrate on the most difficult situations, which should be known beforehand.

Finally, a general word of warning may be appropriate. It is often the case that automation is introduced into such situations as an escape from the stress of human decision making. This is a very dangerous and undesirable process, both from an operational and a sociological and psychological point of view. The automatic systems at present under development are designed with a view to what we expect to be the situation in the forseeable future. This period is getting steadily shorter as the rate of the technological change accelerates. The only certain feature of the future is that it will involve change, much of which will not be only quantitative, but also qualitative. Not only will there be more aircraft to cope with, but there will be a steadily widening range of type of flight. Most aircraft of the present day fly at between 100 and 600 knots, carry between ten and one hundred passengers, and take off and land on conventional runways. The occasional rotating-wing aircraft can be treated as special cases.

In the foreseeable future, the system may have to cope with 'Jumbo Jets' carrying up to a thousand passengers, 'SSTs' carrying a more normal number, but not very manoeuverable, and very short of stacking time, and 'V STOLS' carrying passengers to dispersed terminals and operating from within the airports, using subsidiary take-off and landing strips, to say nothing of any other unforeseen developments.

It is extremely unlikely that a contemporary automatic system could handle all this traffic without extensive modification, and without human supervision.

The psychological danger of a completely automatic system will be familiar to anyone who has had to do with a computer installation. These installations are only as good as their programming, but within those limits are virtually infallible. As soon as their limits are exceeded, they become fallible to an equally marked extent. The operators of computing equipment are not usually of high intellectual calibre, being selected to be obsessional, routine minded and reliable. They rapidly develop an emotional attachment to their equipment, (or leave and take another job). When a person not skilled in their art approaches them with a complaint, they react defensively. Most often they are justified, but in some cases they are not. In digital computer installations, the result is usually a sharp argument, a full-scale row or an appeal to higher authority. In on-line air traffic control the result could be several hundred tons of aluminium, aviation spirit and human lives arriving in Oxford Circus in the rush hour. In an early report on this research, possible casualties were estimated at probably hundreds, possibly a thousand. Developments since that time make the figures probably a thousand, possibly five thousand. Such risks are not to be taken lightly.

Finally, what are the implications of this work for the future air traffic control systems. It may be assumed that most future air traffic control systems will employ remote radar installations, that the radar information will be filtered, and that the information will be presented on a sophisticated display. It is probable that secondary surveillance systems will be introduced to carry out routine information transmission from aircraft to ground and vice versa. The routine work of the controller will be considerably lessened. Instead of being an 'operative' he will become increasingly an 'inspector', concerned with supervision of equipment, and monitoring of performance. He will be relieved of a considerable amount of direct stress at the cost of a certain indirect stress, because he will have to allow 'black boxes' to do a lot of what he has been doing himself. He will have to learn at the same time to trust his equipment and to watch it continuously for failure - not an easy task. He will have to develop a high level of alertness - which he already does - in a much less stimulating environment. It may well be that the 'false target' expedient sometimes employed in vigilance tasks may have to be adapted to this similar situation. (The false target technique in radar vigilance work involves the introduction of a number of false alarms at random times at sufficient frequency to maintain peak alertness). It is, however, more likely that a certain amount of the operational task will deliberately not be automated, simply so that the air traffic controller can be continuously engaged at a suitable level of activity. The specific task of conflict avoidance may well be a suitable one for delegation to the controller, since observation of the manoeuvres recommended by controllers suggests that they do not in fact obey exactly the formal rules laid down where such observation is not necessary. The judgement task involved is complex and allows for a range of attention. It is neither excessively irregular nor monotonous, and it is directly satisfying to the controller. It is not a major part of the controller's task, as the system at present runs, but it could well increase considerably if air traffic continues to increase.

5. Recommendations.

The following recommendations are made in view of the results of this experiment:-

1. That the time to go to the time of closest approach should be used as a measure of the urgency of situations, or, alternatively the linear separation between the aircraft. Air traffic controllers will be able to take decisions at between three and two minutes before T6a, or at between ten and thirty miles separation, depending on the situation.

2. That there is no single 'threshold' value for time to go to Tca, or separation, nor for any other measure of the situation developed in this report.

3. That the rate of rotation of the line of sight is not a good measure of whether the situation can be determined, and in particular that the traditional 'three degrees per second' does not apply to situations where the observer is not situated at one end of the line of sight. (See appendix 1, paragraph 1, for the origin of this measure).

4. That unskilled observers may be used to give an idea of the performance of skilled observers, group for group. Skilled observers will show less variation among themselves, and will make their judgements at the same time as the best of the unskilled observers. Skilled and unskilled observers will be equally accurate.

5.That the present simulation method cannot be relied upon for comparative timing of simulations, although it is fairly satisfactory for measuring accuracy.

6. That there are significant differences between observers so that analyses should be based on the performances of sufficiently large groups of observers. It would be unwise to compare the performance of one observer in one situation with that of another observer in a different situation, and to draw conclusions about the situations or the observers.

7. That in future experiments, attention should be paid only to the first decisions made.

The following recommendations are made for further work in the field.

8. The range of simulation techniques should be extended by introducing comparisons with more accurate digital simulation techniques at one end, and with Hopkin and Ledwith's (1963) type of simulation. (This employed pictures on cards, and measured accuracy but not timing). Comparisons of the present situations should be made to determine which type of simulation is more at fault.

9. Situations involving fast rogue aircraft, and head-on conflicts should be examined in more detail.

10. Shorter simulations should be employed, and only first decisions recorded.

11. To extend the investigation in the opposite direction, a 'critical incidents' survey should be carried out in which practicing air traffic controllers are asked to recount occasions when conflict or near conflict situations have occurred. It might be possible to co-ordinate this with a systematic analysis of 'air-miss reports' where these refer to incidents in controlled airspace. A systematic analysis of video-tape and voice recordings, where these are available, might also be rewarding.

The following general recommendations are made:-

12. That the possible occurrence of optical illusions and distortion should be considered when design of advanced systems is in progress.

13. That controllers should be shown examples of illusions,and practice given at resolving situations of particular difficulty.

14. That in automatic systems sufficient work should be left unautomated to allow the operators to maintain full alertness.

15. That consideration should be given to the changing nature of the task in the recruitment of future air traffic controllers.

APPENDIX 1.

Literature Survey of the Visual Perception of Motion

Historically, the first reference to the perception of movement is by Porterfield (1759) who discusses the idea of a 'threshold of movement' (although he did not use those terms). He stated that "an object moving with any degree of velocity will appear at rest if the space it runs over in one second of time is to its distance as 1 to 1400".

Czermak (1847) first stated that movement was "phenomenally" - subjectively - different from point to point within the eye. By a process of subjective comparisons he determined that the movement appeared to be slower at the periphery of vision than at the centre.

Fleischel (1882) investigated the problem of 'phenomenal' velocity. He found that the velocity of an observed object seemed to be twice as great when the eyes were held stationary as when they were allowed to follow the moving object. Similar results were produced by Aubert (1886).

Bourdon (1902) devotes a chapter to the perception of motion (pp 176 - 204). He found that the threshold of movement was larger for a large object than for a small one. (In other words, the large object must be moving faster to be seen to be moving at all). Grimm (1911) found that the threshold for movement depended on the curvature of the track on which the object was moving. The more curved the track was, the more readily was movement perceived.

Wertheimer (1912) found that the perception of velocity by observers was extremely variable - previous research workers had made now allowances for differences between observers - but was not able to ascribe any systematic causes for this variation.

All these research workers employed highly subjective methods, such as following the minute hand of a watch, or some similar approximately constant motion.

Dembitz (1927) originated an extremely simple method of measuring observed motion, using a broad belt of white material moving over rollers and viewed through a slit. A diagonal line was drawn on the material, and gave the impression of a moving point.

Dembitz used a belt 90 cms. wide,and asked his subjects to estimate the time at which the point would reach a mark 72 cms. further on. He found that the errors made were inversely proportional to the velocity of movement of the point. (The greater the velocity, the less the error). Dembitz concluded that the human mind operated by judging the time taken to travel a given distance rather than the distance travelled in a fixed time. It should be noted however that Dembitz was specifically asking his subjects to make a judgement of this type. Had he asked his subjects to mark the positon to which a point would have travelled in a given time, he might have observed considerably different results.

Dembitz carried out his work in Brunswick, and similar work was carried out in Berlin,using similar techniques by J.F.Brown (1931). In three papers (1931 a, b, c) Brown summarises extensive work in the perception of motion.

Brown's equipment consisted of two boxes containing motor-driven bands; one being of a fixed (pre-set) velocity ,the other variable by using a potential divider. The bands employed had markers on them which moved across the face of the box.

Brown investigated a considerable range of phenomena, and obtained a considerable number of experimental results. He summarises these in general as indicating that motion percieved appears to be more constant than motion as it actually takes place. For example, suppose the subject is viewing the two moving bands in total darkness. Let one box be at a distance of three feet, and the other at a distance of thirty feet. If the speed of the nearer band is fixed,then the subject will perceive the two speeds to be the same when the more distant band is adjusted to travel ten times as fast,provided that he has no clues to show him that it is more distant.

If the same experiment is carried out in broad daylight,so that the distance of the moving band can be judged by looking at the background,then the more distant band need only move at 1.56 times the speed of the nearer, to be perceived as moving at the same speed.

In general, Brown stated, perceptual velocity is proportional to perceptual distance divided by perceptual time. In less technical terms, he is saying that where perceptual distortions occur the perceptual velocity is consistent with these. For example, returning to our example of the previous paragraph, the subject would judge that the second box, ten times further away, is really only 1.56 times further away. (In practice, of course, the human adjusts to this phenomenom by a trial and error process, and learns to judge distances by comparison with memories of similar distances rather than by direct perception - although the apparent distortions of near objects in photographs are examples of occasions on which the adjustment system fails).

A similar example is that of watching the minute hand of a clock as it passes one of the graduations of the dial. In this case, the hand seems to move faster when it is actually passing the graduation than when it is against a blank background. However, the apparent time taken is less, so that the overall effects cancel out. The precise statement of the effects of visual distortion is complex and unrewarding, but Brown listed the following specific differences.

The apparent speed increases under the following conditions:-

1. Smaller Distance
2. Varied Background
3. Smaller Field Width
4. Smaller Object

5. Object Oriented in Direction of Movement
6. Object Moving Vertically
7. Brighter Illumination
8. Eyes Fixated, Rather than following Object.

Brown used two 'permanent' experimental subjects, of whom he was one himself, the other being his assistant. These two observers were supplemented by undergraduate students from time to time. Brown took care to avoid providing visual cues for his observers, and used a method of adjustment to 'phenomenal equality'. (In other words, he got the subject to adjust the variable speed box until it appeared to be going as fast as the fixed speed box). It is not easy to assess the reliability of his results from the published data, and some reservations must be attached to the "Gestalt" theory interpretations given. His summary of findings, however, provides a useful guide to visual effects.

Certain reservations however must be made. Brown worked under circumstances very different from the present investigation. He used for the most part only two trained subjects, both presumably sophisticated in this type of task.

There is some evidence that 'phenomenal' judgements depend to a very great extent on the observers previous experience - dwellers in conventional houses observe trapezoidal window shapes as being square - whereas Zulus do not. The experience of the radar observer of the present day may be very different from that of the psychologist of forty years ago.

Gottsdanker (1952, 1955) describes experiments using an apparatus essentially similar to that of Dembitz, but using a pointer held by the subject to indicate the expected track of the apparently moving point after its disappearance. Gottsdanker found that subjects could maintain constant velocity motion for about six seconds after the disappearance of the object point. If the object point had been accelerating, however, the subjects maintained a constant velocity, less than the final velocity, but greater than the average velocity of the object point. A later experiment by Gottsdanker and Edwards (1957) deals specifically with the prediction of conflicts and is discussed in Chapter II.

Weiner (1962) studied the effects of the duration of target presentation and the speed of the moving target. He used apparatus similar to that of Gottsdanker, and employed ten undergraduate observers 'inexperienced in tracking, motion prediction, or radar'. He found that, over a minimum of two seconds, the length of time for which the target was visible had little effect on estimation of speed.

Weiner measured the absolute error in speed measurements, by extending the lines drawn by the observers to a terminal line, and measuring the displacement from the correct point of intersection. In order to obtain a measure of 'relative error' he divided the 'absolute error' by the distance the point would have travelled during the nine seconds during which the subject was predicting.

He found that the mean relative error fell with increasing speed, although the mean absolute error increased. This is a general type of finding in similar situations.

Johansson (1950) considered velocities in the region of 20mm/sec., and used a method of adjustment similar to that of Brown (1931). Although the actual experimental work is not reported in detail, the general results obtained are discussed by Johansson in terms of Gestalt psychology. Some relevant conclusions are that where two objects are moving they tend to form a simple 'configuration of motion'. The impression of velocity is formed by their relative displacement, not by the background (this difference from Brown's findings may reflect the slower speeds employed by Johansson). Where two objects are in motion and one at rest, there is a greater tendency to form a group of the two moving objects than of the object at rest and a moving object. It is possible for two different effects to occur, cancelling each other out. (For example, apparent time may be reduced at the same time as apparent distance, resulting in apparent constant velocity).

A final conclusion of Johansson is that occurrences independent of visual motion may influence the perception of motion - even events observed from another sensory mode. (An interesting example of such an occurrence is provided by one of the last types of steam locomotive employed by British Railways. This suffered from few mechanical faults but always ran late. Investigation showed that the driving wheels were some four inches smaller in diameter than was traditional, so that the drivers, who relied on the sound of the driving pistons rather than the speedometer, consistently ran the engine about five per cent too slowly. Eventually, the class of engines had to be discarded.)

Slater-Hammel (1955) used the same general type of apparatus to estimate the time that a disappearing target passed a marker. The disappearing target was in the form of a bar, travelling at 1¾ in. per sec. A total of 90 observers was employed, all being physical education students at an American university. Slater-Hammel found that the overall error in timing increased as the distance of the marker from the point of disappearance was increased. In addition the mean error for all observers tended to be an overestimate of the time needed (1½ secs.) when the marker was at 2 5/8 in. from the point of disappearance, and an underestimate when the marker was at 5 1/4 in. (3 sec.) and 7 1/8 in. (4sec.) The times and distances employed in this experiment are rather shorter than those employed in other experiments. The possibility that some of the systematic variation is attributable to simple reaction time cannot be excluded.

APPENDIX 2.

Glossary

This glossary is provided to define or explain various terms used in the text of the thesis. In order to make the thesis as easily understood as possible, explanation of some terms that might be considered well known to all radar users are included.

Angle of Approach (Type of Conflict)

This is the angle marked in Figure 37. Under the title "Type of Conflict" it is one of the factors used in this experiment. In this study four angles were used, 45, 90, 135 and 170 degrees.

Blips (Paints)

Blips or Paints are the bright spots produced where the radar trace passes over the point corresponding to an aircraft, or in this case, a simulated aircraft. They lose brightness over an interval of about 40 seconds. The decay time is a property of the tube used, and depends primarily on the condition of the phosphor coating on the tube.

Collision

A collision is the physical contact of two aircraft. A "Collision Situation" is a situation in which, unless action is taken, a collision will occur.

Conflict

A conflict is the passage of two aircraft dangerously close to each other. For the purposes of this experiment "Dangerously Close" was defined to be within five miles, whatever the speed of heading of aircraft. A "Conflict Situation" is one in which a conflict may occur if no action is taken.

Control (Controlled Aircraft, Control Aircraft)

This is the aircraft considered to be under the control of the controller. The controller is informed of its heading and speed.

Correct Decision

In this report a Correct Decision means a decision which corresponds with the objective fact that the Rogue will, or will not pass within five miles of the Control.

Criterion

A measure of the situation which may be used to describe the performance of a subject. For example, the "Time to go to Time of Closest Approach", or the "Separation" (as in Figure 37.)

Factor

In this experiment, a factor is a parameter of the experimental situation which is altered in a controlled manner, four levels of each factor being used. The levels of the factors used are listed in Table 1. Factors employed were:

Heading of Control
Type of Conflict
Speed of Closing
Nature of Miss

Track Intersection Distance

Position on PPI

For detailed explanations of the meanings of these, see the relevant headings in this glossary, or Section

First Decision

In this report a First Decision is the first distinguishable decision made by the subject, whether or not it is correct. This decision serves in part to assess the extent to which the subject perceives the situation as difficult. The accuracy of this decision (see Chapter V) gives some indication of the actual deceptiveness of the situation.

Heading

The heading of an aircraft is the direction in which it is going. This is expressed in degrees, measured clockwise from due North. Throughout this experiment, all aircraft were assumed to be maintaining constant headings at constant speeds and at the same height.

Image

The image of an aircraft is the representation of that aircraft on the P.P.I., which is composed of a series of paints of decreasing brightness. The distance apart of these paints, and their direction give an indication of the speed and heading of the aircraft.

Level

The level of a specific factor in any particular situation is its value in that situation. The values of the four levels of the six factors used are listed in Table 1.

Line of Sight

The line of sight is the line drawn from the Control Aircraft to the Rogue. (CR in diagram 37 The speed with which the line rotates and the rate at which the speed of rotation changes are important criteria. Formulae for the derivation of these are given in Chapter VIII Section 1

Metrovick Film Recorder (Metrovick)

The Metrovick film recorder is a special purpose recorder, used to record and display radar pictures. It operates by recording on a continuous film, 35 mm. wide, the sweep of the radar. It is not a "Frame-by-Frame" system. Points displayed by the P.P.I. in polarco-ordinates are stored in cartesian co-ordinates. It is, therefore, necessary to provide a "North Marker" as a reference point for joining film.

Miss Distance

This term is used as an abbreviation for Track Intersection Distance for technical reasons connected with computer storage. It is also sometimes used (not in this report) to indicate the separation at the point of closest approach.

Nature of Miss

This is one of the factors used in this experiment. It was originally made up of a 2 x 2 combination of the passage of the rogue ahead or astern, and the freedom may be sub-divided into those due to the two factors and that due to the interaction between these. However, examination of the situations shows that this interaction is in fact identical with the starting of the rogue on the controlled aircraft's left or on its right. This factor may, therefore, be partitioned into three orthogonal two-way choices.

North Marker

In this experiment, on all films, a North Marker in the form of a vertical line from the centre to the circumference of the tube was included. This made it possible to join films, so that faulty sections could be replaced.

Observer

The term "Observer" is used to cover any person looking at a radar screen for experimental purposes. Experienced subjects are referred to as "Skilled Observers".

Paints

See "Blips".

Point of Cross-Over

This is the point of intersection of the tracks of the two aircraft. It is marked X in Figure 37.

Point of Closest Approach

This is the position of the rogue aircraft at the time of closest approach. It is not used in this report.

Position on P.P.I.

This factor was included in the experiment in an attempt to determine whether the quality of the picture affected judgement. (The characteristics of the recorder included a tendency for errors in the positioning of blips to be exaggerated towards the edge of the P.P.I.). The levels used were:-

1. Outer Heading Outwards. In this case, the conflict took place near the edge of the screen, with the controlled aircraft heading towards - and becoming more erratic.
2. Outer Heading Inwards. In this case, the conflict took place near the edge, but the controlled aircraft was heading towards the centre.
3. Median. In this case, the conflict took place between about 30 and 60 miles from the centre.
4. Central. In this case, the conflict took place within about 30 miles of the centre.

For technical reasons, on initial filming, certain aircraft did not initially appear on the screen, so that certain conflicts had to be moved inwards from the edge, or outwards from the centre. Moves made were held as small as possible.

P.P.I.

A P.P.I. or Plan Position Indicator is a radar screen arranged to provide a two-dimensional display similar to an ordinance survey map. Aircraft appear at positions corresponding to those they would assume on a map of the area. This is the type of radar display used in Air Traffic Control. North is invariably assumed to be the vertical in the display.

Rogue

In this experiment, the Rogue or Rogue Aircraft, is an aircraft which is involved in a conflict situation with the controlled aircraft. The Observer is told only that it is at the same height as the control, and that it is flying a steady course at constant velocity.

Safe.

A situation is safe when the aircraft visible will not pass at any time dangerously close to each other.

Script

In this experiment, a script is a series of sixteen simulations.

Separation

In this experiment, the separation of any two aircraft is the distance S (See Chapter VIII) between the control and the rogue. The separation is a possible criterion.

Simulation

In this experiment, a simulation is a single situation, as described in Chapter IV.

Skilled Observer

In this experiment, the term "Skilled Observer" is used to denote a member of the combined group of Service and Civil Controllers.

Speed of Closing

The speed of closing is the vector difference of the velocities of rogue and control, It is not quite the same as the relative velocity for aircraft not on collision courses. It is the limit to which the relative velocity tends as the aircraft are considered at increasingly early times. Four values are used in this experiment, 240, 360, 480 and 600 knots. A knot is one nautical mile (6020 ft.) per hour. It is traditional to express aircraft speeds in knots.

Time of Closest Approach

This is the time at which the two aircraft are at their closest. For mathematical derivation see Chapter VIII Section 1

Track Intersection (Distance)

This is the distance of the rogue from the point of cross-over when the control reaches the point of cross-over.

Type of Conflict

This is an alternative name for the Angle of Intersection.

Unskilled Observer

Observers who have no experience of radar observation are called "Unskilled" for the purposes of this report. See Chapter IV.

APPENDIX 3.

References

This list of references includes a number of 'background' references, not referred to in the text. These are references of historical or purely academic interest. They have been included in this appendix for the convenience of subsequent research workers in this field. They are distinguished from the more relevant references by asterisks.

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APPENDIX 4.

Briefing of Subjects.

This appendix contains examples of the materials used during the briefing of the subjects (referred to in section 7, Experimental Procedure).

A/4.1 is the form used for briefing skilled subjects, and A/4.2 is the form used for briefing unskilled subjects. These briefs were read to the subjects and any queries were explained. A/4.3 is an example of the sheet showing the details of the clock face indicating method, the four possible headings of the control aircraft, and the size of a 5 mile radius circle, drawn to scale.

A/4.4 is an example of the sheet giving the initial information which was provided to each subject and A/4.5 is a sheet giving the required procedure, which was also given to the subjects to act as an aide-memoire.

During the running of the experiment a watch was kept for misunderstandings of the instructions, and, where it was possible to do so, these misunderstandings were eliminated individually.

A 4.1

Brief for Skilled Subjects - Electronic Sumulation

Good Morning/Afternoon.

First of all I must thank you for coming here to help us.

What we are trying to do is find a way of saying what an Air Traffic controller does when he makes a judgement by watching a P.P.I. Radar set. We are NOT - I repeat NOT - trying to test you either as individuals or as a group. You are part of a representative sample of people who do this sort of job, and we are after the average sort of ability. We are not going to report the performance of individuals to ANYONE.

You are going to watch four sets of sixteen short simulations. (Two in the afternoon, two in the morning). The radar will be set to have a centre scan, six sweeps per minute, that is 12 seconds per sweep, and a range from centre to edge of 100 miles.

In each short simulation you will be given the approximate position, in terms of the clock face direction from the centre, and Outer, Middle or Centre, the type, the speed in knots, and the direction of a control Aircraft. This will always be the first to appear on the screen. After about three sweeps, the rogue will appear, and the situation will develop for four minutes. You may switch on range rings if you want them.

In all cases the aircraft will travel on a straight course without altering speed, although there may well be some jumping of the blips owing to irregularities in the recording process. All aircraft are assumed to be travelling at the same height. At the end of each four minute simulation there will be at least one blank sweep.

This is what you have to do.

At the start of each excercise give your console No.

When you see the control say "CONTROL ON"

When you see the rogue say "ROGUE ON"

A 4.2

Brief for Unskilled Subjects - Electronic Simulation

Good Afternoon.

First of all I must thank you for coming here to help us in this experiment. I had better explain that this is a special research unit of the Ministry of Aviation, which is devoted to making it safer to travel by air, by keeping aircraft from bumping into each other in mid-air.

We are investigating how people can watch radar screens. It is obviously better to use the people who normally do this, but they are few and far between, and very much overworked. We are therefore carrying out a study to see if unskilled people react in a similar way. If this is so we can use the results of a lot of experiments people have done already. If it isn't we know that those experiments may be misleading.

An Air Traffic Controller is a skilled man who sits in front of a radar console, and makes decisions. You are going to try to copy just one of his functions, though it is one of the more important ones. The controller sits at his console, which is like a large desk, with a radar tube set into it. He sees the beam swinging round six times a minute, like the hand of a clock. As it passes over spots which correspond to the positions where aircraft are, it leaves little blobs of luminous green. These blobs get slowly fainter, but at any time there is a fading trail of blips, showing where each aircraft is coming from, and how fast it is going. What the controller has to watch is where two aircraft come together. It is the rule that aircraft must never be less than five miles apart, so that if he sees any aircraft coming close to the aircraft he controls, he must tell the CONTROL aircraft to turn to avoid the ROGUE, which is what they call the other aircraft. To help him judge the scale, he has range rings, which are circles at 2 mile intervals, with a heavier one at 10 mile intervals.

You are going to watch four sets of sixteen simulations, each being about four minutes. At the start of simulation you will be told the shot number, the position of the CONTROL aircraft from the centre, i.e. 6 o'clock being straight down, and central Outer or Middle, as in the diagram. You will also be told the type of aircraft, the speed in knots, which are near enough miles per hour, and the direction it is heading in. I have given you all a sheet with the four directions indicated on it. In practice, these directions may not be followed exactly, and the blips you see may not be in a dead straight line, owing to the age of the machine. In general all the aircraft are supposed to be travelling in straight lines at the same height.

After the Control has been on for three sweeps, the Rogue will appear. They will both move steadily in straight lines. At the end of each four minute simulation there will be at least one blank sweep.

When you see the CONTROL: say "Control on"

When you see the ROGUE: say "Rogue on".

When you are sure that the aircraft will pass within five miles of each other say "CONFLICT".

If you are sure they won't say "SAFE".

If you are sure there will be a conflict, that is to say that the aircraft will pass closer than five miles say "CONFLICT".

In either case, say what you think the rogue is going to do, i.e. ROGUE CROSSING AHEAD, or ROGUE CROSSING ASTERN.

Then way how near you think they will be at their closest point, i.e. 4 miles. Carry on watching. If you decide to revise your estimate say CORRECTION and give your new estimate.

Do you have any questions?

Brief for Skilled Observers - Paper Simulation

The idea of this experiment is to compare a series of situations drawn on paper with a series recorded on a radar simulator. We are measuring in general the way in which people are affected by four factors - and by the type of simulation.

You will be shown a series of sixteen simulations, each lasting 200 seconds. Each simulation is made up of 20 pictures representing the radar picture diagrammatically. The scale is 20 miles to the inch., the radius of the screen being 100 miles, and the range rings are at 10 mile intervals. You will see each picture for 10 seconds.

At the start of each simulation you will be told the type of the controlled aircraft, its speed, and its heading. This is the BLUE aircraft. The RED aircraft is a ROGUE. Both aircraft fly at constant speeds, on constant headings, and are at the same height.

We want you to:-

1. As soon as the first picture is shown, press the button, and when the light comes on say "SHOT ONE - or TWO - or whatever". Then release the button.
2. As soon as you are sure say "CONFLICT" if you think that the rogue is going to pass within give miles of the control at any time. If it will not pass within five miles of the control say "SAFE".

3. Say what instruction you would give the "control", i.e. "TURN LEFT FORTY DEGREES".

4. Say what you think will happen if no action is taken. Say if the ROGUE is going to pass AHEAD of or BEHIND the Control, and how far apart they will be AT THEIR CLOSEST, i.e. "ROGUE BEHIND - 3 MILES" or "ROGUE AHEAD - 7 MILES".

If you wish to make any revised estimates, simply press the button, say "CORRECTION" and give your new estimate.

Have you any questions?

Brief for Unskilled Observers - Paper Simulation

The idea of this experiment is to compare a simple type of paper simulation with a more elaborate type of electronic simulation. We are measuring in a general way the extent to which people are affected by four factors - and by the type of simulation.

You will be shown a series of sixteen simulations, each of which lasts for 200 seconds. Each simulation is made up of 20 pictures representing the picture you would see on a radar plan position indicator, which resembles a map. Normally there is a sweeping line of light which puts in the new position of aircraft, so each aircraft is visible as a bright dot, with a trail of fading dots. In our experiment, we cannot produce any bright dots, so we represent the aircraft by circles, and the trail of fading dots, which usually overlap, by a diminishing tail. The length of the tail gives an idea of how fast the aircraft is going, and the direction of the tail shows where it has come from. Each simulation is made up of 20 sheets, with pictures of the radar screen, including two aircraft. After you have seen the first one for 10 seconds, you will be shown the next, and you will find that the two aircraft have moved slightly closer. The scale used is 20 miles per inch, the radius of the screen is equivalent to 100 miles, and the range rings are ten miles apart. At the start of each simulation you will see two aircraft, one RED, which is the ROGUE, and one BLUE, which is the CONTROL. You will be told what type of aircraft the controlled aircraft is, what speed it is flying at,and in which direction it is heading. Both aircraft fly at constant speeds in straight lines.

We want you to do the following things:-

1. As soon as you see the first picture say "SHOT ONE" and so on for each new simulation. (When you speak, press the button, and speak when the light comes on - hold the button down until you have stopped speaking).

2. As soon as you are sure say "CONFLICT" if you think that the aircraft are going to pass within five miles of each other, or "SAFE" if you think they aren't.

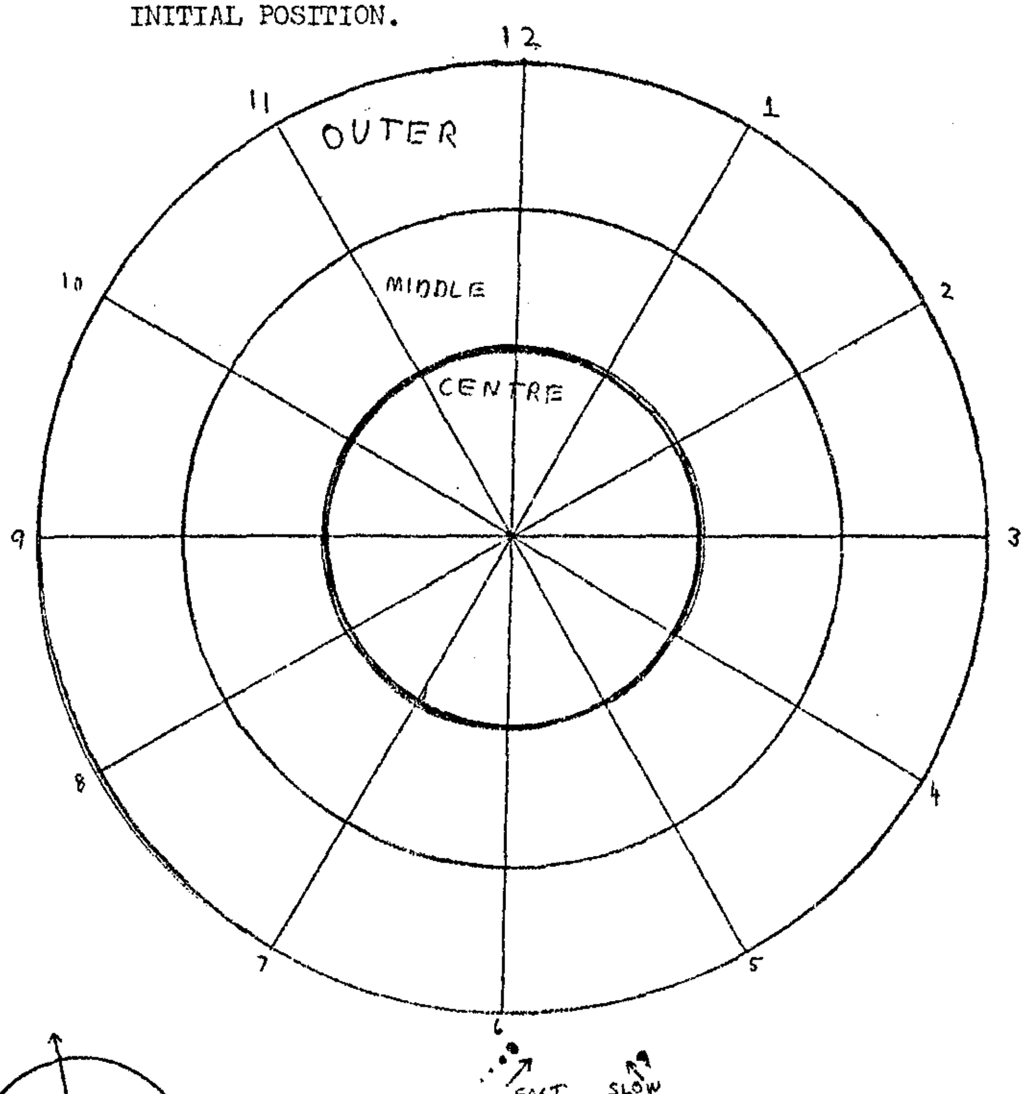
3. Say what you think is going to happen. In particular, say whether the ROGUE is going to pass AHEAD of, or BEHIND, the controlled aircraft, and try to estimate how far apart they will be at their closest, i.e. "ROGUE AHEAD - FIVE MILES".

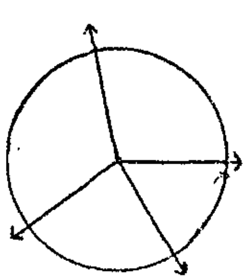
If you want to make any revised estimates simply press the button, say "CORRECTION" and give your new estimate.

Have you any questions?

Sheet giving Details of Clock Face Indication and Directions of Motion

INITIAL POSITION.





DIRECTION OF MOTION

OF CONTROLLED

AIRCRAFT

DANGER ZONE

A 4.4

EU.S/2/10

ATCEU Project No. EU. 12 - Determination of Radar Information Threshold. Details of 'Controlled' Aircraft

SCRIPT No. 1

SHOT IDENT NO.	AIRCRAFT TYPE	STARTING POSITION ON PPI	SPEED	TRACK	FINAL POSITION (CONTROL TO ROGUE)
1	VISCOUNT	1 OUT	360	225	NOT USED
2	DAKOTA	3 OUT	180	090	
3	VISCOUNT	6 MID	360	090	
4	AMBASSADOR	9 OUT	370	090	
5	"	9 OUT	320	090	
6	"	6 OUT	310	350	
7	"	12 OUT	320	350	
8	VISCOUNT	10 OUT	420	090	
9	AMBASSADOR	11 OUT	330	350	
10	VISCOUNT	8 CNTR	400	350	
11	"	2 MID	400	350	
12	DAKOTA	7 MID	200	350	
13	AMBASSADOR	11 MID	310	225	
14	VISCOUNT	4 OUT	400	150	
15	"	2 MID	420	225	
16	DAKOTA	2 OUT	170	225	

A 4.5

Example of Procedure

You hear:-

"Shot Number 65 - Control is at 10 o'clock, middle, speed 400 knots, heading 090 degrees"

When you see control aircraft, YOU SAY "CONTROL ON"

When you see rogue aircraft, YOU SAY "ROGUE ONE"

When you decide YOU SAY "SAFE" or "CONFLICT"

Then if you say conflict you order "Alter course 60 degrees RIGHT"

Then you say "ROGUE CROSSING ASTERN - 2 MILES"

If you revise your distance estimate for example SAY

"CORRECTION - ROGUE CROSSING ASTERN - 3 MILES"

EXAMPLE OF YOUR RESPONSES

"CONTROL ON"

"ROGUE ON"

"SAFE"

"ROGUE CROSSING ASTERN - 6 MILES"

"CORRECTION"

"CONFLICT"

"ALTER COURSE 20 DEGREES RIGHT"

"ROGUE CROSSING ASTERN - 4 MILES"

ORGANISATION EUROPEENNE
POUR LA SECURITE
DE LA NAVIGATION AERIENNE

CENTRE EXPERIMENTAL

EUROPEAN ORGANISATION
FOR THE SAFETY
OF AIR NAVIGATION

EXPERIMENTAL CENTRE

ATE : 28 JUIN 1991

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OUR REF. :

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The Librarian ,
University of Technology,
Loughborough,
Leicestershire,
LE11 3TU,
Angleterre

Dear Sir,

Somewhere in your archives you may have a copy of my doctoral thesis 'Human Factors in Air Traffic Control; A study of the Ability of the Human Operator to predict dangerously close approaches between aircraft on simulated radar displays.'

This thesis was submitted in the (then) Department of Ergonomics and Cybernetics, in July 1969.

Rather to my surprise, I have recently seen several references to this thesis, which I thought long buried. Subsequent experience has shown that this thesis is in some respects potentially misleading. Please will you insert this letter and the attached copy of a paper I presented to an Ergonomics Society Conference some time ago, which which records a substantial modification of my initial position on the detection of conflicts by controllers?

Yours Sincerely,

EUROCONTROL CENTRE EXPERIMENTAL

Dr. H. David.

Attached : -
'The Radar Air Traffic Controller - A Paradigm Shift' In 'Contemporary Ergonomics 1984' Taylor and Francis ISBN 0-85044-268-0

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7 Transport control

THE RADAR AIR TRAFFIC CONTROLLER
A PARADIGM SHIFT

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ABSTRACT

The ability of the Radar Air Traffic Controller to prevent dangerously close approaches between aircraft has been described by a mathematical model of the extrapolation of future relative positions of aircraft.

Evidence from previous experiments and real-life observation shows that controllers appear to be able to make predictions long before it is possible to do so according to this model.

This and other observations, and consideration of human information handling abilities, suggest that the controller does not extrapolate, but recognises previous configurations of aircraft in terms of position relative to boundary points and of aircraft types.

A crucial experiment is proposed to choose between these hypotheses, and the implications for display design are considered.

1 INTRODUCTION

Air Traffic Control is a particularly satisfying field for the ergonomist. Methods and equipment are evolving rapidly, the allocation of tasks between man and computer is constantly being revised, and man-computer interfaces are critical aspects of the system. The flows of information and control are well defined, and reasonably accessible. The judgements made by the controller are hard to quantify, but an understanding of these judgements is necessary if adequate controller-computer interfaces are to be developed.

Radar Air Traffic Control

Radar was initially introduced as an auxiliary technique, to allow closer spacing of traffic at points of congestion (such as the Terminal Areas surrounding airports) and to ensure separation from traffic (usually military) crossing the airways. ICAO (the International Civil Aviation Organisation) requires that aircraft should be separated vertically by 304.8 m (1 000 ft) below 8 839.2 m (29 000 feet) or 609.2 m (2 000 feet) above that level or by 9 266 m (five nautical miles) laterally - apparently because at that distance the 'blips' on early radar screens merged. The radar controller was assigned pairs of aircraft by the procedural controller.

In recent years, the radar controller has become an executive controller, using synthetic radar and electronic data displays to monitor and maintain traffic separations, while the procedural controller has become a planning controller, assigning cruising flight levels in advance and maintaining a steady flow of traffic with the minimum of potential conflicts.

2 BACKGROUND

Investigations into the ability of the air traffic controller fall into three broad categories, which will be discussed separately, although they have taken place concurrently. Limits of time and space preclude an exhaustive discussion, but reference is given to major works.

Observation

Direct observation of the radar controller has been attempted on many occasions. It is subject to practical and ethical problems. The infrequency of radar conflicts requires prolonged periods of observation and the difficulty of judging potential conflicts requires observers to be at least as alert and as skilled as the controller. Controllers do not like being observed, and the presence of an observer may interfere with the efficiency of control. There can also be ethical problems - if the observer is aware of a potentially dangerous situation when the controller is not, should he alert the controller?

These problems have been to some extent eased by the introduction of continuous recording from which incidents may be isolated - although even with modern digitised radar records it is still not easy to identify and reconstruct incidents, particularly where several aircraft are involved.

In spite of such difficulties, valuable information has been derived from such studies - for example Lafon (1978) recorded horizontal and vertical separations, analysing these in terms of the dimension in which the contrôller did NOT intervene.

Experiment

Early experimental studies adopted the methods of experimental psychology, attempting to model aspects of the task in the laboratory. For example Hopkin & Ledwith (1963) presented static pictures containing dots representing aircraft trails, and asked observers to find which trails were in conflict. Later studies used radar simulators - David (1969) varied the position, closing angle, relative speeds and other features of pairs of aircraft in an attempt to find a suitable threshold criterion at which correct judgements were made, and to identify factors affecting the controllers' judgement.

More recent simulators have made possible similar experiments, in which ATC experience has been taken into account, to include the special problems of climbing and descending aircraft, and of aircraft on the same or opposing headings. Such experiments (David 1980) show that, given a simple radial structure of airways, controllers could make judgements of the future relative positions of aircraft separated by as much as 180 km (100 nautical miles) - and that performance was not significantly affected by the provision or absence of a simulated radar trail or speed vector.

Modelling

In parallel with attempts to measure empirically the radar controller's ability to resolve potential conflicts, attempts have been made to develop a mathematical model of the process. Dunlay and Horonjeff (1974) made use of David's (1969) results to develop a mathematical model for the frequency of intervention to resolve conflicts. Similarly Bisseret (1981) used a signal detection model to define the ability of controllers to detect conflicts, and to explain the differences between trainees and experienced controllers.(The research team based at INRIA has used a combination of system analysis, experiment observation and interviews to study conceptual problems in air traffic control - Leplat & Bisseret 1965, Leplat & Hoc 1981 etc.)

3 UNRESOLVED PROBLEMS

In spite of the efforts devoted to the analysis of the radar controller's strategy and perceptual abilities, some significant anomalies remain: -

- Controllers appear to be able to make judgements of potential conflicts long before they should (on the basis of the information given on the display) be able to do so.
- Controllers do not appear to need an indication of the actual speed of the aircraft (provided they know where it is going).
- Controllers attach great importance to the types of aircraft involved in a potential conflict situation.
- In discussion controllers emphasise that the strategic organisation of air traffic flow is more important than the solution of specific short-range conflicts.
- Controllers prefer to intervene as soon as they see a possible conflict, even if it is not necessary to do so, in case they are unable to intervene later.

4 ALTERNATIVE PARADIGM

Consideration of these anomalies suggested to the author an alternative paradigm: -

The controller, on assuming control of an aircraft, compares its position with those of aircraft on potentially conflicting routes, on the basis of his previous experience of similar types of aircraft in the same configuration.

(It may be of interest that this paradigm shift occurred in exactly the manner described by Poincaré (1908) except that the vehicle involved was a BAC 111 airliner rather than a horse-drawn omnibus.)

5 DISCUSSION

The immediate reaction must be that there are so many types of aircraft and entry points to sectors that such a method would require an unacceptably large number of situations to be learned. In practice, for the civil en-route controller, the bulk of the traffic is made up of a few types of airliners, falling into similar performance categories, and following a few well-used routes. Radar conflicts tend to occur where routes converge, since crossing traffic is separated by the planning controller, or when one aircraft is climbing or descending. Climbing and (to a lesser extent) descending aircraft tend to be subject to more individual variation than cruising aircraft, but even here, the controllers are aware of general rules - aircraft leaving Europe for America climb more slowly, because they have full fuel loads - aircraft climb more slowly in hot weather, etc.

The alternative paradigm must not be over-extended. The original paradigm was derived from military air traffic control, for which it is probably still valid, as it may be for off-route or area navigation of civil aircraft.

Experimental Validation

A crucial experiment could easily be devised to decide between these hypotheses. For example, if controllers are practiced with a limited number of aircraft types in a familiar route structure, they should subsequently produce better performances with that route structure than with identically placed aircraft in an unfamiliar region.

Consequences

In the immediate future, the acceptance of the alternative paradigm has consequences for the design of future ATC displays. Rather than attempting to present relative velocity data, (Falzon 1982) we should perhaps aim to present relative distance markers for converging routes to which aircraft can be referred on entry to the sector, or generalised warnings of abnormal meteorological conditions which may affect the normal traffic pattern.

In the long term, the increasing allocation of direct routings to aircraft equipped with precise navigation capabilities may call for reversion to the 'extrapolation' strategy, while, paradoxically, the changes in the functional design of fifth-generation computers may render the 'recognition' strategy more efficient for the computer.

ACKNOWLEDGEMENTS

The author wishes to thank his colleagues at Eurocontrol Experimental Centre, Bretigny-sur-Orge for their patient explanations of the art and mystery of Air Traffic Control.

The author is also indebted to the Director-General of the European Organisation for the Safety of Air Navigation (Eurocontrol) for permission to publish this paper, which reflects only the opinions of the author and in no way represents Eurocontrol policy.

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