# APPENDIX A

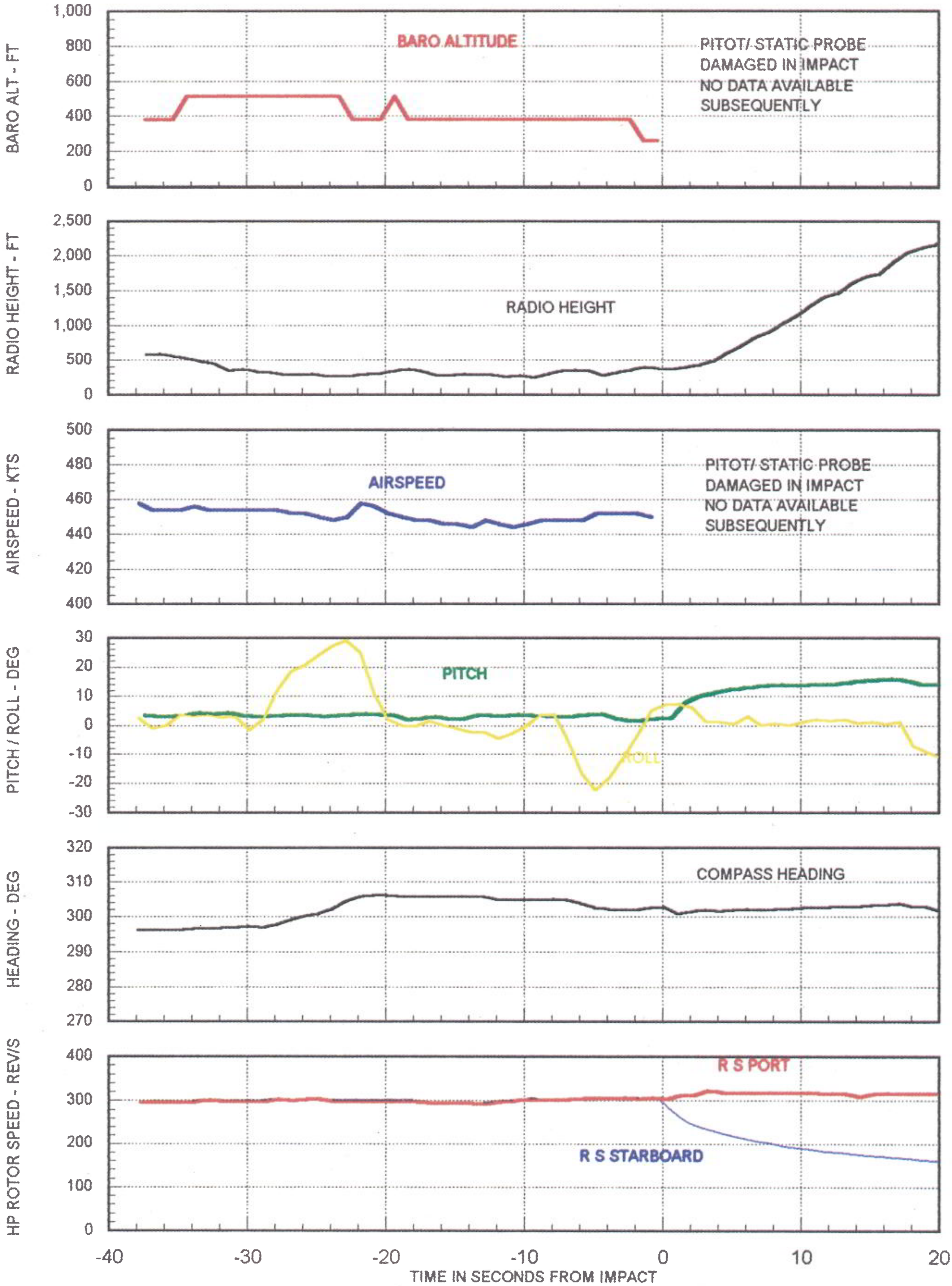
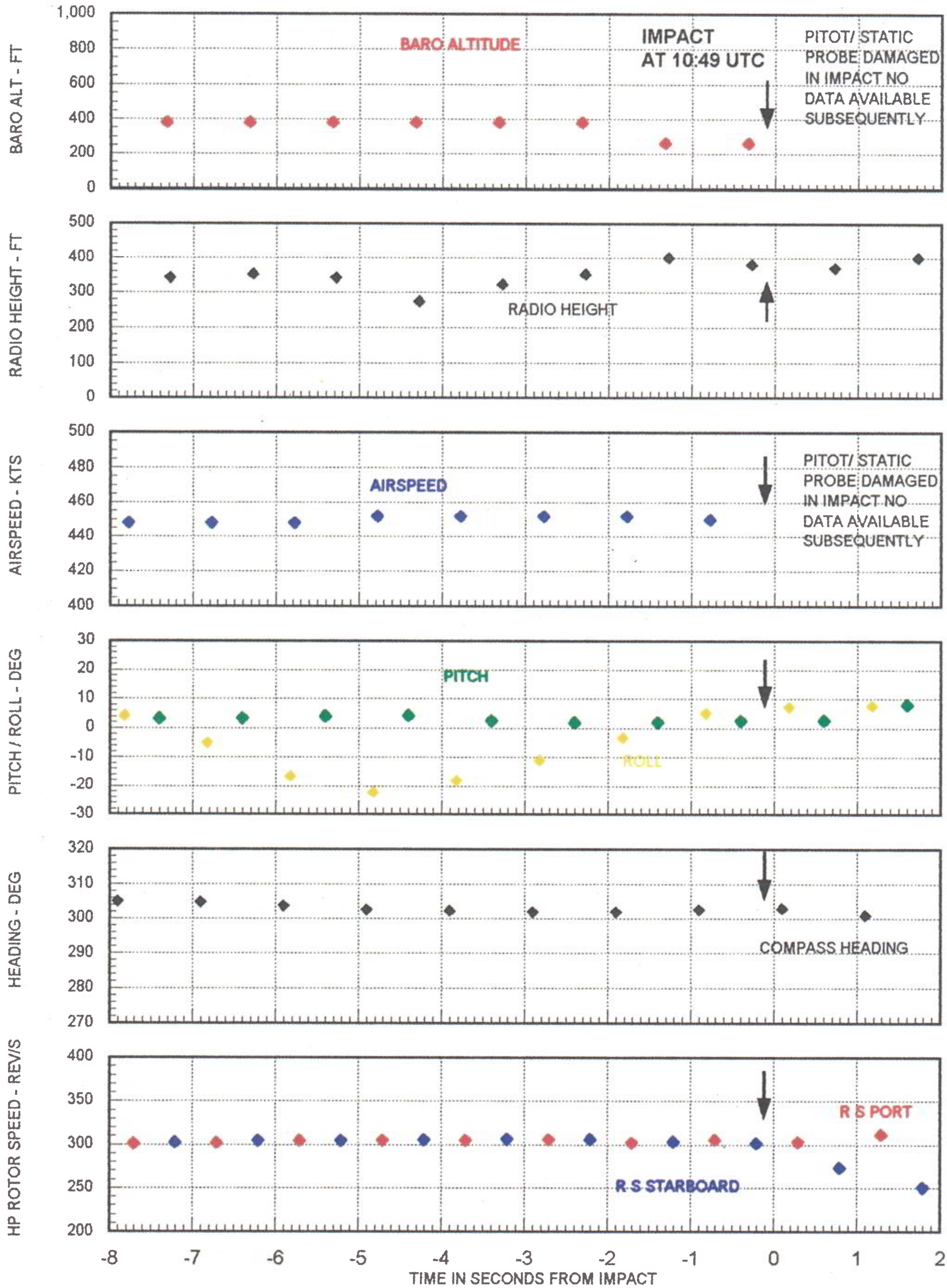



**Figure 1**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RADIO HEIGHT - FT
500
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RADIO HEIGHT
AIRSPEED - KTS
500
480
460
440
420
400
AIRSPEED
PITOT/ STATIC
PROBE DAMAGED
IN IMPACT NO
DATA AVAILABLE
SUBSEQUENTLY
PITCH / ROLL - DEG
30
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-10
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-30
PITCH
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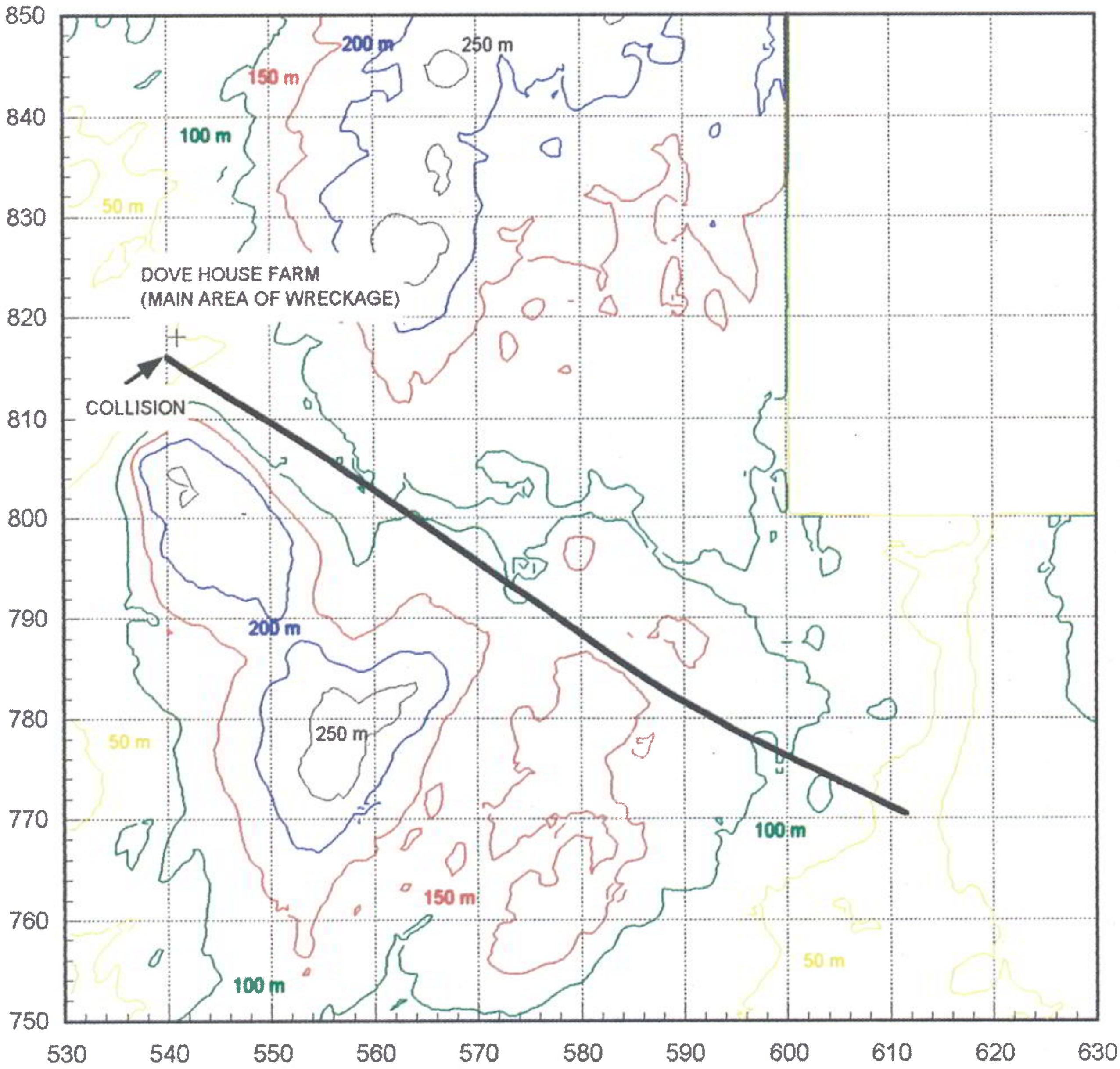
320
310
300
290
280
270
COMPASS HEADING
HP ROTOR SPEED - REV/S
400
350
300
250
200
R S PORT
R S STARBOARD
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
TIME IN SECONDS FROM IMPACT

**Figure 2**

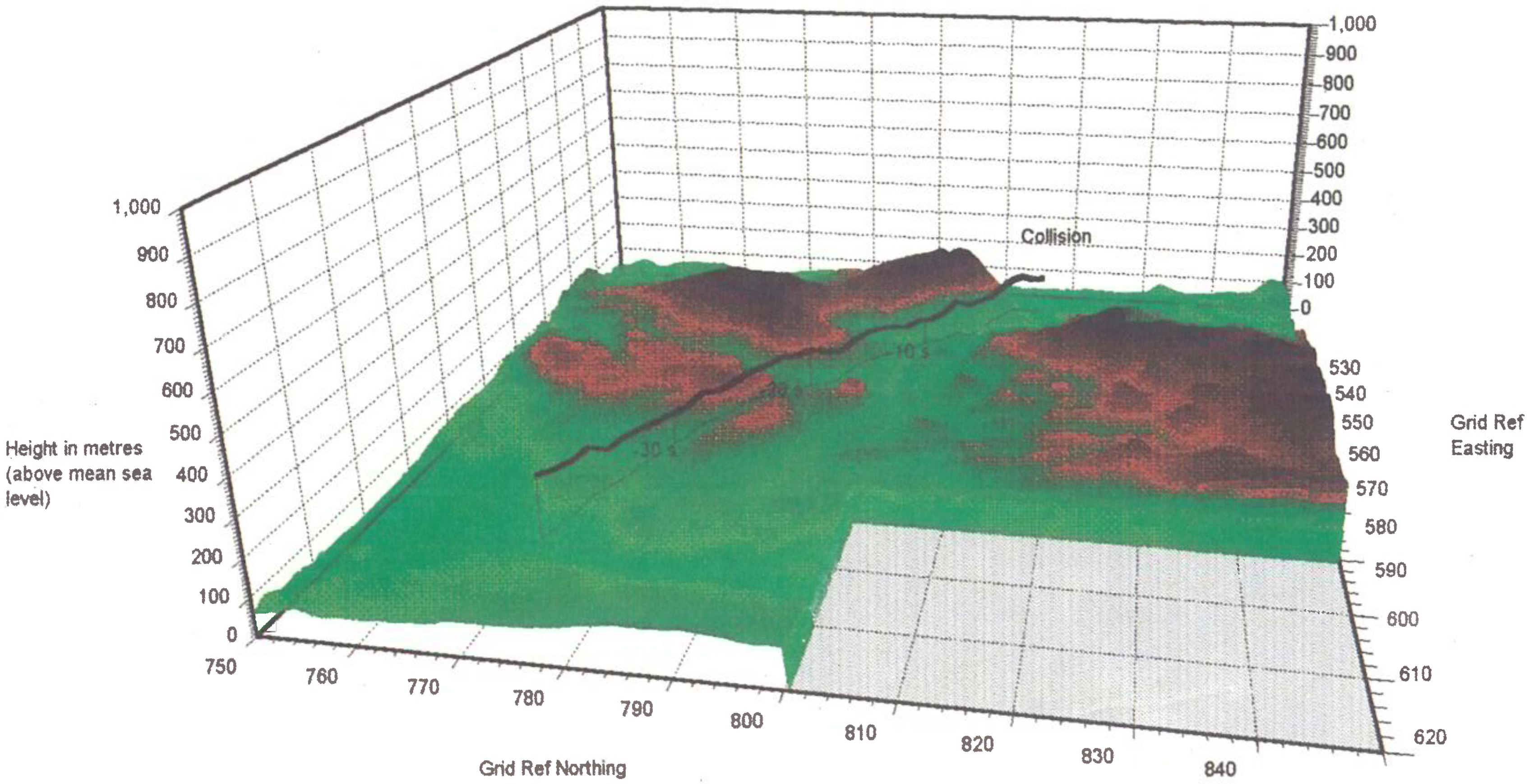
Derived Ground Track for Tornado starting 38 seconds before the collision




Ground Contours at 50 m intervals calculated from Ordnance Survey Digitised Terrain Data (no data obtained for area north/east of Grid Ref 600800)

Estimated position of Collision 540816

**Figure 3**




Three dimensional view of the estimated track for the Tornado

Surface plot calculated from Ordnance Survey Digitised Terrain Data (no data obtained for area north/east of Grif Ref 600800)

Figure 4

# RAF IAM Accident Report 002(P)/93

## Mid-air collision: Tornado and Jet Ranger on 23 June 1993

## 1. Resume of events

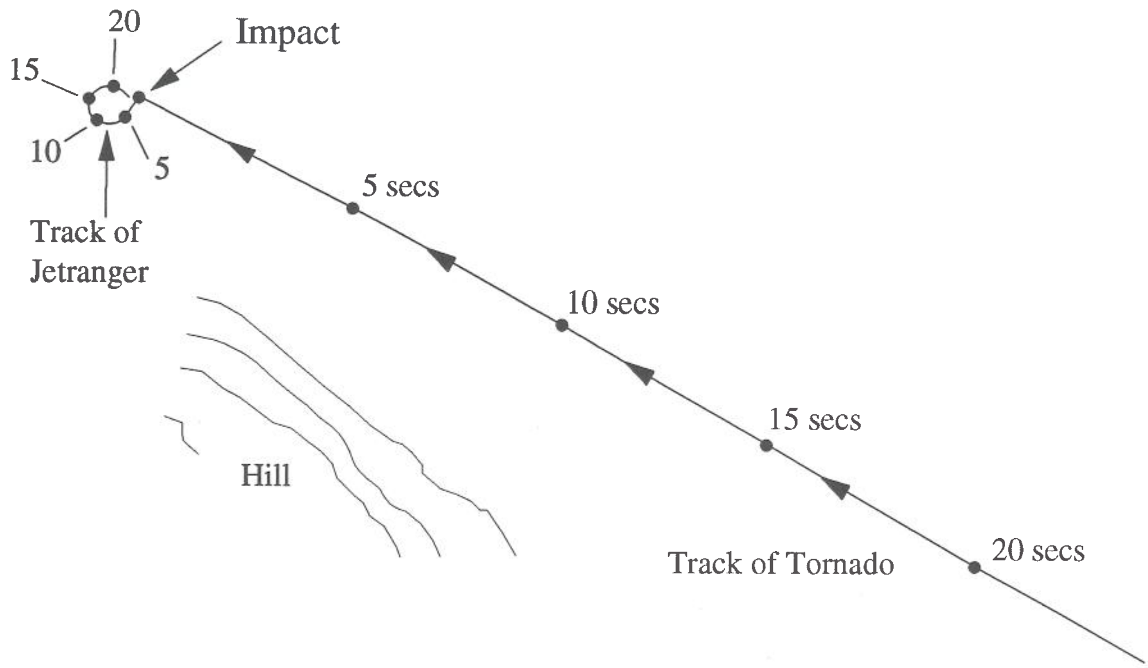
The crew of ZG754 were flying as number two on a pairs low level sortie. Approaching a turning point to the south of Kendal, they entered a valley heading 300°, and the leader passed behind a hill to their south in battle formation. As they emerged from the valley, the aircraft struck a Jetranger helicopter engaged in pipeline inspection. The helicopter was destroyed and the crew of two killed. The Tornado was successfully recovered despite serious damage.

## 2. Discussion

This report will concentrate on factors involved in visual look out, there being no other human factors of note to consider.

Figure 1 shows the positions of the two aircraft in the last 25s before the collision. In the case of the Tornado these are derived from ADR data; for the helicopter they are based on eye-witness reports and so are less reliable. Contours on a hill to the south are also marked. Figure 2 represents the view from the Tornado pilot's position and shows that the helicopter would have been generally in the head up display (HUD) field of view throughout the critical period (initially about 4° right of centreline, eventually about 9° left of centreline). At about five seconds from impact the helicopter could have been sufficiently close to the left forward windscreen strut to impede detection. From the navigator's point of view (Figure 3) the helicopter would have been concealed behind displays and other equipment, and the potential for him to contribute to visual search in the critical area was negligible.

## Figure 1




Relative positions of Tornado and Jetranger prior to impact

Annex A describes the procedure adopted to arrive at estimates of the detectability of the Jetranger during the 25s preceding the collision. Figure 4 presents a summary of these estimates. It shows curves for the cumulative probability of detection assuming both visors and clear visor only in use. A range of assumptions (specified in Annex A) are involved in these estimates. Both aircraft had high intensity strobe lights (HISLs) showing, but these would have made a negligible contribution to conspicuity becoming readily detectable probably less than three seconds from impact.The curves in Figure 4 represent a best guess at the performance of a reasonably diligent observer engaged in unrestricted visual search over a reasonable area (90° by 20°). There is evidence in a timely pull up to avoid birds during the flight down the valley that the Tornado pilot may properly be regarded as such an observer. A factor not allowed for is the effect of information displayed in the HUD. The width of lines in this display was similar to the apparent size of the helicopter during most of the critical period. Although it is not possible to estimate the magnitude of the effect, it is clear that clutter and even obscuration would have reduced the likelihood of early detection of the conflict.

It is apparent in Figure 4 that the helicopter was effectively invisible until about 17s from impact. The cumulative probability of detection then rises slowly, but stagnates at I-13s to I-8s when the aspect of the orbiting helicopter reduces its conspicuity to negligible values (i.e. the probability of detection was close to zero). During the final five to seven seconds the cumulative probability rises steeply (and the instantaneous probability is substantial). The chances of detecting the helicopter would have been good unless:

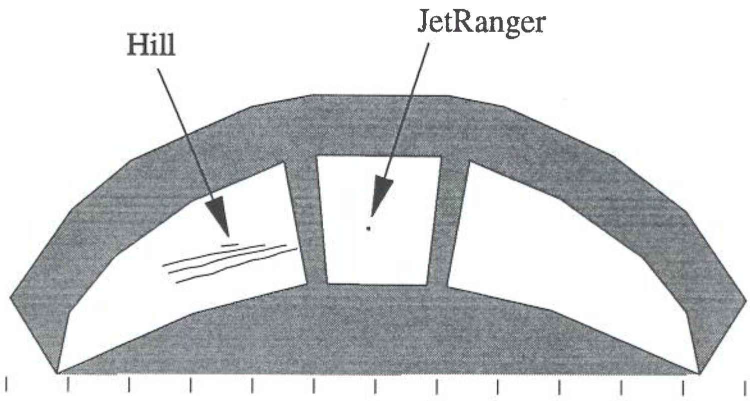
(a) the helicopter was obscured; or

(b) the pilot's gaze was positively directed away from the helicopter during this period.

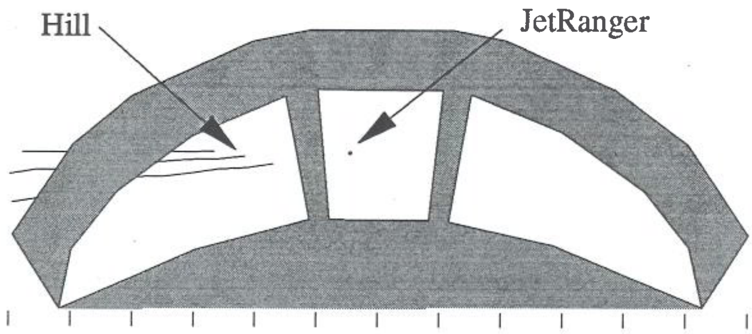
There is evidence for the first of these possibilities in Figure 2, particularly if the pilot's head movements changed the apparent relationship of the left forward windscreen strut to the helicopter. As for the second, at about five seconds to go the Tornado was emerging from the valley and an uninterrupted line of sight to the formation leader became possible. The Tornado pilot looked left in order to re-acquire the leader in time for their planned turn to the north, and did not see the helicopter.

## 3. The view from the helicopter

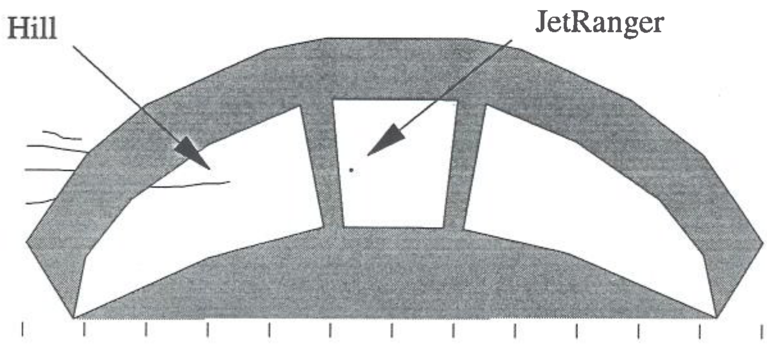
Given that the helicopter spent most of the 25s before impact orbiting a party of workmen, there was only a brief opportunity for the crew to scan the area from which the Tornado was emerging. This opportunity started shortly before completion of the orbit (when the helicopter was orientated towards the valley), and continued after it had rolled out on a northerly heading. Between these two periods, the pilot's view to the south west would have been restricted by the helicopter's roll angle. A scan covering a relatively large area (180° by 30°) and starting at 15s from impact results in a probability plot as shown in Figure 5. On this basis, and given that the helicopter pilot was wearing prescription sunglasses, the cumulative probability of detection before he went belly up to the Tornado could have been as low as 0.35 (depending on the darkness of the sunglasses). Without sunglasses there would have been a better chance of detecting the conflict in good time, but Figure 5 is probably an optimistic estimate of the performance to be expected of the helicopter pilot given the demands on his attention during the critical period.



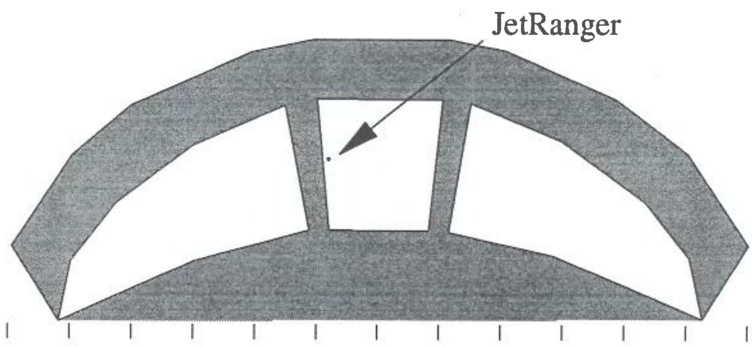

20 seconds before impact




15 seconds before impact




10 seconds before impact




5 seconds before impact

Figure 2: Pilot's view

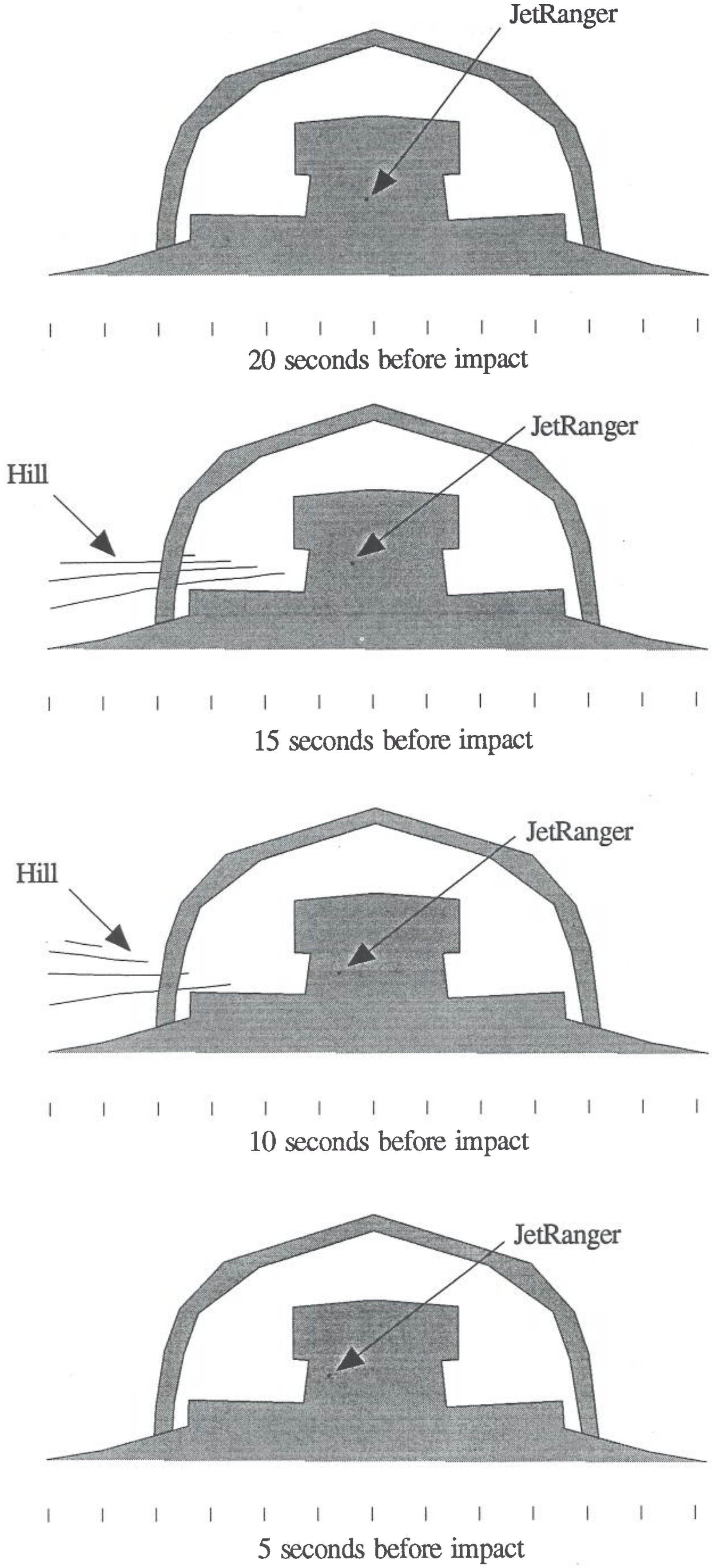



Figure 3: Navigator's view

Figure 4 Estimated probability of detecting the JetRanger

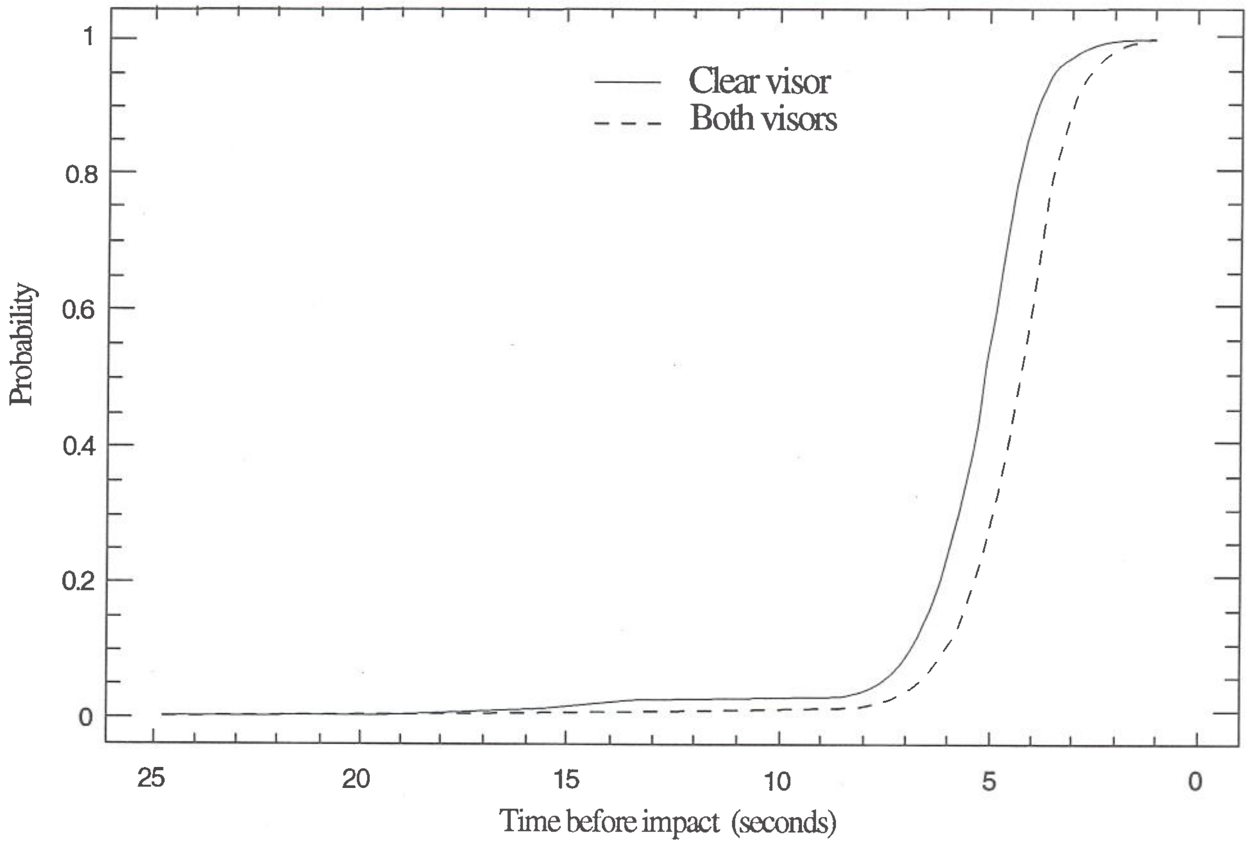
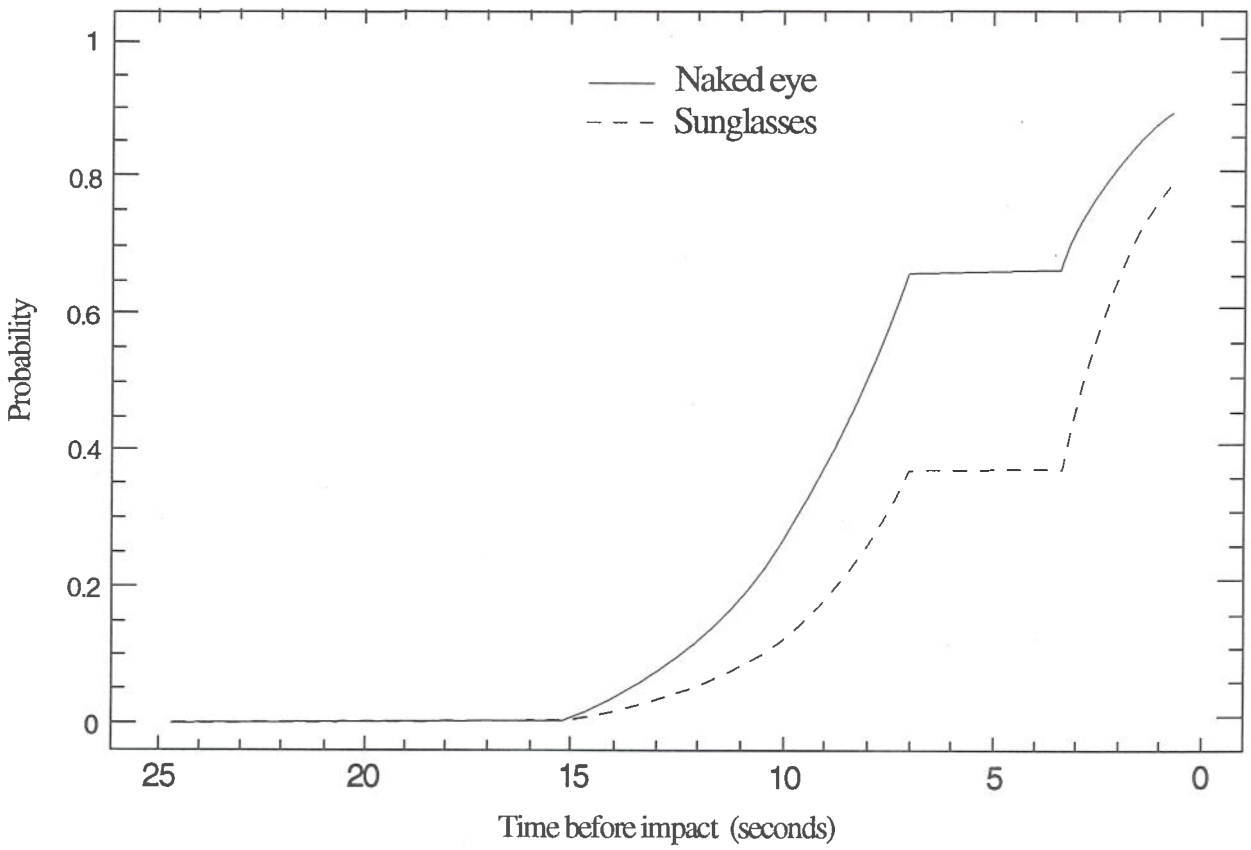



Figure 5 Estimated probability of detecting the Tornado



## 4. Conclusions

The circumstances of this accident illuminate the general problem of collision avoidance. Given the difficulty of detecting small aircraft, a fast jet pilot needs to sweep his forward sector roughly every five seconds - including head movements to clear canopy obstructions - in order to have a reasonable chance of avoiding conflicts. This is clearly a tall order given the other demands on his attention at low level. The pilot of a slow moving aircraft needs to scan an even wider area. It is possible to enhance the conspicuity of aircraft by a suitable choice of paint scheme and by the addition of sufficiently bright lights. (Lights considerably brighter than HISLs are currently being inves-tigated.) The risk could also be reduced by ensuring better co-ordination between operators in the lower airspace. Collision warning systems would enhance the effectiveness of visual look out, but are unlikely to prove a complete solution unless employed in combination with improvements in aircraft conspicuity.

J W Chappelow
Principal Psychologist
Psychology Division
for Commandant

9 July 1993

## References

A. Chappelow, J W and Belyavin, A J. Random mid-air collisions in the low flying system. RAF Institute of Aviation Medicine Report No. 702, April 1991.

B. Chappelow, J W and Belyavin, A J. A trial to assess aids to conspicuity. RAF Institute of Aviation Medicine Report No. 723, July 1992.

C. Camouflage handbook. Avionics Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright Patterson Air Force Base, Ohio. AFWALTR-86-1028, April 1986.

D. Smith, A J and Chappelow, J W. Agricultural aircraft anti-collision lighting for daytime use. Tech. Memo. FS(B)685. Royal Aircraft Establishment, Bedford, 1988.

# ANNEX A TO APPENDIX B

## Estimation of the probability of detection

## 1. Basic data

The Jetranger was examined in a hangar at the Air Accidents Investigation Branch, Farnborough. The reflectances of the two colours in its paint scheme were estimated by comparison with a standard reflector using a Minolta spot photometer. Intact Jetranger aircraft were examined in lighting conditions similar to those on the day of the accident, and at about the same time of day, in order to estimate the apparent reflectance of the perspex-enclosed cockpit area and side windows with the helicopter head-on to the Tornado's line of flight, and at right angles to it. The reflectances were 0.666 for white paint, 0.035 for grey, 0.275 for the front cockpit, and .028 for the side windows. The total visual area of the helicopter, and the component grey, white and perspex areas were estimated by reference to front and side plan views, and mean reflectances for front and side views were calculated.

Data were already to hand on grey/green disruptive camouflage (mean reflectance 0.127) and Tornado visual areas.

The route of the Tornado was inspected from the air (using a Gazelle helicopter) at the same time of day as the accident, and in similar weather conditions. Luminance readings were taken from a variety of positions and heights (determined by reference to the Tornado ADR) of the horizon sky and hills in the direction from which the Jetranger would have appeared, and, from the Jetranger's point of view, in the opposite direction. The hills forming the background to the Jetranger were found to have a luminance of about $3850cdm^{-2}$ as seen from the collision point, and the sky above them was $5950cdm^{-2}$. The sky background to the Tornado was found to be $9300cdm^{-2}$. Illuminance measures in appropriate directions were taken at ground level. In the calculations that follow values of 44000 lux (in the direction of the Jetranger) and 14700 lux (in the direction of the Tornado) were used. The calculated apparent contrast of the Jetranger is close to zero and very sensitive to changes in assumed illuminance. The value chosen, being the maximum of those recorded, is conservative in the sense of tending to lead to higher rather than lower estimates of the probability of detection.

Estimates from other pilots in the area on the day of the accident put the visibility at more than 30km. Aftercasts from meteorological stations around the area estimated about 65km. The higher value was used in calculations. Cloud cover was about two oktas.

## 2. Probability of detection

### (a) Jetranger

At one second intervals throughout the 25s preceding the collision, the positions and orientations of the two aircraft were calculated using the Tornado's ADR data and a reconstruction of the helicopter's trajectory based on eye-witness reports. At each step the effective visual area and mean reflectance of the Jetranger as seen from the Tornado were estimated taking into account the orientation in azimuth to the line of sight:

$$A = A_f * \cos(\mathcal{T}) + A_s * \sin(\mathcal{T}) \qquad (1)$$

and

$$R = R_f * \cos(\mathcal{T}) + R_s * \sin(\mathcal{T}) \qquad (2)$$

| | | |
|---|---|---|
| where | $A$ | is effective area and R is effective reflectance. |
| | $A_f$ | is frontal area and A is side area. |
| | $R_f$ | is front reflectance and $R_s$ is side reflectance. |
| | $\mathcal{T}$ | is angle to line of sight |

No account was taken of the roll or pitch angles of the helicopter. The Jetranger's apparent contrast and apparent size as viewed from the Tornado were calculated. These data were used, with interpolation, to estimate the probability of detecting the Jetranger at one third second intervals throughout the final 25s using techniques described in Reference A and slightly modified in Reference B. Assumptions were:

(i) The Tornado pilot's scan was centred on dead ahead and covered 90° by 20°.

(ii) The scan was essentially random, with shift of gaze three times a second.

(iii) The detectability of the rotors could safely be disregarded.

The accident happened in almost clear sky conditions. It was, therefore, necessary to estimate the total illumination on the Jetranger taking account of both direct and indirect sources. Reference C provided data relevant to this partition.

The cumulative probability of detection was calculated at one third second intervals for an observer with both visors in use, or only the clear visor in use. It was the Tornado pilot's practice to use only the clear visor at low level, but it is not completely certain that he did so on this occasion. Figure Al presents these curves. The cumulative probability of detection does not exceed 0.5 until, at best, some seven seconds from impact, when the apparent size of the helicopter would have been increasing through about five minutes of arc.

In Figure A2 the curve for the clear visor case is compared with two hypothetical conditions - first, against a sky background, and second, for a helicopter always side on to the line of sight. The comparison suggests that circumstances did conspire to make the Jetranger somewhat less detectable than it might have been, but not by an enormous margin. Bear in mind also that the accident happened close to mid-summer, close to noon, with only slight cloud cover, and excellent visibility.

**(b) Tornado**

Essentially similar methods were used to estimate the detectability of the Tornado from the Jet Ranger's position. In this case assumptions were:

(i) A scan area of 180° by 30°, centred on dead ahead.

(ii) The scan was essentially random, with shift of gaze three times a second.

(iii) Relevant scanning was initiated at 15s from impact, interrupted (due to aircraft attitude) at 7s to go, and resumed at 3s to go.

The resulting cumulative probability estimates are plotted in Figure A3. The pilot wore sunglasses of unknown transmissivity, so the figure includes curves for the naked eye and for a transmissivity of 0.14 as likely extremes.

## 3. Conclusions

The Jetranger was unlikely to be detected much before five seconds from impact. Thereafter the probability of detection would have risen sharply - as long as the scanning assumptions remained valid and obscuration did not play a part.

The Tornado, having better contrast and being a larger target, would have been in principle somewhat more detectable if the Jetranger pilot had had no other demands on his attention and an uninterrupted opportunity to scan the relevant area.

## 4. Remedies

In Figure A4 the clear visor curve is compared with predictions for helicopters with an all white paint scheme and an all black paint scheme.

Using the techniques described in References A and B estimates were made of the likely detection time for the high intensity strobe light (HISL) on the Jetranger (assumed to have an output of 2000cd) and for a hypothetical 80000cd beacon. The cumulative probability of detection for the HISL would pass 0.5 less than three seconds from impact. This is not inconsistent with the results of trials evaluating the detectability of HISLs in daylight (Reference D). For the brighter light, the estimate is more than 16s.

Figure A5 compares the clear visor case with estimated performance following a collision warning system alert at 25s to go. The pilot's scan is assumed to reduce to 30° by 10° following the alert. There is a clear benefit between I-18s and I-13s, but the changing aspect of the helicopter still renders it invisible between I-13s and I-8s. A collision warning system would, however, clearly make a useful contribution to collision avoidance on the 'see-and-avoid' principle if used in conjunction with conspicuity enhancing measures.

**Figure A1** Estimated probability of detecting the JetRanger

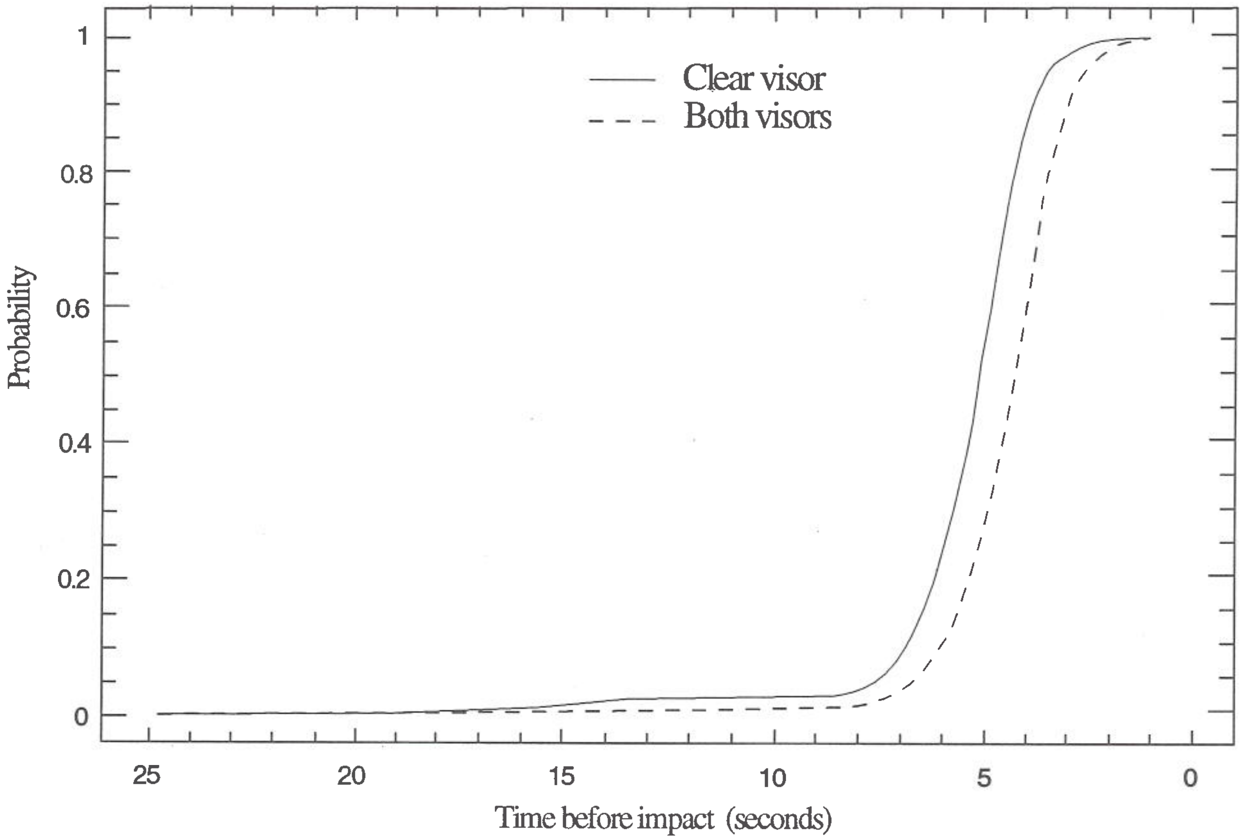



**Figure A2** Estimated probability of detecting the JetRanger

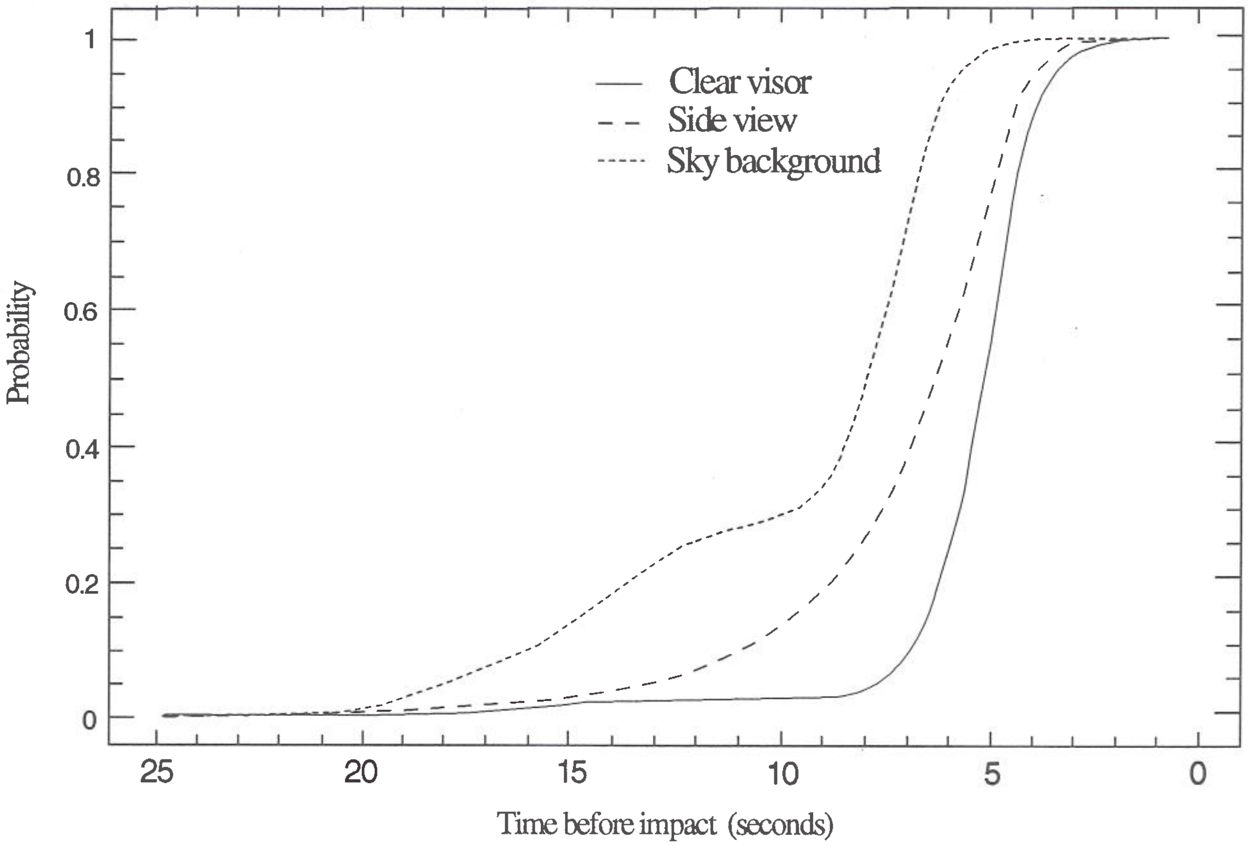


Figure A3 Estimated probability of detecting the Tornado

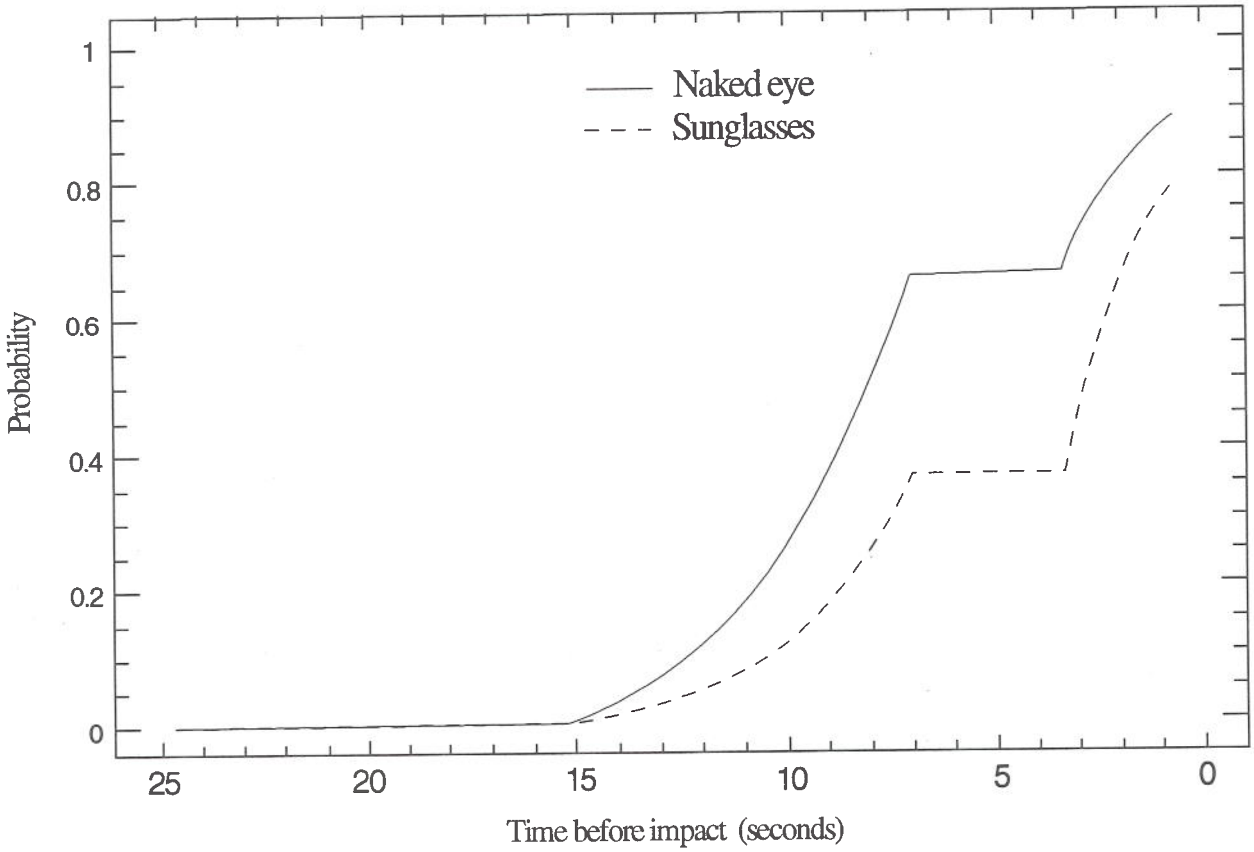



Figure A4 Estimated probability of detecting the JetRanger

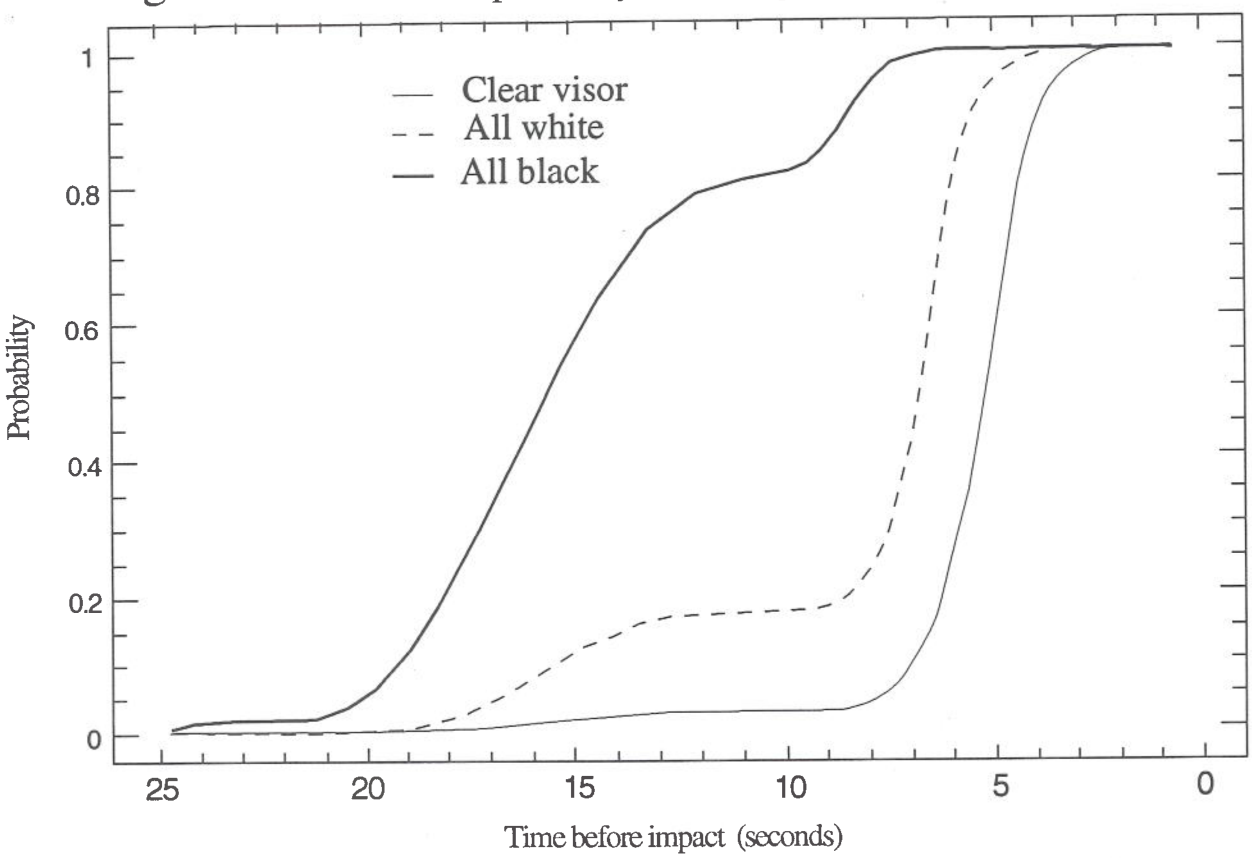
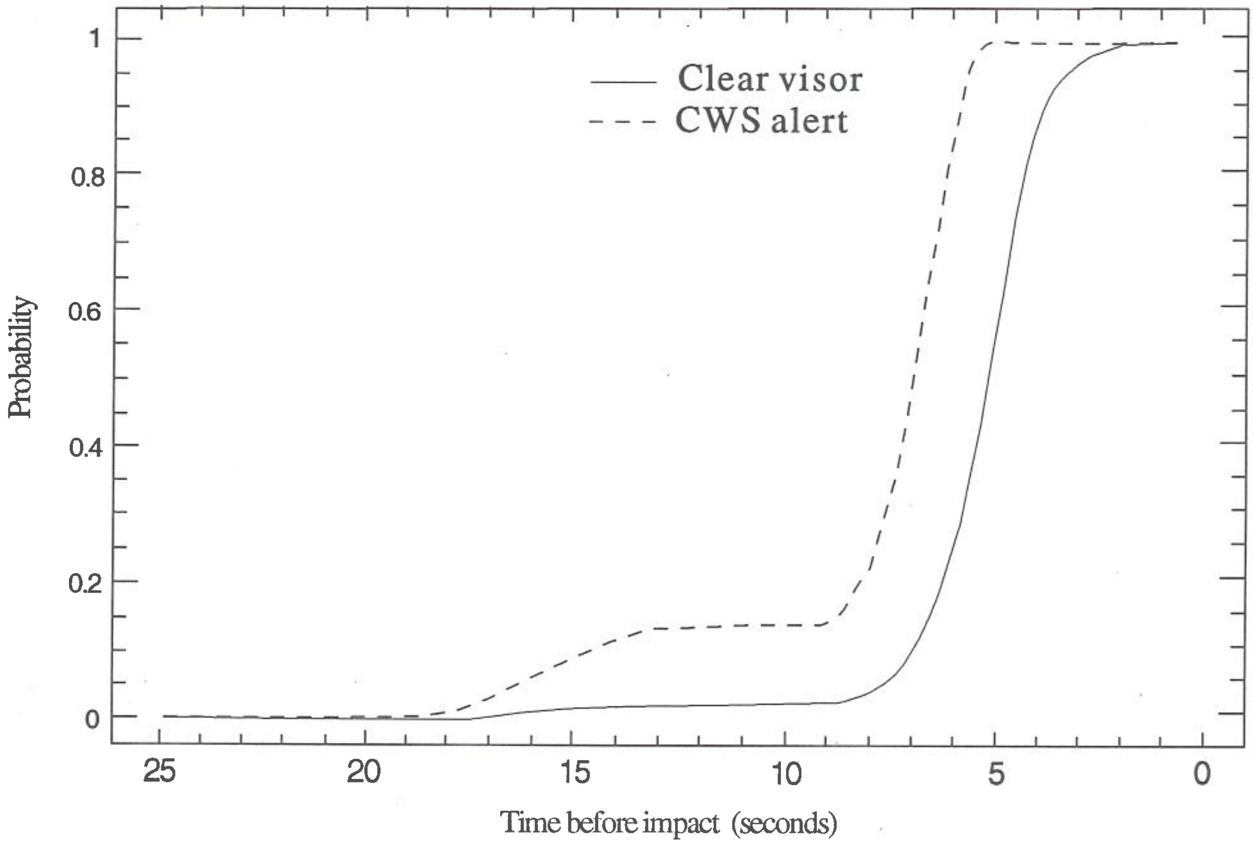


Figure A5 Estimated probability of detecting the JetRanger



## APPENDIX C

# LIMITATIONS OF THE SEE-AND-AVOID PRINCIPLE

*[ A summary of the Bureau of Air Safety Investigation Research Report on the Limitations of the See -and -Avoid Principle]*

### 1. Role of see-and-avoid.

See-and-avoid serves three functions:

a. Self-separation of aircraft outside controlled airspace.

b. As a separation procedure for VFR aircraft in controlled airspace. This procedure only operates when the pilot can see the traffic and is therefore significantly different to other types of see-and-avoid which may involve unalerted searches for traffic.

c. Last resort separation if other methods fail to prevent a confliction, regardless of the nature of the airspace.

It is important to distinguish between unalerted and alerted see-and-avoid. In alerted see-and-avoid, the pilot of an aircraft in controlled airspace is assisted to sight the traffic and an important back up exists because positive control will be provided if the traffic cannot be sighted. Unalerted see-and-avoid on the other hand, presents a potentially greater safety risk because it relies entirely on the ability of the pilot to sight other aircraft. For these reasons the following paragraphs concentrate on unalerted see-and-avoid. However, many of the problems of unalerted see-and-avoid apply equally to alerted see-and-avoid.

### 2. Potential for mid-air collisions.

The probability of a mid-air collision in a given airspace grows faster than the traffic growth. One of the factors which determines the probability of a collision is the number of possible collision combinations in a particular airspace. The number of possible collision pairs is given by the formula: $P = N \times (N-1)/2$ where N is the number of aircraft operating in a given airspace. For example, with only two aircraft there is only one possible collision pair, with five aircraft there are ten possible pairs and with ten aircraft there are forty five. The figure illustrates the increase in possible collisions which accompanies increasing traffic density .

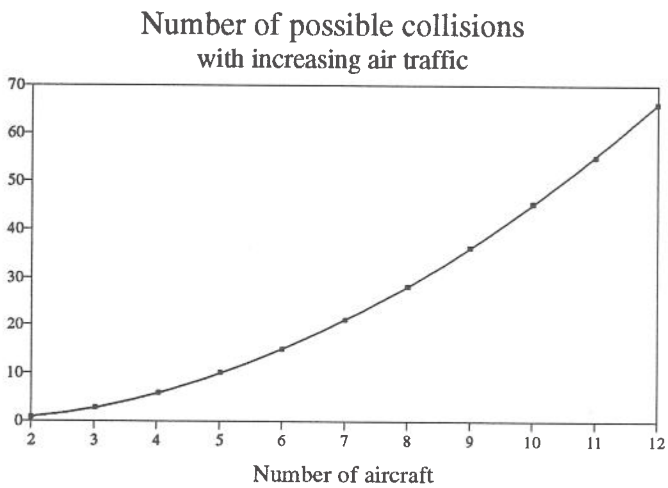



Figure 1

Fortunately, the frequency of collisions has not increased as steeply as figure 1 would suggest because various safety systems have prevented the full expression of the collision potential. Air traffic services (ATS), flight rules and visual sighting are three such systems.

## 3. Reliability of see-and-avoid.

See-and-avoid has been described as a maritime concept originally developed for slow moving ships which is now out of place in an era of high speed aviation.

There is a growing case against reliance on see-and-avoid. A report released in 1970 concluded that although see-and-avoid was often effective at low closing speeds, it usually failed to avert collisions at higher speeds. It was estimated that see-and-avoid prevents 97 percent of possible collisions at closing speeds of between 101 and 199 knots but only 47 percent when the closing speed is greater than 400 knots.

A 1975 Federal Aviation Administration (FAA) study concluded that although see-and-avoid was usually effective, the residual collision risk was unacceptable. Accident investigations in Australia and in the U.S. are increasingly pointing to the limitations of see-and-avoid. The Americans, having recognised the limitations of the concept, are looking to other methods such as the automated airborne collision avoidance system (TCAS) to ensure traffic separation. TCAS equipment carried on board an aircraft will automatically provide information about any nearby transponder-equipped aircraft which pose a collision threat. It is planned that by the mid 1990s all large civil passenger aircraft operating in the U.S. will be fitted with this system.

Perhaps the most damning evidence against see-and-avoid comes from recent trials carried out in the United States which have confirmed that even motivated pilots frequently fail to sight conflicting traffic.

In one of these studies, twenty four general aviation pilots flew a Beech Bonanza on a VFR cross country flight. The pilots believed that they were participating in a study of workload management techniques. In addition to providing various information to a researcher on the progress of the flight, the pilots under study were required to call out any traffic sighted.

The pilots were not aware that their aircraft would be intercepted several times during the test by a Cessna 421 flying a near-collision course. The interceptions occurred when the Bonanza was established in cruise and the pilot's workload was low, however, the Bonanza pilots sighted the traffic on only thirty six out of sixty four encounters - or 56 percent.

**4. Steps involved in seeing and avoiding.**

a. The pilot must look outside the aircraft.

b. The pilot must search the available visual field and detect objects of interest, most likely in peripheral vision.

c. The object must be looked at directly to be identified as an aircraft. If the aircraft is identified as a collision threat, the pilot must decide what evasive action to take.

d. The pilot must make the necessary control movements and allow the aircraft to respond.

Not only does the whole process take valuable time, but human factors at various stages in the process can reduce the chance that a threat aircraft will be seen and successfully evaded. These human factors are not 'errors' nor are they signs of 'poor airmanship'. They are limitations of the human visual and information processing system which are present to various degrees in all pilots.

## 5. Limitations of see-and-avoid.

a. Looking for traffic.

Obviously, see-and-avoid can only operate when the pilot is looking outside the cockpit. According to a U.S. study, private pilots on VFR flights spend about 50 percent of their time in outside traffic scan.

The time spent scanning for traffic is likely to vary with traffic density and the pilot's assessment of the collision risk. In addition, factors such as cockpit workload and the ATS environment can influence traffic scanning.

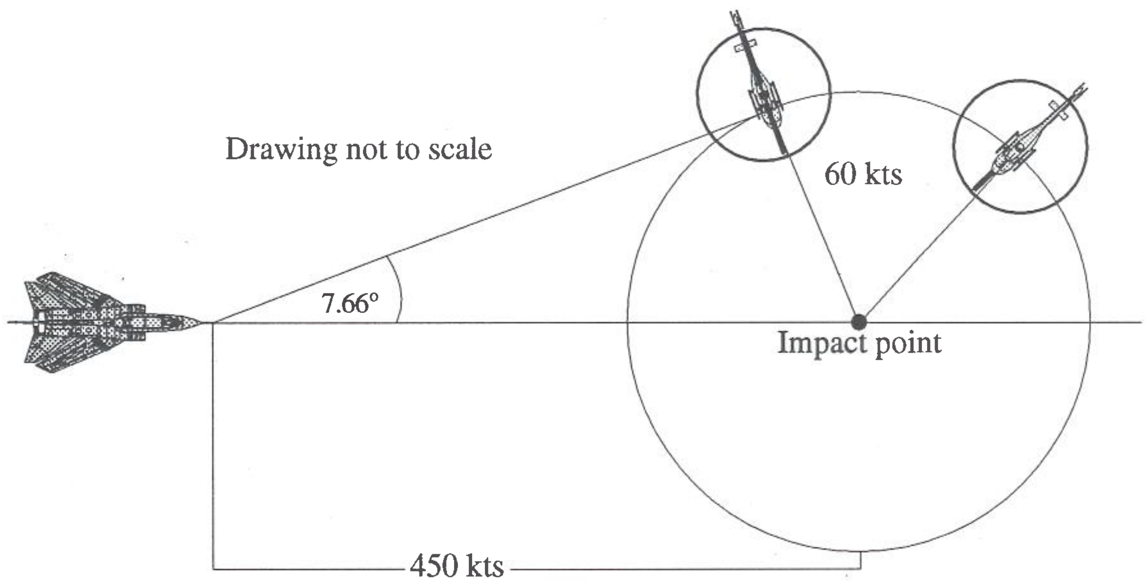



Figure 2

*In the case illustrated, two aircraft are converging on an impact point at different speeds. The jet is travelling nine times faster than the helicopter and at any time proir to the collision, will be nine times further away from the collision point than the helicopter. One result of this is that the faster aircraft will always have the slower aircraft in front of it. At all times leading up to the collision, any slower aircraft with which the jet may collide will appear at a point relatively close to the centre of the jet's windscreen. From the slower aircraft's point of view, however, the jet can approach from any angle, even from part of the sky not visible in the windscreen*

b. Workload.

Many tasks require the pilot to direct attention inside the aircraft. Cockpit workload is likely to be high near airports where traffic is most dense and where an outside scan is particularly crutial. Most of these cockpit tasks are essential, however some of the workload is less critical and could be performed at other times.

c. Diffusion of responsibility.

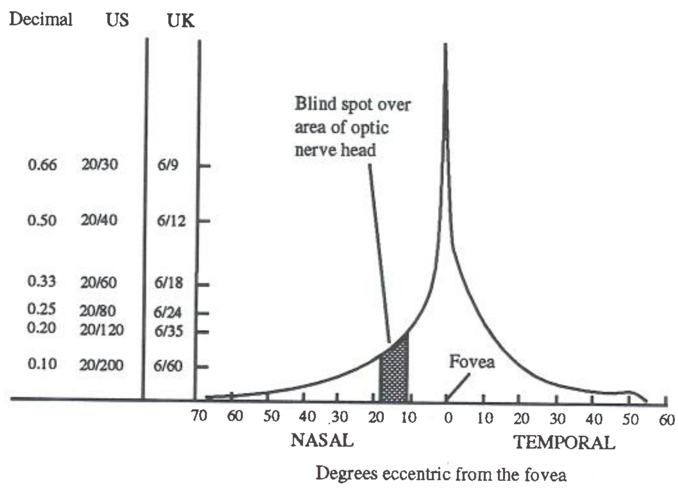
Diffusion of responsibility occurs when responsibility for action is divided between several individuals with the result that each assumes that somebody else is taking the necessary action.

d. Visual Search.

The average person has a field of vision of around 190°, although field of vision varies from person to person and is generally greater for females than males. The field of vision begins to contract after about the age of 35. In Males, this reduction accelerates markedly after 55 years of age. A number of transient physical and psychological conditions can cause the effective field of vision to contract even further. The quality of vision varies across the visual field, largely in accord with the distribution on the retina of the two types of light sensitive cells, rods and cones. Cones provide sharp vision and colour perception in daylight illumination and are concentrated at the fovea, the central part of the retina on which an object appears if it is looked at directly. Rods are situated on the remainder of the retina surrounding the fovea on an area known as the peripheral retina. Although rods provide a black and white image of the visual field, they continue to operate at low light levels when the cones have ceased to function.

Vision can be considered to consist of two distinct systems, peripheral and foveal vision. Some important differences between the two systems are that colour perception and the detection of slow movement are best at the fovea, while detection of rapid movement is best in the periphery. In daylight, acuity (sharpness of vision) is greatest at the fovea, but with low light levels such as twilight, acuity is fairly equal across the whole retina. At night, acuity is greatest in the peripheral retina.

VARIATION OF VISUAL ACUITY




*The variation of visual acuity (expressed in decimal, British and USA notation) at retinal sites eccentric to the fovea. The acuity at 5 degrees eccentric to the fovea is only one-quarter that at the fovea.*

Figure 3

Figure 3 shows acuity in daylight is dramatically reduced away from the direct line of sight, therefore a pilot must look at or near a target to have a good chance of detecting it.

Peripheral and foveal vision each perform different functions in the search process. An object will generally be first detected in peripheral vision but must be fixated on the fovea before identification can occur. Searching for traffic involves moving the point of gaze about the field of view so that successive areas of the scene fall onto the high-acuity area of the retina. The eye movements in a traffic search occur in rapid jerks called saccades interposed with brief rests called fixations. We only see during the fixations, being effectively 'blind' during the saccades. It is not possible to move the eyes smoothly across a view unless a moving object is being tracked.

## 6. Factors limiting the effectiveness of visual searches.

a. Cockpit visibility.

Most aircraft cockpits severely limit the field of view available to the pilot. Figure 2 illustrates that a typical general aviation aircraft, because of its relatively slow speed, can be approached from any direction by faster aircraft. Visibility is most restricted on the side of the aircraft furthest away from the pilot and consequently, aircraft approaching from the right will pose a particular threat to a pilot in the left seat and vice-versa.

b. Obstructions.

Obstructions to vision can include window-posts, windscreen contamination, sunvisors, wings and front seat occupants. The instrument panel itself may obstruct vision if the pilot's head is significantly lower than the standard eye position specified by the aircraft designers. The effects of obstructions on vision are in most cases self-evident. However there are some less obvious forms of visual interference. First, an obstruction wider than the distance between the eyes will not only mask some of the view completely, but will result in certain areas of the outside world being visible to only one eye. A target which falls within such a region of monocular visibility is less likely to be detected than a similar target visible to both eyes. A second undesirable effect of a window-post or similar obstruction is that it can act as a focal trap for the eyes, drawing the point of focus inwards, resulting not only in blurred vision but distorted size and distance perception.

c. Glare.

Glare occurs when unwanted light enters the eye. Glare can come directly from the light source or can take the form of veiling glare, reflected from crazing or dirt on the windscreen.

Direct glare is a particular problem when it occurs close to the target object such as when an aircraft appears near the sun. It has been claimed that glare which is half as intense as the general illumination can produce a 42 percent reduction in visual effectiveness when it is 40 degrees from the line of sight. When the glare source is 5 degrees from the line of sight, visual effectiveness is reduced by 84 percent. In general, older pilots will be more sensitive to glare.

## 7. Limitations of visual scan.

The individual eye movements associated with visual search take a small but significant amount of time. At most, the eyes can make about three fixations per second however, when scanning a complex scene pilots will typically spend more time on each fixation.

An FAA Advisory Circular ( 90-48 C) recommends scanning the entire visual field outside the cockpit with eye movements of ten degrees or less to ensure detection of conflicting traffic. The FAA estimates that around one second is required at each fixation. So to scan an area 180 degrees horizontal and thirty degrees vertical could take fifty four fixations at one second each = 54 seconds. Not only is this an impracticable task for most pilots, but the scene would have changed before the pilot had finished the scan. Under certain conditions, the search of an area 180 degrees by thirty degrees would require 2700 individual fixations and take around fifteen minutes!

## 8. Limitations of vision.

a. Blind spot.

The eye has an inbuilt blind-spot at the point where the optic nerve exits the eyeball. Under normal conditions of binocular vision the blind spot is not a problem as the area of the visual field falling on the blind spot of one eye will still be visible to the other eye. However, if the view from one eye is obstructed (for example by a window post), then objects in the blind spot of the remaining eye will be invisible. Bearing in mind that an aircraft on a collision course appears stationary in the visual field, the blind spot could potentially mask a conflicting aircraft.

The blind spot covers a visual angle of 7.5 degrees vertical and 5 degrees horizontal. At a distance of around 40 centimetres the obscured region is about 1.5 cms. The obscured area expands to around 18 metres in diameter at a distance of 200 metres, enough to obscure a small aircraft. The blind spot in the eye must be considerewd as a potential, albeit unlikely accident factor. It should be a particular concern in cases where vision is severly limited by obstructions such as window posts, wings or visors.

b. Threshold for acuity.

There are times when an approaching aircraft will be too small to be seen because it is below the eye's threshold of acuity. The limits of vision as defined by eye charts are of little assistance in the real world where targets frequently appear in the corner of the eye and where acuity can be reduced by factors such as vibration, fatigue and hypoxia. Research has shown that certain types of sunglasses can also significantly reduce acuity .

There have been attempts to specify how large the retinal image of an aircraft must be before it is identifiable as an aircraft. For example an National Transportation Safety Board (NTSB) report into a mid-air collision suggested a threshold of twelve minutes of arc whereas a figure of between twenty four and thirty six minutes of arc has been suggested as arealistic threshold in sub-optimal conditions.

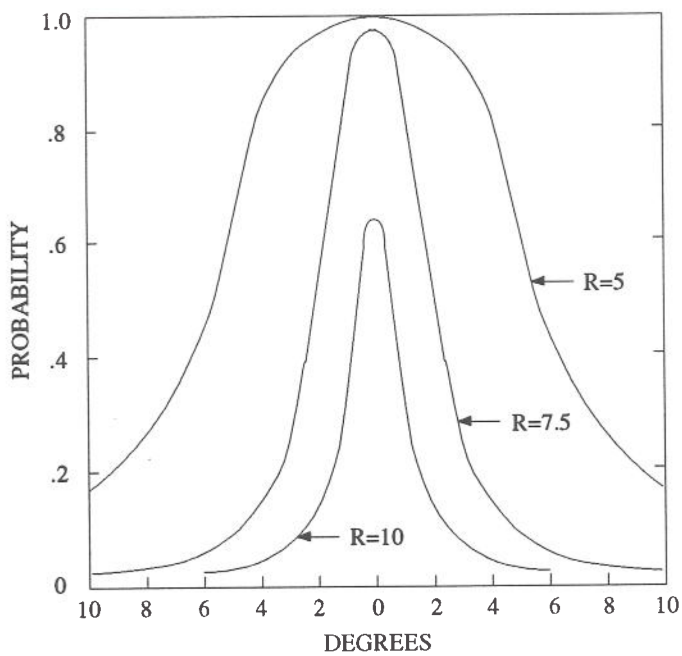



Figure 4

Unfortunately it is not possible to state how large a target must be before it becomes visible to a pilot with normal vision because visual acuity varies dramatically across the retina. An effective way to visualize the performance of the eye in a visual detection task is with a visual detection lobe such as figure 4 which shows the probability of detecting a medium sized aircraft at various ranges and at various degrees away from the line of sight. The figure illustrates that the probability of detection decreases sharply as the aircraft appears further away from the direct line of sight.

c. Accommodation.

Accommodation is the process of focussing on an object. Whereas a camera is focussed by moving the lens, the human eye is brought into focus by muscle movements which change the shape of the eye's lens. A young person will typically require about one second to accommodate to a stimulus, however the speed and degree of accommodation decreases with age. The average pilot probably takes several seconds to accommodate to a distant object. Shifting the focus of the eyes, like all muscular processes can be affected by fatigue.

d. Empty field myopia.

In the absence of visual cues, the eye will focus at a relatively short distance. In the dark the eye focuses at around 50 cm. In an empty field such as blue sky, the eye will focus at around 56 centimetres. This effect is known as empty field myopia and can reduce the chance of identifying a distant object.

e. Focal traps.

The prescnce of objects close to the eye's dark focus can result in a phenomenon known as the Mandelbaum effect, in which the eye is involuntarily 'trapped' at its dark focus, making it difficult to see distant objects. Window-posts and dirty windscreens are particularly likely to produce the Mandelbaum effect.

## 9. Psychological limitations.

a. Alerted search versus unalerted search

A traffic search in the absence of traffic information is less likely to be successful than a search where traffic information has been provided because knowing where to look greatly increases the chance of sighting the traffic. Field trials found that in the absence of a traffic alert, the probability of a pilot sighting a threat aircraft is generally low until a short time before impact. Traffic alerts were found to increase search effectiveness by a factor of eight. A traffic alert from ATS or from a radio listening watch is likely to be similarly effective. A mathematical model of visual acquisition was applied by the NTSB to a mid-air collision between a DC9 and a piper PA28. Figure 5 shows the estimated probability that the pilots in one aircraft could have seen the other aircraft before the collision.

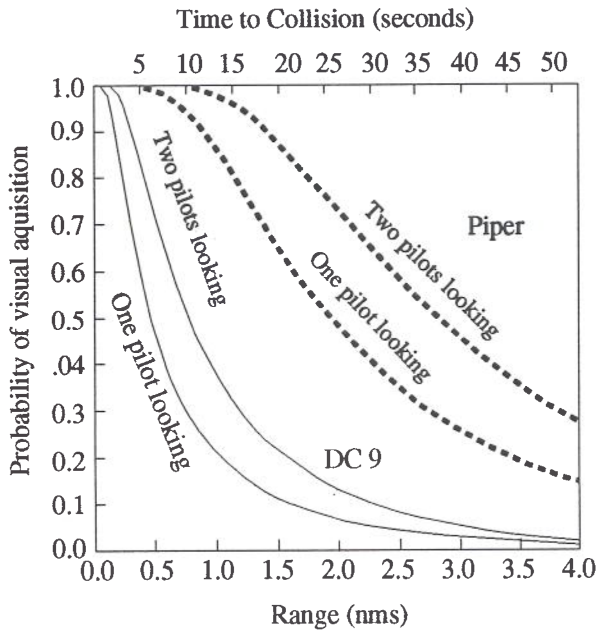



Figure 5

b. Visual field narrowing

An observer's functional field of vision can vary significantly from one circumstance to another. For example, although a comfortable and alert pilot may be able to easily detect objects in the 'corner of the eye', the imposition of a moderate workload, fatigue or stress will induce 'tunnel vision'. It is as though busy pilots are unknowingly wearing blinkers.

Visual field narrowing has also been observed under conditions of hypoxia and adverse thermal conditions. However, in aviation, cockpit workload is likely to be the most common cause of visual field narrowing.

c. Cockpit workload and visual field narrowing

The limited mental processing capacity of the human operator can present problems when there is a requirement to fully attend to two sources of information at the same time. An additional task such as radio work, performed during a traffic scan can reduce the effectiveness of the search, even to the extent of reducing the pilot's eye movements and effectively narrowing the field of view.

A number of researchers have shown that peripheral stimuli are more difficult to detect when attention is focussed on a central task or an auditory task. Experiments conducted at NASA indicated that a concurrent task could reduce pilot eye movements by up to 60 percent. The most difficult secondary tasks resulted in the greatest restriction of eye movements. Talking, mental calculation and even daydreaming can all occupy mental processing capacity and reduce the effective field of vision.

**10. Target characteristics.**

a. Contrast with background.

In determining visibility, the colour of an aircraft is less important than the contrast of the aircraft with its background. Contrast is the difference between the brightness of a target and the brightness of its background and is one of the major determinants of detectability. The paint scheme which will maximise the contrast of the aircraft with its background depends of course, upon the luminance of the background. A dark aircraft will be seen best against a light background, such as bright sky, while a light coloured aircraft will be most conspicuous against a dull background such as a forest.

b. Atmospheric effects.

Contrast is reduced when the small particles in haze or fog scatter light. Not only is some light scattered away from the observer but some light from the aircraft is scattered so that it appears to originate from the background, while light from the background is scatterd onto the eye's image of the aircraft. The result is a 'washed out' and indistinct image.

c. Aircraft paint schemes.

From time to time, fluorescent paint has been suggested as a solution to the contrast problem. However, several trials have concluded that fluorescent painted aircraft are not easier to detect than aircraft painted in non fluorescent colours.

Trials of aircraft detection carried out in 1961 indicated that in 80 percent of first detections, the aircraft was darker than its background. Thus a major problem with bright flouescent aircraft is that against a typical, light background, the increased luminance of the aircraft would only serve to reduce contrast. In summary, particularly poor contrast between an aircraft and its background can be expected when:

(i) A dark aircraft appears against a dark background.

(ii) The background luminance is low.

(iii) Atmospheric haze is present.

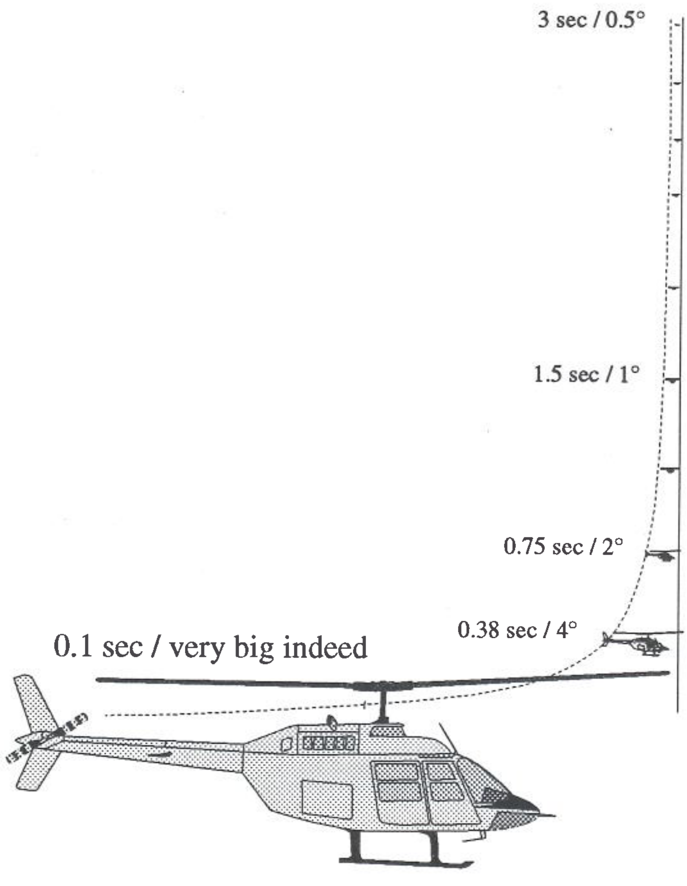
(iv) Lack of relative motion on collision course

The human visual system is particularly attuned to detecting movement but is less effective at detecting stationary objects. Unfortunately, because of the geometry of collision flightpaths, an aircraft on a collision course will usually appear to be a stationary object in the pilot's visual field.

If two aircraft are converging on a point of impact on straight flightpaths at constant speeds, then the bearings of each aircraft from the other will remain constant up to the point of collision. From each pilot's point of view, the converging aircraft will grow in size while remaining fixed at a particular point in his or her windscreen.

e. Visual angle.

An approaching high speed aircraft will present a small visual angle until a short time before impact. The diagram (see Figure 6) illustrates the case of a helicopter approaching a military jet where the closing speed is 600 knots. Not all situations will be this severe, first because only about one quarter of encounters are likely to be head-on and secondly because many encounters involve slower aircraft. Given the limitations to visual acuity, the small visual angle of an approaching aircraft may make it impossible for a pilot to detect the aircraft in time to take evasive action. Furthermore, if only the fuselage is used to calculate the visual angle presented by an approaching aircraft, i.e. wings and rotor blades are considered to be invisible, then the aircraft must approach even closer before it presents a target of a detcctable size.




Time to impact and angular size of oncoming aircraft

Figure 6

f. Effects of complex backgrounds

Much of the information on human vision has come from laboratory studies using eye charts or figures set against clear 'uncluttered' backgrounds. Yet a pilot looking out for traffic has a much more difficult task because aircraft usually appear against complex backgrounds of clouds or terraln. The pilot is faced with the complex task of extracting the figure of an aircraft from its background. In other words, the pilot must detect the contour between the aircraft and background.

Contours are very important to the visual system. The eye is particularly attuned to detecting borders between objects and in the absence of contours, the visual system rapidly loses efficiency. A finding of great importance to the visual detection of aircraft is that target identification is hampered by the close proximity of other objects. A major cause of this interference is 'contour interaction' in which the outline of a target interacts with the contours present in the background or in neighbouring objects. Camouflage works of course, because it breaks-up contours and increases contour interaction. Contour interaction is most likely to be a problem at lower altitudes, where aircraft appear against complex backgrounds. Contour interaction occurs in both foveal and peripheral vision but is a more serious problem in peripheral vision.

## 11. Anti-Collision Lighting.

a. Effectiveness of lights.

There have been frequent suggestions that the fitting of white strobe lights to aircraft can help prevent collisions in daylight. At various times BASI and the NTSB have each recommended the fitting of white strobe anti-collision lights.

Unfortunately, the available evidence does not support the use of lights in daylight conditions. The visibility of a light largely depends on the luminance of the background and typical daylight illumination is generally sufficient to overwhelm even powerful strobes. Some typical figures of background luminance are as follows:

| BACKGROUND | CANDELAS PER SQUARE METRE |
|---|---|
| **SKY** | |
| Clear day | 3,000.00 |
| Overcast day | 300.00 |
| Very dark day | 30.0 |
| Twilight | 3.00 |
| Clear moonlit night | 0.03 |
| **GROUND** | |
| Snow, full sunlight | 16,000.00 |
| Sunny day | 300.00 |
| Overcast day | 30 to 100.00 |

Figure 7

In theory, to be visible at three nautical miles on a very dark day a strobe light must have an effective intensity of around 5,000 candela (see Figure 7). In full daylight, the strobe must have an effective intensity greater than 100,000 candela. Most exsisting aircraft strobes have effective intensities of between 100 and 400 candela. Trials conducted by the US Military have generally confirmed the ineffectiveness of strobes in daylight.

A major U.S. Army study was conducted in 1970 in which observers on a hilltop were required to sight approaching helicopters equipped either with strobes of 1800, 2300 or 3300 effective candela or a standard red rotating beacon. It was found that none of the lights were effective against a background of daytime sky, however strobes were helpful when the aircraft was viewed against the ground.

FAA studies have also concluded that there is no support for the use of strobes in daylight. A 1989 FAA study of the effectiveness of see-and-avoid concluded that 'Aircraft colours or lights play no significant role in first directing a pilot's attention to the other aircraft during daytime'. An earlier FAA study considered that there was 'little hope that lights can be made bright enough to be of any practical value in daylight'. A major FAA review of the aircraft exterior lighting literature concluded that 'During daytime, the brightest practical light is less conspicuous than the aircraft, unless there is low luminescence of backgroud.

b. Use of red lights.

The use of red warning lights in transport has a long history. Red lights have been used in maritime applications since the days of sail and red became the standard colour for danger on railways. An 1841 convention of British railwaymen decided that white should represent safety, red danger and green caution. It is likely that the widespread use of red as a warning colour in aviation has come about more because of common practice than any particular advantages of that colour.

c. White lights versus red.

There are reasons why red is not the best colour for warning lights. Humans are relatively insensitive to red particularly in the periphery. About 2 percent of males suffer from protan colour vision deficiency and are less sensitive to red light than people with norrnal vision. A protan is likely to perceive a red light as either dark brown, dark green or dark grey. Any colour involving a filter over the bulb reduces the intensity of the light and field trials have shown that intensity is the main variable affecting the conspicuity of warning lights. Given a fixed electrical input, the highest intensities are achieved with an unfiltered white lamp. In a comparison of commercially available warning lights, white strobes were found to be the most conspicuous. If an aircraft does carry an anti collision light, then it should be an unfiltered white light rather than a red light.

## 12. Evasive action

The previous paragraphs have dealt with the 'see' phase of see-and-avoid. However, it should not be assumed that successful avoiding action is guaranteed once a threat aircraft has been sighted.

a. Time Required to Recognise Threat and Take Evasive Action.

FAA advisory circular 90-48-C provides military-derived data on the time required for a pilot to recognise an approaching aircraft and execute an evasive manoeuvre. The calculations do not include search times but assume that the target has been detected. The total time to recognise an approaching aircraft, recognise a collision course, decide on action, execute the control movement and allow the aircraft to respond is estimated to be around 12.5 seconds.

b. Evasive manoeuvre may increase collision risk

An incorrect evasive manoeuvre may cause rather than prevent a collision. For example, in a head-on encounter, a bank may increase the risk of a collision. There is a limited number of ways in which the aircraft can collide if they maintain a wings-level attitude, and the area in which the two aircraft can contact or the 'collision cross-section' is relatively small. However, if the pilots bank shortly before impact, so that the aircraft approach each other with wings perpendicular, then there is a much larger collision crosssection and consequently, a higher probability of a collision. This is not to suggest that banks are always inappropriate evasive manoeuvres, but that in some cases, evasive action can be unsuccessful or even counterproductive.

# UNITED KINGDOM AERONAUTICAL INFORMATION CIRCULAR

AIC 156/1993
(Yellow 126)
21 October

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## HELICOPTER PIPELINE AND POWERLINE INSPECTION PROCEDURES

### 1 Introduction

1.1 Pipeline and powerline inspection helicopters which operate in the airspace below 1000 ft agl are not normally able to predict their movements with sufficient accuracy to utilise the CANP system for advising military aircraft of their activities.

1.2 In order to reduce the potential for confliction between **pipeline** inspecting helicopters and low flying military aircraft a number of measures have been introduced including a notification system specific to the pipeline activities.

1.3 The nature of **powerline** inspections and the height at which they are flown is such that helicopters engaged on these duties are less likely to be in confliction with low flying military aircraft when actually engaged in the inspection. However, when transiting between individual tasks they are recommended to conform to the height criteria specified in paragraph 3.

### 2 Pipeline Inspection Notification System (PINS)

2.1 The system allows for the collation of information on pipeline inspection programmes and its distribution to military operators. It is known as the Pipeline Inspection Notification System (PINS).

2.2 Details of all inspection flights should be notified in advance to the Tactical Booking Cell (TBC) of the London Air Traffic Control Centre (Military) (LATCC (Mil)) - telephone number 0895-426701 or Freephone **0800-515544**, using the regions and/or routes shown at Annexes A and B. This information will be distributed by TBC to military operators to assist in flight planning. Amendments to notified flights should be passed to TBC as soon as they are known.

2.3 Annexe A shows the division of the country into a number of regions each of which has a designatory letter. Notification of inspections which fall within a particular region should be made using the appropriate letter. In the case of major pipelines which cross the regional boundaries each pipeline route has been allocated a letter which is shown at Annexe B, hence in the case of such an inspection flight the designating letter of the pipeline should be used in the notification.

2.4 Advice on any particularly intense military low flying activity will be notified in advance to known helicopter operators by the Manager of the Military Low Flying System in order to assist with the planning of inspections.

### 3 Recommended Height Profiles

3.1 Helicopters engaged on pipeline inspection flights are recommended to operate in the height band 500 ft to 700 ft agl where they will be above, and skylined to, the majority of military low flying aircraft which operate below 500 ft agl. However, since both pipeline inspection and military low flying aircraft can be expected to operate outwith these specific height bands pilots are not absolved from maintaining and applying a normal lookout and avoidance criteria. In particular, it should be noted that helicopters involved in inspections will continue, when required by the inspection, to descend to 300 ft agl in accordance with their dispensation from the provisions of the Rules of the Air Regulations 1991, Rule 5 (1) (e).

## 4 Implementation

4.1 The PINS will be operational with effect from **25 October 1993** and the recommended heights are effective immediately.

4.2 It must be emphasised that the procedures detailed in this Circular are advisory and that the promulgation of activities will be in the form of warnings not avoidances.

4.3 This system will be reviewed after six months operation and users are invited to forward comments or recommended improvements by **1 May 1994** to HQ NATS at the following address:

National Air Traffic Services
Airspace Policy 6
Room T1022
CAA House
45-59 Kingsway
London. WC2B 6TE

Tel: 071-832 5459

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This Circular is issued for information, guidance and necessary action.

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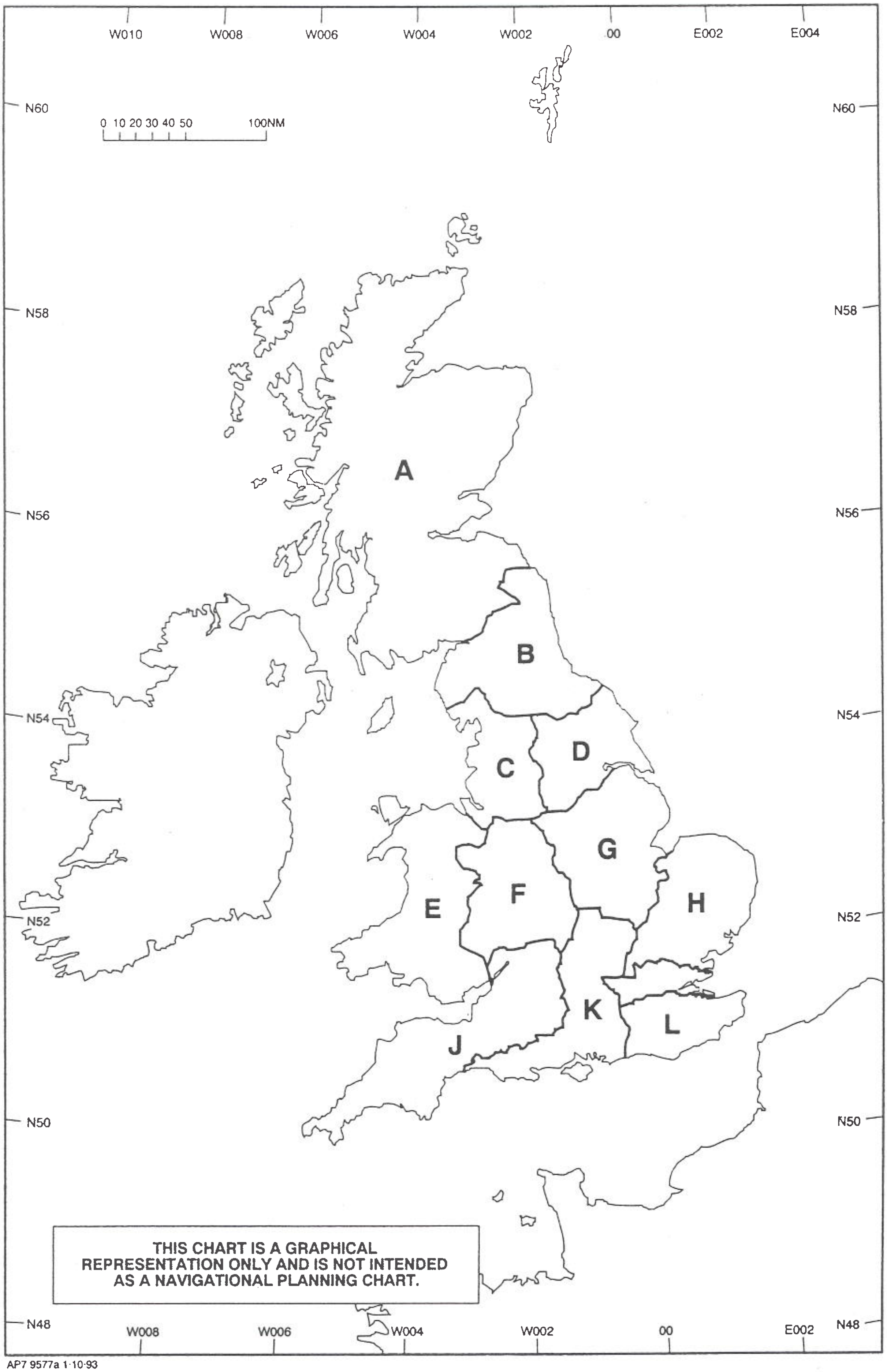
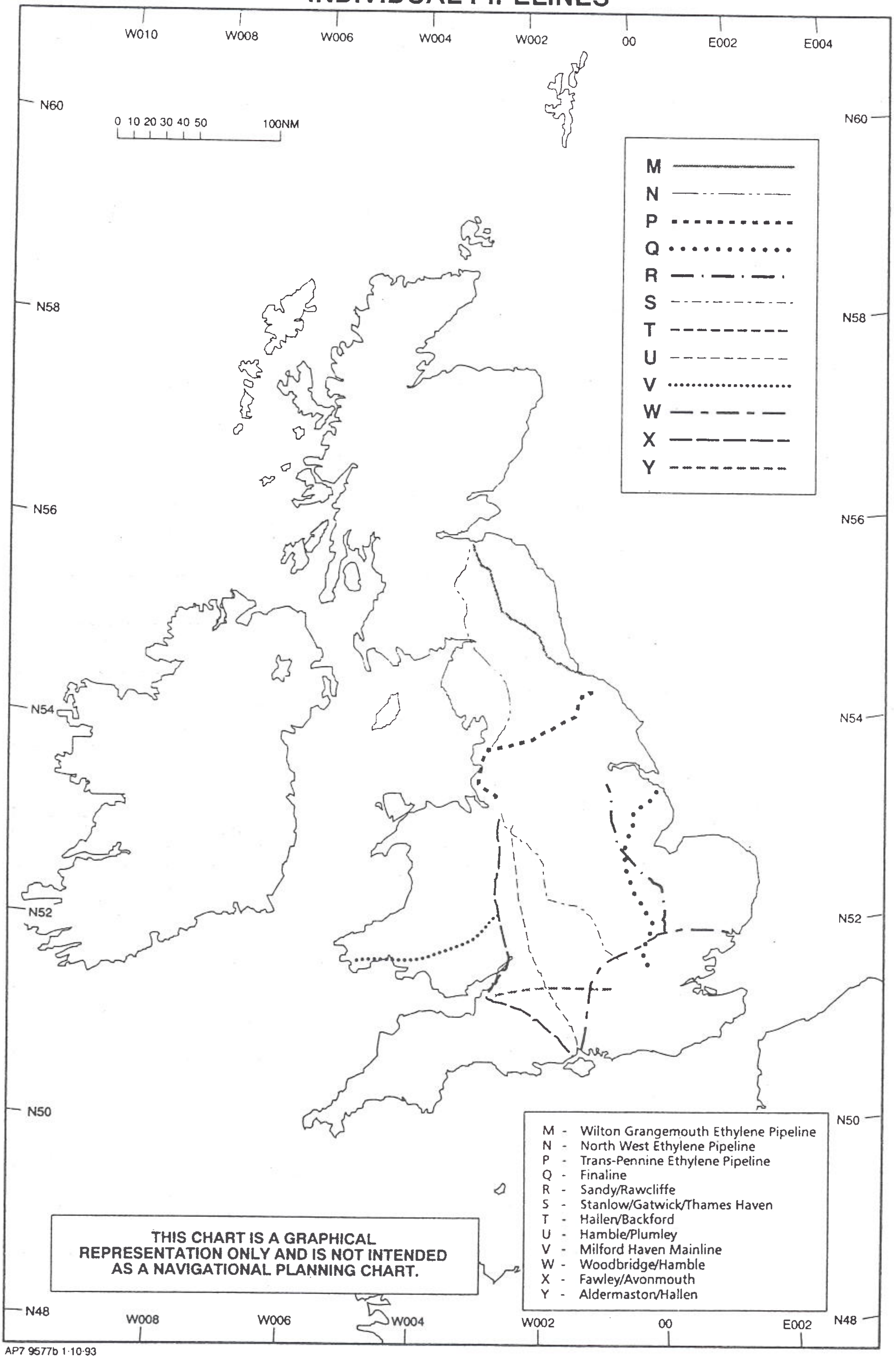
# PINS REGIONS



# INDIVIDUAL PIPELINES



## MID-AIR COLLISIONS INVOLVING UK CIVIL, POWERED LIGHT AIRCRAFT, MAY 1977 TO JUNE 1993

| DATE | AIRCRAFT TYPES | CIRCUMSTANCES | FATALITIES |
|---|---|---|---|
| 15 May 1977 | Bell 206<br>Tigermoth | Helicopter on takeoff collided with aircraft on final approach | 1 |
| 25 Nov 1978 | MS Rallye<br>Cessna 150 | Aircraft collided in visual circuit | 1 |
| 8 Sep 1979 | Piper PA 38<br>N/K | Collision whilst in cruise | 0 |
| 8 Mar 1981 | Robin<br>Glider | Collided with glider during descent | 0 |
| 22 Apr 1981 | Quickie<br>Cessna 152 | Collided while engaged in air-to-air photography | 1 |
| 30 Apr 1981 | Piper PA28<br>Piper PA28 | Aircraft collided on final approach | 2 |
| 26 Aug 1981 | SF25 Falke<br>Capstan Glider | Collided 'head-on' on finals with aircraft carrying out opposing circuits | 2 |
| 18 Apr 1982 | Piper PA18<br>Glider | Tug collided with glider during descent | 0 |
| 16 Jul 1983 | Cessna 182<br>Mooney 20K | Collided during practice air race | 1 |
| 29 Feb 1984 | Cessna 150<br>Military A10 | Aircraft collided 'head-on' at approximately 1,000 ft in poor visibility | 1 |
| 12 May 1984 | Rockwell 112<br>Glider | Collided at 3,000 ft in VMC | 1 |
| 29 Jun 1984 | Pitts Special<br>Pitts Special | Collided during practice formation aerobatics | 2 |
| 19 Aug 1984 | Bolkow 209<br>Piper PA28 | Collided during air race | 2 |
| 10 Nov 1985 | Cessna 152<br>Piper PA28 | Collided at 3,000 ft | 0 |
| 5 Feb 1986 | Bell 47<br>Hughes 369 | Collided in the cruise at 1,500 ft | 0 |
| 29 Aug 1986 | Rallye<br>Glider | Tug collided with glider during initial climb | 0 |
| 25 Feb 1987 | Cessna 152<br>T67B | Collided at 10 ft on finals | 0 |
| 10 Aug 1987 | Piper PA 28<br>Piper PA 28 | Collided with one ac climbing and one descending | 0 |
| 18 Jul 1988 | Piper PA38<br>Piper PA38 | Collided during unauthorised 'dog-fighting' manoeuvres | 1 |
| 6 Aug 1988 | Pitts Special<br>Yak 50 | Touched wingtips during formation manoeuvre | 0 |

| DATE | AIRCRAFT TYPES | CIRCUMSTANCES | FATALITIES |
|---|---|---|---|
| 4 Sep 1988 | DG-400<br>CAP 21 | Collided during takeoff / landing | 0 |
| 22 Jan 1989 | Cessna 182<br>Cessna 152 | Collided over airfield | 0 |
| 10 Feb 1989 | Cessna 152<br>Microlight | Collision at 400 ft after takeoff | 1 |
| 13 Nov 1990 | SA 350 Ecur<br>Bell 206 | Collided during formation filming | 0 |
| 3 May 1990 | Grob 109<br>Robin | Collision with both aircraft in the cruise | 2 |
| 19 May 1990 | Tigermoth<br>Piper PA28 | Collision between departing and joining aircraft | 4 |
| 14 Apr 1991 | Great Lake<br>N/K | Collided in cruise | 0 |
| 17 Aug 1991 | Piper PA 28<br>N/K | Collided during air race | 0 |
| 29 Aug 1991 | Cessna 152<br>Military<br>Jaguar | Collision at low level. Cessna involved in photography. Jaguar on low level training flight | 2 |
| 23 Jun 1993 | Bell 206<br>Military<br>Tornado | Helicopter involved in pipeline inspection. Tornado on low level training flight | 2 |



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