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ELECTRONICS DIVISION

Colloquium on

'HELICOPTER GUIDANCE AND NAVIGATION SYSTEMS'

Organised by

Professional Group E15
(Radar, sonar, navigation and avionics)
Monday 12 January 1981

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THE INSTITUTION OF ELECTRICAL ENGINEERS

A colloquium on

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ELECTRONICS DIVISION

Colloquium Organised by Professional Group E15 (Radar, Sonar, Navigation and Avionics) on "Helicopter Guidance and Navigation Systems" to be held at Savoy Place on Monday, 12 January 1981

PROVISIONAL PROGRAMME

Topics included

	10.00 am	Registration and coffee	
Session 1		**Operational Requirements**	**Chairman: J Morrall (CAA)**
1.	10.30	"Recovery of helicopters in poor visibility"	G Harrison (RAE Bedford)
2.	10.55	"Requirements for navigation and guidance"	Captain A C Gordon (Bristow Helicopters)
3.	11.20	"Navigation of helicopters in support of the North Sea oil industry"	Capt T C Porteous (British Airways Helicopters)
4.	11.45	"The development of MADGE as a precision approach aid for helicopter operations on an offshore structure"	D E Helmore (CAA) and H L Derwent (MEL)
	12.10	Discussion	
	12.35	LUNCH	
Session 2		**Solutions and Unsolved Problems**	**Chairman: G E Beck**
5.	1.45	"The application of inertial and associated autonomous guidance techniques to helicopters"	W H McKinlay (Ferranti Edinburgh)
6.	2.10	"Helicopter night vision piloting systems"	Dr J Barrett (RAE Farnborough)
7.	2.35	"Possible techniques for wire detection"	Dr K E Potter (RSRE Malvern)
8.	3.00	"Abnormal behaviour of Doppler navigation systems"	K Gray (Racal Decca)
	3.25	TEA	
9.	3.45	"Rotor blade radar as a navigation and approach aid"	D Roger (RSRE Malvern)
	4.10	CLOSE	

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RECOVERY OF HELICOPTERS IN POOR VISIBILITY

G. Harrison

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Background

Much thought and activity has already been devoted over the years to the needs of conventional fixed-wing aircraft and, as a consequence, the poor visibility landing systems requirements have been fairly accurately established. Although the more recent debates linked to the ICAO microwave landing system (MLS) have endeavoured to encompass VSTOL aircraft and helicopter operations, these aspects have been somewhat more speculative because there has been less practical experience of them in poor visibility.

It may be useful, therefore, to recall the essential differences between helicopter and conventional fixed-wing aircraft operations which affect consideration of the recovery systems. In the case of fixed-wing operations to runways, accurate flightpath alignment with the runway CDM and the need to constrain the touchdown rate of descent and longitudinal scatter at constant and relatively high approach speed, linked to the need to limit the effects of guidance system noise on automatic flight control systems and on control surface movements, leads to the now familiar azimuth and elevation angular guidance accuracy specifications for ILS and MLS. These reflect the need for high angular accuracy, stability and low guidance noise. The provision of range information, unless needed to compute flare-out guidance, is not particularly critical: its use is then primarily for monitoring distance-to-go, for control law optimisation, or for indicating decision heights on glidepaths where radio altimeter information suffers terrain profile errors. Helicopter operations to small restricted landing areas, on the other hand, are not critical in respect of precise approach direction or glidepath, but do need accurate deceleration guidance and, because of low speed handling problems when flying on instruments, need especially low pilot workload guidance displays. The latter require low guidance system noise, similar to that required for fixed-wing operations.

The operational requirements

The probable UK user applications for helicopter recovery aids in the foreseeable future include Naval operations from ships, Army and Air Force field support, civil off-shore support operations and shuttle flights in support of civil Category II and III fixed operations. Most other helicopter flights over land can be made in reasonable visibility and in visual contact with the ground. Operations to runways should present no undue problems when ILS is available, providing that the visual lighting aids are suitable. Restricted sites are often thought of as posing the need for steep approach angles but it is found that, in most situations, approach angles up to 6° will suffice, although exceptionally there may be sites which need an approach angle up to 15°. The most stringent requirement on guidance arises when, as in the Naval case,

G. Harrison is at the Royal Aircraft Establishment at Bedford.

a small landing area is co-located with obstructions and, additionally, ship motion and manoeuvre have to be accommodated.

The cost-benefit of achieving particular operational weather minima in relation to weather statistics needs very careful assessment. For operations which are not critical in respect of timing, or diversions are available, annual percentage weather occurrence is relevant. For critical operations, however, the likely duration of individual occurrences is the more relevant aspect: when transitions to the very low visibilities occur, the low visibility tends to persist, and hence a low percentage occurrence can mean a few occasions but each being of long duration. Transitional visibilities tend to reduce to 50 to 100 m, or clear to 300 to 400 m relatively quickly in general. The implication of this is that, to be cost effective, low visibility aids should be geared to a meteorological visibility of either about 300 m or 50 m, broadly speaking. Typically, visibility is less than 300 m for about 300 hours/year in the UK.

The Problems

The problems which helicopter recovery presents in these low visibilities fall into a number of areas.

If it is essential to fly steep glidepaths, then there is the danger of encountering vortex ring problems if the rate of descent is too high; if, as a consequence, the rate of descent is kept low, then forward speed must also be low, thereby increasing the low-speed handling problems. This latter is a demanding piloting task when flying on instruments below the minimum power speed, especially in crosswind conditions. At night and in poor visibility it is difficult visually to judge range and deceleration when the angular extent of forward visual cues is small. The Naval environment probably presents the most severe challenge in respect of the limited extent of visual cues, and of EMC, vibration, salt spray, icing and radio signal multipath interference from ship structure and sea surface. Ship freedom to manoeuvre, ship motion in high sea states, and high wind conditions make wide azimuthal approach guidance coverage essential. Electronic guidance compensation can be employed for ship heading changes but, because of sea multipath effects, ship roll stabilisation of azimuth guidance on small ships will probably need to be effected physically to avoid undue tilting of the ship antenna aperture relative to the sea and consequent excessive signal amplitude and phase distortion across the antenna aperture. Sea surface reflections in typical north Atlantic sea conditions will cause signal fades of 10 dB or more at the shallow angles corresponding to low-level helicopter approach paths. The need to recover helicopters in fog or heavy rainfall limits the electromagnetic frequency spectrum practically available to below about 20 GHz. If the approach is flown manually, then pilot workload will be high during the instrument deceleration unless the cockpit display of guidance and attitude is reasonably noise-free and is easily and quickly assimilated. Automatic flight control systems, if simplex, must have authority limitation at the expense of rapid response as the hover is approached but, if multiplex, are expensive in size, weight and cost of ownership. The cost-benefit of low visibility landing aids is not easily proven prior to accidents occurring and, when operating economies have to be made, it is easy to regard them as something of a luxury. The process of civil certification of new operations must not be under-estimated.

Recent work

The aim of recent work has been to evolve a minimum cost helicopter system for use in visibilities down to 50 m which is capable of being flown manually and, if necessary, using existing flight instruments. Any autopilot assistance should be no more than simplex self-monitored. For over-sea operations,

economy can be made by utilising the radio altimeter in conjunction with range information to provide elevation guidance. For the range and azimuth guidance, a 5 GHz transmission frequency has been adopted, with interferometer angle measurement and ranging transponder adjacent to the landing area. Flight and simulator investigations at RAE Bedford have been followed by flight trials to an off-shore platform and to ships. This has enabled flightpath profiles, procedures, handling characteristics, pilot factors, guidance, cockpit displays and visual aids to be assessed. A system has been evolved which enables the pilot to manually decelerate to the hover with an acceptable workload when using only conventional electro-mechanical instruments. It employs pitch, roll and height directors with heading held steady for the final part of the approach to the landing area. The additional use of simple autopilot heading and height hold modes, if available, reduces pilot workload to a very low level. The guidance format for an integrated electronic display for the whole terminal navigation and deceleration manoeuvre is being developed and evaluated in flight. Complementary visual lighting aids for use during clear day and night approaches are being refined, and the special visual aids to assist the final landing manoeuvres following an instrument approach to the hover are being assessed. The mechanisms and magnitudes of sea multipath effects at 5 GHz have been studied and measured in some detail as a necessary input to the total radio system design.

The messages

The salient messages which have emerged from the development and proving work to date of low visibility helicopter recovery systems can be summarised as follows. The helicopter handling factors - stability and control at low air speeds in adverse winds - are dominant. The minimum airspeed, when using only visual lighting aids or only positional radio guidance, is about 60 km; head-winds will reduce the corresponding closing speed. Visual deceleration even on a clear night or dull day is difficult to judge correctly when only the distant landing area is visible. Given well developed flight directors and control laws, manually flown instrument approaches to the hover are quite practicable. Simple autopilot modes give a very worthwhile benefit. Instrument deceleration requires very good and sensitive pilot displays if workload is to be kept down to an acceptable and safe level. This in turn demands low noise guidance signals. Accurate range and velocity guidance is crucial. All the experience to date confirms the view that the logical break-point between instrument and visual guidance is at or close to the hover. It follows that electronic aids for the land-on manoeuvre are unlikely to be cost-effective. Operators will only subscribe if the costs are reasonable, so that complexity must be minimised and what is readily available must be fully exploited.

The recovery of helicopters to airfield runways, given existing aids such as ILS, is essentially a visual problem. Improvements to approach lighting patterns to match the lower helicopter approach speed and to runway lights to increase higher angle intensity seems likely to offer considerable benefit. Recovery to off-shore platforms, in the absence of an instrument deceleration capability, appears to warrant the use of a visual glidepath indicator in conjunction with radio altimeter to deduce range and assist deceleration, and possibly the addition of an omni-directional visual beacon to replace the disappearing flare-stack.

In respect of the radio recovery guidance system, adequate built-in performance monitoring is essential if equipment redundancy is to be minimised, or eliminated, in order to assure adequate integrity and safety and to minimise complexity and cost. Guidance system requirements appear to be broadly as follows:-

Coverage:	Azimuth - ideally 360° and not less than 120°
	Elevation - 1 to 10° at long range 1 to 45° at short range
	Range - minimum less than 50 m maximum at least 5 miles
Accuracy:	Azimuth - 1 to 2°
	Elevation - 0.25° at long range 1 to 2 m in height at short range
	Range - 3 m at short range
	Velocity - 2 to 3 km
Noise (rms):	Azimuth - 0.05°
	Elevation - 0.08° at long range 0.7 m at short range
	Range - 1 m at short range
	Velocity - 1.5 km
Output filter:	Azimuth, Elevation, Range, < 0.3 Hz Velocity < 0.1 Hz

The inclusion of a datalink to permit ground, or ship, monitoring of the approach and a talk-down mode is clearly advantageous. The system power budget must take account of typical sustained signal amplitude variations at 5 GHz of - 2 to - 9 dB due to sea reflection multipath, reaching - 20 dB on occasions. Radio altimeter height guidance will require inertial smoothing to counter the effects on guidance noise of sea motion at low helicopter speeds.

Conclusions

In summary, we can say that piloted landings in low visibility are practicable using available technology. The final landing from the hover is best achieved visually. An instrument approach from 5 miles to the hover requires a radio system supplemented where necessary by inertial smoothing. The key areas demanding enhancement are the helicopter out-of-wind limits and stability, pilot displays and workload and safety aspects rather than radical advances in guidance. Finally, the complexity and cost of recovery systems must be kept to a minimum if operators are to be encouraged to insure their operations in respect of landing success and safety in low visibility.

Helicopter Guidance and Navigation

1980 will be noted as the year that I.F.R. operations in various overland roles joined the already extensive Offshore applications of the Sixties and Seventies. This has been brought about by the advent of the Twin-Engined Executive helicopter with full stabilisation and state-of-the-art Avionics.

Whilst Offshore and Onshore detailed requirements may vary, the Guidance and Navigation needs fall into the same categories, i.e., a) En Route, b) Terminal Approach and c) V.H.F. Homing. It would be desirable for the first two of these requirements to be met by one item of airborne equipment.

Existing En Route Navigation reflects the fact that helicopters often operate away from VOR beacons and at low altitudes, and consequently Decca, Loran and the available VLF services provide the navigation capability. However Precipitation Static continues to present a problem which has only partially been overcome by 'H' field antenna improvements. Any future aid must include a DR function to take account of this and any other period of loss of signal.

Although the trend is towards digital display of position, track and speed information a case still exists for a supplementary flight log to give a pictorial representation. This is most useful in the inter-rig shuttle phase of Offshore operations and would also provide a valuable aid in the overland en-route emergency descent situation.

The capabilities of Airborne Radar have expanded significantly in recent years so that what was once a Weather Avoidance Aid now provides not only Offshore En-Route Navigation Guidance but also per its Terminal descents to the lowest minima so far experienced Offshore. The continued progress towards integrating Radar with a digital en-route aid, thereby providing the possibility of pictorial positioning, is to be encouraged.

A C Gordon (Bristow Helicopters)

Existing Precision Approach Aids such as ILS continue to satisfy aerodrome approach requirements, particularly if, with a marginal reduction in Decision Height approaches can then be completed in all weathers by the use of directional high intensity lighting.

Away from the fixed aerodrome the area open for maximum improvement is the heliport, both Onshore and Offshore, where constraints of physical size have lead to the concept of the Mobile M.L.S. with minimal aerial array. Even here good lighting is necessary to complete the transition to a visual landing.

An attribute always associated with helicopters is Search and Rescue. Often the only available Search aircraft is one from the same base as the helicopter that is missing. Both in the North Sea and in the jungles of Indonesia civil helicopters are equipped with Homing devices. Our experience to date is not very good and again antenna design seems to be the problem area.

NAVIGATION OF HELICOPTERS IN SUPPORT OF THE NORTH SEA OIL INDUSTRY

T C Porteous

When gas was first found in the southern part of the North Sea in 1964, there were only a few mobile drilling platforms, some forty to sixty miles off the East Anglian coast. The navigation problem was relatively simple as there were few helicopters required to service these rigs, and for the whole route outbound and inbound the crews were in VHF communication with their home base. This led to easy control of aircraft movements and ensured safety throughout the flight as position reports were easily made every ten minutes. Position was determined by the use of the Decca navigation system, initially by pilots plotting Decca co-ordinates on the charts, but soon the Decca flight log was introduced with its most useful moving map display, on which the required tracks could be drawn. When oil was discovered in the north, the exploration rigs were much further offshore, but were not initially numerous. Therefore, the same navigation system was used with direct tracks being drawn to each installation. Separation was assured by helicopters flying outbound at certain heights, and inbound at other designated heights. Because of the distances involved, usually between 100 and 150 miles from the Aberdeen or Sumburgh bases, HF communications were used to make the necessary safety position reports every ten minutes, although the flight watch was invariably transferred to the destination installation when the helicopter came within VHF range of it. To help in identifying the target rigs, these installations had NDBs, usually of different frequencies. Because frequency allocation was sometimes a problem and frequency coincidence happened, NDBs would not be activated until requested by the helicopter crews. Although initially most flying was done under visual flight rules, the few instrument rated pilots if flying above cloud, could use the NDBs for procedural led downs.

The fact that not all crews were rated meant that on bad weather days aircraft had to fly close to the ground at what ever height they could achieve without entering cloud. This could have had a disastrous effect as the number of helicopters involved increased. The single most important development in recent years has been the wide spread achievement of instrument rated crews, thus permitting aircraft to fly at sensible altitudes so that an acceptable air traffic system could evolve.

Captain T C Porteous is Chief Pilot Technical Services in British Airways Helicopters Ltd.

Present

Since these early days, the search for oil has grown in intensity and there are at present some 34 fixed production platforms in the Northern UK sector alone; In addition 31 mobile installations, excluding diving ships, crane barges, pipe laying barges, drilling ships, exploration rigs and fire fighting vessels. All have to be serviced, that is, men and materials transported between them and shore bases, on a regular basis. Because of formalised work patterns, most of these installations need more than one return journey per day; for example the Forties Field, some 110 miles east of Aberdeen, consisting of four main platforms and one ship, has on average 10 - 12 S61N helicopters to and from it daily. Therefore, you can see from the wide scatter of locations to be supported, and by inference the large number of helicopter movements to be planned, a traffic system acceptable to all concerned had to be devised, with accurate navigational integrity. In the south, because there are few mobile installations and because there are relatively few helicopters in support, some 9 return flights from my company's base per day, the old system of direct tracks to and from the rigs can still be applied. However, an added hazard exists in the form of military activity. So special helicopter zones have been established to protect these helicopters to a degree. The navigation systems used are Decca, Danac, and on at least one aircraft ONTRAC, which uses VLF radio beacons and OMEGA. More of this later. Further north, out of Aberdeen, there is an arc of offshore installations between a bearing of approximately 030° and 120° degrees. To ensure safe separation, all aircraft going outbound fly on certain radials based on the Aberdeen VOR beacon, and returning aircraft fly on other specified radials. For example, outbound to the Claymore Field, the radial is 051, inbound is 054. In addition to keeping strictly to this radial separation, the aircraft fly outbound at 2000 or 3000', and return at 1500 or 2500'. At altitudes above 3000', aircraft fly under the internationally recognised quadrantal separation system; at altitudes below 1000' air traffic will fly at designated hundreds of feet, and keep a sharp look out and listening watch! Right up in the north, out of Sumburgh, the problem of track provision is different. Most of the destination installations are basically in the same area, that is the East Shetland Basin. Therefore a system of parallel tracks has been established for outbound and inbound traffic. Complications which could arise from different airfields being used, like Unst in the far north, are overcome by having specified joining positions, and crossing points. Aircraft from Aberdeen to the East Shetland Basin must join this system. They do so from either overhead Sumburgh, or by joining the tracks at specific positions. Most aircraft are fitted with weather radar which have a mapping mode, and this helps pilots to "see" rigs and platforms, although up until now there has been no way of identifying these targets. However, used in conjunction with rig NDB equipment, to ensure a clear area ahead, crews can perform a letdown through cloud to make a visual landing. Unfortunately, there are so many installations offshore now that dedicated frequencies are hard to find. I'll talk more of this problem shortly.

Now, I'll return to the question of control of this air traffic. In the South VHF communication with home base, the local RAF control at Coltishall, and the rigs is very clear. Out of Aberdeen, the airfield primary radar watches over aircraft in the potentially dangerous closest 40 miles, potentially dangerous that is for aircraft tend to converge on each other. Beyond 40 miles and out to 80 or beyond if possible, Highland Radar watches the aircraft with a secondary radar. Almost all of the helicopters now have transponders which identify individual aircraft. Beyond the range of Highland radar, aircraft revert to the flight watch system, where they report their positions relative to the Aberdeen VOR every 10 minutes. This call is made on VHF to a rig or platform within range or on HF to home base and is purely a safety device to let would be rescuers know their last known position should they disappear. Out of Sumburgh, the parallel tracks are flown by reference to the Decca flight log. The airfield radar controls aircraft out to 25 miles; Shetland Radar, based on the northern island Unst, provides control out to 80 miles or so, at which point aircraft transfer to the East Shetland Basin frequency of Viking control. The East Shetland Basin is a very crowded terminal area. Despite this, all control is exercised by voice only; there is no radar control available. Consideration has been given to providing radar, but because of the number of production platforms, by their nature producing oil and gas, it is felt that radiating radars could cause fire or explosion hazards. Therefore, to date, helicopters are controlled only by voice, reference being made to reporting points, necessarily relying on the crew interpretation of existing navigation aids.

I have mentioned the main aid to navigation, Decca. The Decca Mark 19 is a very reliable equipment, particularly in this part of the world. The accuracy is needed to describe precise tracks as already explained. The latest aircraft on the North Sea, the Sikorsky S76, has not enough room on the instrument panel to place the Decca flight log, and so crews have come to learn how to operate with Decca Tans, Tactical air navigation system, which uses a Decca 19 receiver, and to do without a valuable pictorial representation. The main value of the flight log is in being able to picture where other aircraft are in relation to yourself. For example if an aircraft is reported at 90 miles on the 087 radial, a pilot can see that position on his flight log and relate it to his own position. However progress is away from this, although other forms are becoming available. Other navigation systems are being tried, but have generally proved not to be as accurate as Decca. The VLF/Omega system ONTRAC is in use on an aircraft in the southern North Sea, but even over such distances, its accuracy has been disappointing. GNS 500 is another VLF equipment, and although several aircraft have used it, its accuracy is not as good as Decca's.

Future

So much for the present. I mentioned the difficulty in providing dedicated NDB frequencies for all rigs. Now that most helicopters in the North Sea are equipped with airborne digital weather radars with beacon mode capability, it is possible to install X-band coded transponders on rigs, and perhaps approval can be obtained to use these signals to identify rigs, rather than NDBs and develop a let down technique that does not require the rig to be over flown.

Now that Tans is a part of every day life, pilots are getting used to this new generation of system. Tans is itself regarded as an intrim equipment, with 10 way points (that is selected destinations or turning points) along and across track readout capability, ground speed and wind velocity functions plus reversion to dead reckoning should the receiver fail. The advanced system, Decca Rnav, will have all of this plus the enhanced capability of 100 way points and will be capable of receiving VLF, VOR/DME and Decca. The use of the data link system is envisaged as a possible means of circumventing the short comings of radar control in environmentaly highly sensitive areas. A series of trials is under way, and phase one was satisfactorily completed last April. During this trial the capability of S61 airborne equipment automatically to transmit signals of sufficient strength and quality to pass useful information to be reproduced on a teleprinter was proved. Ranges over which the trial was successful were up to 80+ miles using VHF and 150 miles HF. The second phase of the trial should take place next spring and will prove that relevant information, for example call sign, position, altitudes, destination can be transmitted and presented in a form that permits use in a control situation. This information could be displayed in tabulated form or, more efficiently in my view, on a display similar to the normal radar CRT display. This latter presentation would be most advantageous because each data link aircraft would be interrogated from a ground station every 6 seconds, and just as in the aircraft, the changing pictorial presentation is of most value. There, however, is the weakness in the concept; all aircraft operating within the area in question would have to be fitted with this equipment if ground control were to be exercised. I do not believe this is a barrier, because operators in the North Sea have always shown themselves eager to improve the safety of the whole operation.

Up to now, helicopters have lagged far behind the fixed wing fleets in avionics fits. We are only now seeing helicopters flying with flight directors. My own company is progressing directly from the old fashioned artifical horizon and compass to fully coupled flight directors. We have a Bell 212 based in East Anglia which is so fitted, and our S76 aircraft are similarly equipped. We have found this equipment extremely valuable and its integrity is assured. The equipment flies the aircraft more consistently accurately than the pilot who merely has to instruct the system by heading, height, rate of climb, navigational selection inputs. So, we are proceeding to where pilot induced inaccuracies are reduced, or completely eradicated, and the accuracy of equipment is the base line. However, more is being done, and the whole question of computerised flight management and maintenance surveillance systems has been opened up with a view to providing navigation information which can be fed to the flight director. The basic flight management system considers such items as aircraft weight, outside air temperature, air pressure and will inform the pilots by way of a digital read-out or CRT presentation what its altitude and speed should be for best fuel consumption. It can tell him what maximum range would be if he entered icing conditions, or if he had an engine failure.

Maintenance surveillance takes the form of selected inputs being retained in an aircraft computer to be either interpreted by an engineer directly from the CRT, or drained electronically from the aircraft to a maintenance computer in the main engineering base.

You may have read of a US Coastguard system under development which aptly describes the way ahead. It combines Navigation, Guidance, Flight Control, Communications, Cockpit Controls and Displays, Sensors and Maintenance monitoring to provide a total mission capability. Much work has been done in this country, and I believe that a British system will be flying this year which will be every bit as capable as the US one, and will have other features such as the ability to navigate by reference to NAVSTAR, the Global Positioning System based on satellite reference.

Summary

In summary, then, navigation systems for helicopters in support of the North Sea oil industry have taken great strides in the last 15 years or so. We have come from simple, direct track flying where the rig was identified visually, then by a coded NDB, to sophisticated track systems designed to ensure safety at all times. We are now seeing the beginnings, in the helicopter world, of aircraft being controlled by navigation systems which are merely selected by the pilot, and which are being more accurately flown than in the past. I believe we shall soon see data link systems of reporting and control in terminal areas, particularly offshore, and navigation systems which take several inputs, the most accurate of which will be selected by the on board computer and fed into the aircraft system.

I do not see the pilot being replaced by these computers, but I do see these fascinating systems enhancing safety, economy and efficiency beyond anything we could imagine only a few years ago.

THE DEVELOPMENT OF MADGE AS A PRECISION APPROACH AID FOR HELICOPTER OPERATIONS ON AN OFFSHORE STRUCTURE

H.L. Derwent and D.E. Helmore

The Operational Requirement

Following early work by British Airways Helicopters, the British Helicopter Advisory Board (BHAB) submitted a "Civil Operational Requirement for a Helicopter Instrument Approach Aid" to the C.A.A. in the mid 1960s. In 1969 both NATO and U.K. MOD issued operational requirements for a Tactical Landing System for all classes of military aircraft, which encompassed the civil operational requirement.

Following flight trials in 1976 which involved the Royal Aircraft Establishment, the Department of Energy, Shell (UK) Exploration and Development Ltd., Bristow Helicopters Ltd., British Airways Helicopters Ltd., BHAB and MEL an optimum flight profile for the use of helicopters offshore was evolved.

An Appendix was added to the BHAB operational requirement in 1978 titled 'Operational Requirement for Precision Approach Aid for Helicopter Operations to Offshore Helipads'.

Stated simply this operational requirement included:-

a) Azimuth and Elevation Guidance.

b) Precision D.M.E.

c) Volumetric Coverage.

d) Offset Azimuth Approach Path.

e) Offset Glide Slope plus level segment from 0.5 nms.

f) Visibility minimum of 300 metres.

g) Minimum Decision Height of 100 ft. ASL.

h) Multiple Approach Headings (QDMs).

Mr. H.L. Derwent, Manager, Interferometry Division, M.E.L.
Mr. D.E. Helmore, D.D.A.W.O., C.A.A.

MADGE System Development

The basic MADGE military system consists of:-

Aircraft System

Transmitter/Receiver

Logic Unit

Antenna System

Pilots Controller

Display System

Ground Station

Elevation Antenna Unit (Passive Glide Slope)

Azimuth Antenna Unit (Passive Localiser)

Transponder with Omni Antenna

This system was designed to provide landing guidance to all classes of aircraft in visibilities of 400 metres and decision height of 100 feet in any battlefield environment. The operation of the system will be described.

This system was demonstrated in prototype form in 1974, 1975 and 1976 at Penzance with British Airways Helicopters Ltd. and in France and Italy.

The offshore system was developed from the Tactical System and consists of:-

Aircraft System

Transmitter/Receiver

Logic Unit

Antenna System

Radio Altimeter Interface Unit

Offshore Pilots Controller

Display System

Ground System

Azimuth Antenna Unit (Passive Localiser)

Transponder with Height Diversity Antenna

Offshore Processor

Data Recorder (Optional)

Monitor Beacon

Turntable Assembly

The operation of this system will be described.

This system is installed on the BERYL 'A' Platform of Mobil North Sea Ltd. and in three Sikorsky S61 Helicopters of Bristow Helicopters Ltd.

A programme of Approval and Certification has been carried out since the equipment was commissioned in mid 1979.

Approval and Certification

The ILS CATEGORY 3A partition of risk and integrity criteria have been used as the basis of the General Submission for the Approval and Certification of the MADGE Offshore System.

The flight trials programme will be described and current status of the programme will be reported.

THE APPLICATION OF INERTIAL AND ASSOCIATED AUTONOMOUS GUIDANCE TECHNIQUES TO HELICOPTERS

By W.H. McKinlay

1. Introduction. Because of their versatility helicopters are used in a variety of operational roles. Consequently, there are many different navigation requirements. The purpose of this paper is to examine these different navigation requirements and also to consider the extent to which they can be met by autonomous or self-contained systems.

2. Operational Requirements. Many civil helicopters operate in highly developed countries well served with standard navigation aids. Helicopters operating in this environment have to carry certain mandatory radio aids. Consequently there is not always a case to fit an autonomous system. However, helicopters are also used world-wide, particularly in oil or gas fields. They therefore require either a self-contained system or a universal ground-based aid such as Omega.

   The most stringent requirements for position finding apply to helicopters which are used for survey purposes. The accuracy requirement is of the order of 10 metres and this has led to some interesting work which will be described later.

   Army helicopters operating over land fly at extremely low altitudes. Because they exploit the terrain by flying up valleys or round obstructions, they do not have a navigation requirement to follow pre-planned tracks. They do,however, require the most accurate navigation possible so as to be able to locate themselves continuously.

   Many helicopters are used in naval operations, largely because they can operate from quite small ships. They require a navigation system which can be run up on board a moving ship and which will then give continuous position data with the minimum dependence on ground or ship-borne transmitters.

   All these requirements can be summed up by saying that civil helicopters operating in an airways environment do not normally require self-contained systems. Civil or naval systems for world-wide use require position data to within about one mile. Army helicopters could use high accuracy systems if they were available within stringent cost and weight limitations. There are prospects for any system which can help survey operations in territory in which no ground aids are available.

3. Possible Navigation Systems. The navigation systems which can be considered are either externally derived or self-contained.

   The externally derived systems are outside the scope of this paper. Apart from the standard aids used in airways systems the two most interesting developments are Omega and Navstar GPS. The latter system is not yet operational but clearly any future thinking about

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helicopter systems should include the possibility that it will become available on a wide scale.

The Doppler navigator is the most popular self-contained system. The radiation from an airborne transmitter is reflected from the terrain and when it is received the Doppler shift is measured to give two components of velocity, along and across the aircraft axis. Consequently it is possible to relate these velocity components to earth's axes provided that aircraft heading can be measured. In practice, heading errors dominate the system error.

The simplest system for measuring heading is a standard aircraft gyro-magnetic compass. Its accuracy is dominated by that of the flux valve which is used to relate the gyro heading to the earth's magnetic reference. More accurate heading systems make use of inertial technology.

4. Inertial Systems. An inertial reference consists of an assembly of gyroscopes and accelerometers which can be stabilised so as to measure vehicle accelerations in two rectangular horizontal axes. Successive integration of the accelerations gives velocity and displacement. Current systems include a stabilised platform with gimbals to isolate the instruments from vehicle movements. It is, however, possible to strap the sensors down to the aircraft structure in which case their outputs include its angular movements and the gimbal function is mechanised in software.

It is necessary to allow the system to determine true North so as to relate its outputs to earth's coordinates. This is done by causing it to gyro-compass and find North to within about six minutes of arc. The best available magnetic references have accuracies of the order of one degree.

A pure inertial system is subject to errors which propagate with time and include an 84 minute Schuler oscillation.

It is possible to use an inertial reference in a hybrid system which also has a second input of velocity which may be from a Doppler system or an externally derived radio aid.

It is possible to update helicopter inertial systems in one way which is impossible with fixed wing aircraft. If the helicopter alights, the velocity seen by the INS will be zero in earth coordinates and this track can be used to update the system.

5. Helicopter Inertial References. The following is an approximate comparison between the accuracies of a number of autonomous systems. They are expressed as a percentage of distance flown. Exact comparisons are difficult unless the errors of alternative systems are modelled in the context of particular flight profiles.

A Doppler system based on a gyro-magnetic compass has an accuracy of about 1.5% of distance flown. This accuracy will be degraded over the sea depending on conditions and a full definition of such system behaviour is outside the scope of this paper. A reasonable assumption is that the error will not exceed 2% of distance flown.

An inertial navigator operating in a helicopter should have an accuracy of about .8% of distance flown. It is not possible to operate inertial systems from ships without special alignment procedures which take

account of ship's motion. One possibility is to align the inertial system as if it were a magnetic reference and operate it in a mix with a Doppler. The accuracy will start at the same level as that of a Doppler system but as the airborne alignment proceeds it will improve.

The ultimate potential accuracy of inertial systems is considerably greater and it is possible to find references to special airborne systems with accuracies of the order of .3% of distance flown.

Finally, inertial survey systems can attain sub-metre accuracy when velocity updates are carried out at intervals of from 4 to 5 minutes with at least 20 seconds spent in contact with the ground. The measured velocity error is fitted to a computed error curve which can either be extrapolated back in time or forward to improve the position computation (prediction).

6. Conclusions. It has been shown that pure inertial systems and hybrid systems including IN and Doppler are both possible. Inertial systems tend to be more accurate and the technology has reached the stage at which accuracies from 1% of distance flown down to sub-metre position errors are possible.

The inertial reference has a number of advantages over other autonomous systems or external radio aids. It does not depend on ground-based transmitters and in military use it does not radiate, being thus non-detectable. An inertial sensor can be integrated into an avionics package to give three components of velocity as well as heading and attitude information, all of which are valuable in flight control. The sensor output is smooth and is therefore ideal for use in a hybrid system having radio inputs which are either noisy or liable to interruption.

Inertial sensors are becoming smaller and lighter. In many current installations, the weight of an INS is about 25Kgs. This is now coming down to 17Kgs with prospects of sensors weighing as little as 7Kg. All inertial systems include digital computers and can thus accept other computing tasks as part of an integrated avionic system.

So far the main applications of inertial technology have been in fixed wing aircraft, missiles or space vehicles. The technology has matured and the emphasis is now on smaller, lighter systems. The application area has already extended to land systems and inertial surveyors. Next-generation helicopter systems should provide new opportunities for IN and in particular for its inclusion in highly integrated systems.

HELICOPTER NIGHT VISION SYSTEMS

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Introduction

Over the past several years, there has been an increasing emphasis within the military field, on the development of avionics systems which will improve the day and night operation of helicopters. This has followed the realisation that the helicopter has an increasingly important role to play, which can only be fulfilled with a true all-weather capability. This paper examines the impact of these requirements on the low level mission at night and in poor visibility, and describes the exploration and development of different forms of electro-optical imaging systems.

In normal day visual meteorological conditions, the helicopter is designed to be used for a wide range of operational missions. This flexibility of operation particularly at low level, depends to a large extent on the pilot's ability to maintain visual ground contact in order to identify and recognise features. When ground contact is prevented by low seen illumination or poor visibility, the mission capability is lost, particularly for those missions involving flight at or below the local obstacle clearance level. To re-establish the mission capability under these flight conditions, it is not sufficient to present the pilot with processed flight or navigational information. Rather, means must be devised to provide the pilot with some indirect view of the ground, to re-establish ground contact and restore the mission capability.

In the commercial field, there is also growing interest in the possible exploitation of military all-weather aids to improve off-shore helicopter operations. This application is more tightly constrained by economic considerations, but this paper describes a system which could usefully used as a self-contained approach and landing aid for operations in the North Sea, without the overhead of an expensive ground guidance equipment installed at the landing zone.

The research programme described in the paper was run by the Helicopter Section in the Display Division of Flight Systems Department, mainly using the Royal Aircraft Establishment Sea King helicopter which was equipped with a number of electro-optical imaging systems and supporting avionics.

Airborne System Description

Various forms of night vision systems were investigated during the trials. The first comprised a forward-looking externally mounted sensor, driving a 220 mm diagonal head down display mounted in the left-hand instrument panel of the cockpit. The early trials were done with this system to highlight the fundamental problems of using a television image of the terrain to pilot the vehicle, and to establish the

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essential requirements of the system in terms of camera field of view, resolution and image magnification presented on the television monitor, together with the supporting navigation and guidance systems required to achieve an acceptable safe operation.

For the purposes of the night vision trials, the Sea King was fitted out as a flying laboratory with special video processing and data recording facilities. Three types of sensor were available on the aircraft. The nose of the Sea King was modified to accept a Forward Looking Infra-Red Sensor contained within a panning and tilting platform. An intensifier image Isocon low light television was mounted on the starboard side of the airframe immediately below the cockpit. In addition, for training purposes, a Vidicon daylight camera was rigidly mounted in the corresponding position on the portside of the airframe, each sensor output could be selected individually on to the electronic head down display by a selector control in the cockpit. To augment the sensor information, a symbol generator was used to provide overlay flight information on the TV image. This comprised height, speed, heading, attitude and vertical speed. An essential part of the overall night vision system was the navigation aid. This comprised a Doppler and a gyro magnetic compass system coupled to a TANS digital navigation computer.

During the series of flight trials passive night goggles were also evaluated as an alternative type of night vision aid. Their advantage over the fixed sensor was that the pilot could scan the scene as he does normally when flying in day visual conditions. The goggles gave a 40° field of view of the outside world at unity magnification.

The night vision concept which combines the advantages of an externally mounted sensor, with the look around capability of passive night goggles is the visually coupled helmet mounted display system. This concept to date has only been evaluated in a flight simulator, but will be flight tested in the Sea King commencing in early 1981. In the normal airborne installation, the visually coupled system comprises a head sighting system coupled to a slewable platform in the nose of the aircraft. Within this platform, a suitable night vision sensor is mounted, either low light television (LLTV) or Forward Looking Infra-Red (FLIR). The sighting system measures pilot head angular orientation in azimuth and elevation, and these signals are fed to the platform so that the night vision sensor is locked to the pilot's line of sight. The sensor output is fed to a helmet mounted display which presents to the pilot a collimated scene image at unity magnification. As the pilot moves his head, the platform follows giving a continuous view of the outside world as if the pilot were looking through the windscreen. Because of the elevation coverage, the pilot can actually 'look through the floor' of the helicopter vertically downwards. Provided potential disorientation effects can be overcome, the visual coverage at night is much greater than with passive night goggles. This can be very advantageous during search and rescue missions or when landing in a restricted site.

System Assessment

During the early TV flights, it was found to be difficult to assess aircraft height or speed by reference to the two-dimensional TV image. Frequent reference had to be made to the aircraft's conventional instruments, particularly the radio altimeter. Also the pilots were reluctant to take their eyes off the TV screen, because ground features were best recognised during the few seconds when they appeared in the immediate foreground of the picture. For these reasons overlay flight information was added to the

forward view as this was felt to be essential to the piloting task. The most important piece of flight information was felt to be radio height, and this was presented as a digital readout on the right-hand side of the TV screen. The second most important piece of information was felt to be heading. This became apparent after some pilots became 'lost' on what was to them a well known route. With heading available the pilot would know the heading to steer to the next known ground feature without having to scan across to the horizontal situation indicator. Additionally, attitude information was found to be essential for orientation purposes especially when flying towards sloping or rising ground when the real horizon could disappear out of the TV field of view.

For the first part of the TV trials, a basic training route was used for each sortie. Although the evaluation pilots were thoroughly familiar with this route, navigation from memory whilst flying on the TV still proved to be very difficult. There was a continual conflict between wanting the widest possible field of view to be able to see as many ground features as possible, and the highest resolution to identify those features, which only came with the narrow fields of view. A compromise had to be accepted, and because the pilots tended to favour wider fields of view for flight at lower clearance heights, a horizontal field of view of around 40° was selected. When flying at 100 ft, foreground features became markedly larger than at 300 ft and hence some reduction in their subtense by increasing the camera field of view could be accepted without pilot performance loss. However, at 100 ft the whole aspect of the terrain was different. Groups of trees for example, instead of having a recognisable plan-form took on a totally different vertical significance. Rising ground ahead could fill the picture with the resulting loss of the horizon. These effects are commonly experienced when low flying, but were greatly amplified when using the TV system. The overall effect of reducing clearance height appeared to be that height judgement was easier than at higher altitudes, but navigation and orientation more difficult. All pilots found that at night the navigational task was more difficult than during the day training flights due to the reduced image resolution and dependence on feature contrasts for identification. This led to a greater reliance being placed on the Doppler TANS navigation system as back-up, with the safety pilot reading off range and bearing of the next turning point. All pilots found that at night they did not have the spare capacity to operate the TANS whilst flying on the TV picture. Although it was originally intended to maintain around 90 kn whilst flying at low level, the flexibility of the helicopter was not ignored and speed was frequently reduced when the pilot required additional time to assess a situation.

After the very promising results achieved in the earlier stages of the trials using the basic training route, flying was undertaken over essentially an unknown piece of terrain at low level by night where the navigation aid was supplemented by a moving map display. This moving map display was up-dated from the TANS navigation computer. Within the confines of this 'advanced flying area' various routes were flown using way points. In addition tactical flying was undertaken along valleys taking advantage of ground cover. Another feature available at this stage in the trials was the "heading to-steer" director on the TV display. This enabled the pilot to select the next way point previously entered in the navigation computer, the steering director when nulled providing the correct aircraft heading to this way point.

Over the advanced route flights were undertaken at low level both by day and night. Although the work load and degree of concentration required

were high, they were well within the pilot's capabilities as evidenced by the fact that some monitoring of engine temperatures and pressures, and dialling in of new radio frequencies could be undertaken. It was felt that this was achieved due to the large amount of experience already built up on TV flying along the training route. The moving map display was found to be easy to use both by day and night. Its central position between the pilots was not ideal for viewing by the evaluation pilot, but this only became a real problem when the aircraft's position was close to the edge of the map strip and the pilot's look ahead capability was temporarily lost. Because the aircraft's present position on the map was determined by the combination of the roller and cursor positions, the map was not track orientated, and the pilot had to scan the map for several seconds to determine track departures. Once the desired track and selected way-points were marked on the roller map, this problem was overcome to a large extent. For unplanned tactical flying however, the pilot had to look away from the TV picture for several seconds to gain an impression of aircraft movement. This initially caused work load problems which disappeared as experience increased. When looking away from the TV picture the pilot's reaction was to increase height. Under some situations, height gains of 100 ft were experienced, but this was found to reduce with pilot learning. With the addition of the heading-to-steer director on the TV picture the total pilot work load was further reduced when flying directly between way-points. In this situation the TANS computer only had to be referred to for the selection of way-points. When navigating using the roller map and steering director, the TV picture was used to confirm the aircraft's position and prevent the clearance height becoming too low. Thus the TV assumed a secondary role in the navigation task. This situation was reversed if a hand-held map was used. Here so much time was spent undertaking the navigation task in conjunction with the TV picture as the aircraft height could not be monitored satisfactorily. This in turn demanded a second crew member to undertake the piloting. The accuracy of the Doppler TANS system was adequate for all the night flying tasks, although only a 40° forward segment of the terrain could be seen this was adequate under most circumstances, to up-date the drift in the Doppler system during long sorties. Furthermore, if the TANS and moving map display were correctly set at the beginning of the flight, the system did not need to re-fixed during a typical trials sortie. Overall this would indicate that a self-contained navigation aid of this sophistication is adequate for the task of flying a helicopter either unaided by day or with the assistance of an electro-optical system by night.

Night Vision Goggles

In general, many of the problems of the TV system which were caused by the fixed camera and limited field of view were overcome with the night vision goggles. However, a whole new range of problems was found. The pilot still required information from the instruments. With the 40° field of view bi-focal goggles, this could be acquired by using the lower near focus section of the goggle optics. However, the depth of field was not adequate to allow the pilot to use all the instruments without leaning backwards or forwards to bring them into focus. Some illumination of the instruments were required and in many cases the minimum settings were far too bright to be usable with the goggles. It was necessary for some lighting to be on for the safety pilot to monitor the flight and engine instruments. This lighting caused reflections in the transparencies which under some conditions could obliterate the pilot's view through the goggles. Towards the end of the trials, a new system for viewing the cockpit instruments was devised which eliminated all the problems described above. The image intensifier tubes fitted to the goggles are most sensitive to light with wavelengths towards the red/infra-red end of the spectrum. Fortunately, light reflected from the terrain at night is

predominately towards the same end of the spectrum. The addition of a red (minus blue/green) filter to the objective lens of the passive night goggles does not result therefore in a serious loss of performance. In addition, the low sensitivity of the goggles to the blue/green end of the spectrum means that this colour can be used to illuminate the cockpit at a reasonably high level without overloading the goggles. To implement this concept, the goggle objective lenses were fitted with a red filter containing a small blue tinted convex lens in the centre. The focal length of this lens was chosen so that the instrument panels and consoles in the aircraft would be in focus. The cockpit instruments were then floodlit by blue/green light. This light was accepted by the small lens into the goggle objective and rejected by the red filter. Because of the small size of the convex lens relative to the total goggle objective and the insensitivity of the image intensifier to the blue/green light, the lighting level in the cockpit was high enough to read a standard map without difficulty for the co-pilot who was not wearing goggles. Also because of the small size of the convex lens, a large depth of focus was achieved, some .25 metres compared with .05 metres for the previous bi-focal arrangement. The advantages of this system were as follows; without refocusing, the instruments and outside world stayed in focus over the complete field of view, stray internal reflections did not affect goggle performance, the depth of field when viewing the instruments was so great that no adjustmentment of the filter or lens characteristic was needed to cater for variations in aircraft configuration or pilot size. In addition, the crew member not wearing goggles could use the navigation system and moving map display with little difficulty, whereas before in order to read the moving map or the TANS computer, the self-luminous readouts had to be turned to a minimum and then only turned up when required to be read by the co-pilot. Overall the navigation system required for use with night goggles was found to be the same as for the fixed sensor system. Although the goggles allowed full look around capability this did not obviate the need for the roller map display, because the pilot wearing the goggles could not undertake the full piloting and navigation task over unknown terrain without assistance from the second crew member who relied on the automatic up-date of the roller map since he could not himself see the outside world.

The flying undertaken with the passive night vision goggles demonstrated that they offer a viable alternative solution to the night piloting problem. Although having a theoretically lower performance capability than low light television or forward-looking infra-red they can be used down to comparable lighting conditions, possible due to their unity image magnification and the ability to scan the scene.

Helmet Mounted Display

The flight simulator trials demonstrated the feasibility of this type of system for piloting a helicopter at low level. The main advantage of the system is that it provides the pilot with a complete look-around capability, where the area of coverage is dictated solely by the platform freedom. In addition, the night operating capability is determined by the platform mounted sensor, which is not constrained by aperture size and unit weight in the same way as the passive night goggles. The main human factors problem is that the image is injected into one eye. This causes binocular rivalry which could produce serious flight safety problems when operating at low level. It was concluded that the development of a biocular viewing system was mandatory if the visually coupled system was to be operationally viable. The trials also demonstrated that overlay flight information on the image from the helmet display was essential if pilot disorientation was to be prevented. The trials also demonstrated that platform slew rates and accelerations were critical

in maintaining orientation and it was found that in order to prevent perceivable lag behind pilot head movement, the platform required an angular acceleration of the order of 900 - 1000° per second^2 to reach a rate of 120° per second. The system also had to be critically damped to prevent over-shoot or under-shoot. When system lags were present, the pilot was forced to reduce his head rotation rate to keep the platform in step, and this not only added to the general task level, but prevented the pilot identifying targets of opportunity. This problem was highlighted when flying at very low level, since small undetected descent rates could quickly increase whilst the pilot was looking off track, resulting at best in large uncontrolled collective inputs, and at worst in a crash.

Navigation was not a problem using the helmet display when a pre-planned route was followed, and the way-point number, range to that way-point, and the heading to steer were presented on the overlay symbology, together with the basic flight information. Unplanned navigation over essentially unknown terrain was only possible as a two-crew operation, since the pilot was unable to read a map successfully with the left eye and relate this to the outside world image in the right eye.

Approach and Landing Aid

One aspect which has not been discussed hitherto in this paper, is the use of an external sensor as an approach and landing aid. During the trials of the system fitted to the Sea King it was found, that an alternative approach technique had to be developed to prevent the runway disappearing out of the camera field of view. Normally during an approach the helicopter is flared several degrees nose up to wash forward speed off. Without a tilting facility on the sensor this would mean that the landing zone was lost to the pilot's field of view. To prevent this the speed was washed off very slowly over a longer distance during the approach phase so that attitude changes were minimised. This kept the landing zone itself in the centre of the sensor field of view continuously. The hover and landing phase was found to be very difficult initially using the two-dimensional TV image. Pilots experienced difficulty in resolving the difference between forward movement descending or pitching nose down. Similarly in azimuth it was difficult to initially tell the difference between a heading change and a lateral displacement. After some flight experience each participating pilot found that it was possible to land the aircraft safely with sole reference to the TV display.

This system concept has aroused considerable interest from a number of commercial organisations, since it is seen as a viable approach and landing aid for poor weather off-shore operations. The forward-looking infra-red sensor has the ability to penetrate certain types of sea mist and fog. Coupled with a heat source at the landing zone it may be feasible to use this type of sensor to lower the weather minima for helicopters approaching and landing on gas or oil rigs. Flight trials to investigate this system concept further will be carried out during 1981 using the Sea King helicopter with its currently installed forward-looking infra-red sensor mounted on a panning and tilting platform.

POSSIBLE TECHNIQUES FOR WIRE DETECTION

K E Potter

Introduction. The problem of helicopter wirestrikes has existed for many years and has been costly both in terms of military hardware and human lives.

The overhead wire being a smooth linear filament is not detectable by conventional microwave radars and so other techniques must be considered. In this paper three possible techniques will be described :

1. mm-wave
2. Passive detection system
3. CO_2 laser system

Accident statistics show that the high damage categories and hence cost are attributable to collisions with overhead power cables since these are the thickest of all cables. A large effort has therefore been devoted to solving this particular problem.

mm-wave detection system

Power cables are generally of a wrapped construction comprising a high tensile steel core surrounded by aluminium strands which carry the current as seen in Fig 1.

One method of detection is to shine a high frequency mm-wave radar onto the cable. In addition to the specular return at normal incidence there will be returns at other angles when the path length difference between strands is a multiple of half a wavelength. Fig 1 shows the principle at Q-band for which the returns are approximately 20° apart. In principle, therefore, it should be possible to identify a power cable using a pattern recognition algorithm which operates on these secondary returns.

Of paramount importance when considering the feasibility of this system is the magnitude of the secondary returns. Fig 2 shows the radar cross section per metre as a function of incidence angle for a 2.86 cm diameter British power cable. It is seen that the first grating returns occur at $\pm 20^\circ$ and are 15dB down on the main return. The second returns are about 25dB down and occur at $\pm 43^\circ$. Field trials carried out using an experimental Q-band radar showed that the secondary returns were detectable. However, as might be expected, in view of the 20° spacing of returns the overall operation of the system was poor since for ranges one might usefully employ (around 1 km) an insufficient length of cable was visible to see all returns due to masking by trees etc. Indeed, at 1 km range the pylons themselves are only 20° apart.

However, with the principle established more successful results might be forthcoming at higher frequencies. For example in the 140GHz window the returns are every 5° and in the 220GHz window they are 3° apart. In

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addition to the closer spacing of secondary returns at higher frequencies, there is some evidence that the scattering from cables starts to become diffuse rather than entirely specular. Fig 3 shows what one might expect to see at 2203Hz at 1 km range on a C-scan radar display.

Passive detection system

This technique uses the fact that many collisions are occurring in peace time for which the cables are live and current carrying, and so a passive technique has been developed to give warning of such cables.

A study of the two fields surrounding live cables shows that there is a larger energy density in the magnetic field than in the electric field which together with the ease of coupling this energy using a coil makes it an obvious choice.

The fields from 3 phase overhead lines are quite complex, and their exact magnitude and range law depend strongly on the phase rotations and balance between phases. For example in a perfectly balanced system at 500m range and with identical phase rotations the horizontal component of field is two orders of magnitude larger than the vertical component and falls off as $1/R^2$. The vertical component falls off as $1/R^3$.

For a more realistic overhead line in which there is a phase unbalance of random rotation of phases, Fig 4 is a typical result. In this case the vertical component of field is larger than the horizontal component and falls off as $1/R$ whereas the horizontal field falls off at $1/R^2$ as before. Also shown in Fig 4 is a range of measured values at 500m giving an average flux density of 1nT.

The operational philosophy of the system is to detect the composite vector field using 3 orthogonal coils and to use the magnitude of this to trigger a threshold switch to indicate the proximity of a cable. The horizontal component of field when of sufficient magnitude is then used to indicate the likely direction of the cable.

A block diagram of the direction indicating system is shown in Fig 5. A horizontal field of 1nT (Fig 4) gives a resulting S/N ratio of typically 30dB. The two horizontally sensing coils produce outputs proportional to B sin θ and B cos θ. These are then pre-amplified and filtered using an active filter centred on 50Hz with a bandwidth of 4Hz, and then rectified using op-amp rectifiers having linearity from 0.5mV to 10V rms. The two resulting signals are applied to a ratio A/D converter having 4 outputs one of which will exclusively carry a logical '1' depending on the ratio of the two signals i.e. depending on the tangent of the angle. The changeover angles for the outputs are θ = 15, 45 and 75°.

Unfortunately the same output will be energised for θ either +ve or -ve, which would lead to quadrant ambiguity of flux direction. This may easily be removed by realising that the relative phases of the two A-C signals depend on the sign of the flux angle. One method of phase comparison is to use a multiplier followed by an open loop op-amp. The output will be a logical level according to whether the signals are in phase or out of phase.

This signal can then switch the ambiguous outputs of the A/D converter in the quadrant selector to drive the appropriate segment of the display panel. In flight trials to date an experimental system has given good direction indication at ranges in excess of 500m which is adequate for observation and clearance manoeuvres.

CO_2 laser detection system

The CO_2 laser is attractive for the following reasons

i) Small beamwidths in the order of 1 mrad can be achieved from small apertures typically 3 cms dia., resulting in a large amount of intercepted energy even by small wires.

ii) Due to the surface roughness of wires compared to 10.6 μm one can detect all types of wire and not simply power cables or cables having a regular mechanical structure.

iii) Compared to other laser wavelengths the atmospheric attenuation is low. For example at 300m visibility it is 16 dB/km.

iv) The technology is relatively advanced in terms of size, weight, efficiency etc.

v) The system is eyesafe, at least for powers envisaged for this system.

The recent LOTAWS[1] program first demonstrated the ability of a CO_2 laser to detect a fine wire.

The usual field of view requirement for cable warning is 90° in azimuth by 45° elevation and since most cables are horizontal, and also to simplify calculations a vertical scan format is proposed as shown in Fig 6. To determine the p.r.f. of the laser one must determine two parameters

i) The vertical scan spacing in azimuth shown as Δ Ø in Fig 6.

ii) The elevation scan density represented by the circles.

The former is best appreciated from a consideration of a typical dangerous situation. The usual requirement is that the pilot be given 10 secs of warning of wires which together with typical flying speeds results in a warning distance of ~400m.

Fig 7 shows a pilot faced by two trees at this minimum warning distance with the trees separated by twice the rotor diameter. Under normal circumstances the pilot would not hesitate in flying between the lines. However, if he knew that a wire was strung between them he would wish to avoid the area. In order to provide this information we may postulate that it must be cut at least three times or 1 vertical scan every 1.5° azimuth.

Turning to the problem of elevation scan density, intuitively one would expect this to be quite high so as not to miss any cables. A detailed analysis of the cumulative probability of detection of a cable in one vertical scan gives the best power/probability compromise as 1 pulse every transmitter beamwidth, i.e. the beams overlap at their -3dB points.

These two parameters together with a preferred frame time of 1.5 secs. and a 0.5 mrad beamwidth gives a required laser p.r.f. of around 100kHz.

The prime task of the laser cable warning system is to successfully detect the cable on a sufficient number of vertical scans that it can be identified as a cable i.e. either by an observer or automatically.

One may postulate that detecting 4 out of 5 scans with a certain probability P (say) will result in identification and we may call this the probability of identification.

Table 1 shows typical parameters for wire detection. The target is a 3.5mm diameter Army field wire having Swerling 2 fading characteristics at an incidence angle of 60°. The visibility is 200m and the warning time is 10 secs. It may be shown that for high probabilities of identification requiring high single pulse S/N ratios, direct detection is more efficient than heterodyne detection, a 0.9999 probability of identification being attainable with a 4 kW peak laser power. Using a 100 ns pulse width giving 15m range resolution the mean power is 36W.

The processing and display will be similar to the mm-wave system requiring a pattern recognition algorithm to identify the cables.

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1. Laser Obstacle Terrain Avoidance Warning System. R & D Tech Reports. United States Army Electronics Command Fort Monmouth NJ. Contract No DAAB07-72-C-0145.

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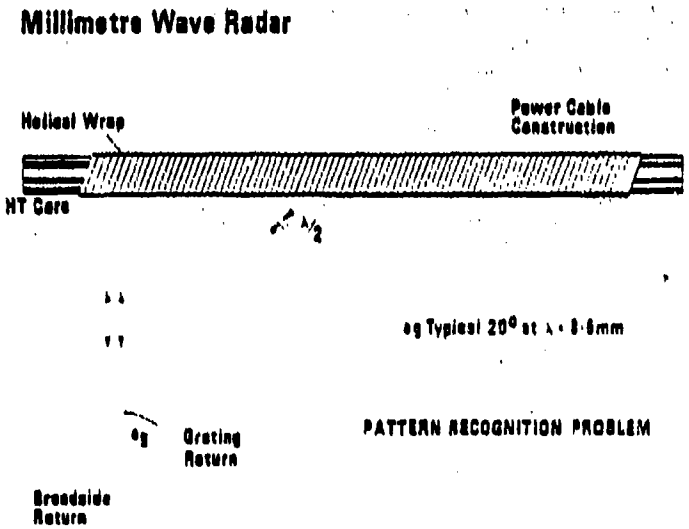

Fig 1 mm-wave cable detection principle

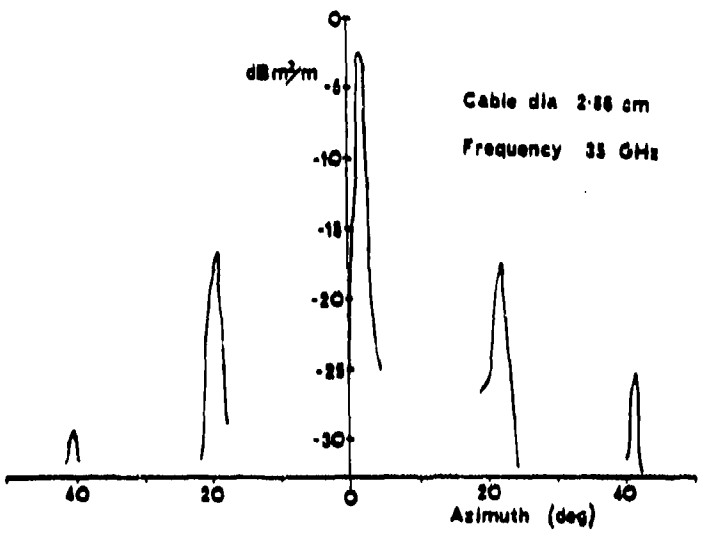

Fig 2 Radar cross section measurements

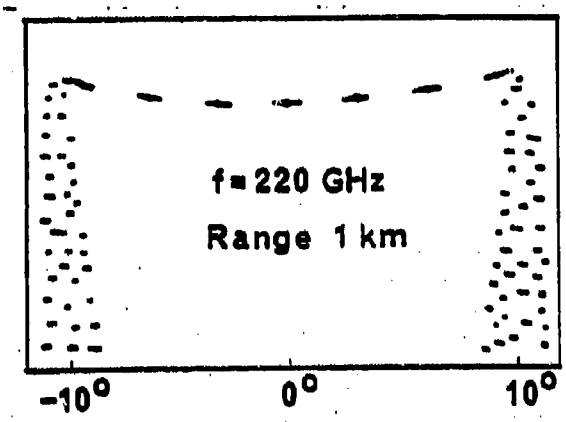

Fig 3 C-scan display at 220 GHz

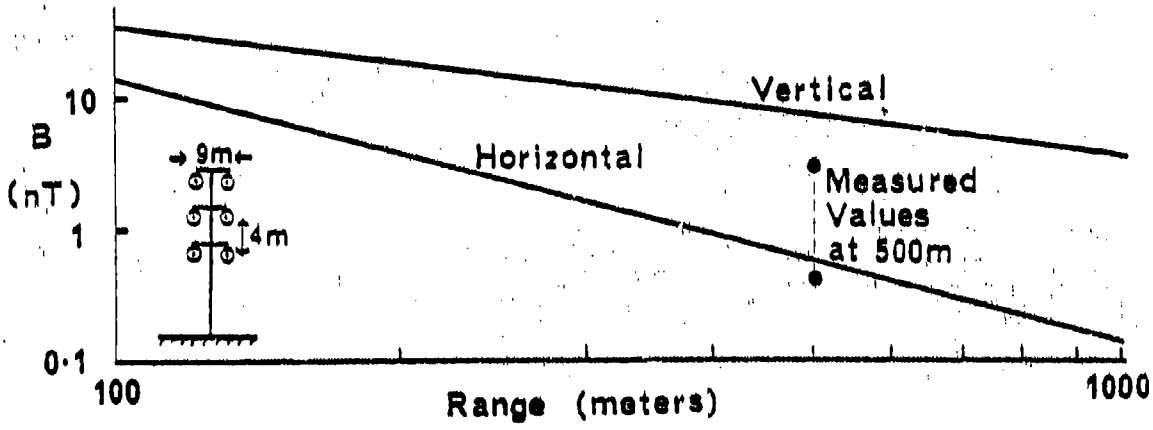

Fig 4 Magnetic flux density vs range

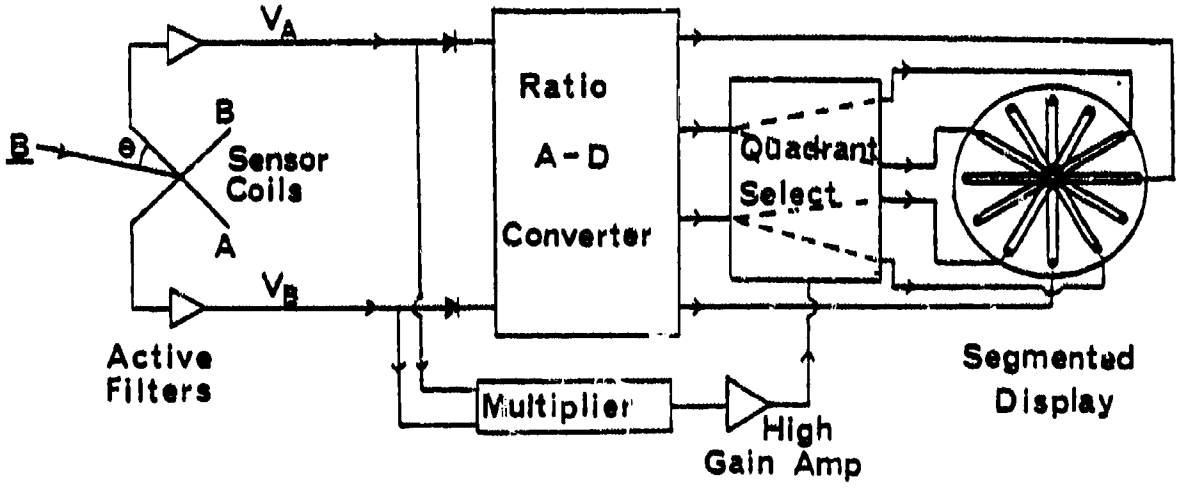

Fig 5 Passive cable warning system

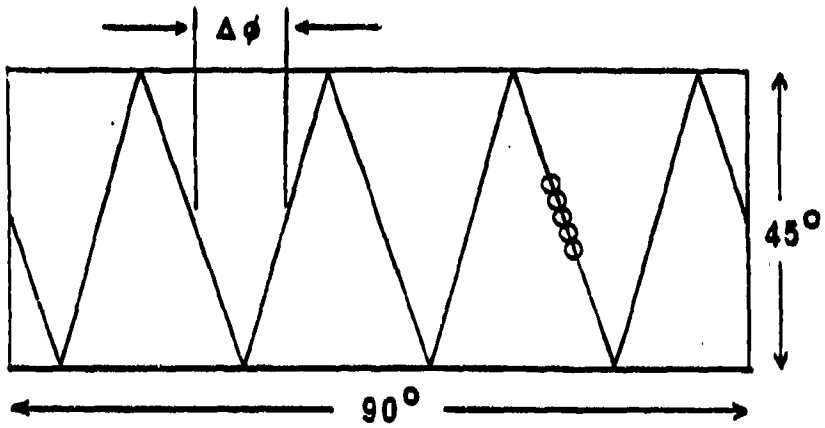

Fig 6 Raster scan for cable detection

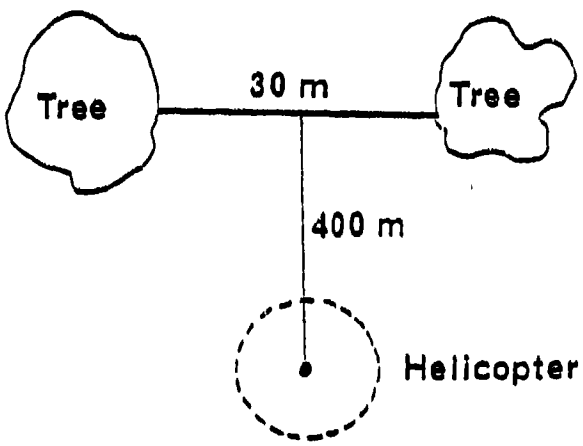

Fig 7 Azimuth scan density determination

Target	3.5 mm army field wire
Fading characteristics	Swerling 2
Incidence angle	60°
Visibility	200 meters
Warning time	10 secs
Detection system	Direct detection & cold shield
Identification probability	0.9999
Peak power	4 kW
Mean power	36 W

Table 1 Laser parameters for cable warning

ABNORMAL BEHAVIOUR OF DOPPLER NAVIGATION SYSTEMS

Trevor Gray

Introduction A Doppler system used as a navigation aid for helicopters will normally provide navigational information with an error of the order of 1% - 2% of distance travelled when a good quality gyro magnetic compass is used, the error falling to well below 1% if inertial quality heading can be provided.

It is not, however, with normal conditions that this paper is concerned but rather with an unusual condition which occurs only very occasionally but which can produce very misleading information unless appropriate measures are adopted. The main purpose of this paper is to publicise this effect which does not appear to be widely known. The effect is associated with flight over a particular type of water surface and will now be examined.

Operation over Water Some increase in error is to be expected from a Doppler system flying over water as compared with the same system flying over land. This is very well known and documented and there are three principal sources of such errors, namely -

1. Error due to the change of backscattering coefficient as incidence angle is changed.

2. Error due to the apparent movement of the water surface, this being wind induced.

3. Errors due to bulk movement of the water promoted by tidal flow.

There are many approaches to the reduction of these errors involving automatic and manual methods but it is not the concern of this paper to describe these again since most have already been adequately treated in the literature.

There is, however, a type of water aberration which has not, so far as the Author is aware been hitherto described. This has been informally referred to as "Medeterranean Sea Effect" since it was first noted off the south coast of France and is an extreme case of the error due to backscatter change.

In order to explain the origin of this effect it is first necessary to examine the character of the error as normally experienced.

It is well known that the energy scattered back from land is relatively independent of the incidence angle over a fairly wide incidence angle range.

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Over water however, it is found in general that the calmer the water the more rapidly does backscatter increase as the incidence angle approaches the normal.

The curves usually considered as accurate indicate that over calm water, the backscattered energy changes at a rate of up to 1.2 db/degree of incidence change whereas over rough water the figure is about one half of this value. The effect of this is to enhance the signals from the steeper part of the beam thus enhancing the lower doppler frequencies and so distorting the spectrum and leading to an underread of velocity.

This underread can be corrected by a number of known methods and no problem arises provided the signal received by the main beam is the only, or at least the dominant signal in the receiver passband.

Antenna Design Criteria In order to ensure that this criterion is observed, it is customary to design the antenna radiation pattern such that the main beam signal is always greater than any side lobe signal, account being taken of the backscatter value in the direction of each lobe.

Since the normally accepted value for the maximum change of backscatter with incidence angle is about 1.2 db per degree over calm water and assuming a doppler main beam depression angle of 67°, it is clear that the rise in backscattered signal between 67° and the vertical i.e. 90° position will be $1.2 \times (90 - 67) = 27.6$ db. The two way side lobe suppression must therefore exceed this value and would usually be set, in a prudent design, at about -45 db.

The "Mediterranean Sea" Effect Such a system operates entirely satisfactorily over most surfaces but in certain isolated geographical areas an abnormality occurs. This was first noted in the Mediterranean sea off the south coast of France when investigations and measurements showed that there was a signal present due to an antenna side lobe which signal exceeded the main beam signal by 6 db.

Since the side lobe (two way) was -45 db with respect to the main beam and situated 16 degrees from it, it would be natural to expect that the side lobe signal would be at $-45 + (1.2 \times 16) = -25.8$ db with respect to the main beam signal. There was thus an unexpected enhancement amounting to $25.8 + 6$ db $= 32$ db or 2 db per degree.

The inescapable conclusion to be drawn from this is that over the angular range considered the rate of change of the scattering coefficient was at least 3.2 db/degree. In fact, it is clear from a study of the recorded spectra that the law is normal over the angular range 67 degrees to 72 degrees but then becomes markedly steeper so that over the range between 72 degrees and 83 degrees the rate of change is no less than 4.5 db per degree.

Since it is usual to design a system so that the tracker locks to the largest signal in the passband, it is clear that a false spectrum as described could provide substantial and undetected errors.

The water surface which gives rise to this phenomenon consists of a long wavelength swell with capillary waves superimposed the two patterns being more or less orthogonal. It is not, therefore, a calm sea phenomenon.

No explanation for the behaviour has been derived but it seems possible that over a certain limited angular range, the water surface forms a series of geometric shapes which behave similarly to corner reflectors.

Although this effect was first noted off the south coast of France it has also been noted in the Stockholm Archipelago and in an area off the coast of Japan. It is virtually certain that it is also to be found elsewhere.

The method of overcoming the effect will depend on the details of the equipment concerned but substantial improvement of sidelobes at the expense of some beamwidth increase represents a good starting point in most cases.

Acknowledgements

The Author wishes to thank the Directors of Racal-Decca Navigator Ltd., for permission to publish the information contained in this paper.

THE ROTOR BLADE RADAR AS A NAVIGATION AND APPROACH AID

D ROGERS

A ground mapping radar has useful properties as an aid to overland navigation and landing site approach. Operation is largely independent of light level and weather, and the system is completely self-contained. For satisfactory and reliable operation however the radar must produce a map of sufficient resolution to enable the pilot easily to recognise and identify common features such as woods, roads, railways, rivers and field boundaries.

Sufficient range resolution is obtained fairly readily by using a short duration pulse, but azimuth resolution relies upon a narrow beamwidth, requiring a horizontal aerial aperture of many wavelengths. For example, to match the range resolution of a 50 nsec pulse (7.5 m) at a range of 1 km requires an azimuth beamwidth of 7.5 mrad, or about 0.4°. For a reasonably tapered distribution this implies an aperture of about 130 wavelengths. To accommodate this in a traditional fuselage-mounted scanner would necessitate a very high radar frequency (65 GHz for 0.6 m for example), but there is available on a helicopter the much wider dimension of the main rotor blades, conveniently spinning in the azimuth plane, and if this is utilised then a lower, more conventional frequency can be used.

At RSRE an experimental rotor blade radar has been installed and flown in a Wessex helicopter. Clearly the major technical problem is in the incorporation of the aerial into the main rotor blade. The solution finally adopted is sketched in Figure 1. The antenna is a 4 m slotted I-band waveguide array radiating through the trailing edge which is constructed of glass/resin skins and a paper honeycomb core. The aerial is situated at the inboard end of the blade and is fed via sections of flexible and rigid waveguide from a rotating joint housed in an assembly on the rotor hub. A waveguide connection is made from the other port of the rotating joint to the radar via the hollow drive shaft of the main gearbox. The assembly also contains a digital shaft encoder to measure rotor position and therefore aerial pointing angle.

The method of antenna construction leaves the blade profile unaffected, and in the particular case of the Wessex the blade weight and balance is unchanged (but it does not follow that this can be achieved with any helicopter blade). The pitch angle of the blade is of course always positive, and varies cyclically in translational flight. To achieve reasonably uniform coverage the peak of the beam in elevation is deflected upwards by foil reflectors in the skins, narrow in the upper surface and wide in the lower. Wires are also embedded in the skins to improve the match at the dielectric/air interface. Figure 2 shows the achieved radiation patterns.

The main characteristics of the aerial are :-

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Length	4 m
Azimuth beamwidth	0.5°
Elevation beamwidth	40°
Gain	31.5 dB
Rotation Rate	1300°/sec

The radar is installed in and controlled from a console in the main cabin of the helicopter, but an additional display is installed in the instrument panel of the left hand pilot's position. The displays use direct view storage tubes giving a green picture bright enough for easy viewing in daylight. The main parameters of the radar are :

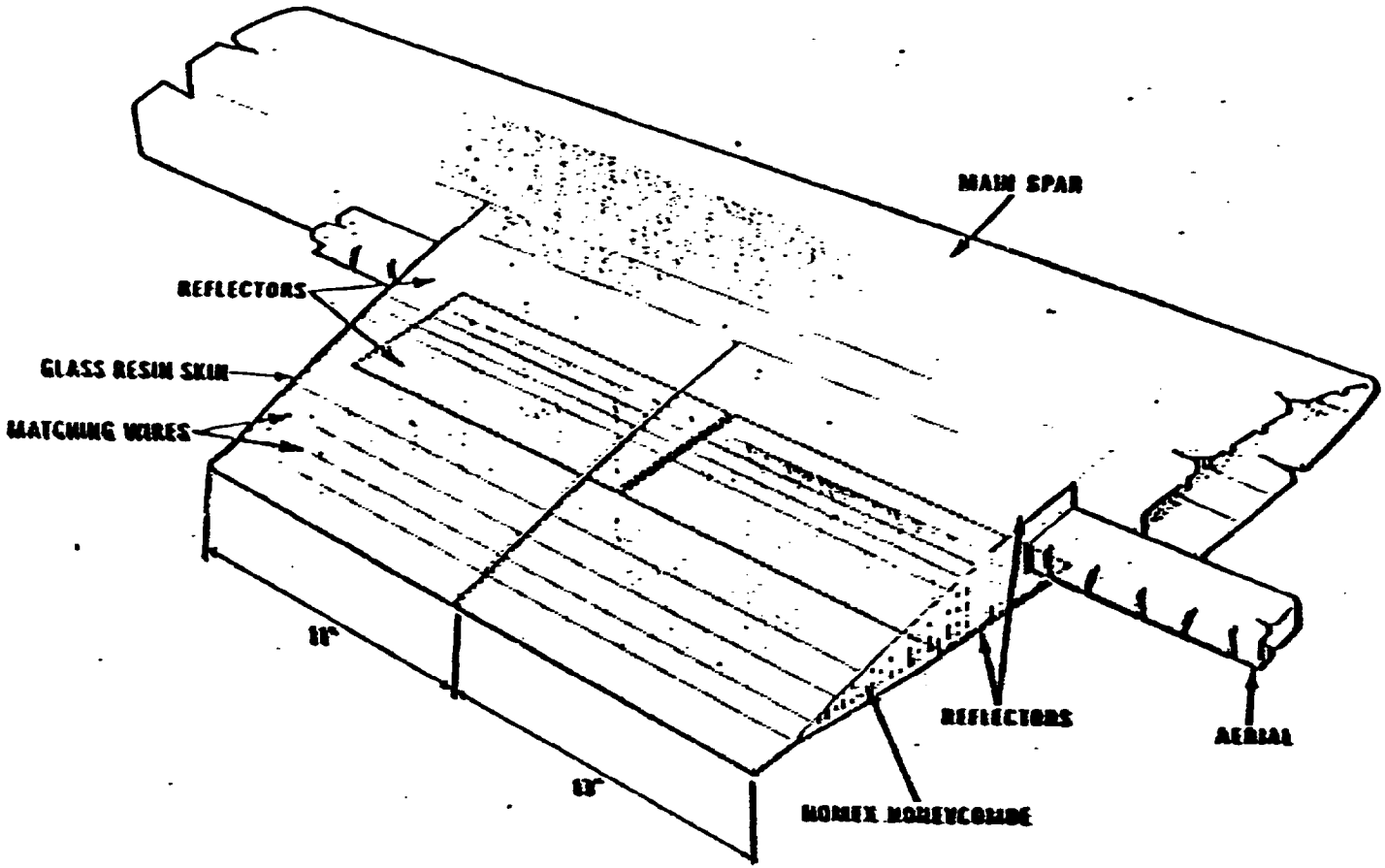
Frequency	I-band
Peak Power	80 kW
Pulsewidth	50 nsec, 100 nsec
P.r.f.	6 kHz, 10 kHz, 20 kHz
Display Scale	0.5 km/radius to 10 km/radius

The relatively high p.r.f.'s are necessary not only to keep up the magnetron duty cycle and therefore the mean power, but also to ensure a reasonable number of hits on an individual target, since the narrow beamwidth and high scan rate impose a dwell time on target of only about 0.4 msec. This short dwell time also sets a limit to the radar's maximum range, since, when the transmit-to-receive time interval becomes a significant fraction of the dwell time, the transmit and receive beams cease to be co-incident. This 'scanning loss" amounts to about 3 dB at 40 km range, and 6 dB at 55 km. Much shorter ranges than this however are adequate for en-route navigation and approach purposes, and in practice it is found that range scales of 2 km/radius and 5 km/radius are the most generally useful.

The system has been flown over a variety of terrains, including rural and urban areas, and coastlines. The most striking feature of the radar over rural terrain is the clarity of the field patterns; this is to be expected since the dominant upstanding targets over open countryside are the hedges and trees of the field boundaries. Roads, railways and rivers are readily identified, again primarily because of the growth alongside them. Since field boundaries are not usually shown on a Survey map, some practice is necessary to relate it readily to the radar picture, but the art is quickly acquired, and on a number of exercises using different subjects pre-planned routes were flown with very little difficulty.

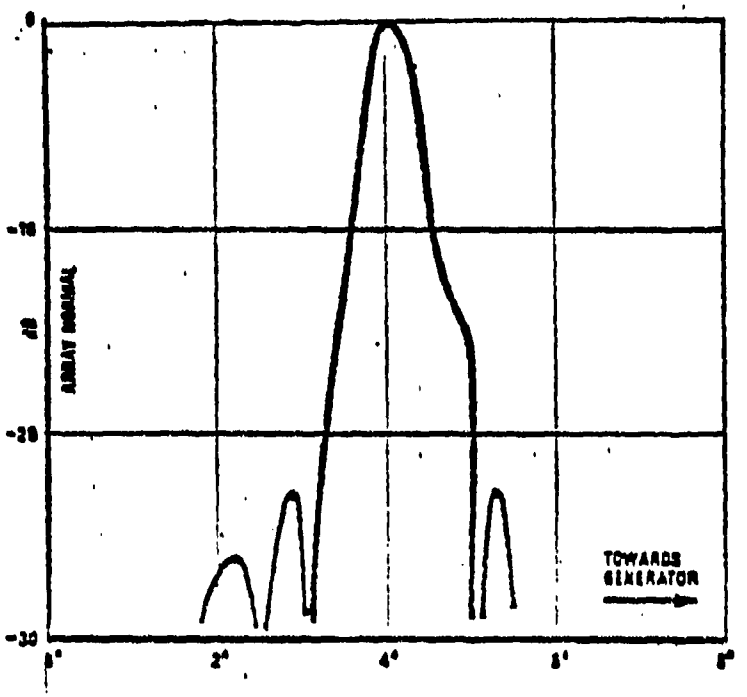
Given an identifiable landing site (and by its nature it usually is readily identifiable) approach is very straightforward; the shortest range scale, with the origin offset to the bottom of the display, gives a picture of the ground to 1 km in front of the aircraft, allowing the pilot easily to approach to a few hundred metres of his landing point. Height of course is not directly given, and an altimeter of some sort is necessary to define a glide path.

<u>Conclusions</u>. The rotor blade radar experiment has successfully demonstrated that a mapping radar of a reasonably high resolution is a very useful navigation and approach aid to a helicopter flying in conditions of poor visibility. The use of the main rotor blade to carry the aerial enables sufficient resolution to be obtained; while it is not easily incorporated into an existing blade design, it should be relatively straightforward to include it in the integrated design of a new blade (not necessarily for a new helicopter) if the potential market, civil and military, should prove sufficient to justify it. No detailed estimates of the likely costs of development and manufacture have yet been undertaken, but it is likely that the price will be fairly high: it remains the case however that the centimetre radar is the only current self-contained technique whose performance is largely independent of weather and visibility conditions.

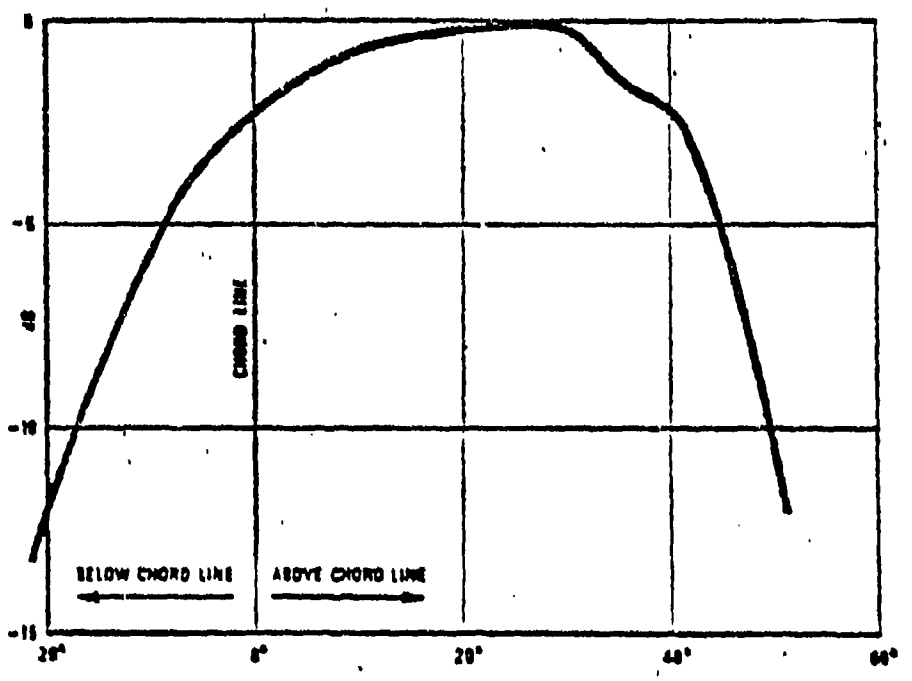


RADAR BLADE CONSTRUCTION

Figure 1



RBR AERIAL HORIZONTAL PATTERN



RBR AERIAL VERTICAL PATTERN

Figure 2