REPORT 1036-1

FREQUENCIES FOR HOMING AND LOCATING IN THE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM (GMDSS)

(Question 45/8)

(1986-1990)

1. Introduction

1.1 Regulations III/6.2.2 and IV/7.1.3 of the 1988 Amendments to the 1974 SOLAS Convention require the carriage of search and rescue (SAR) radar transponders operating in the 9 GHz frequency band for locating the ship when it is in distress or its survival craft following abandonment and Regulation IV/7.1.6 requires a satellite EPIRB to provide distress alerts and positioning.

1.2 These requirements are based on the assumption that through the COSPAS-SARSAT system the satellite EPIRB will provide a position of the ship in distress or its survival craft, with an accuracy of within ten nautical miles, for SAR operational purposes. As soon as its radar triggers the radar transponder a searching ship or aircraft will precisely locate the ship or survival craft.

1.3 Notwithstanding the requirements of the 1988 SOLAS amendments, IMO resolution No. A.616(15) - Search and rescue homing capability, recommends IMO Member Governments to:

a) consider the need and, if appropriate, equip rescue units under their jurisdiction with devices suitable for homing or direction-finding on the appropriate VHF/FM frequencies specified in Appendix 18 of the Radio Regulations and the VHF/AM 121.5 MHz frequency;

b) consider the need and, if appropriate, equip the SAR aircraft under their jurisdiction with devices suitable for homing on satellite EPIRB transmissions in the 406 MHz band.

1.4 The Final Acts of the WARC MOB-83 recommend that studies be made of the feasibility of using 9 GHz radar transponders for homing and also summarize all frequencies allocated for distress and safety. These include, in the MF band, 2182 kHz, in the VHF band, frequencies at about 121, 156 and 243 MHz and, in other bands 406 and 1645 MHz.

1.5 The frequencies listed in §1.4 are all available for use in the locating function in the GMDSS. Several administrations have evaluated some of these for application in the GMDSS. These tests are summarized, and the considerations for use in deciding on homing frequencies to supplement the IMO basic requirement are provided.

2. Considerations in the choice of frequencies for homing

2.1 *Technical*

2.1.1 *Transmitter*

- Transmitter power.
- Duty cycle/battery life.
- Antenna characteristics and siting.
- Modulation characteristics and polarization.
- Environment.

2.1.2 *Receiver*

- Noise figure.
- Antenna characteristics and siting.
- Radio and noise interference.
- Bandwidth.

2.1.3 *Transmission path*

- Propagation effects.

2.2 *General*

- Compatibility with present and future equipment.
- Reliability.
- Cost.
- Compatibility with other GMDSS functions.
- Available and future technology.

2.3 Discussion of each of these factors is contained in Annex I.

3. Tests conducted by administrations

3.1 *Federal Republic of Germany*

The Federal Republic of Germany has carried out several trials on board ships and on aircraft, as well as in connection with the land-based DF network, using a frequency close to 2182 kHz, another close to 121.5 MHz and one around 243 MHz. The results are attached as Annex II. These data also respond, in part, to Question 31/8.

3.2 *United Kingdom*

The use of the frequencies 121.5, 243, 406 MHz and 9 GHz have been investigated to determine their suitability to meet the IMO requirement for a homing range of 10 nautical miles minimum. It should, however, be noted that the frequency 121.5 MHz is designated as the aeronautical emergency frequency in the Radio Regulations.

Field trials on transmissions over sea water at the above frequencies have been completed and the results cast doubts on the validity of the CCIR prediction curves (see Second atlas, Atlas of ground-wave propagation curves for frequencies between 30 and 10 000 MHz, 1959) when considering a V/UHF EPIRB device which has an antenna very close to the sea surface. The maximum range for an audible signal at the receiver exceeded that expected from the CCIR Atlas predictions because under the trials conditions the modulus of the reflection co-efficient for the reflected ray fell below unity and multipath cancellation therefore reached a finite limit. This assumption was not checked by direct measurements of the signal strengths, but was confirmed by a re-appraisal of the theory using published revised reflection co-efficients [Skolnik, 1962] which suggests ranges much closer to those obtained in the trials.

An extension of useful range beyond the normally accepted V/UHF radio horizon has thus been identified for reception of transmissions on these frequencies from radio distress beacons with antennas near the sea surface, ie, floating or in survival craft.

A homing system based on the equipment used in the propagation trials was designed, constructed and deployed in a ship and a helicopter. The homing ranges achieved confirmed the results of the propagation trials. More detailed results of all trials are given in Annex III.

The feasibility of extending the 9 GHz search and rescue transponder (SART) frequency coverage from 9.2 to 9.55 GHz has been demonstrated successfully, thus permitting compatibility with more shore-based and airborne SAR radars. In the United Kingdom, SAR aircraft radars operate above 9.5 GHz. Therefore the extension of the frequency coverage up to 9.55 GHz is considered essential. The detailed trials results are contained in Annex III.

3.3 *Japan*

Japan has conducted sea trials on a newly-developed shipborne radar transponder (SART) in the 9 GHz band. The SART is designed to facilitate search and rescue operations at sea. Results of the trials completed are shown in Annex IV, and are described in detail in Report 775.

3.4 *USSR*

The USSR has conducted sea trials on a 9 GHz radar transponder built into a radiobeacon of the COSPAS system.

The test results are given in Annex V.

3.5 *United States of America*

3.5.1 *Tests*

The United States of America has tested performance of a 156 MHz float-free EPIRB and a 9 GHz search and rescue transponder (SART). Detectability of the SART was measured for both shipborne and aircraft radars. The results of these tests are described in Annex VI.

3.5.2 *Conclusions*

In performing these tests, a study of the operating frequencies of radars used on marine search and rescue aircraft in the United States of America was made. Most of these radars were found to operate on centre frequencies near 9250, 9345 or 9375 MHz. Because the SART only operated in the band 9300-9500 MHz, a significant number of radars would have been unable to detect a response for the SART.

Test results also demonstrated that aircraft detection range measurements to the SART never exceeded 20 nautical miles. An analysis showed that an increase in SART receiver sensitivity could greatly improve detection range without significantly affecting SART design complexity.

3.6 *Canada*

Tests have been conducted in Canada to determine if aircraft can home on the emission of EPIRBs operating in the 406 MHz band in accordance with the characteristics recommended by the CCIR. Results of the tests are shown in Annex VII.

3.7 France

France has conducted tests at sea using new homing equipment specially designed for satellite EPIRBs operating in the COSPAS-SARSAT system on 406 MHz in accordance with the characteristics given in CCIR Recommendation 633. These characteristics, particularly identification, enable homing equipment to provide two different modes of operation: either on a given radiobeacon; or on the strongest signal.

The homing equipment used in this experiment comprised a portable (10 kg) case and an electronic sweep antenna which provides 360° azimuthal cover and can readily be mounted on a ship or helicopter (40 cm x 40 cm).

A range of 4.5 nautical miles was achieved during trials using an antenna fitted 4 m above the water level. The test conditions and results are given in Annex VIII.

4. Summary

4.1 The following is a summary of the work reported.

4.1.1 Homing ranges can be increased by installing antennas on ships at the maximum height possible. The higher the frequency, the smaller the antenna, and the more complex the provisions for compensating a DF bearing.

4.1.2 Considering that the use of 406 MHz would enable the same transmission to be used for both the alerting and homing functions, and that the use of 9 GHz would, in most cases, enable radar equipment carried out board ships and in aircraft for navigational purposes also to be used for homing, it appears that a choice of one or both of these frequencies might result in the most cost-effective solution.

4.1.3 With regard to the IMO requirement of 10 nautical miles, at all frequencies considered in Annex III, the trials have indicated that:

- in the case of ship-to-ship homing, the requirement can be met;
- in the case of survival craft-to-ship homing, the requirement may be met, with some reservations with regard to severe sea states;
- in the case of EPIRB floating in the sea-to-ship homing, the requirement will not be met without optimization of the design and height of both EPIRB and ship antennas and, for some frequencies, both of the design of the EPIRB and of the ship receivers.

4.1.4 The trials at 2182 kHz in the North Sea have indicated that in all the three cases listed in § 4.1.3, the IMO requirement would be met in geographical areas with noise levels similar to those in the North Sea area.

4.2 *2182 kHz*

4.2.1 An EPIRB with 4 mW e.i.r.p. has been tested in the North Sea, and the results are reported in Annex II.

4.3 *121.5 and 243 MHz*

To meet the requirement for terrestrial ship homing, the following system design factors would need to be considered in respect of equipment manufactured to current standards:

4.3.1 *EPIRBs*

- Increase of transmission power above about 250 mW e.r.p. However, such an increase of power on the frequency 121.5 MHz would increase the risk of degradation to the aeronautical emergency service.
- Raising of the beacon antenna height and antenna re-design.

4.3.2 *Ships*

- Design of suitable directional ship antenna array, installed as high as possible.
- Ship receiver processing to take optimum advantage of the transmission format from the beacon. At present there is no requirement for ships to carry equipment to receive or home on transmissions from beacons at 121.5 or 243 MHz.

4.4 *156.8 MHz*

4.4.1 The technical characteristics and design factors for an EPIRB at this frequency are similar to those at 121.5 and 243 MHz.

4.4.2 With regard to the ship system, there is no requirement at present for a ship antenna or receiver optimized for homing in the 156 MHz band.

4.5 *406 MHz*

4.5.1 *Homing by aircraft*

The emission of EPIRBs operating through a low polar-orbiting satellite system in accordance with the characteristics given in Recommendation 633 is a 5 W peak 440 ms pulse every 50 s. Although the 50 s interval may not be compatible with all types of direction-finding equipment, it has been determined that minor modification will allow homing information to be provided by some types of equipment.

4.5.2 The pulse duration of 440 ms is adequate for at least some types of equipment to provide the operator with bearing information.

4.5.3 The possibility of using the Doppler shift in aircraft search should not be discounted. For a realistic aircraft speed there is about 300 Hz shift. Investigations into the use of this shift are continuing.

4.5.4 *Homing by ship*

The antenna on the trial beacon had been designed, primarily, for satellite working, and not for communications near the sea surface. This deficiency could be overcome by minor antenna re-design.

Shipborne direction-finding installations for 406 MHz would differ from that currently used. The frequency range of current equipment does not cover the 406 MHz band, and automatic homing would be required and would need to take account of the burst transmission protocol of the signal used by COSPAS/SARSAT EPIRBs. A requirement for homing on 406 MHz would necessitate the installation of 406 MHz direction-finding equipment on board ships complying with the 1974 Convention for the Safety of Life at Sea.

4.5.5 To meet the GMDSS requirement of 10 nautical miles the following factors would need to be considered:

COSPAS/SARSAT beacon

- Minor re-design of the beacon antenna.

Ship system

- Design of an optimum 406 MHz directional antenna array, installed as high as possible.
- Design of a receiver optimized to the COSPAS/SARSAT transmission format.

There is no requirement for ships to carry equipment for reception of the 406 MHz band.

4.6 *9 GHz*

4.6.1 Locating *by aircraft*

Detailed calculation indicates that a radar with a conventional antenna and 1 kW e.r.p., installed in an aircraft flying at a height of 18 000 m (~60 000 feet) would be adequate to excite a beacon with a 30 dB noise figure and with a simple $\lambda/2$ antenna, at a range of 300 nautical miles. With the aircraft flying at a height of 4500 m (~15 000 feet) a range of 150 nautical miles would be achieved.

4.6.2 Locating *by ships*

To achieve adequate range under moderate sea-state conditions, various system factors need to be considered for the SAR transponder:

- the practical maximum height of the antenna to reduce wave obscuration;
- an increase in receiver sensitivity to ensure reliable interrogation at the required range in severe sea states.

The major advantage of the 9 GHz band is a requirement for fitting of radar in passenger ships and cargo ships of 300 tons gross tonnage and upwards and well over 90% of marine radars operate in this band. Another advantage is that the system would provide range information as well as indicating the bearing on which the transmission was being received. The characteristics of the ship radar, including the height of the antenna are ideally suited to interrogation of an SAR transponder and no design changes to the radar would be necessary, with the possible exception of those radars which include receiver processing which might distort or eliminate the SAR transponder code.

In the case of distress incidents where homing on a ship from a ship is applicable, the SAR transponder would provide identification and would clearly meet the ten nautical miles range requirement as adequate height for the transponder would be available.

In the case of a distress incident where homing by a ship onto a lifeboat, life-raft, etc. is applicable, the SAR transponder would provide both radar echo enhancement and identification. The height of the transponder may be sufficient to meet the IMO requirements.

4.6.3 *Technical characteristics of SART*

An example of the studies on the technical characteristics of the 9 GHz SAR radar transponder (SART) used for locating in the GMDSS is shown in Annex IV.

4.6.4 *Detection criteria*

When considering the use of 9 GHz transponders for locating purposes, the normal criterion of detectibility used in radar operations (i.e. the blip/scan ratio achieved at a given range) does not apply.

In the early stages of a search by ships, when the transponder is at relatively long range, the successful receipt of about one locating transmission per minute may suffice to indicate a course to the searching vessel. As the range is closed, the frequency of receipt of the homing signal will increase.

This question requires further study in order that detection criteria can be developed for both ships and aircraft.

5. Technical studies

To define the technical characteristics of homing systems, and taking into account the ten nautical miles operational requirements, the following studies are required.

5.1 Investigation into the use of Doppler shift from the 406 MHz COSPAS/SARSAT EPIRB transmission for aircraft search.

5.2 Determination of detection criteria for ships and aircraft when homing on 9 GHz SAR transponders.

5.3 Further examination of the characteristics, including antenna siting, of a ship receiving system used for homing at 406 MHz.

5.4 Further examination of the characteristics of 9 GHz SAR transponders. (See also Recommendation 628.)

REFERENCES

SKOLNIK, M.I., [1962] Introduction to Radar Systems. McGraw-Hill Book Company.

ANNEX I

DISCUSSION OF THE PRIMARY FACTORS IN THE CHOICE OF FREQUENCY

1. Transmitter

1.1 The characteristics of the transmission in terms of power, duty cycle, antenna gain and directivity are all interconnected. In the cases of an EPIRB in the sea or on a survival craft, the battery life is an important factor.

1.2 The ranges of acceptable duty cycles are obviously different in the cases of aircraft and ship search, irrespective of whether battery life is relevant.

1.3 Antenna gain and directivity are inseparable. Acceptable directivity is widely different for aircraft and ship search.

1.4 The physical size of EPIRB antenna, which can affect its efficiency, is limited by the need to be self-supporting whilst maintaining EPIRB stability in the sea. In addition, the physical size, and the antenna configuration, are constrained by the need to avoid damage during pre-operational life. The lower the frequency, the greater is the loss in efficiency for practical antenna configurations.

1.5 For an EPIRB, which is subject to severe sea conditions and is battery-life-limited (see Note) in duty cycle terms, it is peak transmission power that is important.

Note. – Current IMO requirements, as set out in the 1983 amendments to the 1974 SOLAS Convention, specify that survival craft EPIRBs shall derive their energy supply from a battery forming an integral part of the device and having sufficient capacity to operate the apparatus for a period of 48 h.

1.6 The choice of the type of transmission modulation and polarization will impact upon the receiver characteristics, as well as the noise environment, and the efficiency of the transmission path to the receiver, in particular in the case of ship search where that path is close to the sea surface.

1.7 The environment, particularly in the case of an EPIRB, is a critical factor. Sea state, which is likely to be high in distress situations, will have a serious effect on the hydrodynamic stability of the system, which is in turn affected by the siting, configuration and size of the antenna, which is a function of frequency.

2. Receiver

2.1 There are various noise sources which arise from man-made and natural causes in the environment as well as the noise temperature of the antenna and components used in the receiver. They are a function of frequency and will clearly differ in the cases of ship and aircraft homing. All such effects can be quantified with reasonable precision.

2.2 Probably the most significant factor, and that which can, if optimized, realize the single largest gain in reliable homing range, is the receiver antenna aperture. This encompasses all the antenna characteristics and, in the ship case, is affected by the height above sea level. There always will be a conflict in priorities for the best antenna sites on a ship. For homing, the size of the antenna system will reduce as the frequency increases but the complexity for compensating DF bearings will increase. The compatibility of the homing frequency with that already used for other ship and aircraft functions, and which would enable any form of common antenna working, may be a significant consideration.

2.3 The bandwidth of the receiver may affect the frequency choice in so far as it is a variable which might be used to advantage, particularly in the case of ship equipment that is not at present fitted.

3. Transmission path

It is self-evident that to achieve the required ranges, adequate signal strength is necessary at the receiving antenna. In the case of ship homing, the transmission path is close to the surface of the sea, which induces propagation losses that increase with frequency. The losses are a combination of cancellation between the direct and reflected rays and absorption due to sea waves. The overall loss is difficult to quantify as the nature of the sea surface is weather-dependent. The losses are fundamentally frequency-dependent, being a function of surface scatter which is related to the irregularity of the surface in terms of the wavelength being transmitted.

4. General

4.1 The frequency choice cannot be made independently of equipment that is already fitted or that has been agreed to be fitted in the future. This applies to aircraft, ships and survival craft.

4.2 The final choices will necessarily take account of system reliability, cost, and the technology available in the relevant time scale.

4.3 The compatibility and combination of the frequency for the homing function with that of other GMDSS functions and other ship and aircraft communication/navigation functions will need to be considered.

ANNEX II

TEST RESULTS REPORTED BY THE FEDERAL REPUBLIC OF GERMANY

Tests were conducted on board two ships (one on 3 August 1982 and the other on 7 February 1984) and a SAR aircraft (on 7 February 1984 only).

The test results collected on board the ships are given in Tables I and II. At distances less than about 10 nautical miles, no important differences in quality, stability and accuracy of either frequency were found. With increasing distances beyond this limit, however, increasing differences in quality between the measurements obtained at either frequency were found. On MF, the final range of satisfactory homing could not be reached, due to the shortage of time. An extrapolation of the field strength indicates that a minimum field strength of 10 μV/m could be assumed at a distance of about 35 nautical miles. In addition, the results of tests taken by a mobile test station indicated that satisfactory homing on VHF can be expected within a range limit of not more than 10 nautical miles.

Test results collected by SAR aircraft are given in Table II.

TABLE I – *Test results on board ship – 3 August, 1982*

Position	Latitude / Longitude	Field strength (dB(μV/m)) 2198.5 kHz	Field strength (dB(μV/m)) 122.95 MHz	Time (UTC)	Distance from a two-frequency ([1]) float-free EPIRB (NM)	Remarks on homing quality 2198.5 kHz	Remarks on homing quality 122.95 MHz
Anchoring position	54°08.2′ N 08°42.8′ E	34	Not measured	1020	0	Satisfactory	Satisfactory
I	54°06.8′ N 08°38.9′ E	30	Not measured	1044	2.70	Satisfactory	Satisfactory
II	54°06.5′ N 08°33.3′ E	26	Not measured	1100	5.85	Satisfactory	Satisfactory
III	54°06.4′ N 08°28.1′ E	23	Not measured	1120	8.90	Satisfactory	Satisfactory
IV	54°06.7′ N 08°22.8′ E	20	Not measured	1145	12.00	Satisfactory	Homing possible, large errors
V	54°06.8′ N 08°17.8′ E	18	Not measured	1200	15.05	Satisfactory	Homing impossible
VI	54°07.4′ N 08°09.2′ E	14	Not measured	1250	19.76	Satisfactory	No signal

([1]) Technical characteristics similar to those for the frequencies 2198.5 kHz and 122.95 MHz of the three-frequency float-free EPIRB described in Table II.

TABLE II – *Comparison of detecting and homing ranges for different frequencies – 7 February, 1984*

<table>
<tr><th rowspan="2">Equipment</th><th rowspan="2">Frequencies</th><th rowspan="2">e.i.r.p.
(mW)</th><th colspan="2">Maximum detecting range
(SAR aircraft)</th><th colspan="2">Maximum homing range
(Ship)</th></tr>
<tr><th>Distance
(NM)</th><th>Field strength
(μV/m)</th><th>Distance
(NM)</th><th>Field strength
(μV/m)</th></tr>
<tr><td>Three-frequency, float-free EPIRB</td><td>245.80 MHz
122.95 MHz
2198.5 kHz</td><td>100
100
1</td><td>62
53
130</td><td>Not measured at aircraft
~ 1-2</td><td>5.3
6.0
6.0 (1)</td><td>4
1
20 (1)</td></tr>
<tr><td>Survival craft transmitter (prototype)</td><td>2189.5 kHz</td><td>2.3</td><td>180</td><td>~ 1-2</td><td>6.12 (1)</td><td>28.2 (1)</td></tr>
<tr><td>Survival craft hand-held EPIRB</td><td>245.80 MHz
122.90 MHz
2198.5 kHz</td><td>800
800
5000</td><td colspan="4">No results. Only one short transmission period because of unacceptable interference on 2182 kHz by this equipment.</td></tr>
<tr><td>Survival radar transponder</td><td>9 GHz band</td><td>400</td><td colspan="2">Not detected by aircraft</td><td>1.5
(at 50% detection rate)</td><td>*Antenna height*
(m)
Ship: 15.0
Transponder: 1.20</td></tr>
</table>

(1) No measurements on 2198.5 kHz beyond the maximum detecting ranges of the VHF/UHF frequencies were carried out. Due to previous measurements on 2198.5 kHz a homing range (2.5 μV/m) of 40 NM for the three-frequency, float-free EPIRB and of 60 NM for the survival craft transmitter (prototype) are assumed.

ANNEX III

TEST RESULTS REPORTED BY THE UNITED KINGDOM

1. Tests at 121.5 and 243 MHz

Emergency beacon (EPIRB/ELT) designs, in particular in terms of power and antenna radiation pattern, have been optimized for aircraft search. Trials at 121.5 and 243 MHz, using a beacon with an e.i.r.p. of 250 mW, and with the antenna at minimum height, achieved reliable terrestrial ranges to ships of about 2-4 nautical miles. Further trials at 243 MHz, with the beacon with an e.i.r.p. of 250 mW and with a sleeve dipole antenna, mounted with its centre at a height of 0.6 m above the sea surface, achieved a reliable range of 12 nautical miles when an 8 element Yagi antenna, mounted at a height of 10 m, was used to received the signals.

2. Tests at 156 MHz

No specific trials have been attempted, but similar results to those obtained at 121 and 243 MHz can be expected.

3. Tests at 406 MHz

The beacon transmission format used was that specified for COSPAS/SARSAT beacons, ie, 0.5s pulses at a repetition interval of 50s. In all trials the beacon eirp was 5 watts.

Propagation trials of an EPIRB in the sea were carried out with a shipborne marine UHF receiver having an 8 element yagi antenna, of 10dB gain, mounted at a height of 10 metres. Using, as a criterion, the signal strength of the EPIRB of 10dB above the audible threshold, repeatable maximum ranges of about 15 nautical miles were obtained.

A directional homing system was developed using two adjacent yagi antennas, of the type used in the propagation trials, angled at 45° in azimuth and feeding the UHF receiver which was equipped with additional circuits to switch between the antennas and compare received signals. The circuitry was also able to measure signal strength and direction during the 0.5s pulse period and to store and present these quantities on meters during the pulse interval.

Static tests on the homing system indicated an unambiguous homing aperture of approx ± 90° about the boresight. Its response in terms of difference in signal strength from the two yagi antennas, in dB versus signal directional offset, was reasonably uniform for approx ± 30° about the boresight with a calibrated accuracy of ± 2°.

The homing system was installed in a small ship with the directional antenna mounted at a height of 10 metres. The repeatable maximum homing range of 15 nautical miles forecast from the propagation trials was confirmed, and homing at about 7 knots was smooth and easy down to visible location range, despite a 4 knot cross tide. Close approach to the EPIRB was indicated by a rapid rise in signal strength.

The homing system was also installed in a helicopter, with the yagi antennas separated for mechanical reasons to be one each side of the aircraft. As the accuracy of direction is more important in aircraft homing, because of the greater distance covered between measurements, the system was carefully recalibrated, The system characteristics were found to be broadly the same as before.

The trials were carried out over land for convenience in deploying the EPIRB and measuring performance. It was considered that the change in propagation conditions would make the results pessimistic compared with those obtainable at sea.

The maximum homing range increased with helicopter altitude and at a typical search approach altitude of 1,000 feet, was about 30 nautical miles.

The helicopter was navigated on the basis of verbal instructions from a trials officer. Track keeping was manual, and there was no automatic correction to helicopter heading to allow for cross wind.

Homing runs were carried out at different altitudes, up to 1,000 feet, at speeds of less than 100 knots and in various wind conditions. The effect of cross wind on tracking was a problem, but in order to evaluate the effect no attempt was made in general to optimise approach directions. Smaller miss distances were obtained, generally, on low altitude trials, but on each trial at least one pass was 200 metres or less from the EPIRB. The trials results are shown in Table III which presents the results of four individual trials each conducted by making, at 70 knots air speed, three passes through the target area starting from roughly 10 kilometres distances and from compass headings chosen to provide error triangles with close to 60 degrees corner angles.

TABLE III

Trial number	Height in feet	Miss distance, Km Pass 1	Pass 2	Pass 3	Location error* Km
1	200	0,15	0,15	0,45	0,33
2	200	0,25	1,30	0,00	1,35
3	500/800	0,60	0,55	0,20	0,75
4	500/800	0,75	0,60	0,20	0,75

* "Location error" is the distance from the true location to the centroid of the error triangle. The wind speed was recorded as 20 knots, therefore the ground speed varied between 50 knots and 90 knots depending upon the angles between the helicopter headings and the wind.

4. Tests at 9 GHz

4.1 Trials of a 500 mW e.i.r.p. 9 GHz SART with −46 dBm trigger sensitivity have been completed.

Transponder heights of 1.0 m and 1.6 m in "float-free mode", and 3.3 m in "on deck mode" were used to represent small and large life-raft situations, and a small vessel deployment.

Search radar heights of 17 m, 20 m and 25 m were used. A low noise figure (7 dB) 25 kW radar with +29 dBi gain antenna on an adjustable telescopic mast was employed.

The prevailing sea states were calm, i.e. no worse than sea state 1, and were therefore representative of worst case multipath propagation conditions.

Consistent results were obtained enabling the SART concept to be defined for a wide range of distress situations.

Flotation mode ranges of approximately 7 nautical miles were obtained for 1.0 m SART height and typical search radar antenna heights, 8 nautical miles for 1.6 m SART height, and 10 nautical miles for a 3.3 m on-deck situation.

4.2 The counting technique was to take 50 successive interrogation blocks and count the missing returns.

4.3 The return echoes from the SART were not as bright on the 12 nautical miles range as those returns from vessels. This effect, which is predictable, arises because the SART-swept frequency return aligns with the search radar receiver frequency for a shorter time than the duration of the transmitted (and therefore reflected) pulse.

4.4 The results are given in Tables IV, V and VI.

For a detection probability of 0.5, the detection ranges and spreads were:

7-7.6 NM SART height: 1.0 m
8.3-8.8 NM SART height: 1.6 m
About 11 NM SART height: 3.3 m

These range spreads are related to the 17 m to 25 m spread of radar antenna heights.

TABLE IV

Range in nautical miles	1.0 m height SART in sea		
	Percentage show rates for radar height of:		
	17 m	20 m	25 m
3	100	100	100
5	80	82	91
7	37	65	75
8.3	Nil	Nil	18

TABLE V

Range in nautical miles	1.6 m height SART in sea		
	Percentage show rates for radar height of:		
	17 m	20 m	25 m
5	100	100	100
6	100	100	100
7	100	84	97
8	63	76	86
9	Nil	10	40

TABLE VI

Range in nautical miles	SART on deck 3.3 m above sea		
	Percentage show rates for radar height of:		
	17 m	20 m	25 m
3	100	100	100
5	96	98	100
6	90	88	90
7.5	80	74	70
9	88	92	83
10.5	94	96	91
11	Nil	Nil	Nil

4.5 The feasibility of extending the band coverage to a band of 9.2 GHz to 9.55 GHz to accomodate additional shore based radars at the low end of the band and SAR aircraft radars at the top end of the band has been demonstrated.

4.5.1 <u>Operational performance</u>

The original SART was designed to operate over a frequency range of 200 MHz and had a period of 5µs which was repeated twenty times to provide a total response time in the order of 100 µs. For a frequency range of 350 MHz a period of 8.75 µs repeated 11 times would provide approximately the same response duration and sweep rate.

A trial was carried out to confirm that the response of a SART modified to cover the band 9200-9550 MHz could readily be identified on a radar display.

4.5.2 <u>Trials</u>

4.5.2.1 The objectives of the trials were:

- to ascertain whether or not there was a significant difference in recognition between a SART conforming to Recommendation 628 and one modified to cover an extended frequency range;

- to ascertain whether or not the fast "flyback" of the band sweeps are suitable for close ranging purposes.

4.5.2.2 The trials were conducted on two SART devices, one with characteristics conforming to Recommendation 628 and the other covering an extended frequency band of 9200 - 9550 MHz and arranged so that the response commenced with a fast "flyback".

The characteristics of the SARTs were:

	Rec. 628	Modified
Sweep repetition period	5 µs	12.5 µs
Number of sweeps	20	8 minimum
Forward sweep time	4.5 µs	11.5 µs
Sweep return	0.5 µs	1.0 µs
Swept frequency band	9.3 - 9.5 GHz	9.2 - 9.55 GHz
Forward sweep rate	44.4 MHz/µs	30.4 MHz/µs

4.5.2.3 Radar display photographs were taken of both devices and the results are summarised in Table VII. These confirm that no loss of detection capability resulted from sweeping the wider frequency band.

The trials also demonstrated that if the "flyback" region preceeds the main slow sweep of a SART, it may be used more effectively for close ranging. With a sweep return in the order of 1 µs, the "flyback" becomes clearly visible at close range. As the return transits the swept band an order faster than the main sweep, if it is initiated immediately by the exciting radar pulse the ranging error will also be an order less.

TABLE VII

	SART range (nm)	Display range scale (nm)	No. of sweeps in display range	No. of sweeps visible	Spacing (nm)
Standard SART	3.8	12	19	19	0.4
Modified SART	2.0	12	9	9 flyback 9 forward	1.0
Modified SART	4.3	12	8	5 flyback 8 forward	1.0

4.5.3 Trials with SAR aircraft

Various trials have been carried out using SAR aircraft (Nimrod) 9 GHz search radar with prototype SARTs. As the results of these trials were inconclusive a study was conducted by the radar manufacturer to determine whether it was compatible with the SART frequency coverage or, if not, whether it could be modified to meet the SART specification. The results of this study showed that the radar was not compatible with the SART frequency coverage and that its modification would be extremely expensive. The study confirmed, however, that if the SART frequency coverage was extended up to 9 550 MHz there would be sufficient commonality with the operating frequency bands of the United Kingdom SAR aircraft radar to provide compatibility.

ANNEX IV

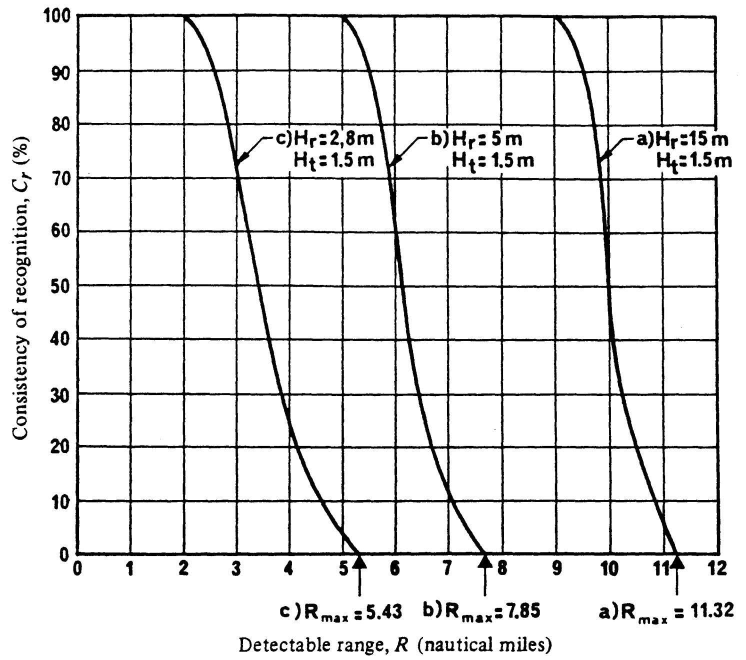
TEST RESULTS REPORTED BY JAPAN

Test results of earlier sea trials appear in Report 775. The SART-A then tested could facilitate the final locating and rescue activities and act as a navigation system following distress alerting, identifying, and positioning by means of a satellite EPIRB or other radiocommunication system.

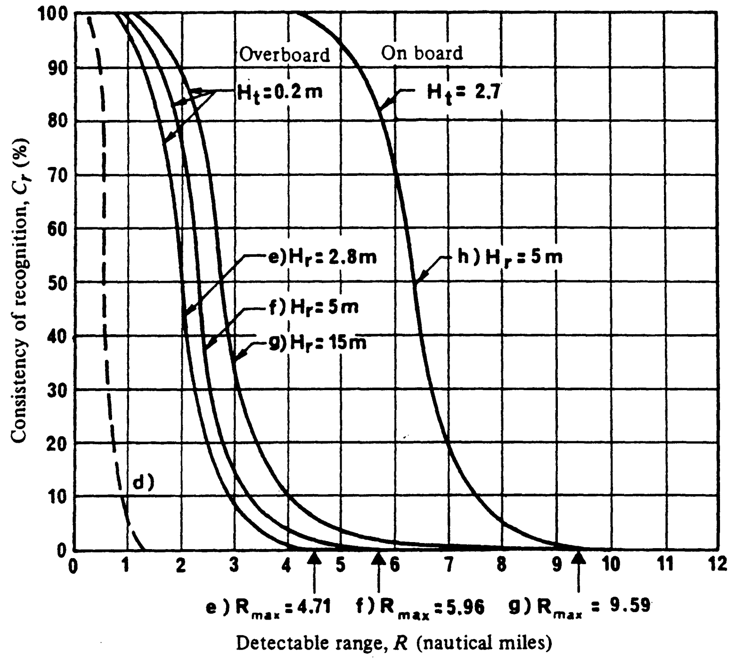
Further tests have been completed using SART-B, designed for fitting on the outside deck of small boats which are not equipped with a life-raft or an EPIRB.

Figure 1(a) shows the search distance (R) versus consistency of recognition (C_r) characteristic of the on-board operation of the SART-B with antenna height of 1.5 m using several radars at Beaufort 1 sea conditions. The C_r figure gives the percentage of scans in which the 20-bip code appeared on the PPI scope.

Figure 1(b) shows the R versus C_r characteristics on the overboard operation of the SART-B in the same condition as for Fig. 1(a). At a distance between 2 to 3 nautical miles on the R-C_r curves, an abrupt decline appears, caused by phase interference due to reflection of the response signal from the sea surface.



a) C_r curves as a function of R of on-board operations



b) C_r curves as a function of R of overboard operations

FIGURE 1 – *Results of further sea trials*

H_t: height of SART (m)

H_r: height of radar antenna (m)

Significant wave height: 0.3-0.5 m

Curve d): night observation with binoculars at a height of 10 m using a search-light with a life-raft with marker lamps and reflective tape.

C_r means, for radar scanning, the percentage of scans in which the 20-blip symbol appeared on the PPI scope, and in the case of visual observation with binoculars, the percentage of observers who detected the distressed object. Because of radar image persistence, the symbol can be adequately perceived even if it does not paint on every scan, so that errors in identification as a result of chance eclipsing of the object or differences among individual observers do not occur. Because of these factors it is considered that a C_r at 10 or more provides adequate assurance of detection.

As a result of further trials, it was found that one radar can recognize five separate SARTs in simultaneous operations which were in line with the radar and spaced 0.2 nautical miles apart.

It was also found that one SART can respond to two radars operating simultaneously and in close proximity, at which time the codes appearing on both radar PPI scopes changed to a series of concentric circles to indicate close proximity to the unit in distress as described in Report 775.

Figure 2 shows the results of a simulation to investigate the performance to be expected in different sea states, with the ship radar antenna 15 m above sea level (H_r), and the transponder antenna at 1.5 m above sea level (H_t).

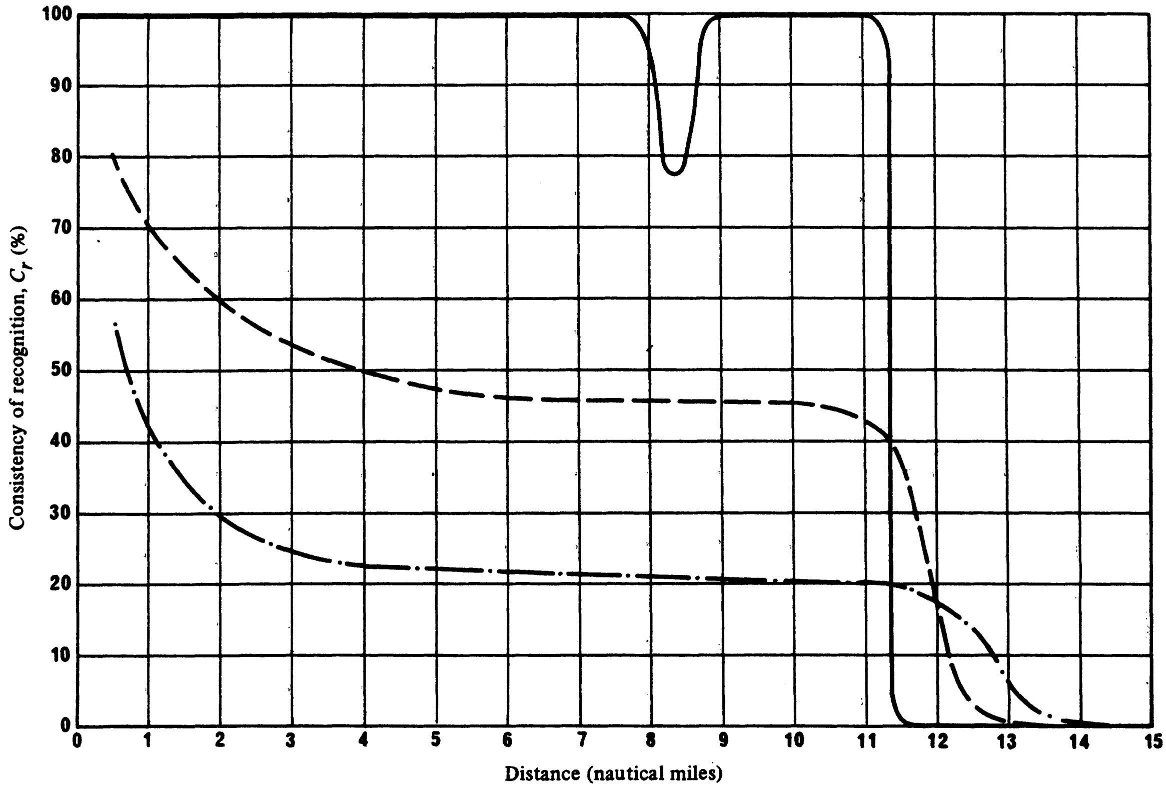


FIGURE 2 – *Simulation of results: search distance versus consistency of recognition*

Encounter angle, $\chi = 150°$
Bearing of life-raft, $\varphi = 0°$
Height of radar antenna, H_r = 15.0 m
Height of SART, H_t = 1.5 m

———— Degradation due to multipath effect on a calm sea surface (Beaufort 2: ≙ 0.42 m significant wave height)

— — — Beaufort 6: ≙ 3.9 m significant wave height

. — . — . Beaufort 8: ≙ 7.1 m significant wave height

C_r means, for radar scanning, the percentage of scans in which the 20-blip symbol appeared on the PPI scope, and in the case of visual observation with binoculars, the percentage of observers who detected the distressed object. Because of radar image persistence, the symbol can be adequately perceived even if it does not paint on every scan, so that errors in identification as a result of chance eclipsing of the object or differences among individual observers do not occur. Because of these factors it is considered that a C_r of 10 or more provides adequate assurance of detection.

APPENDIX

TECHNICAL CHARACTERISTICS OF SAR RADAR TRANSPONDER

Studies on the technical characteristics of the 9 GHz SAR radar transponder (SART) used for homing in the GMDSS are as follows.

1. Signal and code

Signal and code for SART as given in Report 775.

2. Receiver of SART

Figure 3 is a level diagram between a radar and a SART, calculated by using § 2 of the "Radar Handbook" (McGraw-Hill, 1970) for a sea-wave height (h) of 0.3 m.

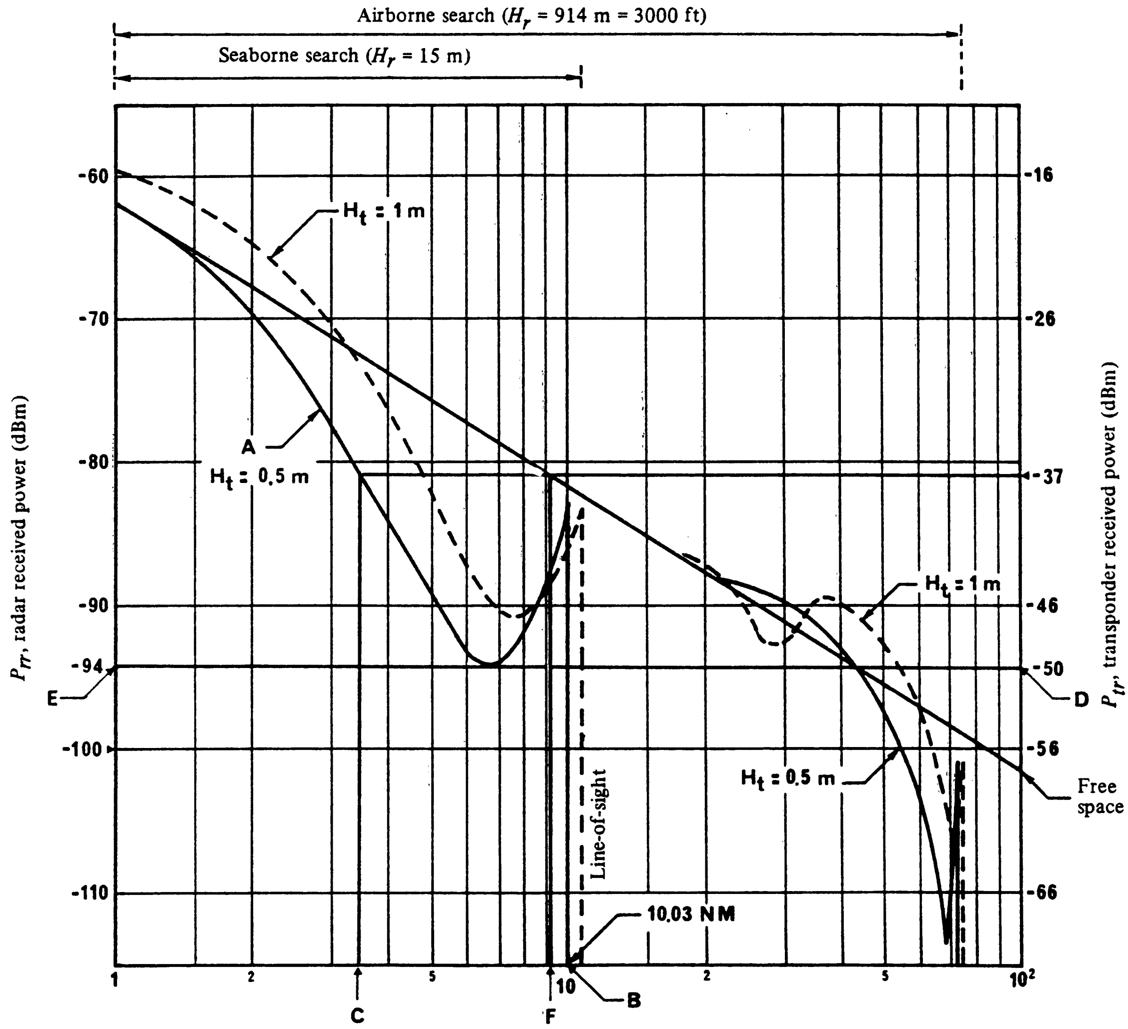


FIGURE 3 – *Power levels received by a radar and by a SART as a function of their respective distance, R (in nautical miles (NM))*

As shown in Fig. 3, range of the line-of-sight in seaborne search using typical shipborne radar with antenna height above sea level (H_r) of 15 m, becomes 10 nautical miles for a SART with antenna height above sea level (H_t) of 0.5 m (point B).

Curve A in Fig. 3 shows the level received by a SART of H_t = 0.5 m. When the effective receiver sensitivity (e.r.s.) (see Note) of SART is −37 dBm, as specified in Recommendation 628, SART cannot respond outside a range of 3.6 nautical miles for the shipborne radar with peak transmitter power: P_r = 10 kW, antenna gain: G_r = 30 dB, and H_r = 15 m (point C).

Considering the above conditions and the fact that the SART should respond to the radar within the full range of line-of-sight (10 nautical miles), the e.r.s. of the SART should preferably be −50 dBm (point D).

Note. – "Effective receiver sensitivity" (e.r.s.) means receiver sensitivity plus antenna gain.

3. Transmitter of SART

Since the noise figure (NF) of the shipborne radar receiver is generally 10 dB, the e.r.s. is calculated to be −94 dBm (T = 27° C, B = 10 MHz and G_r = 30 dB) which means that the response from a SART with e.i.r.p. of 400 mW (mean value of Recommendation 628) could be received for the full range of line-of-sight (10 nautical miles) by the radar, as shown in Fig. 3 (point E).

Therefore, when a SART is being interrogated by typical shipborne radars, the characteristics of an e.i.r.p. of 400 mW, and an e.r.s. of −50 dBm seem to be well balanced.

4. Concerning airborne search

For an airborne radar (H_r = 914 m (3000 feet), P_r = 10 kW and G_r = 30 dB), if e.r.s. of SART is −37 dBm, the SART cannot respond outside a range of 9 nautical miles (point F in Fig. 3). However, if the e.r.s. is improved to −50 dBm, response is possible up to 40 nautical miles.

5. Summary

Taking into account Report 775 and the above studies, the preferred technical characteristics of SART used for homing in the GMDSS are as follows:

5.1 *Signal and code*

See § 4.3.3.1 of Report 775.

5.2 *Equivalent isotropic radiated power (e.i.r.p.)*: 200-800 mW

This value is considered suitable for either seaborne search or airborne search.

5.3 *Effective receiver sensitivity (e.r.s.)*: better than −50 dBm

This value effectively increases discernible ranges of SART for shipborne/airborne radar.

ANNEX V

TEST RESULTS REPORTED BY THE USSR

In November 1983, the USSR carried out sea trials on a radar transponder built into a radiobeacon of the COSPAS system.

The technical data of the transponder used for the trials are listed in Table VIII.

TABLE VIII

Frequency band (MHz)	9330-9470
Output power (mW)	50
Receiver sensitivity (dBm)	−38
Response signal frequency switch-over time (μs)	10
Duration of response signal (μs)	200
Mass (kg)	0.7

The tests used an "Okean"-type ship radar station, the technical and operating characteristics of which meet the requirements of IMO Resolution A.477 (XII) of 19 November 1981. The characteristics of the radar station are listed in Table IX.

TABLE IX – *Technical characteristics of radar station*

Frequency band (MHz)	Transmitter power (kW)	Receiver sensitivity (dBm)	Passband (MHz)
9400-9460	70	−90	12/4 (1)

(1) The band is changed automatically on switch-over of the range scale.

The trials were conducted in open sea at a swell of sea state 1-2. The radar station antennas were installed at a height of 21 m above sea level, the transponder built into the satellite EPIRB being installed at 0.15 m over sea level. In the tests, the maximum detection range of the satellite EPIRB was determined.

The maximum detection range of the radar transponder built into the COSPAS satellite EPIRB was 4.1-4.5 miles for a detection probability of 0.5, i.e. at least five signals out of ten were detected.

ANNEX VI

TEST RESULTS REPORTED BY THE UNITED STATES OF AMERICA

1. Tests at 156 MHz

Tests were conducted using an 8 × 30 cm, 1.25 kg floating EPIRB radiating 1 W on 156.75 MHz (radiation on 156.8 MHz was suppressed). The EPIRB was a commercially available model costing approximately $165. During the tests the EPIRB was tossed overboard in seas of 1 m wave height. The homing range and alerting range to a search and rescue vessel was measured at 6.7 and 8.3 nautical miles respectively. The alerting range to a VHF receiver on shore with an antenna mounted 50 m above sea level was measured at 17.5 nautical miles.

2. Tests at 9 GHz

The United States of America conducted trials using two small, float-free search and rescue transponders (SART) operating in the 9 GHz band. One SART was designed with an antenna height of about 0.2 m and the second with an antenna height of about 1.5 m above sea level. Five different ship navigation radars and one radar installed on a helicopter were used to measure detection range to the transponder. Results for ship radar are shown in Table X and results for aircraft radar are shown in Table XI.

TABLE X – *Ship radar test results*

Radar	Radar antenna height (m)	Transponder detection range (nautical miles)	
		0.2 m antenna height	1.5 m antenna height
A	10	2.3	5.7
B	4	1.2	3.2
C	15	2.2	5.7
D	15	2.9	7.8
E	10	(not tested)	6

TABLE XI – *Aircraft radar test results*

Altitude (m)	Transponder detection range (nautical miles)	
	0.2 m antenna height	1.5 m antenna height
150	5.5-6	10
450	10	14-16
900	10	14.5

ANNEX VII

TEST RESULTS REPORTED BY CANADA*

1. Tests for homing on a 406 MHz EPIRB were conducted by a Canadian government aircraft normally used for search and rescue operations. The receiver was modified slightly with regard to frequency in order to receive 406.025 MHz. The direction-finder was a Collins DF 301E and was modified so that the bearing pointer would remain fixed on its last indication during the time that the EPIRB was not transmitting. As each new EPIRB transmission was received, the bearing pointer aligned to the new direction, and the operator was able to measure the difference in the two bearings and adjust the aircraft heading appropriately. In conjunction with the modification to hold the bearing pointer in place, a circuit was installed that illuminated an indicator light at the beginning of reception of an EPIRB transmission. The light remained on for 7 s, indicating to the operator that the bearing information provided by the pointer was recently received or, if the light was not illuminated, that new bearing information would be received shortly and the pointer direction confirmed or modified appropriately.

2. The exact location of the EPIRB was determined by homing on the beacon and, after passing it, by turning 90° and homing on it a second time. The intersection of the two headings was accurate in all cases to within 61 m.

3. Homing flights were conducted over water and over land at various altitudes. Results varied according to height and environment. Accurate bearings were obtained over land at distances varying from 18 nautical miles at 610 m (2000 feet) altitude to 60 nautical miles at 2900 m (9500 feet) altitude. Accurate bearings were obtained at 17 nautical miles over water from an altitude of 610 m (2000 feet). There was not sufficient programme time to perform tests at higher altitudes over water.

4. In all tests and operations to date, the COSPAS/SARSAT system, operating in the 406 MHz band, has provided location information with an accuracy to within three miles of actual EPIRB location. It is evident, therefore, that a search and rescue aircraft directed to a distress scene in accordance with information provided by a 406 MHz EPIRB will be able to detect and home on that EPIRB from distances well beyond the already known locus of the beacon and in excess of the homing range of about 10 nautical miles required in the GMDSS.

5. **Summary**

All bearing information provided by the direction-finder was positive and accurate. The aircraft crew was able to identify the location of the beacon to within 61 m of its actual position. This was confirmed by flying over the identified location at a reduced speed and a lower altitude (300 m) and locating the EPIRB visually. It has been determined, therefore, that aircraft can home accurately on an EPIRB using signal characteristics recommended by the CCIR on the frequency 406.025 MHz.

* Test results conducted with a 406 MHz beacon and airborne homing devices are also given in Report 919.

ANNEX VIII

Test results reported by France

1. Tests were conducted on board a patrol launch in the Bay of Biscay on 2 March 1988.

Two free-floating COSPAS-SARSAT satellite EPIRBs were used; both were type approved by COSPAS-SARSAT and by the French Administration.

2. Test conditions

- **WIND:** SW 20 knots
- **SEA:** Force 3
- **SWELL:** SW 1.5 m
- **VISIBILITY:** 5-8 nautical miles
- **SPEED:** Vessel carrying the homing equipment: moving at 10 knots
- **HEIGHT:** Homing equipment antenna: 4 m above water level
  Radiobeacon antennas: at water level
- **RADIOBEACONS:** free-floating, the surface of the sea acting as the ground plane of half- or quarter-wave antennas.

3. Test results

- **Moving away from** a radiobeacon at 10 knots:
  bearing indication lost at 5 nautical miles

- **Moving towards** a radiobeacon at 10 knots:
  - bearing indication within 4.5 nautical miles;
  - identical bearing indication by homing equipment and visual observation at 2 nautical miles;
  - no loss of bearing indication close to the radiobeacon.

- **Testing of two** radiobeacons emitting simultaneously:
  - distance between radiobeacons: 50 m;
  - bearing indication given for each radiobeacon with no information mixing whether moving away from or towards the radiobeacons.