SECTION 8J: TECHNICAL AND OPERATING CHARACTERISTICS OF RADIOCOMMUNICATIONS USING SATELLITE DISTRESS AND SAFETY OPERATION AND OF RADIO DETERMINATION SATELLITE SERVICES

REPORT 1045-1*

SATELLITE EPIRB COORDINATED TRIALS PROGRAMME AND PRE-OPERATIONAL DEMONSTRATIONS USING THE INMARSAT GEOSTATIONARY SPACE SEGMENT OPERATING IN THE 1.6 GHz BAND

(Question 90/8)

(1986-1990)

1. Coordinated trials programme

1.1 Introduction

1.1.1 At the twenty-first session of the International Maritime Organization (IMO) Sub-Committee on Radio-Communications (28 January-1 February 1980), the IMO requested the International Radio Consultative Committee (CCIR) to coordinate the trials of various geostationary-satellite Emergency Position-Indicating Radio Beacon (EPIRB) systems being developed by several administrations. This request was brought to the attention of CCIR Study Group 8.

1.1.2 At the same time, the IMO recommended that the International Maritime Satellite Organization (INMARSAT) include a Satellite EPIRB service in the INMARSAT geostationary-satellite system.

1.1.3 In response to this request, INMARSAT indicated its willingness to consult with the CCIR on the space segment performance characteristics suitable for satellite EPIRB operation. INMARSAT also noted that satellite EPIRBs will be an essential element of the IMO Future Global Maritime Distress and Safety System (FGMDSS), and considered that the CCIR should develop the technical characteristics of such an EPIRB service as a matter of priority, taking account of operational needs.

1.1.4 Subsequently, INMARSAT indicated support to the CCIR in its role in coordinating and carrying out the planned trials of various satellite EPIRB designs that would use 1.6 GHz geostationary links, and expressed its willingness to make space segment capacity available for the CCIR coordinated trials.

1.1.5 These views were brought to the attention of the Chairman, Study Group 8, during the Study Group's Interim Meeting in Geneva, 26 November-19 December 1980. In response to the requests from the IMO and INMARSAT, Study Group 8 amended the terms of reference of CCIR Interim Working Party (IWP) 8/7 in order to be able to perform the tasks requested.

1.1.6 At the Final Meeting of Study Group 8 (Geneva, 1981), the Study Group considered the work of IWP 8/7 including the coordinated test plan. Document [CCIR, 1978-82a] describes the objectives of the trials, as agreed by Study Group 8. This document was forwarded for consideration by the INMARSAT Council.

1.1.7 Study Group 8 approved the formation of a Sub-Group of IWP 8/7 under the Chairmanship of Mr. M. A. Johnson (United Kingdom) to agree the details of the trials. The Chairman of the Sub-Group would also provide liaison between the Sub-Group and INMARSAT. The Sub-Group's terms of reference were later extended to include the evaluation of results and the basis for a Recommendation.

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* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

1.1.8 The coordinated trials programme, (CTP) of satellite EPIRBs was conducted between January 1982 and April 1983 in five phases.

Phase 1: Laboratory tests using a test down-converter to replace the satellite link and using a simple simulator.

These tests were carried out in order to evaluate and optimize the design and to analyse interference resistance.

Phase 2: Land tests through the satellite.

Phase 3: Sea trials using a satellite carried out independently at various locations and coast earth stations in order to verify the results of Phases 1 and 2.

Phase 4: Concurrent simulator trials using the satellite. These trials formed the basis of the data on which the comparison of the various systems was made. All systems were subjected to similar controlled conditions to ensure uniformity of evaluation.

Phase 5: Concurrent sea trials using the satellite to verify that the results obtained using the simulator accurately represented those obtained at sea.

1.1.9 The main objective of the trials was to enable a direct comparison of the performance of the various candidate geostationary systems operating at 1.6 GHz by testing them under similar conditions. The tests also avoided duplication of effort by the countries involved and ensured the best use of the available resources.

The specific tasks of the trials were:

- to prepare a detailed operations test plan for a coordinated trials programme (CTP) of satellite EPIRB designs using the INMARSAT space segment;
- to evaluate the test data resulting from the CTP;
- to prepare a report on the final test results of the CTP;
- to prepare a draft Recommendation on the satellite EPIRB characteristics for a geostationary satellite at 1.6 GHz.

1.1.10 Six countries were involved in these trials: the Federal Republic of Germany, Japan, Norway, the United Kingdom, the United States of America, and the Union of Soviet Socialist Republics.

1.1.11 INMARSAT made arrangements for space and ground segments, the European Space Agency provided the earth station for Phase 4 and Phase 5, the German Aerospace Research Establishment (DFVLR) provided the channel simulator in Phase 4, and the German Hydrographic Institute provided the trials vessel for Phase 5.

1.1.12 Japan was unable to participate in Phase 4 or Phase 5 but carried out some simulator trials independently as well as sea trials in an extended Phase 3 campaign.

1.1.13 The IWP 8/7 Sub-Group met on seven occasions. The Final Report was agreed at the final meeting held at the IMO, London from 25 October to 3 November 1983.

1.1.14 This Report is a concise version of the Sub-Group's Final Report and includes a summary of the evaluation procedure, a comparison of the systems' performance parameters together with the conclusions reached, and the basis of the draft Recommendation together with a recommended specification for a future common Satellite EPIRB. The complete Final Report of the IWP 8/7 Sub-Group on the Coordinated Trials Programme is available for consultation in the CCIR Secretariat.

1.2 **Summary of evaluation**

1.2.1 *Correlation of Phase 4 and Phase 5 test results*

A comparison of Phase 4 and Phase 5 test results can be made for the German Federal Republic system since the same buoy was used to record the Phase 4 tapes as was used in the German Federal Republic Phase 5, and the receiver processor was not modified between the two phases. There is good agreement between the results, within the accuracy range of the C/N_0 measurements.

The Japanese simulator tests and sea trials also showed good correlation for both the FSK and PSK systems.

For the other systems a correlation can only be made if the modifications carried out between the Phase 4 and Phase 5 tests are taken into account. These include:

- different buoy design;
- different antenna pattern; and
- modification of the processing technique.

1.2.2 *Message transfer time and the receiver sensitivity of the systems*

The message transfer time (MTT) is defined as the time between the initiation of transmission by the satellite EPIRB and the read-out of an error-free message at the coast earth station. The MTT used in the evaluation is the time interval within which 90% of the messages were received with a 1% or less probability of error (MTT_{90}).

The received sensitivity of each of the systems was measured in terms of the minimum averaged C/N_0 at which the performance of the systems remained within the IMO specified message transmission reliability of 99% for a single EPIRB transmission, taking account of the associated MTT_{90}. The MTT_{90} and the (averaged) C/N_0 were taken by the IWP 8/7 Sub-Group as the most important parameters in the evaluation of the system's performance.

The C/N and MTT_{90} were determined in Phase 4 tests using the DFVLR channel simulator with tape numbers T4 and ST2. Japan carried out independent simulator tests using ST2, T16 and T26. The main characteristics of these tapes are shown in Table I (T26 was a 406 MHz tape and is not included in Table I).

TABLE I – *Tapes used for main test*

	Elevation angle (degrees)	Wave height (m)	Fading margin (1) (dB)	C/M (2) (dB)	Doppler spread bandwidth (Hz)	Maximum long-term Doppler offset (Hz)
T4	2.5	1.5-2.5	18	4.3	0.6	± 15
ST2	5	16	24	2	1	± 17.2
T16 (3)	5	1	16.5	5.4	1	± 25

(1) 98% of all fades are within this range.

(2) Carrier to multipath ratio.

(3) Japan only.

In order to maximize the amount of data obtained, the transmissions were continuous and the signal discontinuity was made at the receiver. To verify that this procedure gave representative results, a comparison was made with the MTT obtained by switching the transmission on/off.

Data obtained in Phase 4 and Phase 5 tests were accumulated within a range of at most 1.5 dB in $<C/N_0>$.

The averaged quantities for $<C/N_0>$ used for further evaluations were obtained by weighting the results with the number of transmissions and $<C/N_0>$ of each particular data set. The following formula was used:

$$<C/N_0> = \frac{\sum_{i=1}^{m} (C/N_0)_i \cdot n_i}{\sum_{i=1}^{m} n_i}$$

In deriving MTT_{90}, all data of the C/N_0 sets within the accumulation range of 1.5 dB were considered.

It was decided to use only ST2 in the final evaluation in Phase 4 as this tape represented the worst-case condition of wave height and elevation angle; however the tape did not include wave blockage effects.

1.2.3 *System capacity*

System capacity was defined as the number of simultaneous satellite EPIRB transmissions that are capable of being processed within a period of 10 min. This parameter, used by the IWP 8/7 Sub-Group for comparative evaluation of the various candidate systems, was derived on the basis of empirical data gathered during the Phase 4 tests and on statistical analysis assuming a 200 kHz bandwidth, transmission time of 2 × MTT_{90} and the recommended duty cycle as proposed in Appendix III of Recommendation 632.

The methodology used in the system capacity computations, takes account of the frequency separation measurements between interfering satellite EPIRBs (obtained during Phase 4 tests), the EPIRB manufacturing process (i.e. distribution of transmitter centre frequencies and oscillator stability tolerances), transmission spectral characteristics (e.g. for the spread-spectrum systems, the amount of power in the side lobes, location of the side lobes, etc.), satellite EPIRB geographical dispersion (limited only to effects from transmissions at high and low elevation angles), duty factor, and the desired probability of non-interference (given by the IMO to be 0.95/0.99 = 0.9596). The detailed description of the methodology used in this computation including the software program listing, is provided elsewhere [Kaminsky *et al.*, 1983].

1.2.4 *Resistance to interference*

The systems' resistance to interference was determined in terms of the minimum frequency separation required between the wanted signal and the interfering signal, at which there was no significant degradation in performance. This was determined in Phase 4 for a CW transmission and an FM simulated voice transmission with e.i.r.p. of 10 dB and 15 dB respectively above the nominal satellite EPIRB e.i.r.p. Δf was determined at the end of the test. The results are given in Table II.

1.2.5 *Multi-channel system implementation*

It should be noted that in developing the system from a single channel to a multi-channel system, the implementation of the processing system may affect the performance due to:

- signal detection in a wide frequency band;
- discrimination of noise and unwanted (interfering) signals;
- correlating a buoy in a multi-buoy and heavy fading environment to the same processor during the whole MTT;
- tracking/demodulating many buoy signals.

1.3 Comparison of performance parameters

1.3.1 Table II provides a comparison of the performance in both Phase 4 and Phase 5 of the various systems in terms of system sensitivity (C/N_0), message transfer time (90 percentile) (MTT_{90}), resistance to interference represented by both CW and voice transmissions in terms of the minimum frequency offset at which there is no performance degradation (Δf_{CW} and Δf_{FM} respectively), and system capacity in terms of:

- the number of transmissions that can be processed in a 10 min period;
- an analysis using the frequency offset of the mutual interferer (Δf_{sc});
- the recommended duty cycle;
- the measured MTT_{90}.

1.3.2 It should be noted that the Phase 4 results in Table II are those obtained using the channel simulator and ST2. Tape ST2 represents the worst-case environmental conditions of 16 m wave height and 5° elevation angle; however, the tape does not include wave blockage effects.

1.3.3 Furthermore, the Phase 5 results quoted for each administration are those obtained on the specific day of the sea trials which provided the maximum number of evaluation points according to previously agreed criteria. In all the tests, more emphasis was given by the IWP 8/7 Sub-Group for nominal performance in high sea states and/or low elevation angles. The results shown in Table II are all from EPIRB deployment at the most northerly latitudes of around 71° N, except for that of Japan which was at around 15° S operating to the Indian Ocean Satellite. Elevation angles < 5° and wave heights of around 1.5 and 2.5 m were encountered.

TABLE II – *Comparison of performance parameters*

	C/N_0 (dBHz)		MTT_{90} (min.)		Interference rejection (Δf) (Hz)		System capacity	
	Phase 4	Phase 5	Phase 4	Phase 5	CW	FM	f_{sc} (Hz)	Number of transmissions
Nominal values	30	30	15	15	1000	1000	Not available	20
Germany (Federal Republic of)	15.6	15.1	7.1	5.9	180	0	280	33
Japan (1) FSK	19.3	18.0	1.1	2.5	570 (calculated)	570 (calculated)	422 (2)	133
PSK	23.4	26.6	2.9	3.4	0 (3)	0 (3)	40 (3)	407
Norway	20.6	19.2	3.3	4.97	1000 (4)	0	340	57
United Kingdom	37	35.5	12	5.6	0	No test	10	218
United States of America	27.5	22.4	3.8	4.2	32	32	90	170
USSR	16.5	18.6	6.4	6	500	0	400	26

(1) Based on independent simulator tests and extended Phase 3 sea trials.

(2) Tape 16 used, not ST2 as with other systems.

(3) Tape 26 used, not ST2 as with other systems.

(4) 5 transmissions showed that the system is able to operate with Δf = 500 Hz.

1.3.4 During the testing of all systems in both Phase 4 and Phase 5, no false alarms occurred.

1.3.5 The system capacity values given in Table II would be greater for an operational system in which the C/N_0 levels would be increased, thereby reducing the message transfer time and required transmission burst duration. Because of the geographical dispersion of satellite EPIRBs, and the relative variation in sea-state conditions, it is expected that the required message transfer time for some of the satellite EPIRBs will be shorter than the transmission period of the satellite EPIRB; under these conditions an increase in capacity will result due to a potential overlap in the start of the transmissions. On the ohter hand, due to possibilities of a non-uniform distribution in satellite EPIRB frequencies the capacity may also decrease.

1.3.6 The nominal chosen values for the parameters are given in Table II. Systems achieving better than the nominal value were considered as suitable. The margin between the nominal value and the recorded value was taken as an indication of the relative quality of the systems. The systems were compared for an optimum combination of minimum elevation angles and high sea states.

1.4 **Conclusion**

1.4.1 The results of the CTP confirmed the expected advantages and disadvantages of both narrow-band and wideband systems. The narrow-band systems provided operation at lower values of C/N_0 and the wideband systems had better interference rejection and a larger multiple access capability.

1.4.2 The three wideband systems (United States of America, United Kingdom and Japan) employed PN-PSK modulation which gave good performance in a Gaussian channel. The United Kingdom and Japanese systems suffered from loss of signal tracking during deep signal fades with fast Doppler frequency shifts. The United States overcame this problem by employing non-coherent detection.

1.4.3 The USSR system employed narrow-band PSK with non-coherent detection. This system provided good sensitivity using a digital processing technique, and showed good potential although it is not fully optimized.

1.4.4 The German Federal Republic system employs FSK modulation and showed the best receiver sensitivity. This system has been developed and tested over a ten-year period and is near to its optimum performance capability.

1.4.5 The Japanese narrow-band system employs FSK modulation and showed good sensitivity and a short message transfer time. Japan realized that further development of their systems (PN-PSK and FSK) beyond the German Federal Republic system would not be finished in time for the pre-operational satellite EPIRB demonstration which is planned to be carried out in the GMDSS transitional period. The Japanese FSK system uses 63 bit/s compared to the German Federal Republic system's 32 bit/s. This enabled the Japanese system to achieve a shorter message transfer time but with a loss of sensitivity.

1.4.6 The Norwegian narrow-band system using PSK sub-carrier modulation, also showed good sensitivity together with a short message transfer time, though it is far from being fully developed. Due to the short time before entering the pre-operational demonstration, Norway has no intention of further developing their system without firm international backing.

1.4.7 As a result of the coordinaed trials programme, the following conclusions can be drawn:

- most systems tested in the CTP achieved suitable criteria for message transfer time and error-free reception, with low satellite EPIRB power requirements;
- in general the narrow-band systems provided lower C/N_0 than wideband systems, but in an operational system could prove to be more susceptible to interference;
- in particular the narrow-band FSK system with binary forward error correction developed by the Federal Republic of Germany demonstrated performance at lower C/N_0 values than other systems.

1.4.8 It was recognized that, in general, all systems had the potential for further development to improve their performance. However, it was also recognized that there is an urgent need to begin the implementation of an operational satellite EPIRB system as soon as possible. It was therefore concluded that a modified version of the German Federal Republic narrow-band FSK system would provide an adequate basis for the CCIR Recommendation for a geostationary satellite EPIRB system operating at 1.6 GHz.

1.4.9 On this basis, the following comments should be noted with respect to the recommended system:

- in the worst case (i.e. severely adverse sea-states, elevation angles less than 5° and a low C/N_0 of around 15-16 dBHz) a mean message transfer time of less than 10 min is achievable;
- a satellite EPIRB e.i.r.p. of 0 dBW appears to provide sufficient system margin and could provide a message transfer time of the order of 1 min;
- the expected capacity based on modified characteristics of the German Federal Republic system, is at least 46 simultaneous transmissions;
- in an operational system, attention needs to be given to the following points;
  - the need to uniformly distribute 1.6 GHz satellite EPIRB transmit frequencies across the total available band in order to minimize the potential for co-channel interference from other satellite EPIRBs;
  - the need to minimize the potential interference effects of unwanted transmissions.

1.4.10 It was recognized that a shorter data frame than was used in the CTP (see Appendix I of Recommendation 632) could result in a reduction of MTT.

1.4.11 The link budgets appropriate to the recommended satellite EPIRB system are shown in Table III for first generation and specified second generation INMARSAT space-segment transponders. These demonstrate that a minimum of 13 dB additional transponder gain so as to provide up-link limited operation, would save 5-6 dB in satellite EPIRB power requirements.

1.4.12 The total transponder bandwidth requirement for an operational satellite EPIRB system has yet to be determined.

1.4.13 The trials programme provided the opportunity to evaluate the candidate systems and to make some comparison between their performance characteristics. A direct comparison of the modulation systems employed was difficult due to, amongst other things, the varying levels of development of each system. Many of the candidate systems are some way from their theoretically expected threshold and given time, effort and money, their performance could further improve. Taking the time-frame of the IMO Global Maritime Distress and Safety System (GMDSS) into account, it was recognized that pre-operational demonstrations of a system intended for full implementation with the GMDSS by 1990, should begin as early as possible. These demonstrations should permit the development of low-cost production satellite EPIRBs including the release mechanism, data interface and homing facility if required. They would also permit a demonstration of the capabilities of the system and confidence to be gained in its operation.

1.4.14 For a pre-operational demonstration using INMARSAT satellites without the high gain amplifier (HGA), a 0 dBW satellite EPIRB e.i.r.p. could still provide adequate performance for pre-operational demonstration purposes but with a lower system margin (see Table III). It is considered that the HGA would be essential for a fully operational service, although the lack of such a facility should not delay the implementation of the system.

1.4.15 It was agreed that the pre-operational demonstrations should be limited to a common satellite EPIRB system. It was accepted, however, that administrations may arrange further national trials and present the results of these trials directly to CCIR Study Group 8. For example, the USSR intends investigating the possible advantages to system capacity of an M-ary (multi-position) coding technique.

1.4.16 Several administrations indicated an interest in being involved in pre-operational demonstrations.

TABLE III – *Satellite EPIRB link budgets*

	INMARSAT space segment		
	First generation		Second generation
	MARECS ([1])	INTELSAT MCS	Specified ([1])
EPIRB-satellite 1.645 GHz			
EPIRB elevation angle (degrees)	5		
EPIRB e.i.r.p. (nominal) (dBW)	0		0
Free-space path loss (dB)	189.2		
Atmospheric absorption loss (dB)	0.4		
Polarization coupling loss (dB)	0.5		
Satellite G/T (dB(K^{-1}))	−10.7	−13.0	−12.5
Boltzmann's constant (dB(J/K))	−228.6		
Up-path C/N_0 (dBHz)	27.8	25.5	26
Satellite C/IM_0 (dBHz)	50.5	34.0	65
Transmitted $C/(IM_0 + N_0)$ (dBHz)	27.8	24.9	26
Satellite-shore 4.2 GHz			
CES elevation angle (degrees)	5		
Satellite e.i.r.p. (dBW)	−27.7	−40.9	−28.6
Free-space path loss (dB)	197.3		
Atmospheric absorption loss (dB)	0.1		
Polarization coupling loss (dB)	0.1		
CES G/T (dB(K^{-1}))	32		
Boltzmann's constant (dB(J/K))	−228.6		
Down-path C/N_0 (dBHz)	35.4	22.2	34.5
Transmitted $C/(IM_0 + N_0)$ (dBHz)	27.8	24.9	26
Resultant link (unfaded) (dBHz) $C/(IM_0 + N_0)$	27.1	20.3	25.3
Required minimum C/N_0 (dBHz)	16	16	16
System margin (dB)	11.1	4.3	9.3

([1]) Assumes 13 dB additional transponder gain.

1.4.17 The schedule assumed by the IWP 8/7 Sub-Group leading to the full implementation of a satellite EPIRB system in 1990 is as follows:

June, 1984	Interim Meeting of CCIR Study Group 8 to produce draft Recommendations;
1984	Development of satellite EPIRB production units;
1985	Planned start of pre-operational demonstrations;
1986	IMO-MSC approve performance standards;
1986	Technical specifications for satellite EPIRB and receiver processor;
1987	Type approval of production units and fitting;
1987	WARC for mobile services;
1988	Planned start of INMARSAT second generation space segment deployment;
1985-1990	FGMDSS transitional period;
1990	FGMDSS implementation.

1.5 Recommendations by IWP 8/7

1.5.1 The transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through geostationary satellites at 1.6 GHz as given in Recommendation 632 is based on the evaluation of the data presented in each participant's test report according to the procedures indicated in § 2, a comparison of the performance parameters of each system as summarized in § 3 and the conclusions reached in § 4. This recommendation does not take account of the cost of implementation of the system.

1.5.2 As a consequence of utilizing the satellite EPIRB characteristics given in Recommendation 632 there is a need to distribute the transmit frequencies of all satellite EPIRBs as uniformly as possible across the total available band.

1.5.3 In order that the effectiveness of a 1.6 GHz satellite EPIRB system can be demonstrated, and satellite EPIRB production units can be developed (including release mechanism, data interface and possible homing facilities), it is recommended that pre-operational demonstrations begin as soon as possible.

1.5.4 A number of operational, technical and administrative questions require study to enable the implementation of an operational satellite EPIRB system.

2. Pre-operational demonstrations

2.1 In 1985 the IMO requested that pre-operational demonstrations of 1.6 GHz satellite EPIRBs be conducted.

2.2 Such demonstrations were performed between November 1986 and September 1987, using 11 satellite EPIRB devices provided by the Federal Republic of Germany and installed on 15 vessels from 10 countries.

2.3 INMARSAT coordinated these demonstrations, which made use of a receiver processor installed at the British Telecom International coast earth station in Goonhilly, United Kingdom, and the INMARSAT Atlantic Ocean Region satellite.

2.4 The principal aim of the pre-operational demonstrations was to instill confidence in the overall 1.6 GHz satellite EPIRB system, with the following additional objectives:

- to provide pre-operational experience with 1.6 GHz satellite EPIRBs prior to the introduction of the GMDSS, in order to enable the IMO and national Administrations to define the GMDSS requirements for satellite EPIRBs;

- to provide manufacturers with 1.6 GHz satellite EPIRB production experience prior to the introduction of the GMDSS; and

- to provide INMARSAT with performance data for the development of 1.6 GHz satellite EPIRB technical requirements.

2.5 Operational conditions for the demonstrations included the following:

- examination of the effects on satellite EPIRB transmissions arising from superstructure masking;

- satellite EPIRB transmissions at low elevation angles (i.e., near the edge of satellite coverage); and

- simultaneous satellite EPIRB transmissions.

2.6 The results from the demonstrations are summarized in Table IV where the following definitions apply:

- Category 1: successful satellite EPIRB transmissions supported by correlated ship reports and coast earth station printouts;

- Category 2: successful satellite EPIRB transmissions supported by coast earth station printouts only;

- Category 3a: unsuccessful satellite EPIRB transmissions supported by ship reports only (see footnotes to Table IV); and

- Category 3b: unsuccessful satellite EPIRB transmissions supported by ship reports only and where the lack of coast earth station printouts cannot be explained.

2.7 Out of a total of 1196 satellite EPIRB transmissions, 1104 transmissions were successful and 92 were unsuccessful of which only 8 could not be explained.

TABLE IV

SUMMARY OF 1.6 GHz SATELLITE EPIRB PRE-OPERATIONAL DEMONSTRATION TRANSMISSIONS FROM NOVEMBER 1986 THROUGH SEPTEMBER 1987

SHIP'S NAME	COUNTRY	SUCCESSFUL TRANSMISSIONS			UNSUCCESSFUL TRANS.		MESSAGE TRANSFER TIME (MTT) (minutes)		RANGE OF ELEVATION ANGLE (degrees)
		CATEGORY 1		CATEGORY 2	CATEGORY 3				
		on deck	float free		3a explained	3b unexplained	mean	range	
NORGE	Norway	19	3	0	9[1)]	0	1.72	0.9-3.6	-2 to +3
STRATHCONON	UK	47	0	5	6[2)]	0	1.34	0.7-2.5	11 to 42
MAIPO	CHILE	37	0	3[3)]	2	0	1.40	0.8-2.9	21 to 52
MBMANDAKA	ZAIRE	4	0	8	1[4)]	0	1.18	0.9-1.6	25 to 60
EUGENIOS EUGENIDES /PPLS 80	GREECE	29	1	0	2[5)]	0	1.21	0.8-1.8	23
CLARENCE	NETHERLANDS	89	0	5	5[6)]	2	1.35	0.7-3.6	5 to 40
METEOR	F.R.GERMANY	98	3	5	18[7)]	0	1.29	0.8-10.3	-1 to +43
AMERICANA	ITALY	14	0	3	1[8)]	2	1.31	0.8-1.7	
UBENA	F.R.GERMANY	121	0	6	11[9)]	1[9)]	1.24	0.8-4.1	4 to 43
NUNGU ITTUK	DENMARK	83	3	6	3[10)]	0	1.40	0.7-2.6	
HUMBOLDT E	F.R.GERMANY	264	1	2	12[11)]	0	1.22	0.8-2.1	17 to 48
GAUSS	F.R.GERMANY	52	4	2	0	1[12)]	1.26	0.7-2.3	18 to 26
GEROITE OD /KALIAKRA	BULGARIA	180	2	5[13)]	14[14)]	2	1.23	0.8-2.1	13 to 18
		1037	17	50	84	8			

FOOTNOTES

1) 3 failures were due to receiver processor outage; 6 failures were due to low elevation angle at the satellite edge of coverage.

2) 2 failures were due to outages of receiver processor; 4 failures were due to unusually long periods of no reception (i.e., no signals coming into the receiver processor), 1 of which was reported "problems with gear in Goonhilly".

3) Missing ship reports in July.

4) Receiver processor outage.

5) 1 receiver processor outage and 1 outage from no automatic frequency control being (AFC) applied to receive chain due to CES standby operation or receiver processor maintenance.

6) 1 receiver processor outage; 1 reported CES outage and 3 failures occurred when no AFC was applied to receive chain due to CES standby operation or receiver processor maintenance.

7) 7 receiver processor outages; 11 failures were due to unusually long periods of no reception.

8) 1 outage of receiver processor.

9) 7 receiver processor outages; 4 failures were due to unusually long periods of no reception. Category 3b transmission was at very low elevation angle at the Gulf of Aden, could be a masking effect.

10) 1 receiver processor outage and 2 outages from no AFC being applied to receive chain due to CES standby operation or receiver processor maintenance.

11) 8 receiver processor outages; 4 failures from no AFC being applied to receive chain due to CES standby operation or receiver processor maintenance.

12) Category 3b, probably mutual interference caused by 2 simultaneous transmissions on the same channel (GAUSS & UBENA).

13) Missing ship reports in June.

14) 7 receiver processor outages; 6 failures were due to unusually long periods of no reception; 1 operator failure reported by coordinator.

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[1978-82]: **a.** 8/501 (INMARSAT).