MOBILE RANGE
FOR MEASURING SHIP RADIATED ACOUSTIC NOISE

by

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ABSTRACT

The Mobile Range described in this paper allows measurements of noise radiated from both surface ships and submarines in open seas with bottom depths from less than 100m to 400 meters. The range is being developed and built by Sonomar under contract with the Italian Navy. The system is semifixed, that is, it can be launched, utilized and recovered in short time or else, with some precaution, can be left operational for longer periods. In this paper a description of the system is given; the design criteria for the at-sea measuring equipment, the navigation of the vessel being tested and for at-shore data analysis are discussed.

INTRODUCTION

The system described in this paper will be used to measure the noise radiated by surface ships and submarines in both dynamic and static conditions, in open sea with a bottom depth from less than 100mt to 400 meters.

The system is semi-fixed, that is, it can be launched at sea, utilized and recovered in a short space of time, or else it can be left operational for longer periods, provided certain precautions are taken.

The mobile range is now being developed and built under contract with the Italian Navy.

In this paper a description of the system is given; the design criteria for the at-sea measuring equipment, the navigation of the vessel being tested and for at-shore data analysis are discussed.

1 - SYSTEM REQUIREMENTS

The basic requirements for the mobile range are as follows:

* Measurements of noise radiated by submarines and surface ships with speeds up to 30 knot.

* Measurements to be conducted in areas with bottom depth up to 400 meters; sea state conditions up to 2; survival of the in-water equipment at higher sea states.

* Launching and recovery of in-water equipment to be performed by a small ship with a minimum of expendible parts.

* Possibility to launch and recover the range and to conduct the measurements from the surface ships to be tested.

* Maximum use of reliable commercialy available equipment.

* Computer based analysis on existing facilities.

2 - COMPOSITION OF THE SYSTEM

The system consists of:

a) In-water subsystem, formed by three mooring supporting the required hydrophone stations, a marker buoy and a radio buoy transmitting data to an assist ship.

b) Navigation subsystem, located on the test vessel,having the purpose of giving navigational control with respect to the moorings.

c) Signal acquisition subsystem, located on the assist ship (or else on the test vessel if it is a surface ship), with the purpose of receiving and recording on magnetic tape the signals transmitted from the radio-buoy and controlling the quality of them.

d) Signal analysis subsystem, located on land, utilizing part of the acquisition subsystem and an HP-1000 computer.

2.1 - In-water Subsystem

Fig.1 shows the basic schematic configuration of the in-water subsystem shown for operating on a typical bottom of 200 meters depth. It consists of 3 moorings A,B,C. The hydrophone stations (H_1,H_2,H_3, and H_4) are suspended from moorings A and B as indicated in the diagram and at the required depths. H_1,H_2 and H_3 are called Beam hydrophones and H_4 is called Track.

The range configuration is flexible so that, starting with the basic configuration in Fig.1, it can be adapted for either surface ships or submarines or changed according to marine currents or to the bottom depth on which the system must operate. For operations with submarines hydrophone H_4 is not used.

The composite structure of the cable enables the position of the hydrophone stations to be changed and also to intervene on each connecting electric cables separately.

Moorings A and B both have a Release-Transponder unit (RT) suspended at a depth of 100mt. These units act as an acoustic responder and free the moorings when receiving an appropriate acoustic control signal.

The two moorings A and B are anchored to the bottom (AN in the diagram). They are supplied with two buoyancy units and connected together at the Connection Unit (UC) by means of a hydrophone cable (CAB-3). Mooring A is connected to the Radio-buoy by means of a Vibrating Insulation Module (VIM) that has the purpose of isolating the buoy's oscillations from the mooring and by the piece of cable, CAB.7, which also has a damping function.

The radio-buoy contains the electronics (EL) necessary for the conditioning the hydrophone signals and for the transmission via radio link of the signals and reception of commands from the assist ship to the buoy.

The radio buoy is easy to connect and disconnect from mooring A in case it is required to disactivate the range and leave it in the sea for a period of time.

The radio buoy is about 5 meter high above the sea surface to make it visible from a distance both optically by periscope and by radar (this applies also to the marker buoy). Oscillations due to sea motion are limited within the vertical aperture of the transmitting/receiving antenna.

Anchorage C consists of a marker buoy (mechanically similar to the Radio-buoy) anchored to the bottom by a slack mooring. Both the marker buoy and the radio-buoy contain a radar reflector and a flashing beacon for use during dark.

2.2 - Navigation subsystem aboard the test vessel

Fig.2 is a block diagram of the subsystem. It is used for the acoustic navigation of the Test vessel with respect to the two trasponder (RT) units located on the moorings A and B at a depth of about 100m.

Navigation information are obtained measuring the distance between the test vessel and the two RTs, filtering the data and graphically representing on a video the information necessary for the course correction. The above mentioned information, together with the time (digital clock), is also recorded on a diskette. A VHF radio channel is used for communicating between the assist ship and test vessel and also permits the synchronization of two digital clocks, the first, part of the navigation subsystem on the test vessel and the second, part of the acquisition subsystem on the assist ship.

The possibility of using test vessel's underwater telephone transducer, when available, in order to avoid installing a proper transducer is provided.

2.3 - Acquisition subsystem aboard the assist ship

The system is shown schematically in Fig.3. It provides magnetic recording of the hydrophone signals received by radio and a preliminary data quality control on a 1/3 octave analyser and proper recorder. Digital clock data, informations on operating parameters of the electronics are also recorded.

The system enables one to choose the hydrophone channels to be used as well as their gain, equalization and to calibrate them.

- Auxiliary functions provided by the subsystem are:

a) Measurement of the geometric deformation of the range due to the water current by interrogation of the two transponder units.

b) The possibility of steering the test vessel from the assist ship;this function duplicate the one implemented on board the test vessel and is particularly relevant for operations with a submarine.

c) Rapid electroacoustic calibration in situ of the various hydophone channels.

d) Possibility of measuring precisely the distance between the test vessel and each hydrophone.

e) Activation of the release function of the transponders for recovery of the at-sea equipment.

2.4 - On-land analysis subsystem

Fig.4 is a block diagram of the subsystem. It enables the following operations to be carried out for each hydrophone channel.

a) Riconstruction of the distance between the test vessel and the hydrophone and choice of the sections of the run to be used for signature data.
It makes use of some of the components of both the acquisition and navigation subsystem.

b) Analysis and signature in 1/3 octave bands from 10 to 40000Hz.

c) Narrow band analysis and signature between 5 and 5000Hz.

d) Compensation for the effects of surface and bottom interference.

e) Calculation of statistical averages.

3 - ANALYSIS OF SOME CRITICAL DESIGN PARTS

The performances and reliability of a mobile range is a large number of factors and operations. While setting up the system it has been found that after designing the data telemetry and vibration isolation of the hydrophones the most challenging problems to solve were:

* Measuring hydrophone positions in the range.
* Navigation accurancy and safety of vessel navigating inside the range.
* Launching and recovering of at-sea equipment.
* Compensating of surface and bottom interference in the measurements.

In the following paragraphs the solution being implemented of the above mentioned problems are discussed.

3.1 - Measuring hydrophone positions

It can be easily expected that in any operational area a current will be present deforming the lay-out of moorings from a straight line. In the design phase a model has been used to dimension buoyancies and anchors required to obtain equilibrium and minimize deformation of moorings, but in spite of that deformation cannot be totally eliminated.

For example Fig.5, 6 and 7 show the deformation of mooring A and B when, at its deep configuration is affected by the following current profile:
0.5 knots from 0 to 100 meter;
0 knots on the bottom;
linearly decreasing between 100 meters and the bottom.

In Fig. 5 and 6 the current is assumed perpendicular to the phase containing mooring A and B; in Fig.7 the current is assumed parallel to this plane.

From Fig.6 and 7 it can be observed that there is an offset between the axis of base line H_4-H_1 and the axis of base line joining the two transpoders used for navigation of the vessel under test.

Therefore in order to navigate the ship under test over H_4 (TRACK Hydrophone) the offset must be taken into account. It can be observed that for navigation purposes only the offset in the Y/Z plane is relevant. Therefore a simple last mean square algorithm is used to estimate precisely the projections on plane YZ of distances between H_1, H_2, H_3, H_4, and the two transponders. Measurements are taken from the assist ships before the vessel under test starts a measurement run. Estimated navigation accuracy over H_4 is of the order of 5 meters.

3.2 - Observations on the test vessel's navigation system

Reference is made to Fig.8. This diagram represents an example of the positions on the horizontal plane of the buoys (B_1=radio buoy) the two responders RT_1 and RT_2 and the hydrophones H_1 and H_4 at the head of moorings A and B respectively. Because of the deformation caused by the current H_1 and H_4 are displaced with respect to RT_1 and RT_2.

The navigation of the test vessel will have several phases (see Fig.8):

a) Approach and radar-optical alignment.
The test vessel "sees" the two buoys B_1 and B_2 and sets an appropriate course in correspondence to the radar axis perpendicular to B_1-B_2 and passing through the midpoint.
This phase precedes the use of the acoustic navigation data and, in the case of a submarine, takes place at periscope depth, before diving.

b) Approach and acoustic alignment.
The test vessel modifies its course, moving into the acoustic navigation axis by utilizing the data supplied by the HP-9836 computer.

c) Maintenance of the course.
The test vessel must be on the correct course some time before reaching the maximum distance DM at which radiated noise measurements begin. (DM is about 1200mt for RT_1-RT_2=200mt and minimum aspect angle of 10°).
The test vessel continues on its course with small corrections, as indicated by the computer, up until the end of the course (a distance DM beyond the range).

d) Manoeuvre for moving away with an eventual return towards the range from the opposite side, repeating the above mentioned operations.

The following observations should be made regarding navigation across the range.

- Safe navigation for the submarine.
The navigation system must ensure a 100% non-interference with the structure of the range. The system has been designed to offer this safety; it has infact been verified that when the distance between the anchorages is 200mt, the deformation of the range, even under the influence of unusual current conditions, leaves ample space for navigation.
Moreover the system supplies the data with a precision far superior (1m) to that required to ensure the non-interference.

- Validity of the measurement.
The most critical case is the passage of a surface ship across the hydrophone track (H_4). The assist ship should pass above the hydrophone H_4 with an offset error not greater than the width of the surface vessel. This can be achieved by means of the proposed system that, owing to the combination of high precision measurements with filtering, allows one to

obtain the required precision.

The navigation system utilizes hardware already widely tested both for its functionality and reliability in the offshore field and suitably adapted to the present application.

The test vessel may navigate at maximum speed (30 knots) provided that the induced noise at the transducer installed on the test vessel is contained within the established limits.

The elements installed on the range that are required for the navigation of the test vessel are the two responders RT_1 and RT_2 consisting of the RT units, installed as shown in Fig.8 and defining a system of cartesian coordinates.

The transponders are the reference points with respect to which the test vessel calculates its position. To do this the test vessel interrogates the two transponders RT_1 and RT_2 at a frequency f_1; these respond at different frequencies f_2 and f_3.

The test vessel receives the two responses and recognizes the two units on the basis of their frequencies. Using the time intervals between interrogation and response. Distances R_1 and R_2 between the test vessel and RT_1 and the test vessel and RT_2 are measured.

The position of the test vessel is found from the distances R_1 and R_2. The HP 9836 computer elaborates this information by numerically filtering. Filtering is used to eliminate the effect of the delay in the estimation of the position caused by acoustic propagation time, to estimate the direction and velocity of navigation without the necessity of a gyrocompass and log and to reduce the effect of measurement errors on the global precision of the system.

Errors are essentially:

- Error in the measurement of the delays due to variations in the sound speed.
  The effect is minimized by estimating the appropriate average value from the temperature/velocity profile.

- An intrinsic error in the measurement of the time delays due to the instruments used for the measurements.

- Error in the estimation of the transponder positions.
  The preliminary measurements for estimating the precision of the system

minimize this error.

An extensive simulation study has been carried out in order to calculate the global errors in the positioning of the navigation system. These have proved to be of the order of 1 meter relative to RT_1 and RT_2. The functioning of the navigation system, including the operator, has also been simulated in order to verify the ease with which it can be used. Fig.9 is an example of this simulation showing graphically the horizontal plane containing the range (RT_1 and RT_2).

The y axis represents the navigation axis desired V_o, X_o, Y_o and γ_o represents respectively the speed, the coordinates and the heading of the test vessel measured with respect to the Y axis at starting point. The crosses are the successive positions of the vessel estimated by the system. The system also supplies numerically the successive X and Y values together with the angle. The solid curve represents the real course of the test vessel.

3.3 - Launching and recovering of the system

The method for launching and recovering the range has been designed to operate with an assist ship provided with one derrick, one winch and two auxiliary craft (rubber dinghies).

To carry out the operation with the above hypotheses and the limited manoeuvring capability of the assist ship the sea state must be less or equal to 2 and the direction of the wind must be constant.

The procedure for launching the moorings A and B is a combination of the "anchor first" and "anchor after" methods: each mooring is launched in two sections as shown in Fig.10 (the bottom setting lowered in depth and the top section floating).

The submerged sections are suspended from a reinforced balloon and connected by means of a rapid-release hook.

The two moorings A and B, as shown in Fig.11 are then spaced apart so that there is the desired distance between them (about 200mt). The rubber dinghies are used to join together on the surface the two section of connecting hydrophone cable together with the sinker, kept temporarily on the surface by means of a suitable balloon.

The rubber dinghies are used to uncouple the two supporting balloons.

For recovery, the assist ship activates acoustically the uncoupling of the mooring A releaser and subsequently that on mooring B. The rubber dinghy takes the radio-buoy back to the assist ship and recovery on board begins according to the sequence: radio-buoy, mooring A, mooring B.

An emergency recovery method has been foreseen. This would take place, with the help of divers and only in the unlikely situation in which one of the releasers doesn't work.

3.4 - Compensation for the effects of surface and bottom interference

In order to calculate the acoustic levels at the reference distance of 1 metre from the source using the measured levels, it is necessary to know the propagation loss between test vessel and hydrophone.

Within the geometric conditions foreseen for the range, such losses can be modelled using the classical law (spherical divergence + absorption minus the incoherent contribution of the surface reflections) only for frequencies above 1KHz. For lower frequencies, the difference between the propagation model required and the classical model, becomes greater (and hence also compensation), the lower the frequency.

The order of magnitude of the systematic error by utilizing the above classical model can be of 10-15dB for frequencies of hundreds of Herz and of 15-30dB for frequencies below 100Hz.

This error is caused by interference formed at the hydrophone between the direct sound field and the surface reflected and bottom reflected fields. The bottom reflected field depends upon the frequency and the geometry and nature of the bottom.

A preliminary study, conducted in cooperation with Mr. Schmidt (Salcantcen) using models NISSM and FFP, on propagation over a reflecting bottom has indicated that for frequencies above 1000Hz compensation for incoherent addition of surface and bottom contribution and averaging over values obtained from the 3 hydophones (spacial diversity) gives a reliable result if bottom characteristics are known.

For frequencies below 1000Hz there is no simple rule available. Some modelling work has been started and shall be verified in known areas using the range itself.

4 - CONCLUSION

The system must be delivered for acceptance test in summer '85. Sea trials are also foreseen in order to verify at sea operations of the various parts of the system in Fall '85.

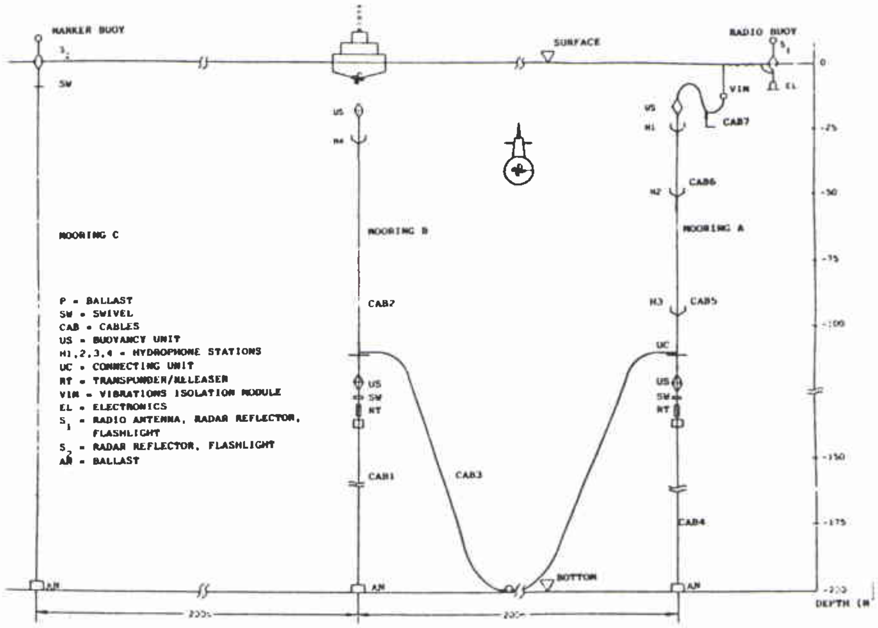

FIG.1 - AT-SEA SUBSYSTEM. BASIC CONFIGURATION

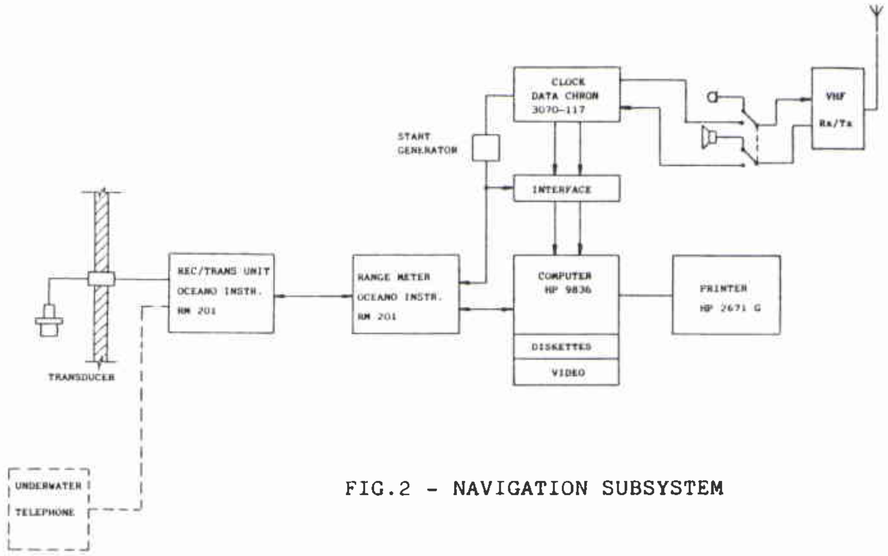

FIG.2 - NAVIGATION SUBSYSTEM

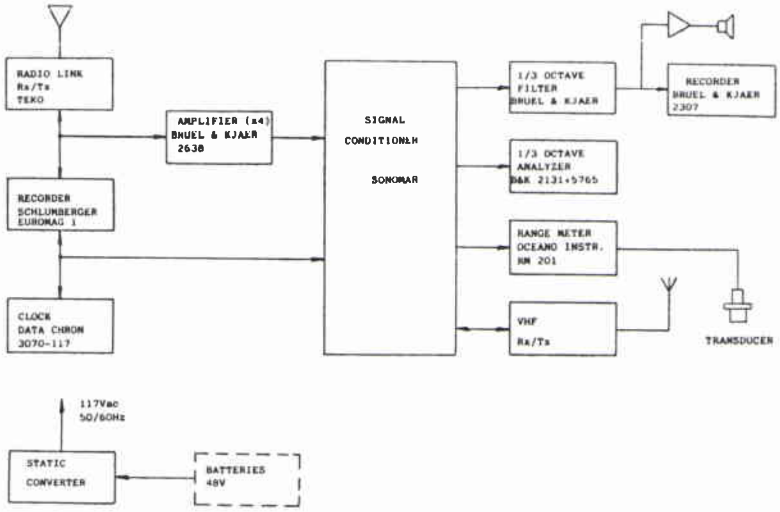

FIG.3 - SIGNAL ACQUISITION SUBSYSTEM ABOARD ASSIST SHIP

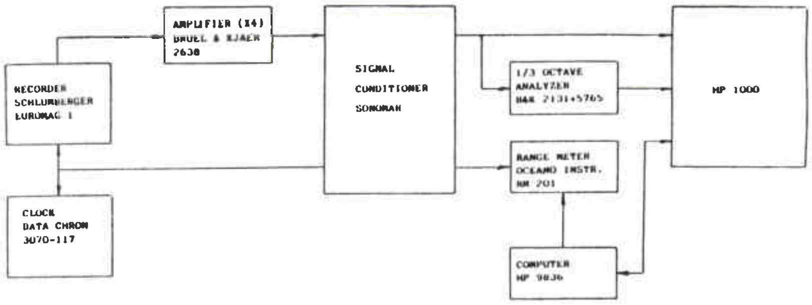

FIG.4 - ON-LAND ANALYSIS SUBSYSTEM

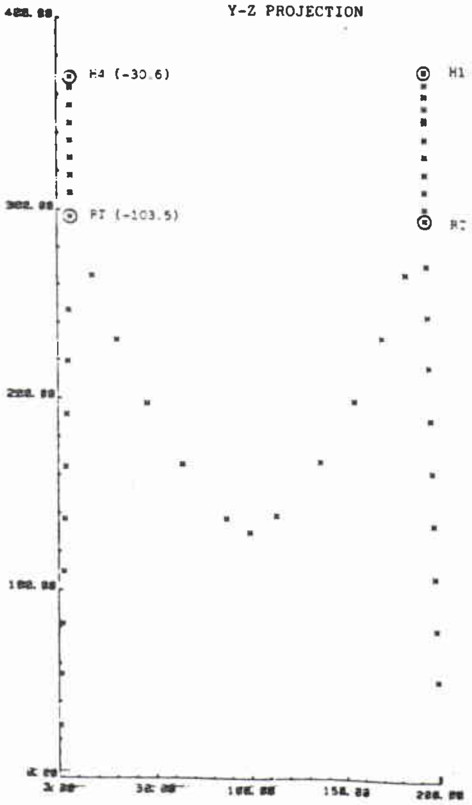

FIG.5 - DEFORMATION OF THE RANGE

CURRENT ⊥ PLANE Y-Z

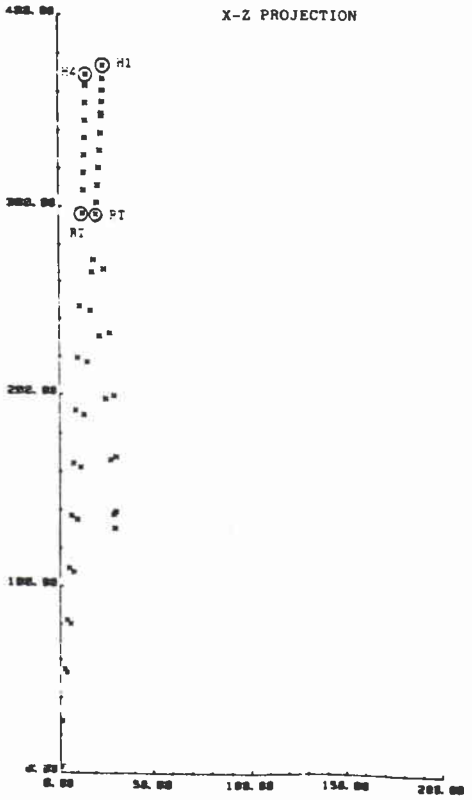

FIG.6 -DEFORMATION OF THE RANGE

CURRENT ⊥ PLANE X-Z

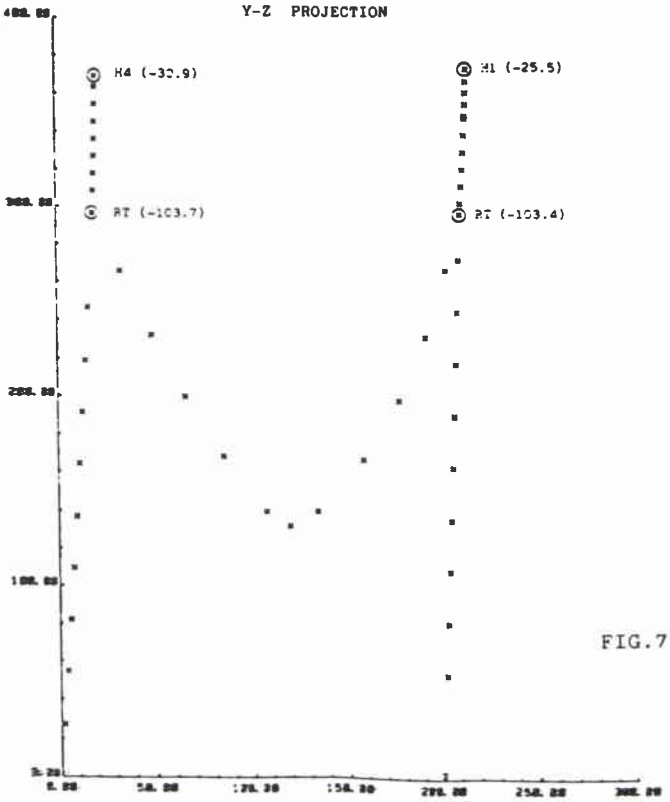

FIG.7 - **DEFORMATION OF THE RANGE CURRENT ⊥ PLANE Y-Z**

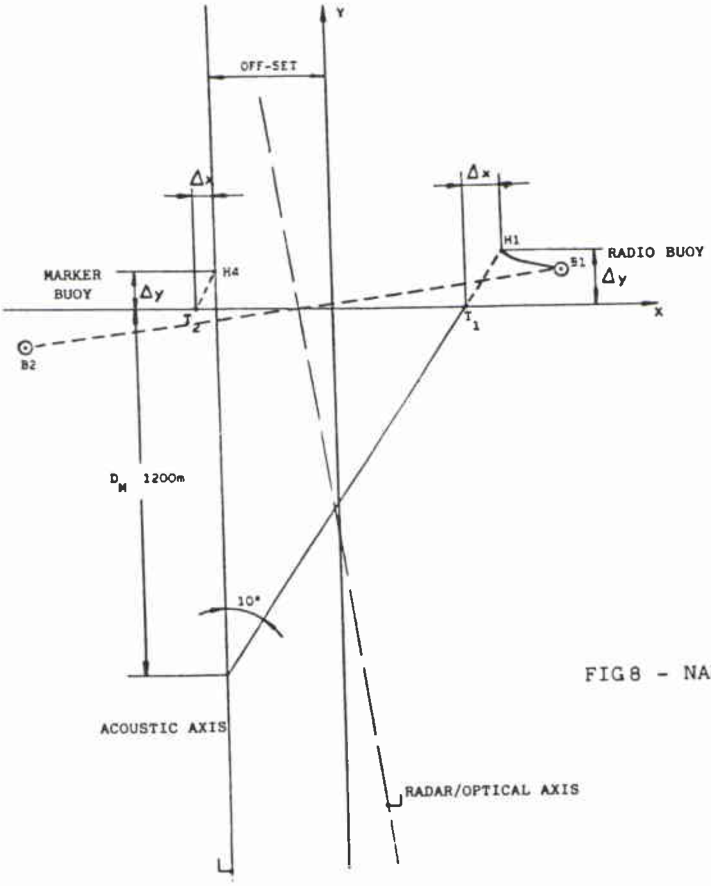

FIG 8 - NAVIGATION GEOMETRY

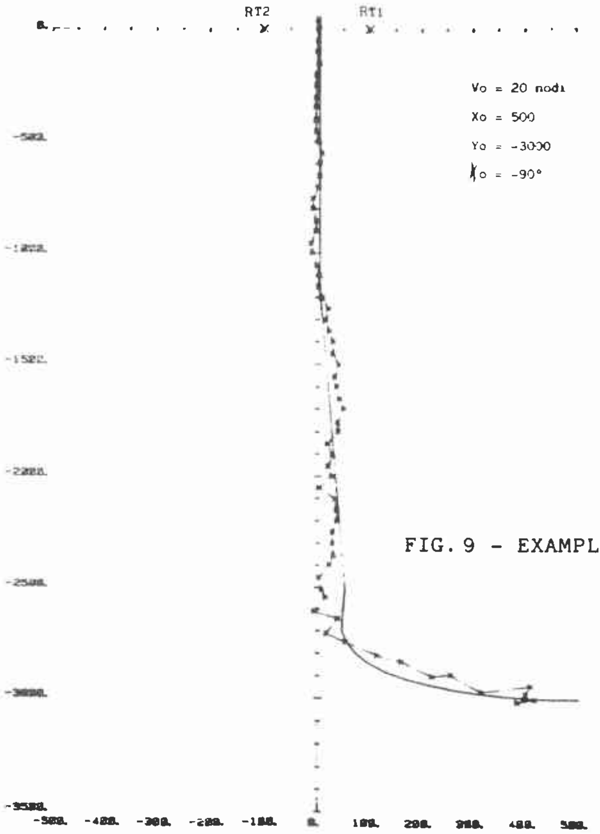

FIG. 9 - EXAMPLE OF SIMULATED NAVIGATION COURSE

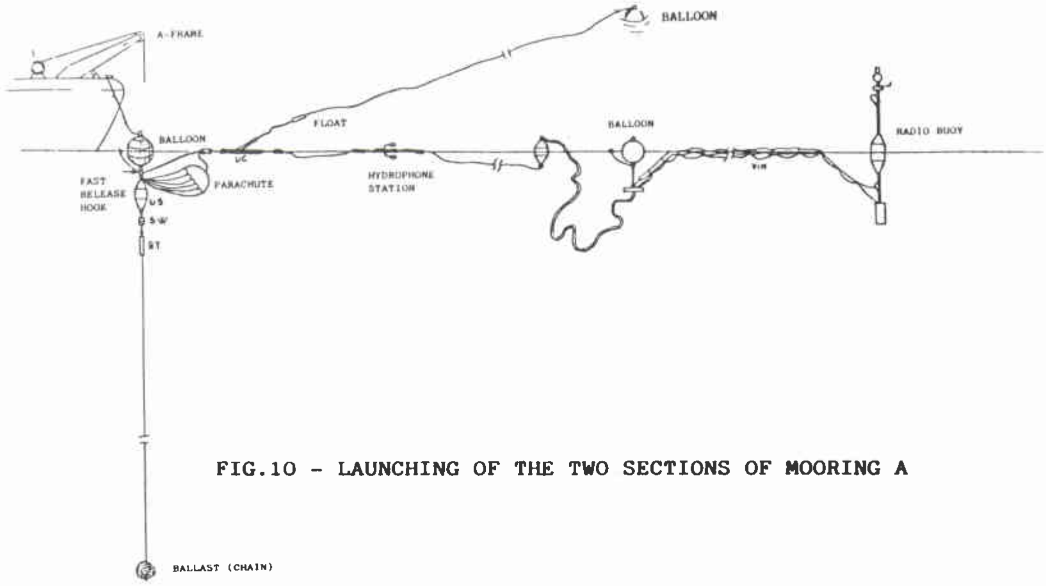

FIG.10 - LAUNCHING OF THE TWO SECTIONS OF MOORING A

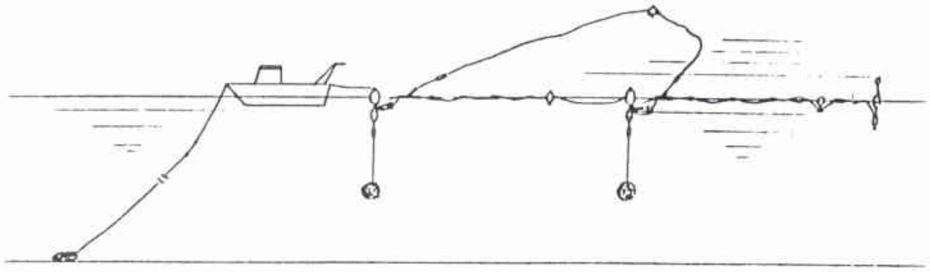

FIG.11 - ARRANGEMENT OF MOORINGS A AND B BEFORE SINKING

DISCUSSION

A.D. Stuart (United States): Does the measurement range have the ability to monitor the aspect angle of the "target" or "test" vessel, as well as its range? If so, how is this to be done?

E. Cernich: Monitoring equipment installed on board the assist ship does not have the capability to monitor the aspect of the test vessel. However, the estimated aspect angle of the test vessel can be made available on-line onboard the test vessel by reference to the transponders' base line; ashore it can be measured by reference to the hydrophone H1-H4 baseline. Real-time ranges to hydrophones H1 and H4 are continuously displayed on board the assist ship.

A.W. George (United States): Does the on-board monitoring (quick-look) system have range correction?

E. Cernich: Ranges are measured direct to the two transponders. On board the assist ship ranges to hydrophones H1 and H4 are directly displayed, thereby providing correct ranges to the above hydrophones.

C.C. Leroy (France): Is there any security danger in transmitting the received signals by radio?

E. Cernich: The need to avoid broadcasting the data was taken into consideration. We should not forget that the transmitting and receiving antennae are operating over the sea surface. By an appropriate choice of the transmitting frequency, the vertical directivity pattern of the transmitting antennae, and the transmitter output power, the surface reflection allows the useful reception distance from the buoy to be limited to a range of about one mile centred at one mile.