SACLANTCEN
Special Report M-93

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SACLANT ASW RESEARCH CENTRE

TWENTY YEARS OF RESEARCH AT THE SACLANT ASW RESEARCH CENTRE 1959 – 1979

by

DONALD ROSS

1 JANUARY 1980

NORTH ATLANTIC TREATY ORGANIZATION

LA SPEZIA, ITALY

Published by

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SACLANTCEN
SPECIAL REPORT M-93

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ABSTRACT

The SACLANT Antisubmarine Warfare Research Centre was established by the North Atlantic Treaty Organization to provide scientific and technical advice and assistance to the Supreme Allied Commander Atlantic in the field of antisubmarine warfare and to respond to the requirements of NATO naval forces in the field. Its first twenty years are described in four broad periods, for each of which is given a summary of administrative matters and detailed histories of the work performed under items of the current scientific programmes. Extensive citations are made to SACLANTCEN research publications and a supplementary volume (published as SACLANTCEN Bibliography SB-3) lists the authors, titles, and abstracts of these.

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*Dr D. Ross was Deputy Director of SACLANTCEN from 1976 to 1979; during the late summer of 1978 he served as Interim Director.

Editorial Note: On his departure from SACLANTCEN, the author left a finished text and a general list of suggested illustrations. In preparing the document in its present form the editor has had to select illustrations according to their availability and to the space at his disposal, and has had to provide titles. The editor wishes to emphasize that any errors or inconsistencies in the illustrations are therefore his responsibility and not those of the author.

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Note

SACLANTCEN Bibliography SB-3, published contemporaneously, provides a reference list to SACLANTCEN documents

FOREWORD

Donald Ross brought to SACLANTCEN a wide experience and knowledge in the field of underwater acoustics and an enthusiasm for scientific research which greatly stimulated the whole Centre. His stay here saw a period of re-thinking and reorientation in the Centre's programme. While the implementation of this occupied much of his attention he was also involved in many management issues, yet he still found time to be active in organising and participating in education seminars for the staff.

This had made him eminently qualified to write this comprehensive record of the Centre's developemtns and achievements. The concept, perspective and weight to be given to each item are essentially his own, but while in conversation he was always ready to discuss the definite and sometimes colourful views he had formed on the relative value of this or that scientific endeavour or personal contribution, he has scrupulously kept these from his text, leaving it as far as possible as a factual record for the reader to form his own judgments. It is essentially a work of reference, which above all will be especially useful to the staff of the Centre and those closely associated with it. In particular it is hoped that it will not only serve as a source of important background information for new Centre scientists but also provide inspiration to them to continue the first rate work of their predecessors.

It is a pleasure that the 20th Anniversary of the Centre's foundation fell within my term of office as Director. After many years' experience of major research and development activities in my own country, and some knowledge of related work in allied nations, I now have the benefit of first hand knowledge of SACLANTCEN and the capabilities of its personnel. All this has left no doubt of the high quality of the Centre's scientific work and the excellence of its technical support, both now and throughout its history. Dr. Ross' document is a fitting acknowledgement of these achievements, also of the contributions from NATO organizations and national authorities that have helped to make it possible - especially significant among these have been the efforts of SACLANT's headquarters staff and the invaluable counsel given by the Centre's Scientific Committee of National Representatives. Above all is it a tribute to the staff of the Centre, not only for the work of the scientists but for the dedicated technical and administrative support they have received throughout the Centre's life.

B. W. LYTHALL
Director, SACLANTCEN

Introduction

In May 1979, the SACLANT ASW Research Centre celebrated its 20th anniversary. Inspired by this occasion, the writer undertook to document the research accomplishments of the Centre since its formation in 1959. For a period of about four months he read in detail each of the annual progress reports and examined some 700 publications as well as interviewing a number of old timers still at the Centre. From this research he acquired not only a knowledge of the individual projects but also a new appreciation for the accomplishments of this relatively small organization.

Working in the specific field of subsurface antisubmarine warfare, the Centre has in its twenty years made a remarkable number of significant contributions. In this volume these are considered to fall into five areas of research:

Environmental Acoustics Research

Active Sonar Research

Non-acoustic ASW Research

Oceanographic Research

Operations Research / ASW Studies

However, clearly it has been the interdisciplinary across-area interactions that have made the Centre's contributions so outstanding. In particular, the combination of strong oceanographic and environmental acoustic research done in a given geographic area, supplemented by active sonar studies in the same area, together with related operations research studies and NATO exercises, enabled the Centre to make important contribution both to scientific knowledge and to NATO ASW operational capabilities.

The writer believes that the Centre's outstanding achievements were made possible not only by the presence of a highly competent international scientific staff but also by the provision, by NATO, of sufficient funds for the acquisition and operation of first-rate research facilities, especially research vessels and their equipments and digital data processors and computers. However, excellent facilities in themselves do not produce first-rate research. The dedication and ingenuity of the technical support staff and the brilliant leadership provided by some directors and group leaders were even more important. The Centre has been fortunate to have had its full share of each of these important ingredients for success.

In conducting the research necessary for the writing of this history, the writer found it expedient to divide the 20 years into four roughly equal periods. The history is therefore divided into four parts, as follows:

I May 1959 – Mid-1964:
Formation and Transition to NATO

II Mid-1964 – Mid-1969:
Period of Growth

III Mid-1969 – Mid-1975:
Period of Transition

IV Mid-1975 – May 1979:
Period of Reorientation

Of these, the last period is too recent to be the subject of a proper history and only a brief summary of programme developments is given. The first three periods are treated in greater detail, each with an introductory chapter covering management aspects and facilities and separate chapters for the five areas of research previously listed.

Many of the higher ranking staff of the SACLANT Centre, including the Director and Deputy Director, come to the Centre from their nations for relatively brief periods of three to five years. For these personnel, there has been no really good way to find out what had previously gone on at the Centre, from which to build their own work. It took this writer almost his entire three-year term to acquire a reasonable background of the Centre's history. The present document is intended to provide such background information for persons newly involved with the Centre, including new SCNR members and SACLANT officers. Since it is especially written for new Centre staff members, it makes extensive reference to Centre reports, memoranda and conference proceedings and includes a full bibliography.

La Spezia
June 1979

Part. I

Formation and Transition to NATO

1959 - 64

MISSION

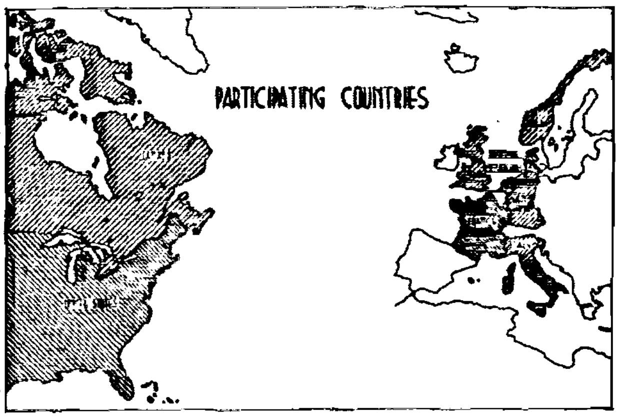
The Centre's mission will be to provide scientific and technical advice and assistance to SACLANT in the field of antisubmarine warfare, and to be in all respects responsive through SACLANT to the requirements of NATO naval forces in this field. As a subsidiary function the Centre may, without prejudice to its main task, render scientific and technical assistance, within the approved programme, to NATO nations requesting aid with antisubmarine warfare problems. The Centre shall perform the following functions:

(a) Operational research and analysis;
(b) Research and limited development (but not engineering for manufacture) in the field of antisubmarine warfare, including oceanography;
(c) Advisory and consultant work;
(d) Exploratory research;
(e) Such other related tasks as may be necessary.

CHAPTER 1 FORMATION AND TRANSITION TO NATO

1.1 Formation (December 1957 - May 1959)

In December 1957, following the launching of Sputnik I, the North Atlantic Council met for the first time at the level of Heads of Government. At this meeting the foundation was laid for increased cooperation in scientific and technical matters amongst the NATO allies. The Heads of Government expressed their desire to increase the effectiveness of national efforts by pooling their scientific facilities and information as well as by distributing specific tasks to individual nations.



The first nine nations to participate in the Centre's activity.

In February 1958, as a result of the NATO meeting and also inspired by the marked increase in Soviet submarine capabilities, United States Navy Admirals Arleigh A. Burke, Jerauld Wright, John T. Hayward, and Rawson Bennett began formulation of plans for a multi-national ASW effort. They requested that a subcommittee of the US Naval Research Advisory Committee (NRAC) investigate the establishment of a multi-national ASW research centre in Europe. Chairman of the subcommittee was Captain Kenneth M. Gentry, USN, who was at that time Deputy Director Research and Development, CNO. The group visited seven nations, the U.K., France, Germany, The Netherlands, Denmark, Norway and Italy, where they talked with high-level naval and scientific leaders and inspected possible laboratory sites.

The Italian representatives were led by the late Professor Maurizio Federici, who was subsequently to play an important role in the Centre's development. They proposed that the ASW research centre be located within the naval base at La Spezia. This offer to provide laboratory and other facilities was welcomed for a number of reasons: La Spezia, a port on the Mediterranean, is suitable for year-around sea operations; location within a naval facility would provide security and logistic support; the existence of a building immediately available to the NATO activity meant that inception of the enterprise would not be delayed; and the Mediterranean was recognized as an area of increasing military importance and one requiring scientific investigation.

Visit of the Head of State of the host nation: Onorevole Antonio Segni, President of Italy.

The Italian proposal was recommended by the NRAC Subcommittee. It was further proposed that nine nations be asked to participate in the Centre's activity: the seven nations listed above, plus the United States and Canada. These recommendations were approved by SACLANT and the U.S. Chief of Naval Operations in June 1958. Two months later the Secretary of Defense of the United States added his endorsement of the site recommendation and approved initial funding of the new Centre under the Mutual Weapons Development Program. The first meeting of representatives of the nine participating nations was held in La Spezia in September 1958 to discuss organization and scope of work.

In March 1959 a Memorandum of Understanding was concluded between the Governments of Italy and the United States relating to the establishment and initial operation of the Centre. The Government of Italy agreed to make available to the Centre without cost, such land, buildings, dock space, utility connections, etc. as might be required for the operations of the Centre.

On 23 March 1959 a contract was signed between the U.S. Department of Defense and the Societa' Internazionale Ricerche Marine (SIRIMAR), a company incorporated under Italian law especially for the purpose of operating the Centre on a non-profit basis. At the time of its creation SIRIMAR was a wholly-owned subsidiary of Raytheon Manufacturing Company, but in January 1961 the Pennsylvania State University succeeded Raytheon as owner and manager of SIRIMAR and remained so until the expiration of the contract on 30 June 1963.

1.2 Initial Operations under SIRIMAR (May 1959 - January 1963)

The Centre was established under the direction of SACLANT, due to his major responsibility in antisubmarine warfare as the senior NATO military authority in this field. SACLANT's guidance was transmitted through a six-officer military staff chosen from participating nations and headed by a SACLANT Deputy. The first SACLANT Deputy was Captain K.M. Gentry, USN, a senior officer with research and development experience. He was succeeded in June 1960 by Captain C.C. Cole, USN. Other SACLANT officers served as Assistant Deputy, Administrative Officer, Financial Comptroller, and Assistant Comptroller. Three ASW officers were provided by the various nations to provide expertise in air, surface, and submarine ASW operations.

The scientific work of the Centre was conducted under a Scientific Director, the first of whom was Dr Eugene T. Booth, an ASW expert and former Director of Columbia University's Hudson Laboratory. He served during the first two years and was succeeded in June 1961 by Dr John M. Ide.

In June 1960, the nine participating nations signed a Memorandum of Understanding that reiterated the mission of the Centre, provided for the creation of a Scientific Council advisory to SACLANT, and stated the specific responsibilities of the Scientific Director and the SACLANT Deputy. Each of the signatory nations agreed to participate in the work of the Centre and to make available to it such information as was required.

The mission of the Centre was to provide technical advice and assistance in the field of antisubmarine warfare to SACLANT, to other NATO Commanders and to the participating nations, and to be in all respects responsive through SACLANT to the requirements of NATO Naval forces in this field. It was stipulated that the Centre's activities were to be limited to research and initial development of equipments

Capt K.M. Gentry USN
SACLANT Deputy 1959-60

Capt J.O. Phillips USN
SACLANT Deputy 1961-63

Capt C.C. Cole USN
SACLANT Deputy 1960-61

Dr E.T. Booth
Director 1959-61

and were not to include final development and manufacture, which would be carried out within the nations.

The SACLANT ASW Research Centre was officially commissioned on 2 May 1959 by Admiral Jerauld Wright, USN, SACLANT. The first six months were largely devoted to organizational activities including hiring of staff and formulation of a research programme. Indispensable to SACLANT in this formative period was the advice given by the Scientific Advisory Council (SAC). This group, composed of top defense scientists from the participating nations, served as a sounding board for development of the programme and gave invaluable liaison between the new Centre and their national ASW laboratories. The first Chairman of the SAC was Dr H.F. Willis of the U.K. Other initial members, in addition to Prof Federici of Italy, included Ir van Batenburg of The Netherlands and Dr H. Nødtvedt of Norway, both of whom later became Directors of the Centre. Meetings were held bi-annually, beginning in April 1959.

By the end of 1962 the scientific staff had grown to 36 and an administrative and technical support staff of approximately 100 people had been built up. By this time NATO was ready to take over the operation of the Centre. Discussions leading to a NATO Charter began in July 1962 with the formation of a working group authorized by the North Atlantic Council with representatives from interested NATO nations and military commands. Discussions held in Paris in the summer and autumn of 1962 led to the NATO Charter (1) which was adopted on 30 October and provided for transfer of assets and funding from SIRIMAR to NATO early in 1963.

Closing of the SIRIMAR/MWDP period was marked by issuance of a final report (2) on activities from May 1959 to 1 February 1963, when the Centre became a NATO operation. This final report, published as a book by The Pennsylvania State University, has been used extensively by the writer of the present report as the single most complete source of information about the formation and first 3½ years of operation of the SACLANT ASW Research Centre.

1.3 Transition to NATO (1963-1964)

The NATO Charter provided for re-organization of the Centre as a NATO international military organization under the continuing policy direction of SACLANT. The mission of the Centre remained unchanged. All fifteen NATO nations became involved in the activities of the Centre and contributed to its funding. The Charter also established the Scientific Committee of National Representatives (SCNR), advisory to SACLANT, consisting of representatives appointed by each of the NATO nations. Its initial members were the nine scientists who had been members of the former Scientific Advisory Council. Terms of Reference were issued by SACLANT for the operation of the Centre, in accordance with the provisions of the Charter.

Inauguration of SACLANT ASW Research Centre by SACLANT Admiral Jerauld Wright USN 2 May 1959

An early meeting of the Scientific Advisory Council; Professor M. Federici is in the foreground.

The Charter prescribed the method of appointment and the duties of the civilian Director and Deputy Director. SACLANT was no longer represented at the Centre by a Deputy, Assistant Deputy, or Comptroller. Instead, the Charter required SACLANT to maintain a full-time Naval Advisor to the Director. In addition, a small NATO military staff of ASW Programme Officers was to be provided by the Nations in turn. Following NATO procedures, the host nation, Italy, was asked to appoint a Financial Controller and a Liaison/Security Officer.

Dr J.M. Ide
U.S.A.
Director 1961-64

SACLANT accepted the recommendation of the first meeting of the SCNR that Dr John M. Ide of the United States, previously Scientific Director for SIRIMAR, be appointed as the first NATO Director of the Centre. Dr H. Nødtvedt of Norway, Chairman of the SAC, became the first Deputy Director, and was also selected to succeed Dr Ide as Director in February 1964.

All staff had to be transferred from SIRIMAR to NATO pay scales. After discussion with the Co-ordinating Committee of Government Budget Experts, it was decided that scientists should be assimilated into the already-defined NATO A-scales. By 1 July 1963, essentially all staff, scientific and administrative, had been transferred from SIRIMAR to NATO pay scales and billets.

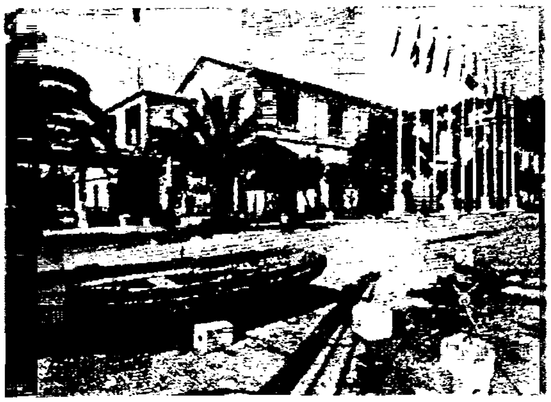
Dr H. Nødtvedt
Norway
Director 1964-67

The Centre was required to prepare budgets for submission to the NATO Military Budget Committee (MBC). The 1964 budget figure, the first full year under NATO funding, was 1400 million lire. This included expenses related to the acquisition of a new computer and new research vessel.

For 1963 the MBC approved a total personnel establishment of 152, including 44 scientists; and in 1964 the SCNR recommended an increase to 50 scientists. By 1964 the total approved complement was up to 174. However, scientific recruiting was difficult in the early years; on-board scientific strength had risen to only 41 by the end of 1964.

1.4 Initial Facilities

The single large office and laboratory building first provided to the Centre by the Italian Navy contains about 4000 m^2 of floor space, is located on the waterfront, and has been used by the Centre throughout its twenty years. The upper floor contains offices, conference room, and library, and the lower floor has laboratories and shops. When given to the Centre the building required extensive internal modifications to adapt it to the Centre's use.



The first building provided to the Centre by the Italian Navy.

In March 1960 SIRIMAR chartered the Italian merchant ship S.S. ARAGONESE, owned by Gastaldi & Company, S.p.A. of Genoa. The ARAGONESE was used extensively as a floating laboratory for underwater acoustic experiments, oceanographic studies, and other sea trials as appropriate.

The limitations of ARAGONESE were recognized by the Centre's scientists and administrators who were concerned with her performance, although both groups also acknowledged the good scientific work that had been accomplished with her. At the fifth meeting of the Scientific Advisory Council, in September 1961, discussion of the long-range programme of the Centre clearly showed the need for a new research ship. In 1964, the Centre terminated its contract with the owners of the ARAGONESE and chartered an eight-year-old, 2100-ton freighter, the MARIA PAOLINA G., which has since been the Centre's research vessel.

The modified Engineering Research Associates (ERA) 1101 high-speed, general-purpose, digital computer that had been loaned to the Centre in June 1960 by the U.S., while useful in the early days, had a number of serious limitations such as lack of a symbolic language and inadequate word length. After four years' service, the ERA 1101 was replaced in mid-1964 by an Elliott 503, which served as the Centre's general purpose computer for the next ten years.

1.5 General Nature of Initial Research Programme

Almost from the beginning, the Centre's research programme has been divided logically into four or five areas of research, each area encompassing from one to six clearly definable projects. Research in such areas as environmental acoustics, active sonar, oceanography, and operations research has been of continuous importance in the programme since the first years. Other research areas, such as non-acoustics, have lasted shorter periods. The first three projects, established at the Centre in autumn 1959, were in the areas of

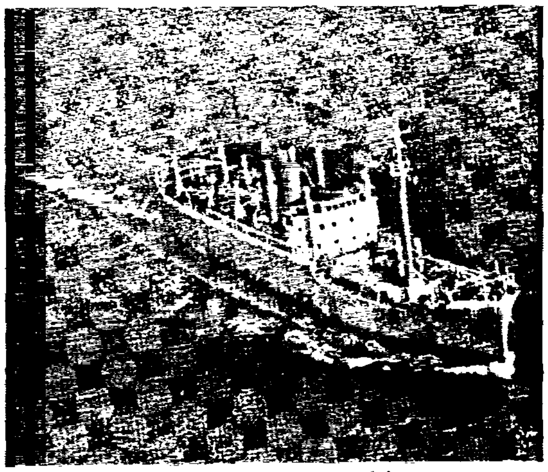
1. Environmental Acoustics
2. Active Sonar
3. Non-Acoustics.

These were followed in the spring of 1960 by projects in

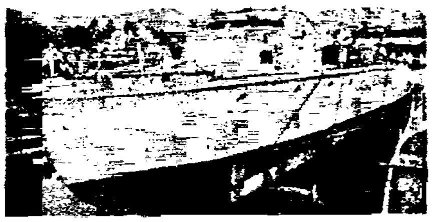
4. Oceanography
5. Operations Research.

Some of the early projects were studies using only library and computer facilities. By far the majority, however, also involved research at sea using the Centre's chartered research vessel and work boat. A large fraction of technical support and some of the efforts of the scientists were of necessity devoted to the development, design, and calibration of special research instruments for this larger group of SACLANTCEN projects. This trend has continued throughout the 20-year history of the Centre, with these technical-development efforts sometimes recognized in the programme as separate support projects and sometimes incorporated within the research projects themselves.

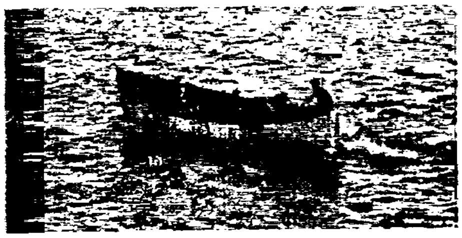
Sixteen specific projects are recognizable in the scientific programme of the Centre in the first five-year period. These are described in



The Centre's first research ship, S.S. Aragonese



First workboat on arrival



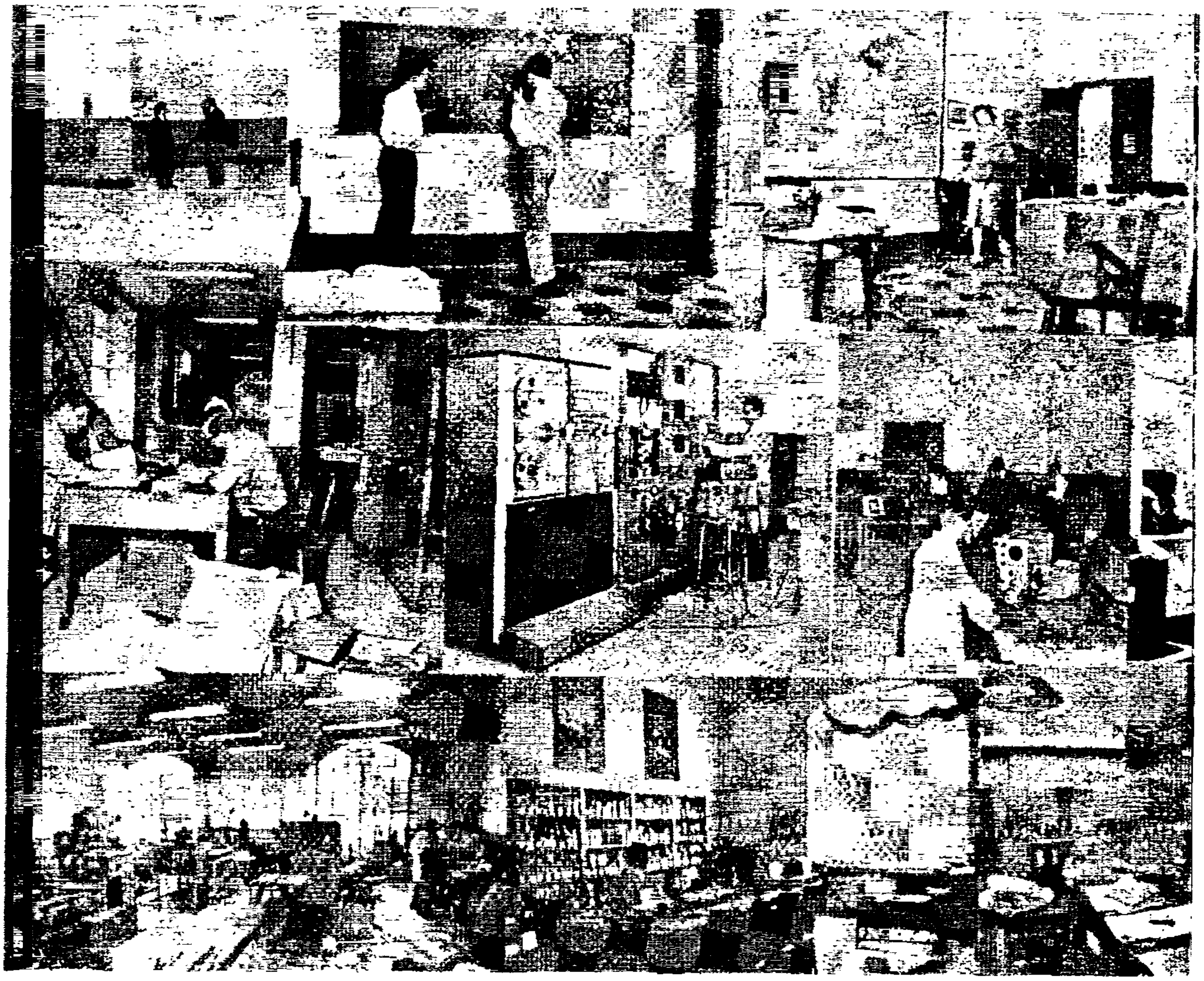
Lifeboat

Italian Navy CTS-61

Calibration barge, Sarzana lake

Vessels used during early research

the following chapters, where they are grouped by research area. Most of the projects were selected from topics recommended by the Scientific Advisory Council, and later by the SCNR, and all were approved by these groups as part of their advisory function to SACLANT. The information presented is taken from the SIRIMAR final report (2) and from Annual Progress Reports for 1963 and 1964, as well as from individual research reports. References are given to these reports when they have been published as SACLANTCEN documents. However, during the first years of the Centre there was only limited support was provided for the publication of research documents and much work remained as internal manuscripts, to which the present author has had access.



Offices, laboratories, library, and workshops in the 1960s.

CHAPTER 2 ENVIRONMENTAL ACOUSTICS RESEARCH (1959-64)

2.1 Introduction

Environmental acoustics projects have been a major part of the Centre's research programme since its inception. Aspects of this subject studied over the years have included both basic and area-related studies of propagation in deep and shallow waters, ambient noise, signal coherence, and reverberation. The Centre has also served as a focus for international co-operation in this field by organizing scientific conferences and multinational measurement programmes.

The first four projects undertaken in this research area were:

- 2.1 Bottom-Reflection Transmission, Sep 1959
- 2.2 Coherence Studies, June 1962
- 2.3 Hydrophone Calibration, May 1963
- 2.4 Sea-Water Attenuation, August 1963

(The project numbers are those used in the 1963 and 1964 Annual Progress Reports; dates are those given as the project start dates.) Since all of the early studies concerned sound propagation, this section of the programme was originally entitled Acoustic Propagation Research and later Sound Propagation Studies.

2.2 Bottom-Reflection Studies (Project 2.1)

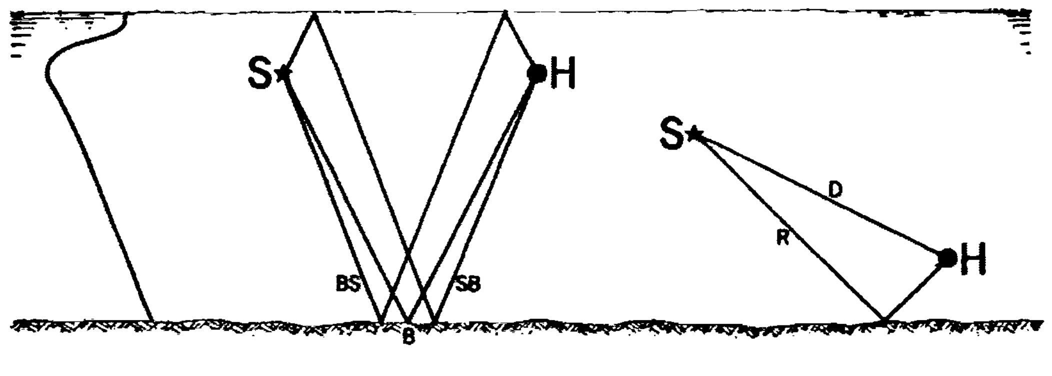
Bottom-reflective paths, because of their relatively large angles with the horizontal, are less affected by thermal inhomogeneities than direct paths. For this reason, there are many ocean areas where these paths offer almost the only hope of achieving ranges in excess of a few kilometres during much of the year. Specifically, in the Mediterranean in the summer, severe thermal conditions limit direct paths from near-surface sources to two to three kilometres, so that, except for convergence zones, bottom paths provide the only reliable coverage for surface-ship, hull-mounted sonars.

In this first study, the Centre investigated energy transmitted along each of several paths having varying numbers of bottom and surface reflections. Instruments had to be designed and built to record the time of arrival of signals by the various paths, to measure the peak pressures, and to square and integrate the arrivals to determine their energy. The explosive sources used were small underwater charges used of the Italian Navy modified so that their hydrostatic firing would take place at pre-determined depths down to 100 metres.

In August 1960, the first experiments were made in a deep water-area near Corsica using one-way paths of up to 130 km. Times of arrival of the signal along its different paths were compared with values calculated from bathythermographs and echo-sounding data, and good agreement was found.

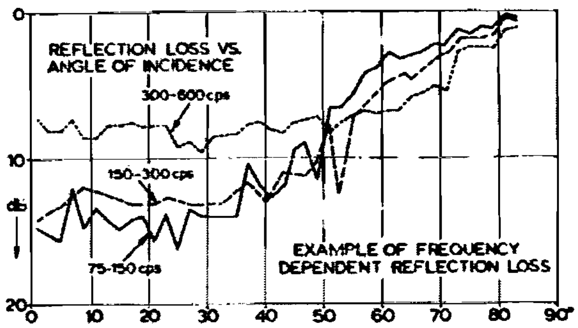
Additional propagation measurements relevant to bottom reflections were made in December 1960 in the Tyrrhenian Sea and in October 1961 in the north-west Mediterranean, the last in cooperation with the French Laboratoire D.S.M. du Brusc. Transmission losses for the various arrivals were determined in octave frequency bands between 75 and 4800 Hz (TR-17). Reflections from the ocean bottom were found to vary considerably from place to place, both in respect to the amount of energy lost in the reflection and to the amount of signal distortion introduced.

In the north-west Mediterranean, where the ocean bottom is flat, there is little scatter in the data and there was evidence of a critical angle of incidence, at least for the lowest frequencies. Critical angles from 30° to 22° grazing and maximum reflection losses of 7 to 15 dB were observed. At grazing angles less than the critical angle, reflection losses were from 0 to 3 dB for the lowest frequency band and from 2 to 7 dB for the highest band studied. In this area of flat ocean bottom, the signal was found to be considerably distorted at angles steeper than the critical



Bottom-reflection studies: S = source, H = hydrophone. [TR-152]

Reflection losses from a flat bottom in the NW Mediterranean, showing dependence on frequency and angle of incidence. [TR-42]



angle, due to penetration into the bottom, but relatively undistorted at angles closer to grazing.

In areas with a very rough bottom, such as the Tyrrhenian Sea, a wide scatter in the energy loss was observed, and evidence of a critical angle was not always found. The form of the bottom-reflected signal often changed completely due to scattering from the rough bottom, the received signal resembling a long roll of reverberation rather than an explosive sound.

In July 1962 a more extensive series of 16 propagation runs was made in several deep areas of the western Mediterranean. In June and July 1963 further measurements were made in the central and eastern Mediterranean, and in February 1964 in the eastern North Atlantic in co-operation with two French Navy ships and the Le Brusc laboratory. A summary of the useful data obtained from all of these early cruises is contained in TR-152.

The emphasis of this early programme was on obtaining a body of typical data, in order to see to what degree results were area-dependent and what features might be common to a wide variety of areas. Much of the effort was devoted to experimental techniques, including hydrophone calibration and the attempted development of a reliable, repetitive, explosive sound source (3), as well as techniques for integrating the energy received (4) and for calculating the actual bottom-loss coefficients (5).

2.3 Coherence Studies of Ocean Acoustic Paths (Project 2.2)

In sonar signal processing, the ultimate limit on improved signal-to-noise ratios, or on time and bearing resolution, is the degradation of the acoustic signal introduced by the ocean medium. This applies equally to all types of sonar, to communications, and to IFF systems. Signal degradation, or loss of information content, can be due to such causes as reflection from ocean surface or ocean floor, interference between multipaths, or wave-front distortion produced by sound speed inhomogeneities in the volume of the ocean.

Early in 1962 a study of the coherence of ocean acoustic paths was undertaken to determine "the information degradation of signals along various acoustic paths in the ocean, relating this to the performance of specific military systems." It was decided to select simple cases for investigation rather than to make measurements of the combined effects of many causes. Attention was first focused on forward scattering due to volume inhomogeneities as experienced along a single direct path (6,7,8). Measurements in March 1963 showed that this was probably a less important cause of phase and amplitude fluctuations than reflections from the rough sea surface and/or bottom.

In mid-1963, measurements were made of sound reflected by a strong thermocline gradient. It was discovered that under these conditions there is a phase change of the order of 90°, independent of frequency (TM-87).

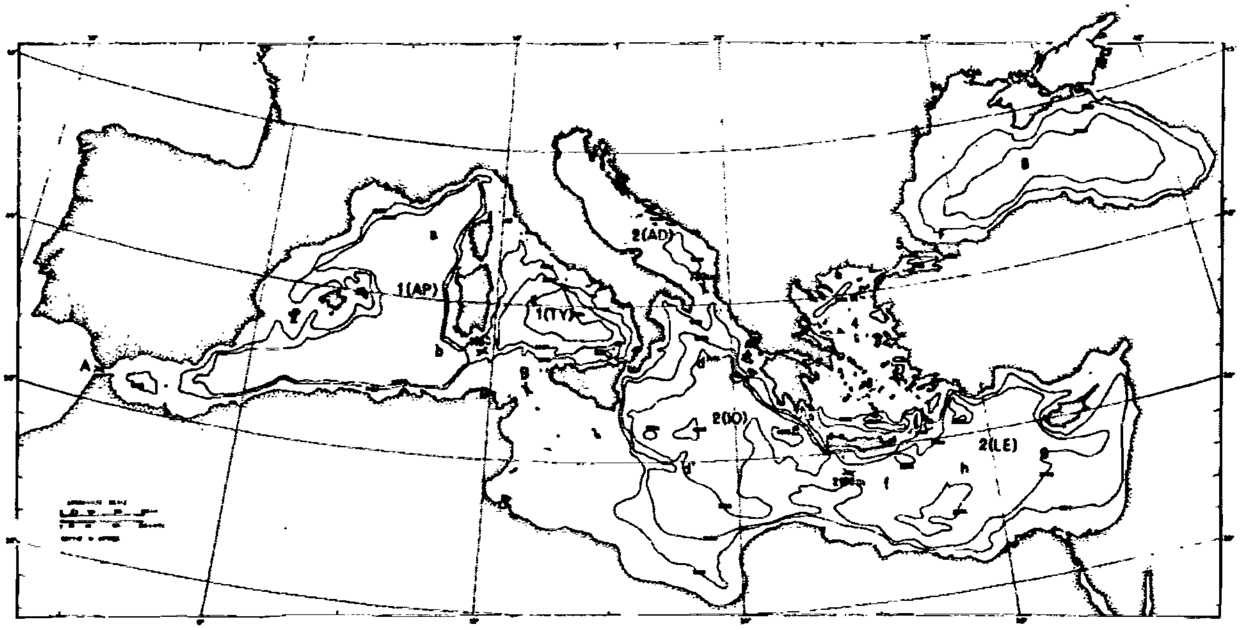
2.4 Sea-Water Attenuation (Project 2.4)

Until the early 1960s most measurements of frequency-dependent sea-water attenuation were for the frequency range above about 5 kHz. The small amount of lower frequency data available showed that the high-frequency formulae could not be extrapolated to the lower frequencies.

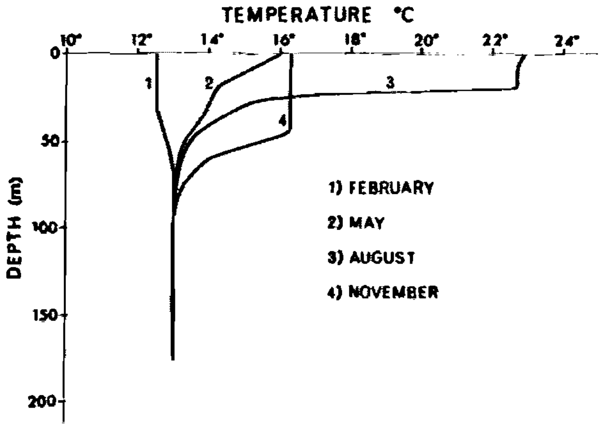
Since the deep Mediterranean water is isothermal below about 400 m, it was realized that the deep refracted ray could be used to measure frequency-dependent attenuation for frequencies from 200 to 10 000 Hz using signals from explosive sources travelling along this path. New values of sea-water attenuation were computed from data acquired during bottom-reflection sea trials (TR-43).

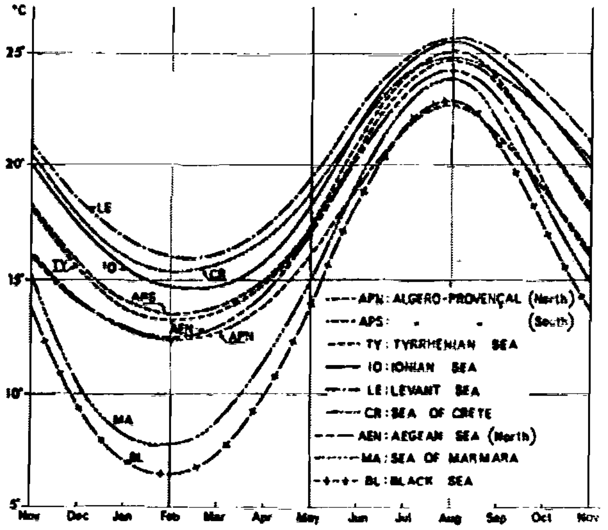
2.5 Nature of Propagation in the Mediterranean

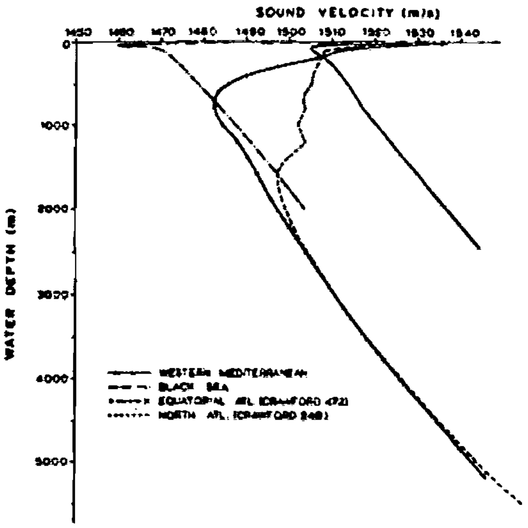
Although the early programme emphasized studies of bottom-reflected paths, a number of measurements also gave valuable information on sound-channel propagation. This was shown to be of considerable significance for military operations in the Mediterranean Sea, since a strong sound channel extends from a shallow depth to beyond the maximum operating depths of sub-



Sound propagation in the Mediterranean and adjacent seas. From its inception the Centre started to study sound propagation in its home waters and to extend these measurements throughout the Mediterranean and adjacent seas. The upper figure indicates the principal basins, sub-basins, and sills of this region. The figure at the right shows typical seasonal sound-speed profiles in the northern part of the Western Mediterranean, that below shows how the surface temperatures vary seasonally in the different basins. The figure at the lower right compares the sound-speed profiles of the Western Mediterranean and the Black Sea with those of equatorial and northern Atlantic waters, illustrating the special characteristics of the former [TR-154].

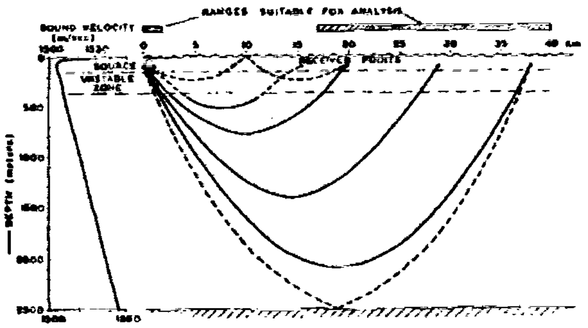




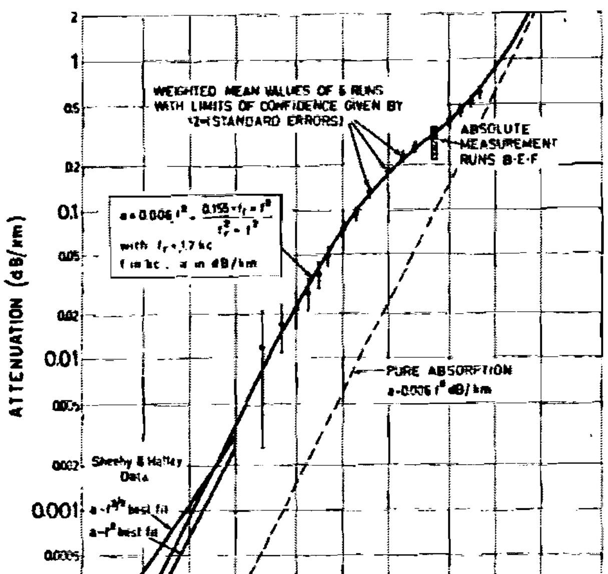


marines. The results showed low transmission losses in the sound channel, and indicated the possibility that location of a sonar transducer within the channel would offer reliable sonar ranges at least ten times those of hull-mounted sonars (9).

The Mediterranean is virtually land-locked and therefore cut off from the cold polar currents. As a result, temperatures in the deep water are about 10°C greater than they are in the deep Atlantic and Pacific. The temperature drop across the thermocline is much less and occurs in a shorter vertical distance. As a result, the axis of the deep sound channel is shallower than in the deep oceans, the critical depth at which the sound speed equals that at the surface is much less, and convergence zone spacings are only about half those usually found in the great oceans. These facts were realized early in the history of the Centre (10). Measurements made in October 1962 in cooperation with the French Le Brusc laboratory confirmed that convergence zones occur at intervals of about 35 km for source depths of 5 to 20 m.



Sound attenuation in the sea. The results shown below were obtained by using the deep refracted rays shown above. [TR-43]



2.6 Hydrophone Calibration Facilities (Project 2.3)

Development and testing of transducers and hydrophones was an important early activity at the Centre in support of its propagation studies, and in May 1963 this was recognized as a separate project. The calibration facilities of the French Le Brusc laboratory were used at first, but it soon became apparent that the Centre required facilities much closer to La Spezia. A calibration raft was built and used in the bay outside the laboratory but this was found to be unacceptably noisy. A barge was then procured from the Italian Navy in co-operation with two neighbouring organizations and installed on a small lake near Sarzana, a few kilometres from the Centre. This facility was used for the Centre's calibration work until about 1968.

Late in 1961 the Centre undertook a coordinating role in the international standardization of hydrophone calibration. A questionnaire was sent to a number of candidate laboratories, and two hydrophones lent by the US Navy Underwater Sound Reference Laboratory were then circulated to eight active participants. The results showed generally good agreement between the facilities (11).

2.7 First Acoustic Propagation Conference

Throughout its 20-year life the Centre has organized a large number of scientific conferences attended by scientists from the NATO community. The subject of the first, in July 1961, was Underwater Acoustics Propagation (TR-9); this was attended by seventeen outside scientists, some of whom continued their connection with the Centre over a long period thereafter. The conference covered nine topics and was of importance not only in establishing international cooperation but also in influencing the Centre's research programme in these early formative years. One result was that emphasis was placed on frequencies below a few kilohertz and on ranges out to 150 km and greater. ■

3.1 Target Classification by FM Sonar Techniques (Project 1.1)

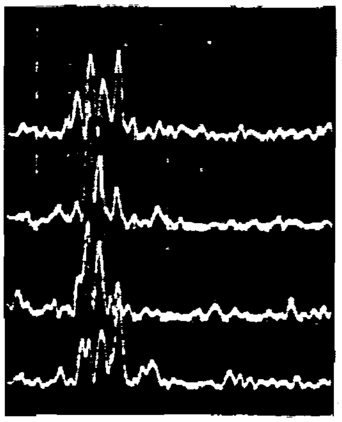
When the Centre was formed, three of the major NATO powers had large research and development programmes related to low-frequency, long-range, passive sonar systems. The Scientific Advisory Council therefore recommended that the Centre confine its relatively small sonar efforts to improving mobile active sonars. The single sonar project undertaken during this first period was concerned with the application of FM sonar techniques to target classification.

World War II sonars used pulse lengths of the order of 20 ms, for which range discrimination is so good that target length, aspect, and other classification clues can be derived. With the need to increase operating ranges, longer pulse lengths were necessary, and practically all this classification capability was lost. Frequency modulation (FM) offered the promise of combining the noise resistance of long pulses with the classification advantages of short pulses. Although this was not a new idea, no extensive application of FM had been made when the Centre began its study.

The first task was a preliminary theoretical study of linear FM pulse operation (TR-4) to derive required parameter values and their tolerances. Then a breadboard equipment was built. Preliminary sea trials with this apparatus in mid-1960 used reflections from the bottom in various depths of water. Later trials tested one-way transmission between two ships to a maximum range of 15 km, using both direct and bottom-bounce paths.

Laboratory analysis of the tape recordings from these trials indicated that effective range resolution was of the order of 10 m when clear echoes were received, corresponding to a short pulse of nearly 15 ms. The signal received on a direct, one-way path was a simple replica of the equivalent transmitted short pulse. Via bottom bounce, the received signal generally contained three or four peaks corresponding to the expected multipath propagation between surface and bottom. In only about 10 to 20% of the records was the received signal so smeared by reflection from the bottom that individual peaks were unrecognizable.

The promise of these experiments was considered sufficient to justify the construction of better engineered electronics with which trials against an actual target submarine could be carried out. With the limited power and small array available at that time it was impossible to obtain echoes via a bottom-bounce path. However, direct-path echoes from submarines were obtained out to a maximum range of between 6 and 8 km. The results of the mid-1961 experiments with the submarines TRUTTA (US) and TOKEN (UK) as targets showed clearly that long FM pulses could produce echo structures com-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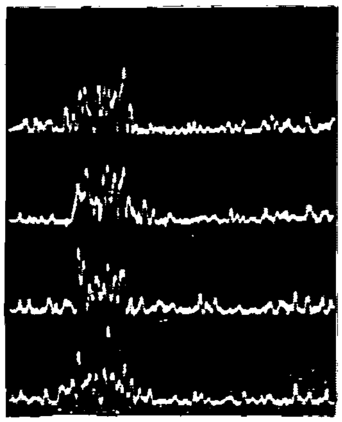
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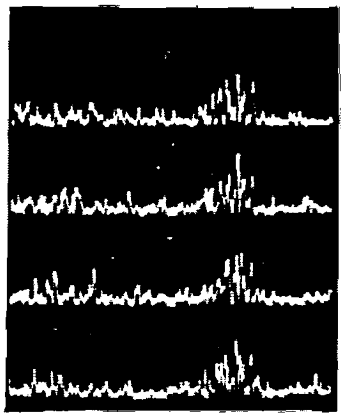
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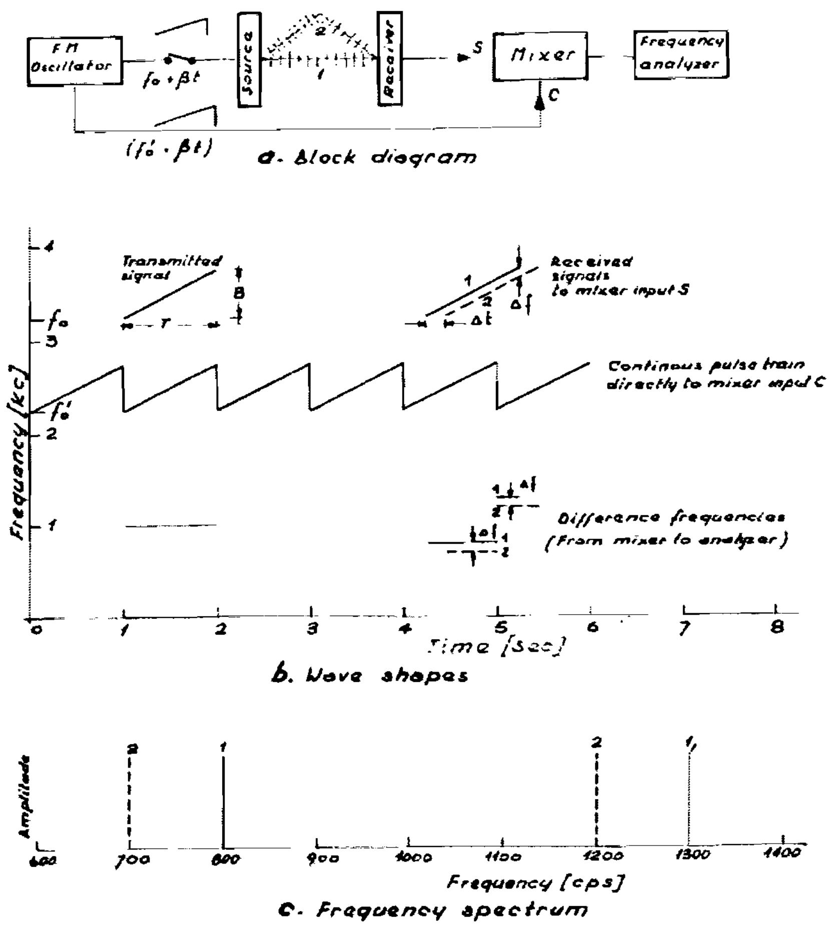
Echo traces of submarine recorded at bandwidths of 110 Hz, 220 Hz, and 440 Hz by FM sonar techniques. Submarine at 45° aspect, 1800 m range, and 140 ft depth. [TR-23]



Simple diagrammatic description of the FM sonar technique. [TR-5]

parable with those obtained with the World War II short-pulse sonars.

While the validity of the FM technique in its proposed ASW role was being established, consideration was given to the form that a practical sonar equipment might be expected to take. The equipment used up to this time had been adequate only for making tape recordings to be subsequently frequency-analyzed in the laboratory, a very slow process. One of the major engineering difficulties in the use of FM for sonar had been the design of the narrow-band filter array required for final frequency analysis and the presentation of this multiplicity of filter outputs on a CRT screen or other display. It was proposed that the whole equipment should be digitized. This would permit shift registers to be used in place of filter arrays and output information could be presented serially as a time intensity function that was immediately applicable to existing displays. The construction and laboratory testing of this first digital equipment was the main task during 1962 (12).

The equipment was tried at sea in October 1962 against a tri-plane target, no submarine being available. Range resolution and general behaviour were as anticipated, although maximum ranges were limited to less than 1 km by severe ray bending at the time of the trial. In early 1963 further proving trials were conducted with a submarine. Sonar conditions were good and ranges in excess of 15 km were achieved. Doppler of 2 to 3 kn was readily detected at ranges of more than 10 km.

Later in 1963, sea trials compared performances of short-CW and long-FM pulses directly. Results confirmed that the theoretical performance of FM transmissions was being achieved and that FM was therefore superior in making possible longer ranges when propagation conditions were favourable.

By the beginning of 1964 experimental FM sonar development had reached a state of potential application in NATO navies. A comprehensive summary report was written (TR-23) and a number of oral presentations were made. All information then available was released to those nations that requested it. The U.S. adopted the digital FM technique for its large surface-ship sonars. Italy also showed an interest, and arrangements were made for tests in 1965 using the SQS-23 on the ANDREA DORIA. ■

CHAPTER 4 NON-ACOUSTIC ASW RESEARCH (1959-64)

4.1 Introduction

Sonar has become the most generally used method for detection of fully submerged submarines at long ranges because of the ease of sound transmission through sea water. Radar and electromagnetic intercept reception are also used successfully, but only against submarines at snorkel depth. Other non-acoustic methods generally have limited range and are primarily useful only in tactical situations. A few national laboratories have carried on research in non-acoustic techniques, both with the hope of achieving long-range reception by this means and to develop sonar adjuncts that would provide classification and localization in tactical situations.

At the Centre, a major effort was undertaken in the area of extra-low frequency (ELF) electromagnetic detection. The project was begun in October 1959 and terminated in 1969 after the work had been transferred to national programmes. A smaller and shorter-lived effort concerned with surface manifestations of the passage of a submerged submarine was begun in July 1963 as a part of the oceanography programme and lasted about two years.

4.2 ELF Electromagnetic Research (Project 5.1)

Of the alternative methods of submarine detection, especially as a classification adjunct, one of the more attractive is electromagnetics. In the frequency range below 100 Hz absorption is small enough to offer the possibility of ranges of the order of a kilometre. Although there had been sporadic work in the electromagnetic field in the twenty years before 1959, this frequency range had not been examined very closely. Also, by 1959, advances in processing techniques made the prospects of success of electromagnetic (EM) systems considerably more likely.

There are two distinct methods for EM detection or classification: active and passive. The active method detects the disturbance introduced by a submarine in an EM field set up artificially by one or more transmitters. The passive method detects EM signals generated by the submarine itself. The research programme begun at the Centre in October 1959 concentrated mainly on passive EM detection in the 1 to 100 Hz frequency range. This ELF band was chosen because submarine-generated signals have their fundamental frequencies in this range, and the attenuation of signals propagating in the two-medium space decreases with decreasing frequency.

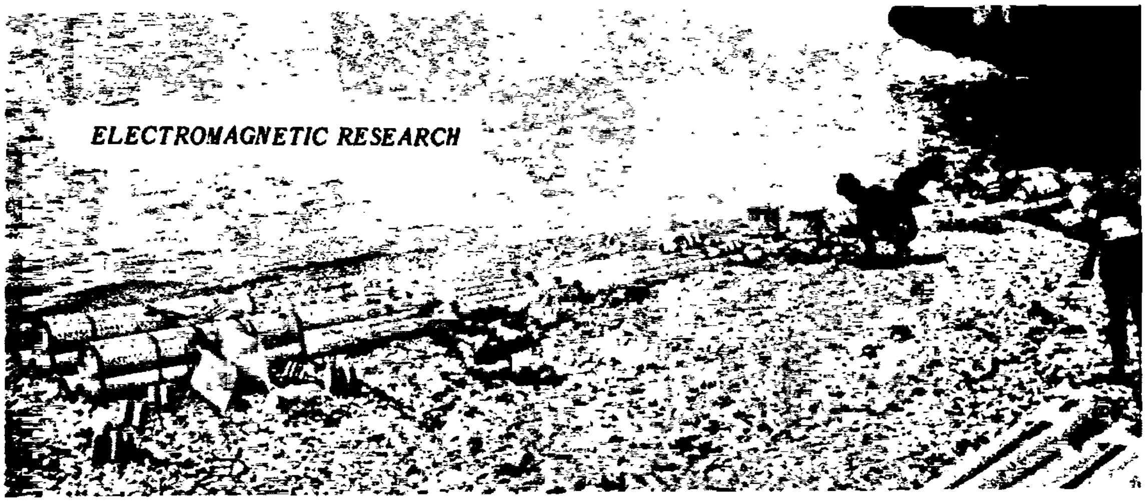
The combined theoretical and experimental programme established at the Centre aimed at increasing knowledge in four basic areas:

(1) Propagation of EM energy in a two-medium space of air and sea water.

(2) Spectral distribution of background noise and its coherence properties.

(3) Signals generated by submarines.

(4) Optimum platforms from which to detect EM signals.



Preparation of ELF electromagnetic passive detection equipment before an experiment.

The experimental part of the programme started in 1960 with the development, design, and construction of equipment, as no commercial equipment was available for this low-frequency range. The first detectors were coils from magnetic mines coupled to low-noise preamplifiers, with the outputs fed to paper recorders. Tino Island in the Gulf of La Spezia, owned by the Italian Navy, was chosen as a site that had a sufficiently low level of electrical power background for this experiment. Two stations were set up and background measurements started (2, pp 77-93). Later, in 1961, experiments were conducted to verify theories on propagation of EM waves from a submerged dipole and to learn about properties of large antenna systems.

The early experiments revealed a number of problems. It was found that mine coils had several disadvantages when working in this frequency range. Further, use of the island was unsatisfactory in that it acted as a large insulator at the surface of a conductor, distorting the field to be measured. Also, submarine operations so near an island were unsafe. Therefore a new measuring facility was designed that could be slung from a buoy 6 miles west of the island in 100 m of water.

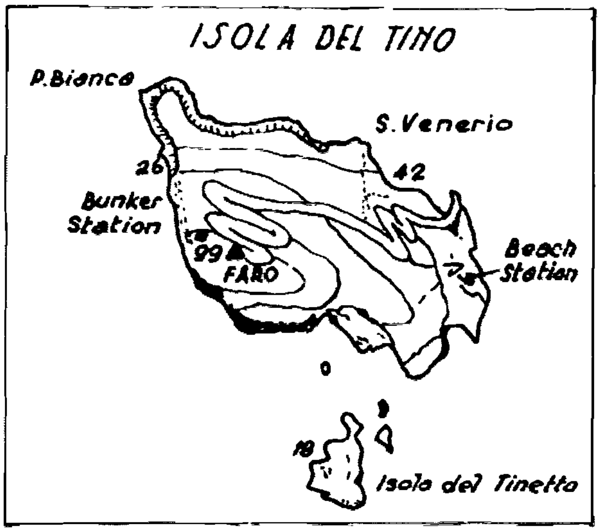
By the end of 1962, ELF electromagnetic passive detection had been shown to be sufficiently promising to merit continuation of the research programme. Ranges of at least the same order of magnitude as MAD appeared to be achievable in deep water, with longer ranges expected in shallow waters.

Experiments carried out with submarines in the area west of Tino in 1963 showed the submarine-generated signature to be of impulsive character with a repetition frequency corresponding to the number of shaft revolutions. Large variations of peak level, repetition frequency, and waveform were found (13). Additional data taken by the British and French Navies at their acoustical test ranges confirmed these conclusions (TM-86).

Much of the effort of the project in 1964 was devoted to the preparation of reports. These included an extensive bibliography (TR-25) and a summary technical report in three parts (TR-36, 37, 38) describing work done from the inception of the project. Some of the experimental techniques are described in more detail in TM-96 and 97. The only experimental work done in this period consisted of background noise measurements with improved electrode systems.

4.3 NATO Conference on EM Phenomena

In September 1962 the Centre sponsored a conference on "ASW Applications of EM Phenomena in the Extremely Low Frequency (ELF) Range (1-3000 cps)" at NATO Headquarters, Paris. There were thirtysix participants, representing all of the NATO naval nations, and one observer Mr L. Brock-Nannestad, of the Centre's EM team, served as Chairman of the conference. Twenty



Tino island, off La Spezia, where two stations were established to make ELF measurements. [TR-37]

papers were presented, and complete proceedings were issued subsequently by the Centre (TR-14).

4.4 Study of Surface Manifestations of the Passage of a Submerged Submarine (Project 4.4)

In mid-1963 the Centre's Oceanography Group started work to achieve a better understanding of near-surface and surface phenomena, motivated by the possibility of detecting surface effects caused by submarines passing through water having a density gradient.

The particular surface manifestation studied was that caused by the near-surface convergences and divergences related to the vertical collapse and horizontal spreading of the wake of a submerged self-propelled body travelling in a density gradient. Results reported in the literature had shown that wake collapse could be an efficient generator of internal waves, which would then manifest themselves by changes at the surface. The Centre's contribution was controlled tests in a small, transparent tank in which stable and unstable density gradients could be introduced by thermoelectric heating and cooling elements. From the results of the tank experiments, a relationship was derived that gave the extent of surface thermal manifestations as a function of the density gradient and the depth of the submarine.

Fluctuations of temperature gradients existing naturally in the ocean in the upper 10 to 20 cm constitute the background noise against which a submarine-generated thermal signal would have to be detected. Some preliminary measurements were made (TR-35), but the project lost its impetus when the originator, Dr Allen Schooley, left the Centre in mid-1965. ■

CHAPTER 5 OCEANOGRAPHIC RESEARCH (1960-64)

5.1 Introduction

The Centre's Scientific Advisory Council, at its initial meeting, held in the spring of 1959, proposed a variety of subjects from which it felt the Centre might usefully select its initial scientific programme. Among its other recommendations the Council stated:

> "Oceanography itself is of the greatest importance to the ASW problem," and "A continuous effort should be maintained to preserve the closest possible relationship between oceanography and its military acoustic consequences."

Two years later the Working Group on Geophysics of NATO's Von Karman Committee (14) also concluded:

> "Improved understanding of oceanographic phenomena depends on the advance of fundamental research which must be supported by the military. In general, significant scientific advances can be expected.....
>
> The development of oceanography must be accelerated if we are to meet future military requirements. Fundamental research is required in nearly all areas to extend our understanding of the phenomena involved.
>
> .....Oceanography is, therefore, a field in which allied cooperation could be effective and valuable....."

In the beginning, the Centre's research concentrated on the Mediterranean, for which there was a clear need for oceanographic information. Four projects were undertaken in the first five years:

- 4.1 Military Oceanography (Prediction of Oceanographic Conditions and Their Correlation with Sonar Performance), Jan 1960.
- 4.2 Submarine Geophysics, April 1960.
- 4.3 Study of Internal Waves, Jan 1961.
- 4.4 Near-Surface Phenomena, July 1963.

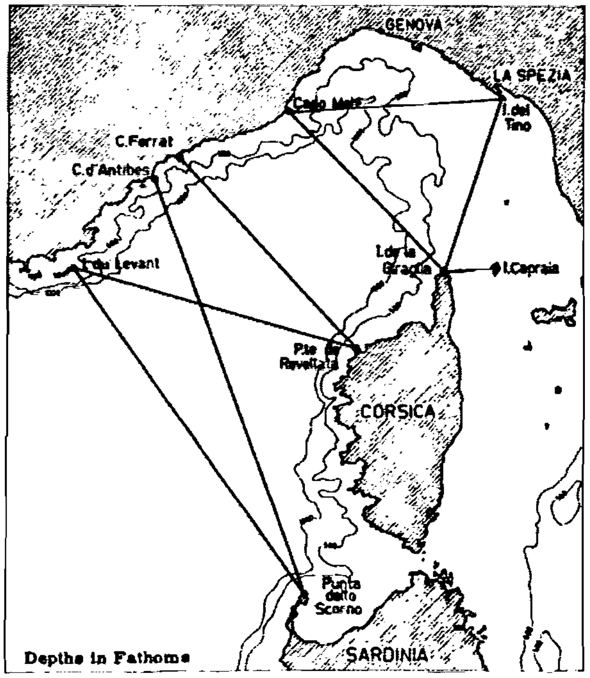
Originally the Military Oceanography Project was assigned to the Applied Research Group so that the Oceanography Group could concentrate on unclassified pure research. This work was merged with the other oceanographic projects in 1963. The problem of finding the proper balance between research for military applications and unclassified basic oceanographic research has been a continuing challenge for the Centre's management.

5.2 Military Oceanography Project (Project 4.1)

In the field of military oceanography the Centre selected for its study the prediction of oceanographic conditions and their correlation with sonar performance (2, pp 95-104). During January-February 1960, two members of the Military Oceanography Group and an officer from the SACLANT Deputy's International Staff visited scientific institutions and military commands in Canada and the United States that were concerned with the problems of oceanography and, in particular, with its application to ASW. They were seeking to determine which oceanographic factors were, or might become, important to the military in successfully meeting the ASW threat. Visits by this team to each of the other seven participating nations had been made by the end of 1962.

The conclusion of the first trip was that, in spite of present knowledge, much more research was needed to better understand how oceanographic factors influence sonar range. It was also decided that the required understanding could best be obtained by concentrating initially on a particular body of water of moderate size. The study could then be extended to larger ocean bodies, concentrating on those factors shown to be of primary importance as a result of the work on the smaller, "typical" ocean area.

As its small ocean area, the Centre's scientists selected part of the Ligurian Sea between Corsica and the coastline of the French and Italian Rivieras. Repeated surveys were made in this area, at roughly monthly intervals,



Area chosen for initial detailed studies of how oceanographic parameters influence sonar range. [TR-8] between July 1960 and October 1961 (TR-8). During these oceanographic surveys, bathythermograph readings and water samples were taken to get an idea of the horizontal gradient and of changes in the vertical gradient of temperature and salinity. Measurements of atmospheric conditions were also included. Propagation-loss measurements were obtained from the work of the Acoustic Propagation Research team. A computer program was developed to expedite the handling of future data by converting measured values of temperature, salinity, and pressure (depth) into sound speed. The Group also assembled pertinent, previously-collected data on the Ligurian Sea.

Hydrostatic corer designed for sea-floor studies. [TR-34]

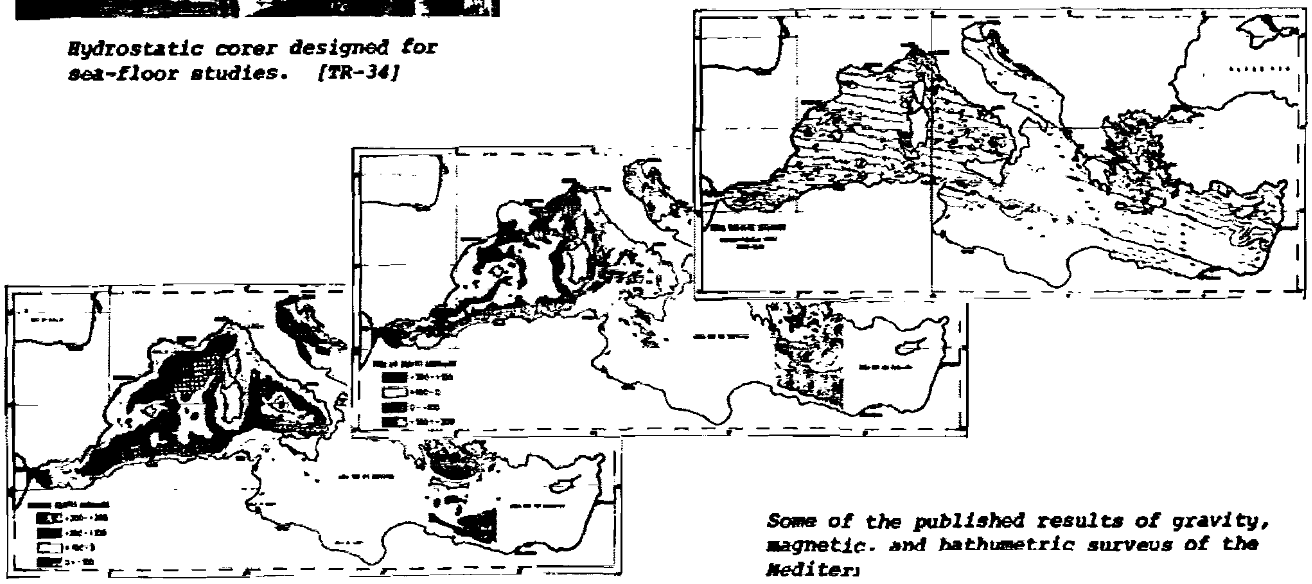
The study of oceanographic prediction for military applications was merged with the pilot study (PASWEPS) of the U.S. ASW Environmental Prediction System (ASWEPS) in the EASTLANT area, and by 1964 the major activity of the Group had become participation in NATO's MILOC surveys.

5.3 Submarine Geophysics (Project 4.3)

Knowledge of the structure of the layers below the ocean bottom is important in understanding the character of reflections of sound from the bottom. Studies of the bottom were therefore introduced at an early date into the Centre's oceanographic research programme.

In the few years prior to the establishment of the Centre there had been considerable advance in instrumentation necessary for the study of the ocean floor. In particular, in 1956 Cambridge University had developed the nuclear-spin magnetometer for use at sea, towed behind a ship. Between 1956 and 1960 this had been used successfully in six cruises. Dr T.D. Allan of the Cambridge group joined the Centre in mid-1960 and initiated a project in which a Cambridge magnetometer and two gravity meters were used for geophysical surveys of the Mediterranean and Red Seas.

After initial engineering tests of the new proton magnetometer in May and June 1961, the group embarked on a series of ten month-long cruises between July 1961 and June 1964. They made complete gravity, magnetic, and bathymetric surveys of the Ligurian, Tyrrhenian, Aegean, Ionian, Eastern Mediterranean, and Red Seas (2, pp 142-158). The results were presented to the Royal Society, London (TR-183) and to the 19th Meeting of the International Commission for the Scientific Exploration of the Mediterranean Sea. Aspects of the work were also published in Nature (TR-39), Geophysics, and the Journal of Geophysical Research. The Centre's bathymetric survey of the Red Sea was published as U.K. Admiralty chart C6359.



Some of the published results of gravity, magnetic, and bathymetric surveys of the Mediterr

5.4 Sea-Floor Studies

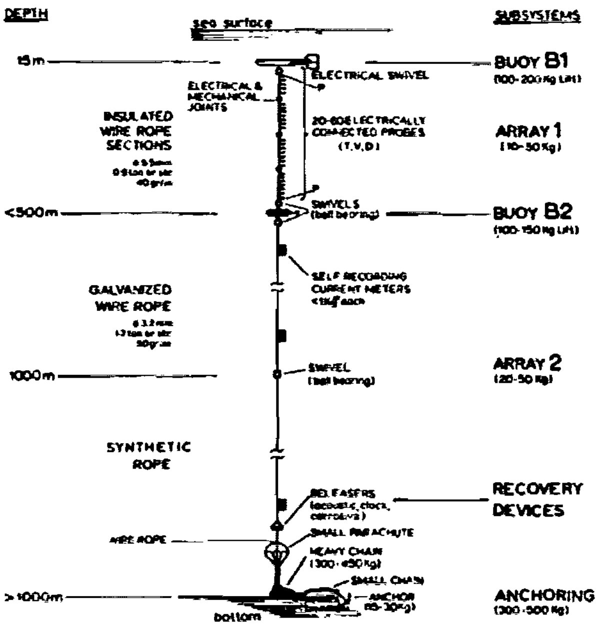
Magnetic and gravity surveys do not directly provide the type of information required for acoustic modelling of the bottom and for understanding bottom-bounce transmission. In April 1963, the Centre initiated a sub-project of Project 4.3 to provide basic information on the sedimentation of the sea floor and on the structure of the upper layers of the substructure.

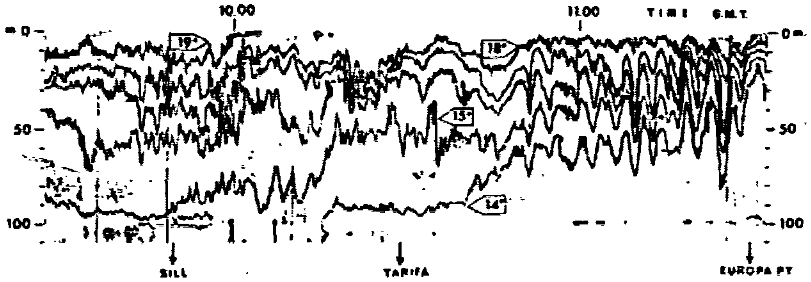
A gravity corer that had been used in the geophysical studies was unreliable. A new hydrostatic corer was designed and a prototype tested in 1964 to water depths of 1700 m. In 1964, a new wide-diameter, sphincter-closing, gravity corer was also developed and tested (15) (TR-34,112). This device, which has been used extensively ever since, was first used in December 1964 to take cores in areas studied by the Sound Propagation Group.

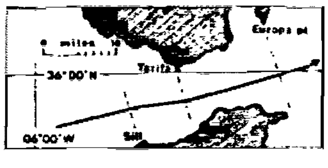
5.5 Study of Internal Waves (Project 4.2)

A major cause of fluctuations of sound propagated in the sea is the strong modification of the thermal stratification by the turbulence associated with internal waves. These internal waves had been investigated in the 1950s by Dr J.B. Hersey of the Woods Hole Oceanographic Institution plotting isothermal lines measured by a long, towed-thermistor chain. The Centre's early interest was in internal waves in so-called transitional areas such as the Straits of Gibraltar and Sicily.

Much of the evidence for internal waves had been obtained from the variation of thermal microstructure in the top hundred metres of water. To show that there is actually a wave motion and to study its properties, it was thought necessary to have arrays of fixed sensors moored to the bottom and recording continuously for considerable periods. An array of this type was completed and tested in 1962 and several models were assembled for field tests in 1963. The temperature-sensing elements used were thermistors, the temperatures at various depths being recorded at time intervals after an initial voltage was applied. This permitted the use of a single-core cable. The array was held vertical by a submerged buoy free from surface-wave effects and of special low-drag design so that it was barely affected by tidal currents. The data were recorded on magnetic tape in the buoy and







7 JULY 1958

Studies of internal waves. A bottom-moored array of sensors is shown above [TR-65]; records made off Gibraltar with a thermistor chain are shown at left. [TR-30] transmitted to a ship via an FM radio link with a floating buoy (TR-65). An acoustic releasing system for recovering submerged oceanographic buoys was also developed for this project (TR-19).

In the Gibraltar area in 1958-59, internal waves had been found of from 40 m to 110 m amplitude and of periods from 15 to 30 minutes, recurring with the tidal period. Dr Frassetto of the Centre participated in a cruise of the Woods Hole RV CHAIN in that area in September 1961, during which these internal waves were studied with a 200 m long thermistor chain towed at 10 km. A similar survey was made by the CHAIN in the Strait of Sicily in September 1962. Data from both these cruises were analyzed at the Centre (TR-30).

The initial internal waves project merged with other studies of the Gibraltar area by late 1964. The subject of internal waves has, however, recurred a number of times in the Centre's history, both in connection with their acoustic effects and as newer instrumentation made possible the acquisition of more definitive results.

5.6 Studies of Surface and Near-Surface Phenomena (Project 4.4)

The project on surface and near-surface phenomena begun at the Centre in July 1963 by Dr Allen Schooley was a fundamental research approach to an aspect of oceanography thought pertinent to the possible detection of submarines by surface thermal observations. Studies specific to the surface manifestations of the passage of a submerged submarine have already been covered in Sect. 4.4 in the chapter on non-acoustic ASW. In addition, Dr Schooley initiated studies of the turbulent boundary layer in air above wind-generated water waves, and of the interaction between wind-generated water waves and surface currents. This work was short-lived, since Dr Schooley returned to the U.S. in September 1965. Instrumentation developed for measuring temperature gradients at the sea/air interface and some preliminary results are given in TR-35.

In connection with this aspect of oceanographic research, the Centre provided the conference director and otherwise participated actively in a NATO Advanced Study Institute on Air/Sea Interaction held at the Imperial College in London in September 1962. ■

Instrumentation for measuring fine details of the temperature gradients at the air/sea interface in an attempt to identify surface manifestations of the passage of a submerged submarine. [TR-35]

CHAPTER 6 OPERATIONS RESEARCH (1960-64)

6.1 Introduction

Early in the Centre's history, it was recognized that a research establishment in a remote area might become disconnected from the real ASW world. To counter this, the nations provided ASW programme officers and the Centre formed Operations Research (OR) Group to:

(1) Investigate existing systems operated by the NATO navies.

(2) Assist other groups in the Centre in the planning and analysis of their experiments.

(3) Consider possible future ASW systems.

Projects undertaken by the OR and Theoretical Studies groups in this first period included:

3.1 Investigation of False Sonar Contacts
March 1960

Multiple Salvo Investigation
1961-62

Position at Sea by Triangulation
1961-62

3.2 Tactical Studies
July 1961

3.3 Significance of Satellites to ASW
April 1962

3.4 Exercise Analysis and Data Collection
March 1962

OR projects by their very nature are generally much shorter-lived than research projects, which require extensive measurements at sea. Thus, of the above list, only the Tactical Studies and Exercise Analysis projects lasted more than a few years.

6.2 Investigation of False Sonar Contacts (Project 3.1)

In January 1960, SACLANT suggested that the Centre investigate submarine-like false contacts made by sonars in the open oceans. An area of approximately 1000 $n.mi^2$ west of France and Portugal was selected. SACLANT formally requested all NATO navies to report any sonar operations in this area to the Centre. Over a four-year period the Centre received approximately 700 such reports, in which 80 false contacts were noted. The reports covered 7500 hours of sonar watches and about 100 000 n.mi of track. This false-alarm rate of one per 1200 n.mi found under uncontrolled conditions was ten times lower than that experienced in the NATO ASW exercise MAGIC LANTERN in 1963. It was therefore concluded in November 1964 that any future work done by the Centre on this subject should be based on data from NATO exercises rather than from non-exercise conditions (TR-27).

6.3 Multiple Salvo Investigation

This study was an assessment of the logistic cost of a certain type of saturation barrage employing a simple contact projectile for destroying a located submarine. Although the number of projectiles likely to be required would be high, the cost of individual sophisticated weapons had soared enormously, and the disparity in overall cost might not be large. The problem proved especially useful to the Centre as an exercise in collecting realistic weapon data, and in programming the computer to take account of a wide variety of parameter variations. It was concluded that a case could be made for an inexpensive weapon having a relatively low probability of detection (2, pp 108-112) (TR-12).

6.4 Position at Sea by Triangulation

The acoustic propagation and oceanographic experiments conducted at sea by the Centre's research ship ARAGONESE revealed the need for accurate knowledge, to within a few metres, of the geographical position of a single ship, the precise distance between two ships, and the velocity of a ship over the ground. In 1961, the Centre tested a method of measuring a ship's position to an accuracy of a few metres by simultaneous optical observation from two points on shore. The method chosen was the simple surveying procedure of triangulation, i.e., measurement of the horizontal angles between a precise base line and the lines of sight from each end of this base line to the ship. The test used a base line of about 10 km, and, for this, plane trigonometry was accurate enough to permit calculation of the distance of the ship from one or both ends of the base line. However, measurement of geographic position of the ship required use of spherical trigonometry modified by the introduction of corrections for a spheroidal earth (2, pp 112-3).

6.5 Tactical Studies (Project 3.2)

There are certain classes of theoretical problems in antisubmarine tactics that can be studied without direct contact with ships, and weapons. One such class concerns the geometry of moving objects such as aircraft, ships, and submarines; it can be applied to the design of convoy escort screens, aircraft search patterns, and other tactical formations of practical importance. Considerable progress in this field had been made during World War II, much of which was described in Report No. 56 "Search and Screening", issued by the U.S. Navy Operations Evaluation Group (OEG). The methods used were those of orthodox mathematical analysis and probability theory. Although these methods were adequate for the simpler problems, limitations were encountered when the number of objects, their motions, or the assumptions regarding detection probabilities, became complicated.

The Centre's OR group undertook two approaches to the kinematical study of ASW tactics: mathematical probability analysis, and simulation on an electronic computer (2, pp 122-132). Some of the specific topics explored during the first years of this long-lived project included:

1. Submarine penetration of a line barrier (TM-85).

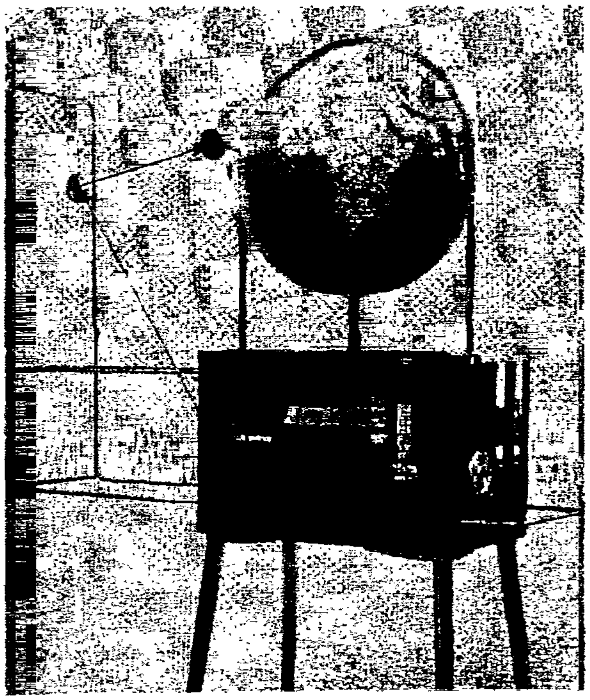
2. Interception of a moving target based on intermittent position reports (TR-28).

3. Development of computer simulation methods (TM-82, 88).

6.6 Significance of Satellite Reconnaissance for Submarine Warfare (Project 3.3)

One of the events leading to the establishment of SACLANT ASW Research Centre was the launching of the space age with SPUTNIK I. The availability of such earth-orbiting satellites led to an early OR project at the Centre to examine the implications thereof to a submarine power. Submarines face major problems in acquisition of intelligence to decide where forces should be concentrated and also in communication among themselves. Artificial satellites were recognized to be potentially powerful in both of these roles.

The study divided into three phases: geometrical, physical, and tactical. The first concerned the surveillance coverage that a satellite might provide as a function of its path, height, rate of orbiting, range of vision, etc. The second covered the limitations on this surveillance by natural physical phenomena such as cloud cover. The tactical phase naturally had aspects of both attacker and defender. The two-year study (2, pp 113-122) was begun in April 1962 and was completed with the writing of a final report in 1964 (TR-29).



Analogue device to simulate the behaviour of reconnaissance satellites in circular orbits of various altitudes and inclination. [TR-29]

6.7 Exercise Analysis and Data Collection (Project 3.4)

Several NATO ASW Exercises are performed each year. Participation in their planning and analysis has been recognized since 1962 as an important contribution of the Centre to NATO ASW capabilities, as well as being a prime way for the Centre's scientists to become aware of ASW problems in the real world. Because of limitations in time and manpower, the Centre's efforts have been limited to extraction of performance figures for antisubmarine vehicles, weapons, and tactics from a small number of selected exercises.

In the early period, the Centre participated to some degree in three exercises per year:

1962 DAWN BREEZE 7
on board a Canadian destroyer

SHARP SQUALL 6
on board a Canadian destroyer

MEDSUBEX 13
on board French submarines

1963 DAWN BREEZE 8
on board a French submarine

FISHPLAY 7
in Maritime Headquarters

MOON TIGER 2
on board an Italian frigate

1964 MAGIC LANTERN
on board British frigates

LONG LOOK
on board a U.S. submarine

TEAM WORK
in Maritime Headquarters

In the case of FISHPLAY 7, the Centre provided three members of the data collection team and two members of the EASTLANT analysis team. At least two Centre members also participated in the analysis phase of each of the three exercises held in 1964.

6.8 First Centre-Sponsored OR Conference

During 1963, a significant fraction of OR Group effort was devoted to organizing, hosting, and preparing proceedings of a NATO Conference on the Application of Operational Research to the Search and Detection of Submarines, held in June of that year. Forty-five scientists attended and twenty eight papers were presented, with a good balance achieved between theoretical and practical expositions (16). ■

Part. II

Period of Growth

1964 - 69

CHAPTER 7 PERIOD OF GROWTH (1964-69)

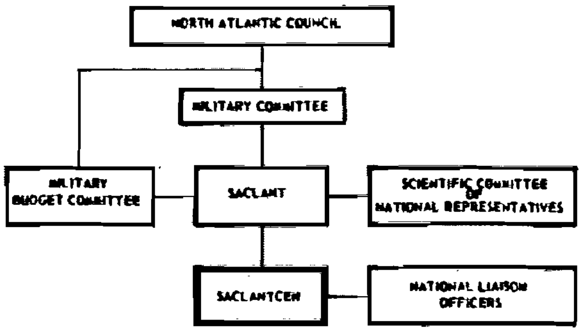
7.1 Management Aspects

The Centre's second five years showed steady growth in numbers of personnel, size of budget, capabilities of facilities, as well as in scientific achievement. The scientific staff grew from 40 in 1964 to the final authorized number of 50. The support staff increased from about 132 in 1964 to 180 in 1969; thus the Centre reached its maximum authorized complement of 230 in that year. Over this same period the budget increased gradually from about 1400 million lire (U.S. $2¼ million) in 1964 and 1965 to about 2200 million lire in 1969. Most of the budget increase was related to the increase in personnel.

Ir M.W. van Batenburg
The Netherlands
Director 1967-72

The Director at the beginning of the period was Dr Henrik Nødtvedt of Norway. From April 1967 the position was held by Ir Maarten van Batenburg of The Netherlands. As has occurred ever since, the position of Deputy Director was filled by a U.S. scientist: the present time, the Deputy Director position was filled by U.S. scientists: Dr William Wineland from January 1964 until June 1966, and Dr Royal Weller from June 1966 until June 1969.

A major upheaval during this period was caused by the French withdrawal from direct participation in NATO military activities in 1967. France was no longer represented on the SCNR and French military and administrative representation was terminated; after lengthy discussion, however, it was agreed that the seven French scientists then on the staff could remain. Six of the scientists, including Group-Leader Robert Laval, fulfilled at least their normal contract dates. Prior to settlement of the issue, the Centre had taken steps to replace the French, so that for a period the number of scientists exceeded the quota. The unsettling effect of the lack of certainty about the French scientists lasted for almost a year.



External organization throughout the NATO life of the Centre.

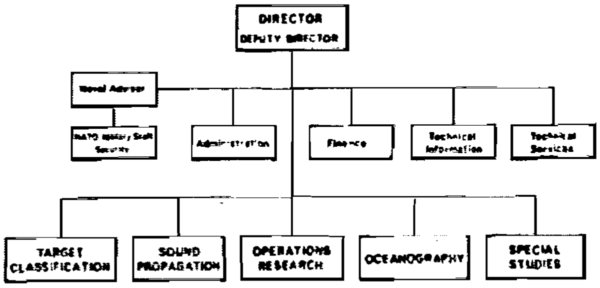
7.2 Revised Terms of Reference

Three areas of research were specifically listed in the Revised Terms of Reference issued by SACLANT for the Centre in January 1964 (17). These were stated as:

a. Applied research directed primarily towards detection, classification, and identification of submarines at sea, with the major emphasis on underwater acoustics.

b. Basic research in oceanography, including physical oceanography and submarine geophysics, with emphasis given to lines of research having potential application to ASW problems.

c. Operational research studies and investigations in support of NATO research efforts devoted to the development or improvement of ASW systems.



Internal organization in the 1960s.

7.3 Trends in Scientific Programme

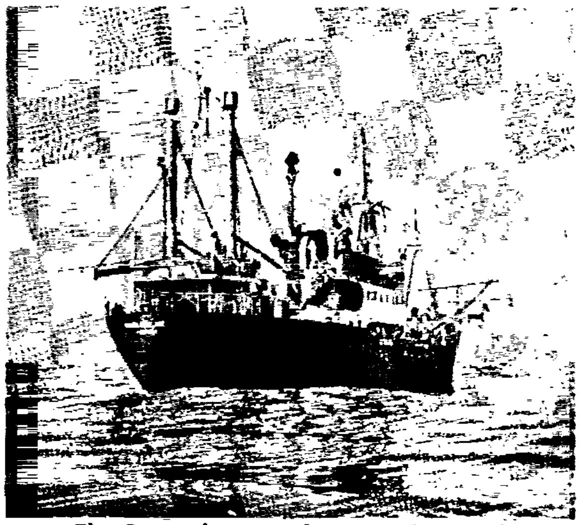
The scientific programme described in Part I was to a significant extent continued in the second five years, but with some notable exceptions. At the request of SACLANT, much of the area-related research and some operations analysis studies were shifted from the eastern and central Mediterranean to the Strait of Gibraltar and the eastern North Atlantic. For much of this period, most oceanographic, acoustic, and electromagnetic measurements were made in the Gibraltar area, while the Operation Research Group studied possible barrier systems for this region. Under the military oceanographic project, the Centre also organized and participated in the first of the multi-national military oceanographic (MILOC) surveys, which were conducted in the eastern North Atlantic in 1965 and 1966.

The capabilities of FM sonar having been shown, emphasis in active sonar research shifted to two other projects: space/frequency classification and the development of a deep panoramic sonar exploiting the reliable acoustic path (RAP). The use of digital techniques, originally chosen for the FM sonar application, was expanded to the handling of acoustic and oceanographic data. Active work on ELF electro-magnetic detection terminated in 1968, and research on non-acoustic detection of submarines was then dropped from the programme for almost ten years.

7.4 Facilities

A serious space problem resulted from the expansion of staff during this period. The majority of the needed space was obtained by building mezzanine floors, by storing research equipments in a small additional building acquired from the Italian Navy in 1967, and by relocating the computer. As a result of these actions, work was frequently disrupted; in fact, the Centre was without the use of its computer for seven months in 1969.

The merchant vessel MARIA PAOLINA G. (MPG), acquired by charter in March 1964, was gradually converted into an outstanding oceanographic/acoustic research vessel. Important modifications made to the ship included a well for suspending large arrays, an active rudder and variable-pitch propeller for station keeping at speeds below 5 kn, improved accommodations for scientists so that longer cruises could be undertaken, improved radar and radio communications, LORAN-C navigation system, 60 Hz ac generators, special booms and winches to handle over-the-side instrumentation, and a new precision depth recorder.



The Centre's second research vessel MARIA PAOLINA G.

Noise radiated by the MPG itself interfered with some acoustic tests and especially limited its usefulness for ambient noise studies. Attempts to quieten the ship were made whenever feasible, and in 1967 its noise output was measured on the French Laboratoire DSM du Brusc acoustic range (18). However, as the main propulsion system uses diesel power it has never been possible to achieve really silent operation.

In 1965 the MPG was at sea for 239 days for 29 scientific cruises. In 1966 this figure was 246 days for 32 cruises in support of 15 projects. Nine of these cruises in 1966 were in conjunction with various NATO warships, submarines, and auxiliaries. Generally, more than half the sea time supported oceanographic research projects, the other major users being the sound propagation and target classification groups. Use of the ship continued at a high level throughout this period.

The Elliott-503 digital computer was received and installed during autumn 1964. Its capabilities were gradually increased by the addition of such peripherals as an XY plotter, magnetic tape units, interface matching unit, line printer, display facilities, and Calcomp plotter.

Use of the computer increased from about 3 hours per day in October 1964, to 5 in 1965, and to 11 by the end of 1966. At this point two-shift operation was required to meet the needs of the research groups. The load gradually became too great, and in 1968 a Honeywell-516 was acquired as a satellite computer to the Elliott-503.

During this period, a Computer Section was part of the Special Studies Group. Although many users provided their own programming, much effort had to be devoted to both general-purpose and specialized programs. Programs that translated from one computer language to another were needed in order to adapt non-Centre originated programs to the Elliott. Computer programming was treated as a separate project (Project 5.4) in the Special Studies portion of the programme.

7.5 Conferences and Publications

The SCNR met regularly each spring and autumn. In September 1967, the Centre organized a conference on the Reliable Acoustic Path, which was attended by representatives from the U.S., U.K. and Canada. In November of the same year, by invitation of the Committee on Undersea Warfare of the National Research Council of the U.S. National Academy of Sciences, the Centre gave presentations on its entire programme to some 140 representatives from U.S. defense activities.

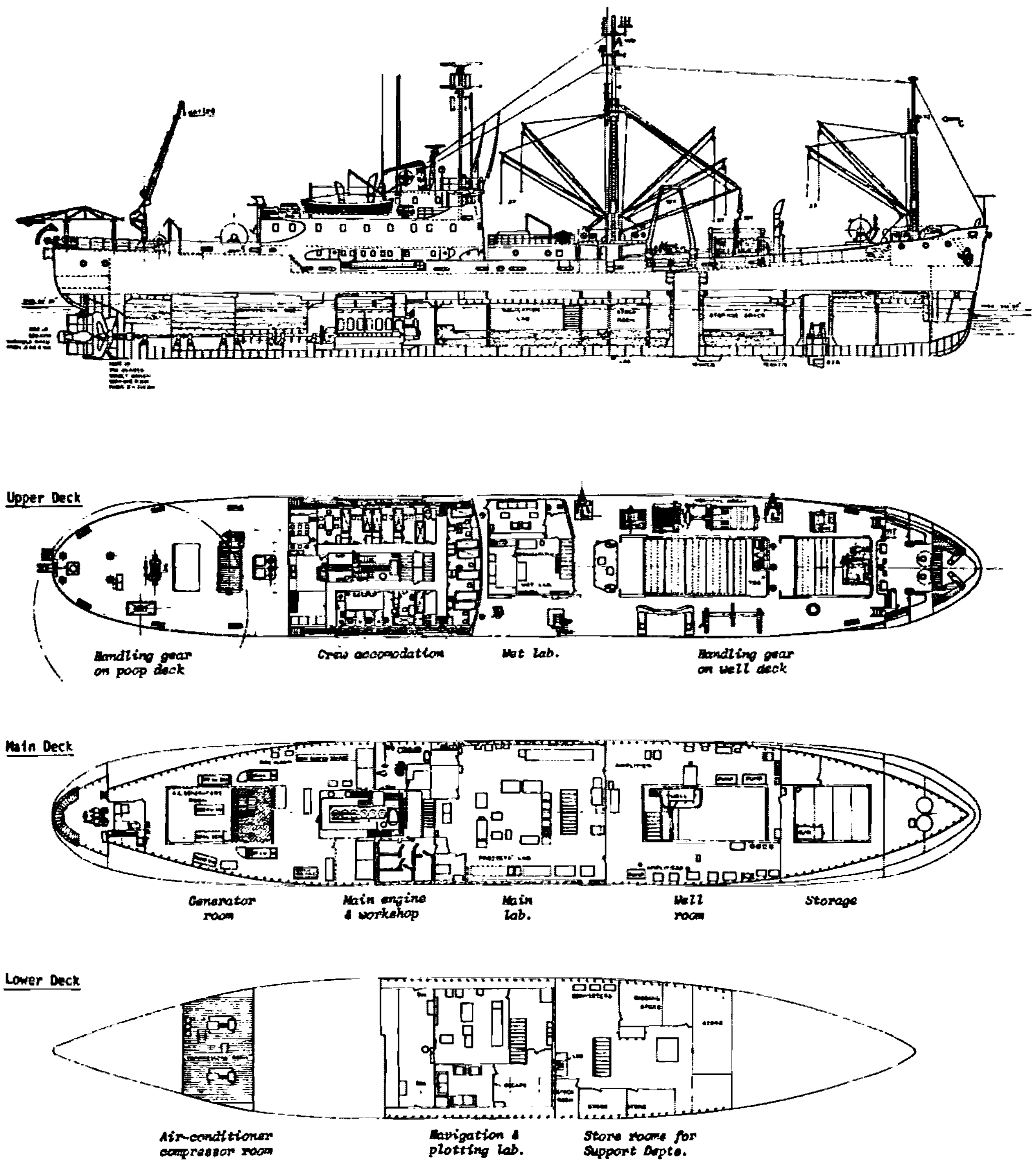
The period from mid-1964 to mid-1969 was very productive as measured by the output of documents. Approximately 185 Technical Reports, Technical Memoranda, and Special Memoranda were produced, recording results of the Centre's research programme and describing special research equipments developed internally to enable the measurements to be made. Some of the more important of these documents are cited in the text. In addition, the Centre's scientists presented approximately 85 papers at meetings of NATO organizations and of scientific societies and published 15 articles in professional journals.

7.6 Tenth Anniversary

On 2 May 1969 the Centre celebrated its tenth anniversary. The programme included a short demonstration cruise aboard the MARIA PAOLINA G. attended by many of the people who had contributed to the Centre's achievements during its first decade.

The Elliott-503 central computer and XY plotter as first installed.

The reinstallation of the Elliott-503 central computer and its peripherals in a new mezzanine.



The merchant vessel MARIA PAOLINA G., as converted into a research vessel (showing final, 1979 configuration).

8.1 Introduction

During the second five years, environmental acoustics studies, primarily on propagation, continued to be a major activity at the Centre. Bottom-reflectivity studies continued, with the emphasis shifting from data collection to development of a detailed physical understanding of the process of sound reflection from a multiple-layer bottom and improvement in measurement and analysis techniques. Coherence studies were related primarily to scattering of sound waves by the rough sea surface and the bottom. Other general propagation studies included completion of the sea-water attenuation study started in 1963, development of a simplified formula for the speed of sound in sea water, and experimental and theoretical studies of the reliable acoustic path (RAP).

Area-related measurements were made in parts of the Mediterranean and in the eastern Atlantic southwest of Portugal. A major effort involved measurements in the Gibraltar area as part of the Centre's Gibraltar Project. In addition to propagation and bottom reflectivity, the Gibraltar Project included ambient noise measurements and also shipping surveys for the purpose of relating low-frequency ambient noise levels to ship traffic. For the higher frequencies, a study was made of ambient noise spectra during rain.

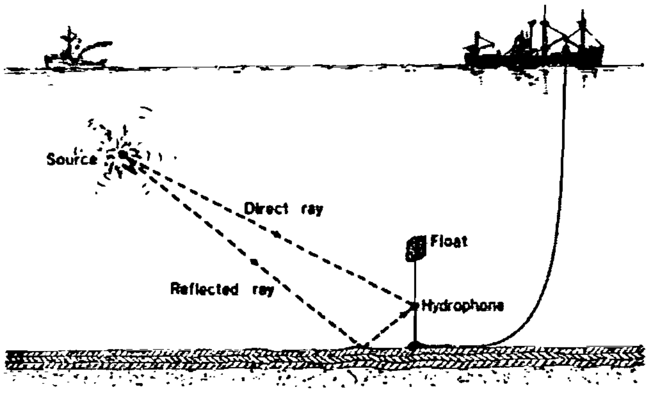
The development and calibration of transducers that could be used over a range of depths and the development of digital techniques for analysis of the data were essential to the success of the experimental programme. During this period, the transducer and digital analysis efforts were both treated as separate projects within the Sound Propagation Group.

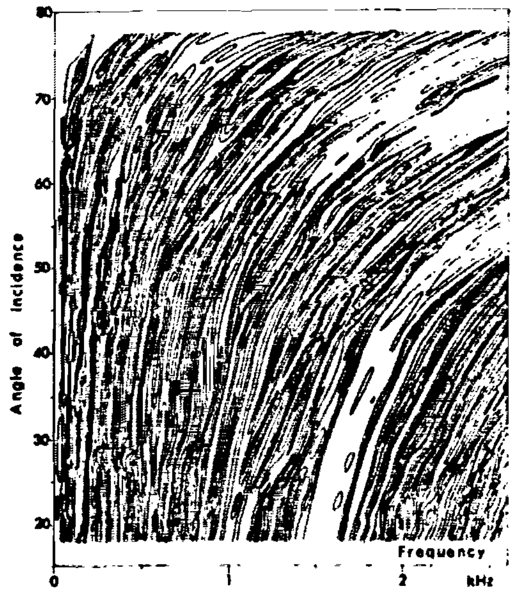
By early 1968, the importance of shallow-water areas was recognized and a new project was started to cover this work (see Sect. 14.10). At the same time, topics pertinent to deeper waters were amalgamated in a deep-water propagation project.

8.2 Bottom-Reflection Studies (Project 2.1)

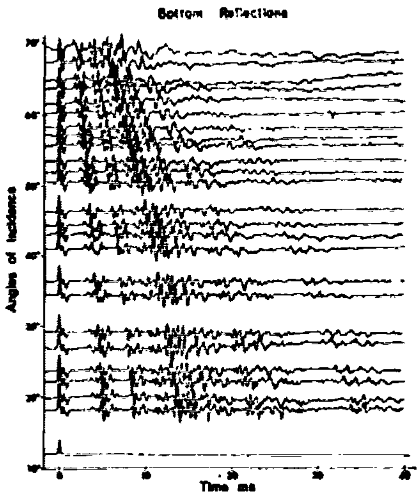
The extensive bottom-reflection measurements made during the first five years had revealed large fluctuations of bottom loss as a function of frequency, angle of incidence, geographic area, and, to some extent, the methods of taking and analyzing the data. During the second five years, measurement techniques were perfected and, even more important, a new physical understanding of bottom-reflection phenomena was achieved.

The early experiments had been made with both the explosive sources and the receiving hydrophones at relatively shallow depths. This had the advantage of giving general information on





Experiments to study bottom reflection, showing (above) the losses as functions of angle of incidence and frequency at (below) the impulse responses. [CP-2a]



all types of sound-propagation paths, but the disadvantage of making bottom-loss calculations dependent on accurate ray calculations of the losses occurring in the in-water path. Also, the analyses were carried out in octave bands, thereby obscuring some important characteristics. Theoretical studies of reflections from multiple-layered ocean bottoms (TR-42,50) showed that it might be possible to correlate observed fluctuations with sub-bottom features if more accurate and more highly-refined measurements could be made.

In January 1967, a controlled experiment was conducted in the Tyrrhenian abyssal plain 140 km southwest of Naples, in water 3600 m deep (TR-145). Explosive charges were detonated at 550 m and the direct and bottom-reflected signals were received by a hydrophone suspended 150 m above the bottom. Analogue signals were recorded and later digitized at a sampling frequency of 24 kHz for FFT spectral analysis.

When bottom loss for a single angle of incidence was plotted as a function of frequency, the results showed apparently random fluctuations of from 25 to 30 dB. However, when the results from all angles were examined together, the individual peaks and valleys were found to be related, with their frequency/angle dependence behaving in accordance with that predicted by multiple-layer bottom-reflectivity calculations (TR-42,50). Phase angles and impulse responses were measured (TR-145) as well, and these were also found to be consistent with theory.

The Centre's innovative experimental techniques and the basic experimental results, which are an important contribution to this field, were disseminated in the open literature (19), in papers presented at a conference held at the Centre in 1970 (CP-2a), and by several SACLANTCEN publications (TR-61,85,149, TM-89).

8.3 Coherence Studies of Ocean Acoustic Paths (Project 2.2)

Signal coherence may often be an important limiting factor in the application of underwater acoustics to sonar and communications. Research was conducted at the Centre on two aspects of this problem: reflection and scattering from rough surfaces, and fluctuations caused by random inhomogeneities in the water. Studies of the fine structure of submarine echoes, using broadband techniques, were also carried out as part of the Coherence Project; however, since this work pertains to active sonar research, it will be covered later under Sect. 9.5.

When CW signals are transmitted in an imperfect medium or by multiple paths, amplitude and phase fluctuations are observed. Since many different causes exist for such fluctuations, and since experiments with CW signals do not distinguish between them, such experiments generally give results that are difficult to interpret in terms of physical mechanisms. It is more useful to deal with the impulse response of the medium, that is, the response in time to a sudden brief impulse, such as from an explosion. A major accomplishment during this five-year period was recognition of the value of this approach and the development of techniques and equipments to make possible the analysis of data taken by using explosive sound sources.

Although explosive signals, through analysis of impulse responses, offer greater physical insight than CW, they pose difficulties for both recording and analysis of the data: the large signal dynamic range exceeds that normally available through analogue equipment, and analogue analysis techniques are slow and tedious. By mid-1964 the Centre's scientists recognized that digital techniques developed for the FM sonar project (Sect. 3.1) could be adapted to analyse signals received from explosive charges. A separate project (see Sect. 8.8), largely staffed by personnel from the Coherence Project, was formed in December 1964 to develop digital recording and analysis equipments. When the equipment was built, it was first used to study bottom reflections and submarine echoes (see Sects. 8.2 and 9.5), and later for scattering measurements of the rough sea surface and the deep scattering layer (DSL).

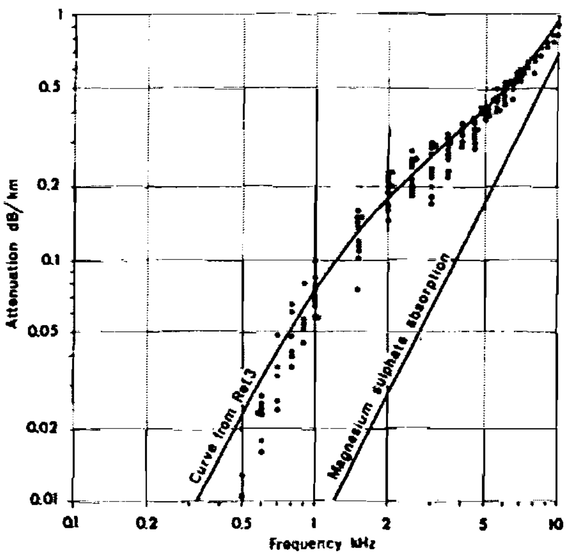
The accurate, direct measurement of the impulse response of a physical system requires single, sharp pulses. Explosive charges produce such a pulse from the initial shock wave. However, this is followed by a bubble pulse that complicates the received record. Initially this problem was overcome for bottom reflectivity measurements by recording both direct and reflected signals and then dividing the latter by the former (TR-104). Later a special computer program was developed that used the Fast Fourier Transform (FFT) to deconvolve the signals in the frequency domain and to reconstruct the impulse response function (20) (TR-140).

While awaiting digital instrumentation, theoretical studies continued. One such study, completed in 1967, was a computer simulation of the distortion of an impulse propagating in a medium that has a fluctuating refraction index (TR-102). In 1968, theoretical studies of scattering from a rough surface were undertaken because the coherence-destroying effects at the ocean boundaries are often dominant limitations to signal-processing techniques. A literature study of this subject was published (21) (TR-138, CP-36) and a short study made of ocean wave statistics (TR-160).

8.4 Propagation Loss Studies (Project 2.4)

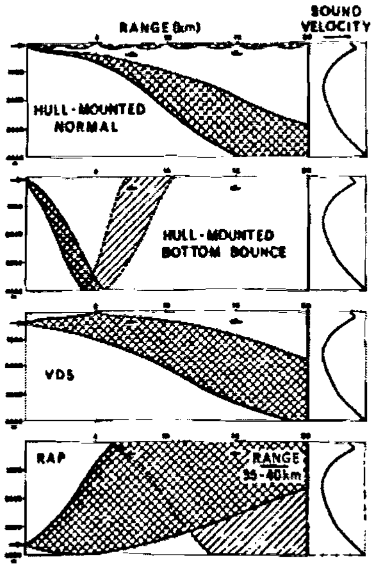
A number of smaller studies having broad applicability to the general subject of propagation were performed and reported in the SACLANTCEN Annual Reports under Project 2.4, using varying titles:

Sea-water attenuation: The analyses in 1964 completed studies begun in August 1963. They used data from transmissions along deep refracted paths recorded during bottom reflectivity experiments with shallow sources and receivers (see Sect. 2.4). These results had revealed absorption losses in the frequency range from 0.5 to 8 kHz greater than that extrapolated from long-range measurements made in the Pacific Ocean and as much as ten times higher than could be attributed to the magnesium-sulphate relaxation process that controls absorption above 10 kHz. Several theories had been proposed to account for the excess absorption, one of which suggested that it might be due to finite-amplitude effects associated with the use of explosive sound sources. The Centre undertook to determine the influence of this latter effect. In experiments in June 1966 and November 1968, direct measurements of propagation loss were made for each frequency using energy from the shock wave and from the bubble pulse separately. The results (TR-156) clearly demonstrated that the excess attenuation was not caused by finite-amplitude effects and confirmed the earlier results.



Sea-water attenuation as a function of frequency. [TR-156]

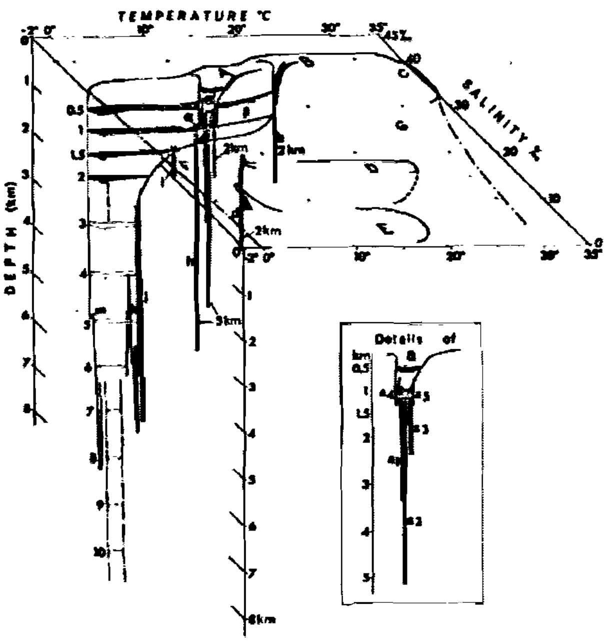
Reliable acoustic path: At this time the Centre undertook measurements and calculations designed to demonstrate the significance of the reliable acoustic path for increased sonar area coverage. Late in 1965, in support of Project 1.2, some preliminary measurements were made that demonstrate RAP propagation. These 5 kHz measurements were made in the Madeira-Azores zone with a transmitting source at 3200 m depth in cooperation with the French Laboratoire DSM du Brusc. Further measurements at 1.8 kHz, made in cooperation with the U.S. Naval Research Laboratory in 1966, further confirmed the validity of the concept that increased continuous coverage could be obtained by using deep transmitters. Maximum coverage was expected by locating the source at the critical depth, which is the depth at which the sound speed has the same value as it does near the surface. This depth varies appreciably both geographically and seasonally, and studies were made to compile data on the critical depth. Ray tracings of a number of typical situations were published in TR-94. Further experiments contributing to a better understanding of RAP propagation were carried out in November 1968 in the Ligurian Sea and in the Levantine Basin in June 1969.



Sonar techniques, showing the significance of using the reliable acoustic path.

Mediterranean Sea propagation: In July 1966, Mr C. Leroy summarized the Centre's knowledge of sound propagation in the Mediterranean in a broad survey for a NATO Summer Advanced Study Institute on Sound Propagation (22) (TR-103). In response to a request by COMSUBMED, the Centre embarked in 1967 on a comprehensive study, involving extensive ray tracing, of sonar coverage for source and/or receiver depths down to 800 m for various areas of the Mediterranean. As reported in TR-154, the main feature that was found was the drastic change in insonification area with relatively small changes of depth. Although surface ship, hull-mounted sonars would experience severe shadow-zone limitations much of the year, deeper sonars such as VDS or those mounted on submarines would be expected to perform more effectively. Critical depths and convergence zone separations were both found to be highly dependent on season of the year, with the former varying between 0 and 2300 m and the latter from about 15 to 45 km. Maxima for both occur in August and minima are found from January to March.

Black Sea propagation: Using bathythermographic data supplied by the Turkish Navy Hydrographic Office, a similar report showing ray traces and sonar coverage as a function of season was produced for the Black Sea (TR-142).



Speed of sound in sea water: three-dimensional representation of the temperature/salinity/depth combinations in the major oceans, together with sea areas having particular combinations. (23)

Speed of sound in sea water: Knowledge of sound speed as a function of depth is fundamental to all acoustic propagation calculations. Like most other groups, the Centre had adopted Wilson's second equation, which gives sound speed as a function of temperature, salinity, and absolute pressure in the form of a long polynomial and which is suitable for computation by a large, high-speed computer. C. Leroy first developed a relatively simple expression connecting pressure with depth (TR-108) and then found a simple approximation to Wilson's equation (TR-128) that could be readily used with desk-top calculators. Published in the Journal of the Acoustical Society of America, (23), these formulas received wide acceptance throughout the underwater sound community and were used exclusively at the Centre until replaced in 1978 by formulas based on new information (SM-107).

Propagation modelling: Ray-trace propagation modelling at SACLANTCEN, although essential to theoretical studies and as a means of visualizing predicted sonar coverage, was of routine character in the first ten years. A multiple linear-segment Snell's Law program was written in ALGOL for use on the Elliott-503 (TM-102) and was then used for the RAP and area-related studies already mentioned. For use on board ship, a program was developed and implemented on an Olivetti-101 desk-top calculator (TR-141), but although more versatile it was relatively slow. In addition to tracing out rays and using Leroy's formulae to convert oceanographic measurements to depth and sound speed, it could also calculate sound intensities and travel times along the rays. This was the predecessor of a versatile program implemented a few years later on a Hewlett Packard-2116B mini-computer (SM-49, CP-5d,61).

8.5 Gibraltar Studies (Project 2.5)

In November 1964, SACLANT, with the support of the SCNR, directed that the Centre should undertake a high priority, coordinated acoustic, oceanographic and operations research programme relevant to underwater surveillance of the Gibraltar Strait. Over the next three years, seven cruises were made to this area to collect acoustic data. On each occasion, retrievable bottom-mounted buoys containing tape recorders were used to collect ambient noise data. Ship traffic surveys were usually performed in support of these studies. On four of the cruises, assist ships were provided by the U.K. or French navies to enable propagation measurements to be made with explosive charges as sources. In two cruises, reverberation data were also collected.

Ambient noise measurements covering the frequency band 30 Hz to 15 kHz were made near the sea floor at a number of locations between 10° and 25°W during all seasons. Ship traffic was found to be responsible for the noise up to at least 1 kHz. A complete summary analysis of the noise data was prepared (TR-89), together with a statistical survey of shipping in the area (TR-84).

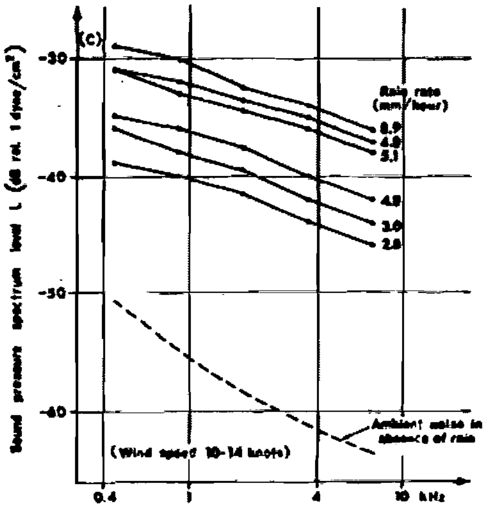
Propagation measurements were made using

Relief model of the Strait of Gibraltar, contour interval of 20 fm, shaded below 200 fm. [TR-30] sources at typical submarine operating depths and both near-surface and near-bottom receivers. Special attention was paid to the effects of internal waves, which are often strong in this area. After finding that signal distortion was not significant, it was decided to devote most of the effort to systematic measurements of bottom losses and to analyse only a few typical propagation runs in detail. The bottom loss results are presented in TR-175. Using the extensive BT data that had been collected in this area, ray tracings were made to show sonar coverage for a wide variety of seasonal and geometric situations (TR-158).

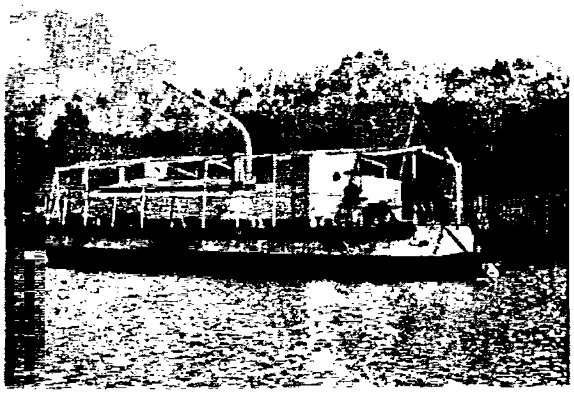
As is typical of the Mediterranean, maximum sonar ranges for continuous coverage were found to be extremely dependent both on season and sonar depth, with the best results being for sonar depths in excess of 150 m.

8.6 Ambient Noise Studies

During the Centre's first decade, interest in ambient noise was small and therefore only a relatively small effort was devoted to ambient noise measurements. However, what was done was unique and of great interest to the larger underwater sound community. In addition to the Gibraltar measurements already described, underwater noise due to rain was measured in a small lake near Sarzana, using the Centre's transducer-calibration barge. During November and December 1967, measurements were made of the noise from 0.4 to 10 kHz and the resulting octave-band levels correlated with rain rate (TR-121). These results were later published (24) and were only the second set of measurements generally available on this subject.



Correlation of underwater noise and rain rate. [TR-121]



Calibration barge on lake near Sarzana.

8.7 Transducer Design and Calibration (Project 2.3)

Throughout the period, this support project was manned at a rather low level. Nevertheless, a large number of hydrophone arrays were developed for use by various research projects. These included three flexible "Sea Snake" multihydrophone arrays to be towed at slow speeds, several rigid arrays for use in space/frequency classification experiments, a 780 m long deep vertical array for sound-propagation measurements, and a number of other special-purpose hydrophones and arrays.

A major activity was the design and testing of prototype hydrophones for the MEDUSA arrays for the Deep Panoramic Sonar Project. As discussed in Sect. 9.4, support work for this latter project required a large effort throughout the period. Calibration work suffered somewhat as a result of the array construction and a shortage of personnel. The barge on the Sarzana lake was used until 1968, after which the required calibrations were obtained through the courtesy of Italian and French national facilities.

8.8 Digital Techniques of Data Analysis (Project 2.6)

In his introduction to a conference on digital analysis of underwater acoustics held in 1971, Mr R. Laval, Chairman of the conference, stated that he "considered the most critical factor ... limiting progress in underwater acoustics research to be the analysis of the acoustic signals collected during experiments at sea. The accumulation of unanalyzed data collected during old sea trials had become the common nightmare of all research organizations". The Centre shared this experience. Analysis of data from the early experiments was painstakingly slow.

As early as 1963, the Centre concluded that the data-processing problem required the use of a high-speed digital computer, and also that limitations of analogue recordings should be overcome by the use of digital data recording.

A design study was started in 1963 in the Coherence Studies Project. In 1964 construction of a digital data-processing unit was started, and in December of that year this effort was established as a separate project. By 1967, development of equipments had progressed to the point where they could be used to analyze previously-recorded analogue tapes, and the following year it was reported that digital techniques of data analysis had superseded the analogue techniques previously used.

Elements of the original digital data system developed at the Centre included:

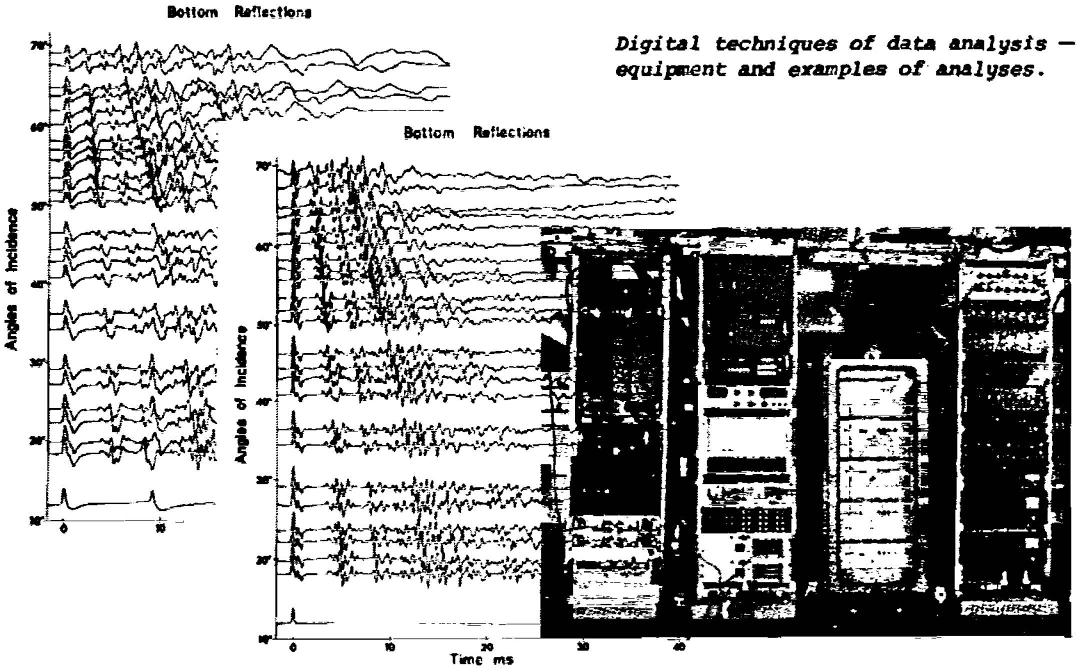
a) A multi-channel receiving system with analogue-to-digital (A/D) converter-amplifiers.
b) A high-density digital magnetic tape recording system.
c) An interface system to transfer data to the Elliott computer.
d) A large capacity, core memory to which portions of a recording could be transferred for useful data block selection.
e) A digital, low-density, magnetic-tape unit for program and data storage.

With this system, analogue or digital data could be acquired, stored, edited, and transferred for analysis to the Elliott digital computer.

To handle the large dynamic range required for experiments using explosive sound sources, a receiving system was designed and built (TR-106) consisting of fourteen variable-gain transistor amplifiers, seven peak-level monitors, and two test sets to handle analogue inputs and convert them to digital outputs. Gains of up to 78 dB were provided in 6 dB steps, with the gain settings indicated by small lamps. The peak-level monitors consisted of high speed A/D converters with a set of lamps to display the highest received level and its polarity.

The high-density digital recorder is especially noteworthy (TR-170) and was the subject of a patent. The system employed a standard, 14-track, instrumentation-type, wide-band tape recorder working in the direct recording mode at 30 in./s. The unprecedented recording density of 12.1 kbit/in of track permitted a recording rate of 364 kbit/s and a total data recording rate of almost 3 Mbit/s for the ten data tracks. Three data bands were available: 50 Hz to 4, 8, and 16 kHz, for up to 20, 10, and 5 input channels respectively. A total of 128 dB of dynamic recording range was available by selecting gain settings, with 80 dB for each. This system, built in 1967/68, has been in continuous use at the Centre since that time.

The Centre's original digital data system was used to analyze tapes from most of the experiments described in this chapter. A second-generation system retaining some of the original components and using a Hewlett-Packard HP 2116B minicomputer was conceived in 1969 and designed in 1970. In 1971, this SPADA system replaced the original system, which used the Elliott for all computerized data analysis. ■



Digital techniques of data analysis — equipment and examples of analyses.

CHAPTER 9 ACTIVE SONAR RESEARCH (1964-69)

9.1 Introduction

From the beginning, the Centre's interest in active sonar had been primarily from the point of view of target classification. In fact, most of this type of work was carried out in the Target Classification Group. The first project, described in Sect. 3.1, was concerned with the utility of digital FM sonar and was motivated by the need to recover the classification capabilities characteristic of the short-pulse sonars of WW II. The usefulness of FM was confirmed by mid-1964 and there remained only to demonstrate the capabilities of the Centre's experimental equipment as a classification adjunct to existing operational sonars.

As early as the autumn of 1963, Dr F. Wiekhorst of the Target Classification Group conceived the idea that long CW pulses might also yield useful classification clues from analysis of the spatial variation of the echo (TM-78). Studies relevant to space/frequency classification became a major project by 1965.

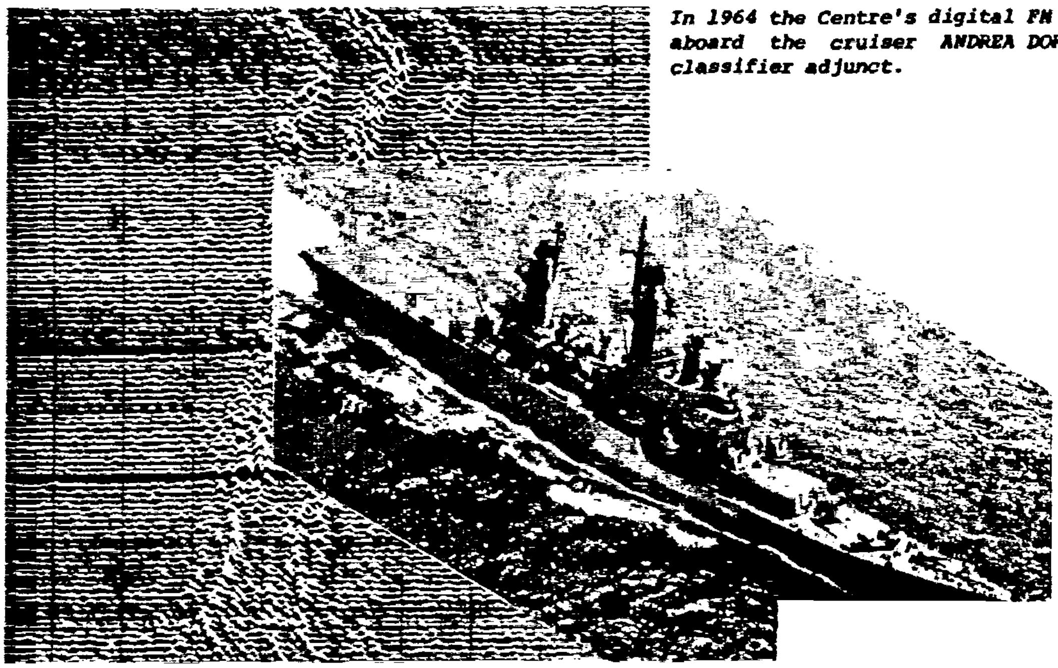
Hull-mounted sonars suffer limitations in maximum power and in area coverage. Ray tracings showed that the area of continuous coverage could be increased if the transducer were lowered well into the sound channel, or even to the bottom of the deep channel. The Director, Dr Nødtvedt, proposed a Reliable Acoustic Path (RAP) Project based on this concept (25) (TM-90). Work began in May 1965 leading to the design and construction of the large MEDUSA 300 array. Since an electronically steered panoramic receiver was to be used, the RAP sonar project was entitled "Deep Panoramic Research Sonar". It became a focus for much of the Centre's programme for ten years.

In addition to active sonar signal-processing studies, the Centre also took advantage of its numerous trials with submarines to study target characteristics. The methods used were those developed for propagation studies, and this work was done as a part of the Coherence Studies Project. As it is more properly active sonar, rather than propagation research, it is treated here.

9.2 Digital FM Sonar (Project 1.3)

By 1964, the Centre's digital FM sonar classification project, described in Sect. 3.1, had reached the stage where further development into a practical system would require incorporation into national programmes, and the United States and Italy indicated interest. Four US Navy representatives and several officers from the Italian Navy observed a demonstration held in March and April 1965 for which the Centre's experimental FM equipment had been installed on the cruiser ANDREA DORIA (IT) as target classifier adjunct to the AN/SQS-23B sonar, with the submarine EVANGELISTA TORRICCELLI (IT) as target. The results fully justified the claims made: high-resolution displays were obtained out to ranges of 20 km and 28 km at 15 kn ship speed. The classifier gave superior target information out to at least the maximum range of the AN/SQS-23 sonar, and it was also less prone to confusion from false targets (TR-57).

A demonstration trial for members of the NATO IEG-2(SWG/3) group was held in the Toulon area in February 1966, and shallow-water trials, observed by representatives of the UK, France, and The Netherlands, were carried out in the southwestern approaches to the English Channel in April of that year. The project was then terminated.



In 1964 the Centre's digital FM sonar was installed aboard the cruiser ANDREA DORIA (IT) as target classifier adjunct.

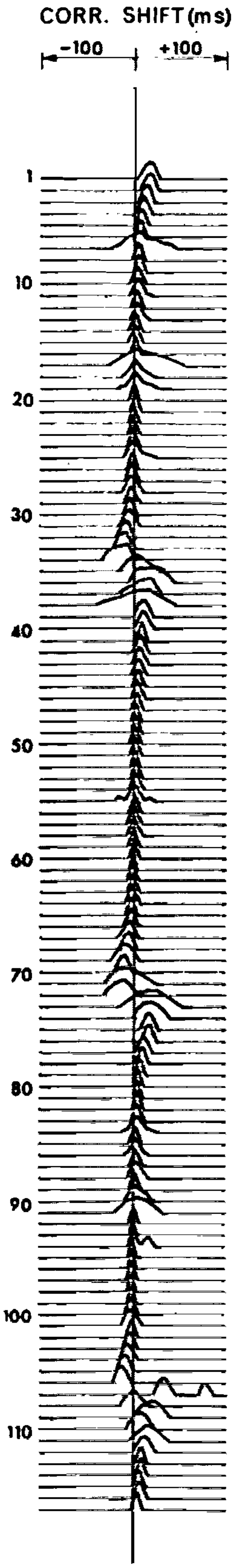
9.3 Space/Frequency Classification (Project 1.1)

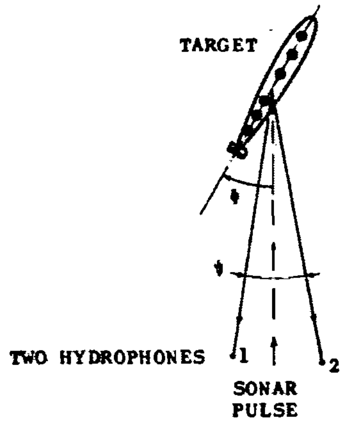
As already mentioned, the possibility of using space/frequency interference patterns of CW signals to classify long, thin targets had been proposed in 1963 (TM-78). By 1965, the theory had been fully developed and also extended to cover FM transmissions (TR-49, TM-91), and preliminary experiments had been carried out to confirm the basic concept.

Analyses of submarine active-sonar echoes with the FM sonar had shown that individual echoes occur from a number of different places on the submarine and that the specific points vary with aspect. However, because submarines have fairly high length-to-diameter ratios, the acoustic scatterers can be considered to be more or less in a line. The theory indicated that reflections from a number of scatterers in a line would produce complex space/frequency interference patterns, and that by sensing these patterns one could recognize a long, thin target. Since submarines are likely to be the only type of underwater target having this property, positive classification would be possible using only a single CW pulse. Use of FM was found to provide additional information on turning rate. No assumption had to be made about spacing or number of the scatterers; the fact of their simply being in a line would be sufficient.

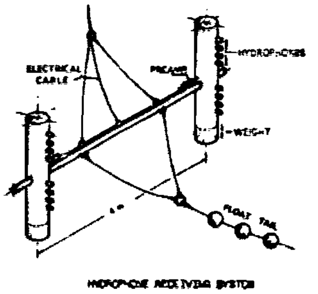
Three trials, each with a different submarine, were conducted in the Ligurian Sea in October and December 1966 and February 1967. Linear FM signals centred at 11 kHz were transmitted from the MPG and the echoes received on two vertical hydrophone arrays mounted rigidly about 4 m apart. Tape-recorded echoes were played back at the Centre, digitized, and analyzed on the Elliott-503 computer. Over a thousand pairs of echoes were cross-correlated and displayed. The results were better than anticipated, clearly indicating the validity of the space/frequency classification technique (TR-120).

Over the next several years, the theory was refined (TR-155, TM-122) the effect was demonstrated by computer simulations (TR-162, TM-123) and further experiments were carried out with submarine targets and employing flexible towed arrays rather than the previously used rigid structure (TR-163). Two of the original investigators, Dr F. Wiekhorst and Mr T. Kooij, had gone to the U.S., where they carried on with this work under the code name STARLITE. The technique is most powerful at close ranges, and by the mid-1960s most interest in the nations was in extending sonar ranges to longer distances, and it was not exploited in national programmes to the same extent as the digital FM classifier sonar development.





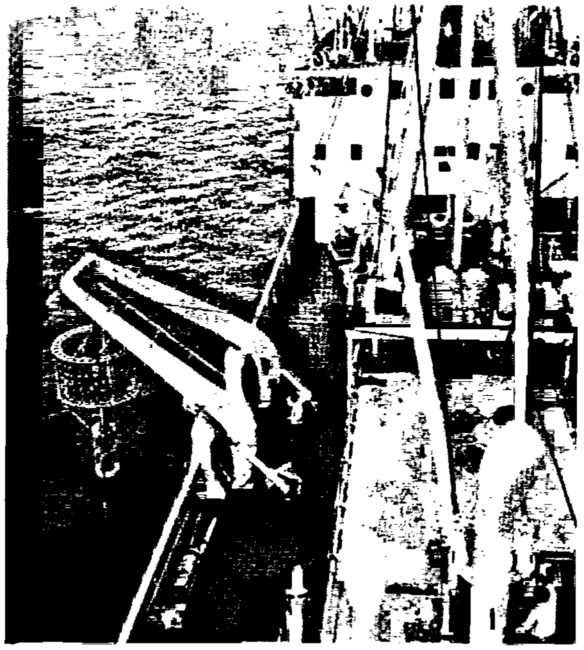
Space/frequency classification: Echoes received on two vertical hydrophone arrays (below) and cross-correlated (at left) identify the interference patterns produced by the scatterers aligned along the long, thin hull of a submarine (above). [TR-120]



9.4 Deep Panoramic Research Sonar (Project 1.2)

Range limitations of conventional hull-mounted sonars caused by adverse thermal structure was considered a major ASW problem. The United States had attacked this problem by building ships with huge, powerful transducers capable of exploiting both bottom-bounce and convergence-zone modes (AN/SQS-26). However, even for this sonar, bottom bounce was unreliable and its size and cost precluded it from being used widely in smaller ships or by other nations. Another possible solution was to lower the transducer below the surface layer, as was done with variable depth sonars (VDS). The further the sonar is lowered, the greater the coverage, until a maximum is achieved at the critical depth for which the sound speed equals that near the surface (RAP). (See also Sect. 8.4).

Following completion of the ANDREA DORIA demonstration of the FM classifier, work began at the Centre on the development of a projector and a receiving array that could be suspended below the MPG for deep propagation experiments in the Mediterranean. Called MEDUSA (Mediterranean Experimental Deep Underwater Sound Apparatus), the first version built in the period 1965-66 was designed and tested for operation down to only 300 m (TR-171).



Lowering the first MEDUSA deep panoramic research sonar from the MARIA PAOLINA G.

This medium-depth unit consisted of:

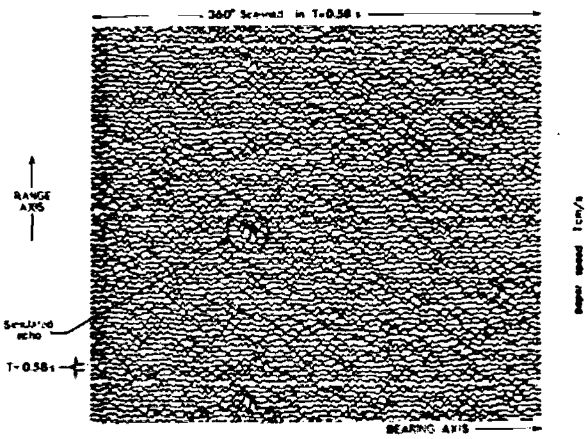
1. A 1.2 m long, cylindrical transmitting transducer having its resonance frequency at 3.5 kHz, transmitting omnidirectionally in the horizontal plane with a source level of up to 113 dB/μbar at 1 m.

2. A receiving array consisting of 32 vertical line hydrophones, each 1 m high, mounted on a circle 2 m in diameter.

3. A source-level monitoring hydrophone.

FM and CW signals could be transmitted. The received signals were handled by a digital multibeam processor that formed them into 32 horizontal beams, the output of which could be processed coherently or incoherently. Analogue and digital outputs were available, the former for absolute level measurements and the latter for panoramic displays.

The medium-depth MEDUSA 300 underwent engineering trials in mid-1966 and was used for preliminary single-beam submarine experiments in November of that year. Digital multibeam operation was achieved in 1967 and trials carried out in May and September with the submarine AMAZONE (FR). Apart from some minor initial problems, all processors and displays worked satisfactorily, although noise from the MPG and power limitations of the projector degraded performance. Further experiments were conducted with submarine targets in 1968 and 1969, which were treated as limited previews of the RAP trials that were contemplated with a deeper version.



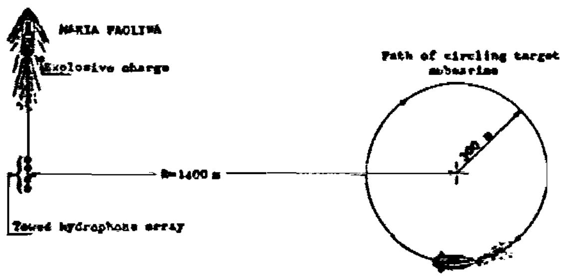
Panoramic display of incoherently processed data from the 32 beams of 'MEDUSA, showing the range and bearing of a simulated echo. [TR-171]

It was recognized from the start that obtaining a system for operation at 2000 m was not merely a matter of increasing the cable length. Extra power was required to overcome cable losses, and a telemetry system needed to convey information from the receiving elements. Design studies started in 1967. Digitized array performance and hydrophone response weighting functions to achieve increased front-to-back discrimination were studied theoretically (TM-135,147). In 1968 specifications were written and a contract was let for construction of all the underwater equipment, to be delivered to the Centre early in 1970.

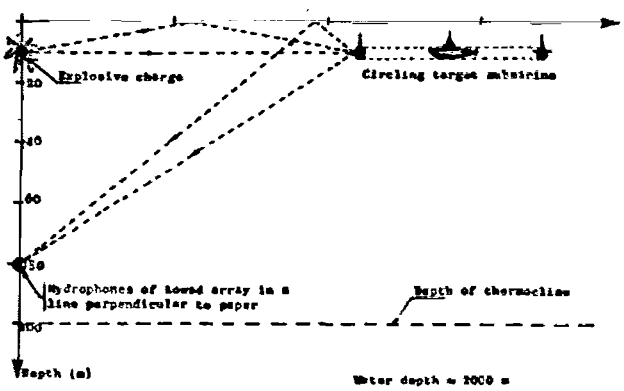
9.5 Spatial Coherence of Submarine Echoes (Project 2.2)

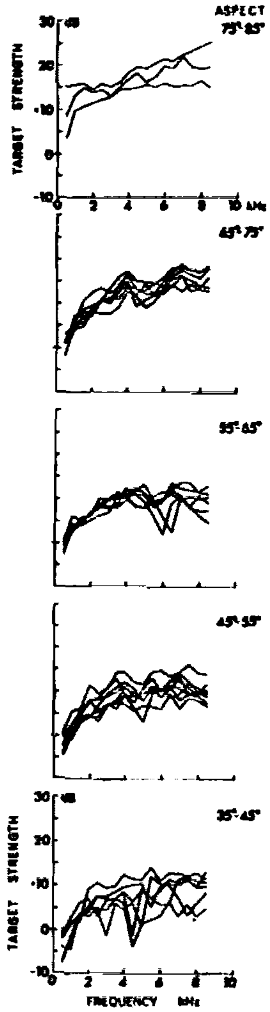
While investigations of submarine classification were being made under Project 1.1 (see Sect. 9.3) using CW signals, a parallel approach was undertaken in the Coherence Studies Project using explosive echo-ranging techniques. The purpose was to investigate the spatial coherence of the fine structure of the echo by using an extremely high resolution broadband source. Initial experiments with submarine targets were performed in February 1965 and in March and November 1966. The data were analyzed in 1967, when digital analysis techniques developed under Proj. 2.6 became usable. It was concluded that a better understanding of the parameters governing submarine classification could be obtained by comparing the results using explosive sources with those obtained using FM and CW pulses.

Cooperative trials with the Target Classification Group in November 1967 and July 1968 failed due to adverse weather, but data were obtained in December 1968 with the submarine EURYDICE (FR) of the DAPHNE class which confirmed high reverberation levels found in February 1967 in a trial with the submarine AENEUS (UK) (TR-116). The data on echo strength obtained from these first measurements were superseded by better results obtained in 1969 and 1970 (TR-193). ■



Measurement of target strength of a submarine for frequencies between 0.5 kHz and 8.5 kHz, using single-shot explosive sources. The results (at right) indicated that off beam aspect the target strength increases with frequency, particularly below 4 kHz. [TR-193]





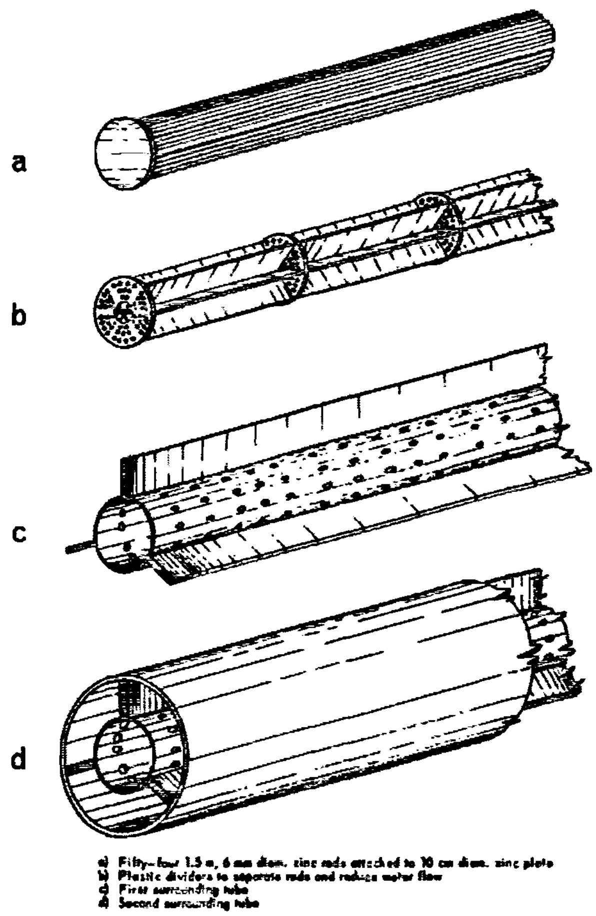
CHAPTER 10 NON-ACOUSTIC ASW RESEARCH (1965-68)

10.1 ELF Electromagnetic Research (Project 5.3)

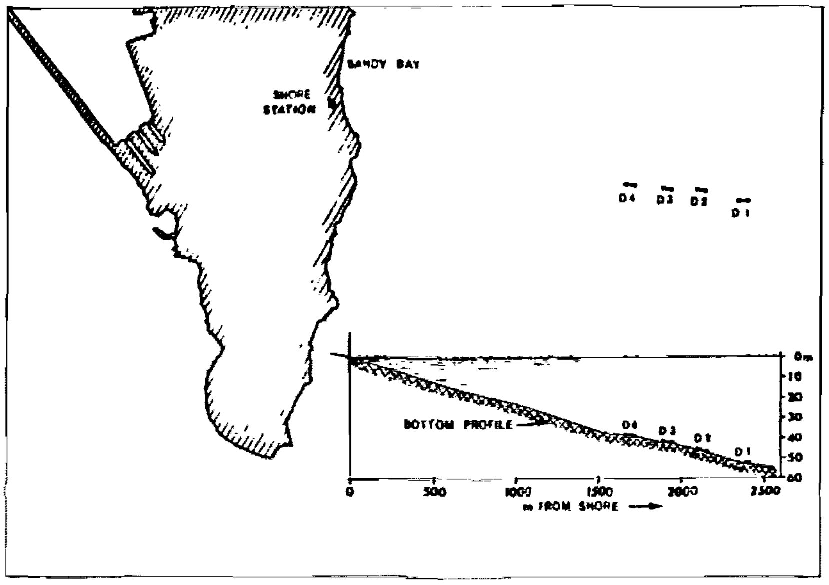
The ELF electromagnetic research programme at SACLANTCEN entered a second phase in 1965. As described in Sect. 4.2, the first was concerned with demonstrating the potential of passive ELF detection in the 1 to 32 Hz region, and emphasized mobile instrumentation either suspended from a buoy or towed behind a ship. During the first phase it was demonstrated that a system using electrodes rather than coils could readily detect the electromagnetic components radiated by submarines at shaft frequency and its harmonics.

In 1965, in support of the Centre-wide Gibraltar Project, *emphasis was switched to* research concerning possible employment of ELF electromagnetic detection techniques in a shallow-water barrier system. The first task was electromagnetic background measurements, which were made in the Gibraltar area in mid-1965 (TM-114). Special instrumentation was then developed for a prototype ELF barrier system (TM-141), and this was laid on the bottom at Sandy Bay, Gibraltar in mid-1967. The equipment consisted of a dipole chain of four horizontal dipoles, with electrode separations of 40 m and dipole separations of 200 m connected to recorders on shore by a 2500 m chain.

Background noise measurements made in La Spezia Bay and in Loch Fyne, Scotland, as well as in the Gibraltar area, showed marked local characteristics. Not only were there some specific, man-made, local sources, but also the field was found to be strongly influenced by the land/sea interface. At Gibraltar, the noise component



Construction of dipoles used for ELF electromagnetic detection of submarines. [TM-141]



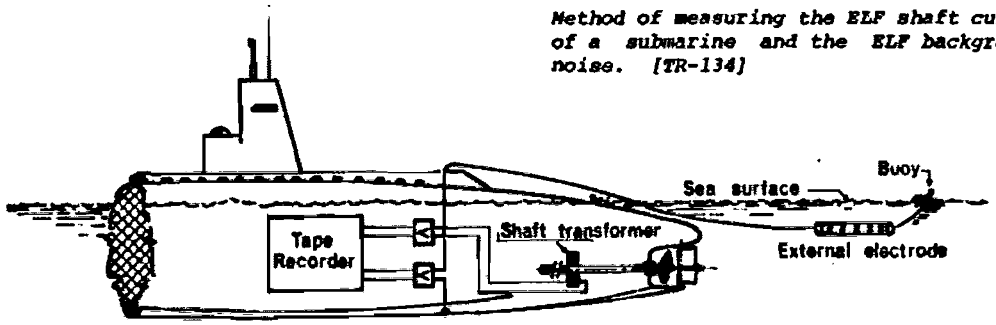
Deployment of a chain of four dipoles at Gibraltar. [TR-134] parallel to the shore line was observed to be several times larger than the perpendicular component (TM-114). It was therefore concluded that for a fixed system in shallow water considerable gain could be achieved by proper location of the elements relative to the field and by employment of a noise cancellation scheme involving two spaced, carefully-aligned dipoles.

The ELF background noise was found to be generally broadband in character, whereas submarine signatures consist of moderate-Q, narrowband tonal components at multiples of the shaft rate. Measurements on a submarine confirmed the source to be corrosion currents between propeller and hull. The detection of the relatively narrowband tonal components against a broadband background was accomplished by the use of sonogram techniques (TR-134). (The results would have been even better had Lofar been available to the Centre.)

Theory and measurements both showed EM propagation to be somewhat more favourable in shallow than deep water. This fact, combined with the feasibility of designing a system to minimize local background noise, led to the conclusion that detection ranges of from 1 to 2 km were possible (TR-134).

Active research on the ELF project ended in 1968, and two final reports were published in 1969 and 1970 (TR-134,165). The Centre's programme in this field has made a major contribution to the national programme carried on since 1965 in Denmark. The equipments developed at the Centre were given to the Italian Navy and later used for a civilian project. ■

Method of measuring the ELF shaft current of a submarine and the ELF background noise. [TR-134]



CHAPTER 11 OCEANOGRAPHIC RESEARCH (1964-69)

11.1 Introduction

Throughout the period covered here, more than half of the time at sea of the research vessel MARIA PAOLINA G. was in support of oceanographic research. Much of this ship time was in connection with the Centre's participation in six month-long multinational MILOC oceanographic surveys. A second major effort, in support of the Gibraltar Project, consisted of eight cruises to that area, six to measure water column parameters and two for sea-floor studies in the nearby Alboran Sea.

In addition to collecting and analyzing data required for sonar range predictions, the Oceanographic Research Group also carried out more fundamental studies of internal waves and air/sea interface phenomena. Beginning in 1965, the development of oceanographic instrumentation was recognized as a separate project.

By the end of this time, the Centre had collected large amounts of data on various parts of the Mediterranean, the Red and Black Seas, and the eastern North Atlantic, and an appreciable effort was devoted to compiling this information in summary reports on such subjects as bathymetry, upper-layer temperature structure, bottom geophysics, and the deep scattering layer.

11.2 Military Oceanographic Surveys (Project 4.1)

Following a suggestion made by the Centre, a series of major military oceanographic surveys was initiated in which research and assist ships from several NATO nations combine to study a single area for a period of about a month at a time. These were christened the MILOC (military oceanography) surveys and have continued in various forms to date, under the direction of the NATO MILOC Group.

For the first four MILOC surveys, conducted in the eastern North Atlantic in 1964/5/6, the Centre provided the chief scientist, Dr A. Dahme, and its research vessel, the MARIA PAOLINA G. and collated and published the resulting data:

MILOC 64: Sep 1964
900 n.mi west of British Isles (OWS JULIET)
(TR-52,53,54, TM-110,111,112)

MILOC 65(N): Jul 1965
900 n.mi west of British Isles (OWS JULIET)
(TR-109,110,124,126,133,139,143,168)

MILOC 65(S): Jul 1965
northeast of Azores (OWS KILO)
(TR-109,130,131,137,139,151)

MILOC 66: Jul 1966
900 n.mi west of British Isles (OWS JULIET)
(TR-179,180, TM-160, M-61,62)

The Centre also participated in and analyzed its own data from three additional surveys during the period

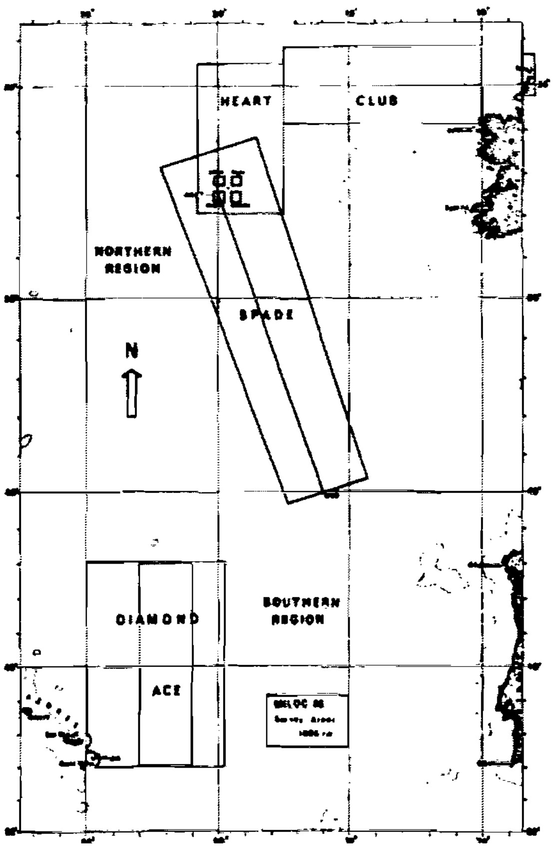
MILOC BALTIC May/June 1967 (TR-125)

MILOC AZORES June/July 1967

MILOC MED 68 May/June 1968 Ionian Sea (TR-173,185, TM-181)

A major objective of these cruises was to evaluate the accuracy of the U.S. Navy's Anti-Submarine Warfare Environmental Prediction System (ASWEPS), which predicted sonar-pertinent environmental conditions in the Atlantic based on in-situ data from transitting ships and weather stations. A comparison of MILOC 64 Phase A data with an ASWEPS analysis for the same area and period (TR-101) showed that the ASWEPS predictions were no more accurate than that possible using climatological data alone. In another analysis a linear relationship was found between sea-surface temperature and both bathymetry and depth of the thermocline (TM-113). A later analysis of data taken in the same area in 1966 (TR-186) showed that neither layer depths nor first-layer thermal gradients were correlated over even two miles. As a final output, sonar ranges for hull-mounted sonars were estimated from the near-surface BT data (TR-166).

The MILOC 65 survey in the eastern North Atlantic. [TR-109]



11.3 Gibraltar Area Oceanographic Surveys (Project 4.4)

During the period from mid-1964 to mid-1969, ten separate series of oceanographic measurements were made in the Gibraltar area as follows:

GIB IV, Oct 1964
Deep Scattering Layer
Internal Waves

GIB V, Apr 1965
Temperature Structure Currents
(TR-45,158)

GIB V, May 1965
Deep Scattering Layer
(TR-55)

GIB VI, Aug 1965
Sea Floor Studies in Alboran Sea
(TM-116,117)

GIB VI, Jan/Feb 1966
Internal Waves
Temperature Structure
(TR-66,158)

GIB VI, March 1967
Temperature Structure
Internal Waves
(TR-158)

GIB VI, Oct 1967
Temperature Structure
(TR-158)

GIB VI, Nov 1967
Internal Waves
Bottom Cores
(TR-127,201)

GIB VI, Sep 1968
Internal Waves
(TR-147)

GIB VI, Jan/Feb 1969
Sea Floor Studies in Alboran Sea
(TR-201)

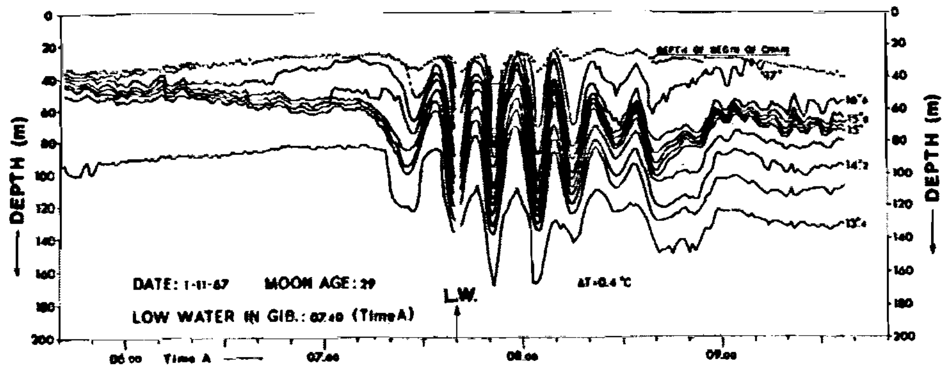
The Strait of Gibraltar has a complex morphology. The sea bed is especially irregular to the west, where there are a number of ridges and troughs. Salinity and current measurements reveal an interchange of Atlantic (low-salinity) and Mediterranean (high-salinity) waters over the sill. A core of Atlantic water carried by a counter-current enters through the Strait to replace Mediterranean water, which spills out into the Atlantic where it sinks to about 1000 m.

The depth of the interface between the two types of water travelling in opposite directions changes with the tides, the prevailing winds, and the passage of weather fronts. The interface is further disturbed by vertical and horizontal eddies generated by current flows over the irregular bottom. High-amplitude internal waves also occur at the interface. As discussed in Sect. 5.5, the Centre's original interest in the Gibraltar area was in these internal waves, which had been observed using thermistor chains. This work was continued during the Gibraltar Studies Project, with data being collected on at least four occasions using the Centre's recoverable vertical thermistor string (TM-144). The internal wave observations are described in detail in (26), TR-127 and TR-147.

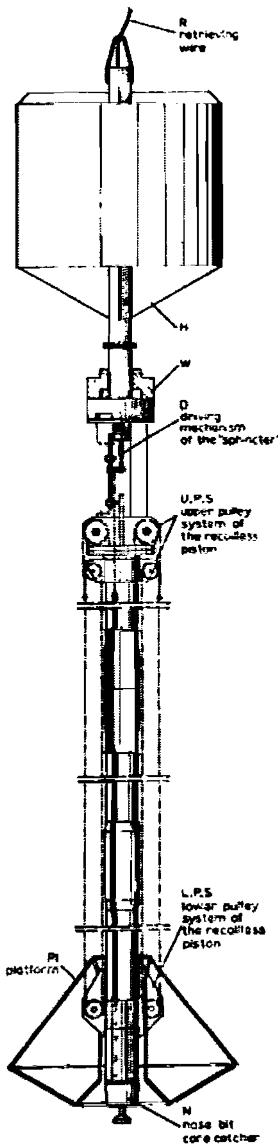
11.4 Sea-Floor Studies (Project 4.2)

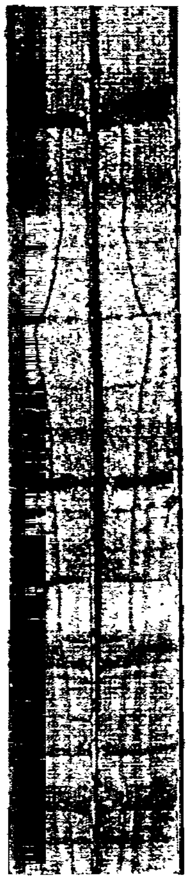
Using its newly-developed Sphincter Corer (Sect. 5.4), the Centre took large diameter, long cores (9 to 12 m) in many areas, a large percentage being in support of other projects. For example, in support of the Gibraltar and bottom-reflectivity projects, extensive work was done in the Alboran Sea (TR-201). Other observations were made in the Ligurian and Tyrrhenian Seas (27) (TR-113,114). From these data it was possible to develop empirical relationships between the physical properties of density, sound speed, reflection coefficient, and porosity (CP-2f).

During this period, improvements were made to the sphincter corer (28) and a method for making rapid analyses of cores was developed (TR-71). A deep-sea probe was developed to enable in-situ measurements of the electrical resistivity, and hence the density and porosity, of approximately the top 8 m of unconsolidated sediments (29) (TR-115). This device gave results with about 50 m resolution and, although successful, has not had much use at the Centre.



Internal waves occurring at the interface between the Atlantic and Mediterranean waters counter-flowing through the Strait of Gibraltar. [TR-147]





A SACLANTCEN-designed recoilless piston corer and a section of a core recovered from the sea bed. [TR-112]

11.5 Air/Sea Interface Studies

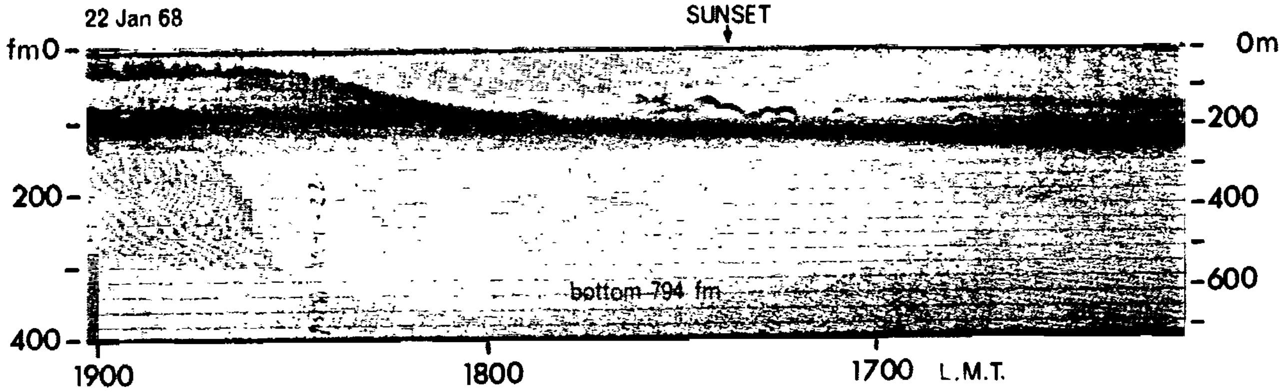
As previously mentioned, the thickness and variability of the upper isothermal layer are important parameters governing hull-mounted sonar performance. A study of the interface was undertaken at the Centre in the late 1960s, in Project 4.1, in order to predict these parameters as a function of weather. Discussions with five investigators in the U.S. elicited the opinion at that time (1967) no satisfactory model existed for describing the temperature distribution in the upper layer and that experiments under strictly controlled conditions were required.

In 1967, simultaneous meteorological and oceanographic data were collected in the Mediterranean and in the Baltic, the latter as part of the MILOC BALTIC survey (TR-125). An attempt to collect data during the MILOC MED survey in the Ionian Sea failed due to instrumentation malfunctions, and, in fact, more such problems forced the cancellation of further experiments. The effort was then turned to theoretical studies of heat and momentum fluxes in a maritime atmosphere (TR-153, M-57,58).

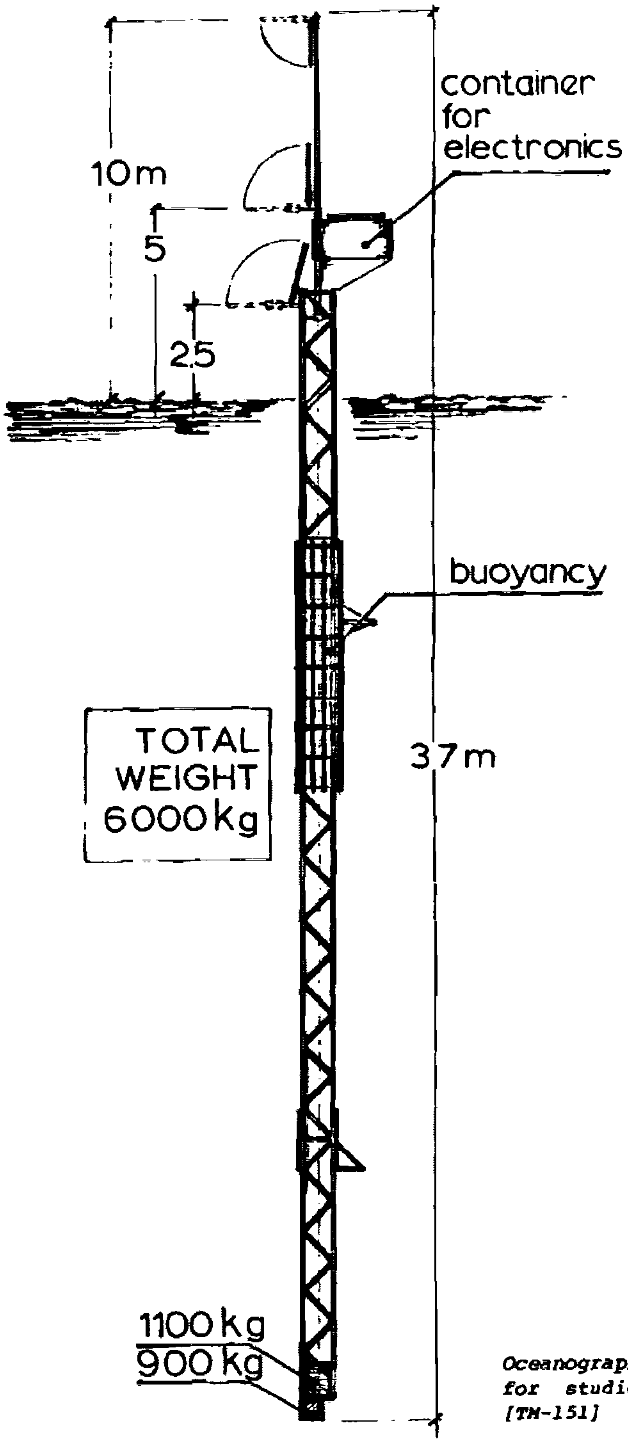
11.6 Deep Scattering Layer Studies

One source of reverberation in the oceans is the deep scattering layer (DSL) composed of biological organisms that migrate virtually as a function of the amount of light The Centre initiated a study of this subject in late 1967 Five short explorations using a precision depth recorder (PDR) were carried out in the autumn of 1967 and winter of 1968 in the Ligurian Sea, where more extensive measurements were also made in April and November 1968 (TR-148).

A broad survey of the literature on sound-scattering layers in the Mediterranean was published (TR-150), and also an analysis of data pertinent to the DSL taken during the MILOC 66 survey in the eastern North Atlantic (TR-179).



The deep scattering layer of biological organisms recorded in the Alboran Sea as part of the layer starts to move nearer the surface after sunset. [TR-150]



Oceanographic/meteorological buoy developed for studies of the air/sea interface. [TM-151]

11.7 Mediterranean Studies

Numerous short oceanographic cruises were made to the Ligurian and Tyrrhenian Seas, and data on temperature structure, currents, and bottom characteristics were accumulated. In addition, the Centre participated in the MILOC MED survey of the Ionian Sea in May 1968.

A summary of typical BT traces was published together with the resultant ray tracings (TR-154). A comprehensive collection of BT data taken in the Ligurian Sea from 1960 to 1967 was also issued (TM-165), and the results of MILOC MED were given in TR-173 and 185. Bottom characteristics in two specific areas were published in TR-157 and 162.

11.8 Oceanographic Instrumentation
(Project 4.3)

In addition to the sphincter corer, deep-sea probe, and vertical thermistor array already described, the Oceanography Group in conjunction with Technical Services developed an oceanographic/meteorological buoy (TM-151) for air/sea interface studies, a 50 kHz in-situ sediment profiler (TR-72) for bottom profiling, and an improved acoustic-releaser system (TM-142) to be used when recovering submerged anchored instrumentation arrays and packages.

Most important, just as the Centre led in applying digital techniques to underwater acoustic measurements, so it was a leader in applying these techniques to the collection of oceanographic data (30); the oceanographic buoy, for example, employed a digital recording system. A digital depth recorder (DDR) (TR-69) and a digital position recorder for the LORAN-C (LDRS) (TR-86) were both developed in the 1964-66 period. ■

CHAPTER 12 ASW STUDIES (1964-69)

12.1 Introduction

During its second five years the Centre's programme of work included a number of ASW studies, of which some were in response to specific requests from other NATO bodies and others investigated ideas generated by the scientific staff. Most of this work was done in the Operations Research Group, whose mission was to evaluate performance of existing systems as well as proposed applications of systems not yet fully proven. Some more theoretical and novel concepts were treated in the relatively small Special Studies Group.

Roughly a dozen topics were investigated during this period. These are grouped under five headings for the purpose of the present survey:

- ASW Exercise Analysis
- Tactical Studies
- Weapons Effectiveness Studies
- Sonar Performance Studies
- Gibraltar Study

In addition, members of the Special Studies Group worked on a novel concept for passive detection, which is included in this chapter although it involved experiments and was therefore more than a theoretical study.

12.2 ASW Exercise Analysis

During this second five-year period, Centre staff participated in and analysed data from eight NATO ASW exercises. Usually the focus was on one or two aspects of the exercise that were the subject of specific studies in the Centre.

Data on false sonar contacts, one of the Centre's interests, were obtained during the post-exercise reconstruction phase of four NATO exercises:

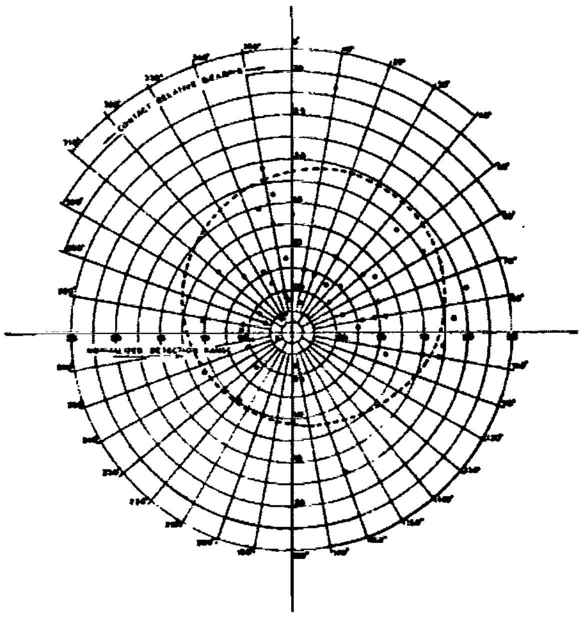
TEAMWORK	September 1964
PILOT LIGHT	March 1965
EMERALD GREEN	September 1965
TOTEM POLE	October 1965

Analyses of false sonar contacts during TEAM WORK, PILOT LIGHT and EMERALD GREEN (TR-47, 59,90) all gave approximately the same results: namely, that false contact rates are significantly higher in shallow water than in deep water and that the rate during exercises is seven to ten times higher than that obtained during non-exercise conditions. The false contact rate was found to exceed the real contact rate by a large factor, and it was concluded that the ability to discriminate against false contacts is therefore an important criterion when evaluating new sonars. Thus, this OR study confirmed the importance of the Centre's target classification projects.

A second objective of the Centre's analyses concerned the ability of merchant ships to keep station within a convoy. This was studied during the merchant-ship convoy phase (MERCONVEX 8) of TEAMWORK (TR-47) and again four years later in SILVER TOWER, which consisted of three convoy operations. Even in poor weather it was found that ocean-going ships had no difficulty in maintaining station, apart from such obvious problems as some ships being unable to maintain sufficient speed. However, ships in a coastal convoy straggled considerably although they were able to maintain the proper distance between columns. A simulated transit through a swept mine field uncovered navigational problems.

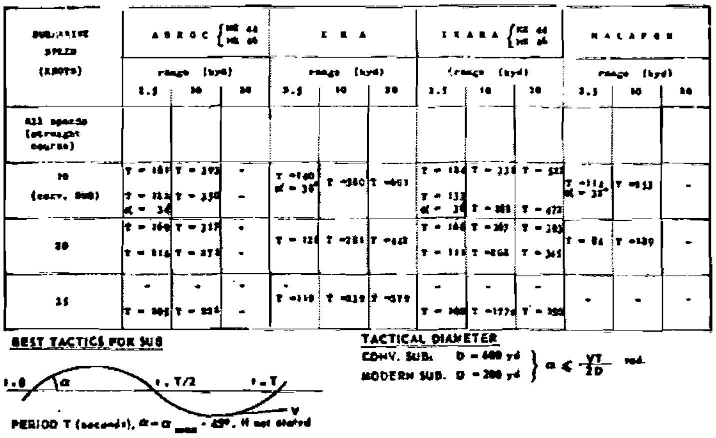
A major interest in most ASW exercises is that of missed submarine contacts. This is a difficult subject, since it requires accurate exercise reconstruction and an adequate model of sonar performance. A first attempt in connection with Exercise PILOT LIGHT showed detection performance as much as 20 dB below the ideal. Exercise STRAIGHT LACED in 1966 revealed that, due to inadequacy of the records kept, only a few incidents could be properly evaluated. The requirement to perform missed-opportunity analyses was one of the motives in the development of the sonar contact model described in Sect. 12.5.

In 1968, Exercise MILOC MED TEST was carried out in the Ionian Sea in conjunction with the MILOC MED oceanographic survey. The object was to measure detection and contact-holding capabilities of active hull-mounted and VDS sonars



Normalized ranges of false contacts as functions of bearing for 54 search sonars during Exercise PILOT LIGHT 1965. [TR-59]

Part of a study on the effectiveness of long-range, shipborne, ASW weapon systems. [TR-100]



in an area where detailed oceanographic measurements were being made at the same time. Although many problems were encountered during conduct of the exercise, analyses that could be performed (TR-164) generally tended to confirm the predictions of the model.

The Centre also investigated performance of submarines in the SSK antisubmarine role, analyzing data from seven SSK barrier exercises held from 1959 to 1965 (TR-157). It was found that, although long-range passive sonars were able to detect noisy transitors at long ranges while missing quiet ones, the performance of high-frequency, short-range passive sonars was not so sensitive to the noise characteristics of the transitors. (This result can be explained in terms of propagation curves, which show a greater change in range as a function of a given change in the figure-of-merit at larger distances.)

12.3 Tactical Studies

Tactical studies at the Centre during this period concentrated on two aspects of the ASW problem: optimum tactics for the submarine, and the design of random ASW patrols and of screens and barriers.

A study was undertaken to examine optimum tactics for minimizing expenditure of propulsion energy during closure of long-range contacts by non-nuclear submarines (TR-68). It was found that in each tactical situation there was a unique minimum-energy closure course that would maximize the energy reserve available for screen penetration, attack, and evasion. In addition, a theory was developed for the optimum avoidance tactic to be used by the submarine to escape after weapon launch (TM-118).

From the point of view of ASW forces, a method was developed for predicting the position of the submarine after it had launched its weapon and had taken avoidance action (TM-120). Another study developed a computer simulation for random surface-ship ASW surveillance barrier patrols (TR-88). These studies tended to be so theoretical that they were not readily translatable into operational doctrine.

12.4 Weapons Effectiveness Studies

In response to a request from The Royal Netherlands Navy, a study was undertaken in 1964 to determine the relative effectiveness of various long-range, shipborne, anti-submarine weapons systems. The various NATO nations were surveyed by means of a questionnaire concerning the characteristics of their systems. The results of the preliminary study of four weapons, ASROC, ERA, IKARA, and MALAFON, were presented in December 1965 and March 1966 to meetings of the NATO Mixed Working Group on a Long-Range Shipborne Antisubmarine (A/S) Weapon System (AC/181). With the addition of information on DASH and MATCH, this weapons study was completed in 1967, and a final report comparing the six systems was then issued (TR-100).

Early in 1966, the Centre was asked if it could undertake a parametric cost/effectiveness study involving sonar and fire control as well as weapons aspects of ASW weapons systems. In 1967 a proposal was made to the NATO Naval Armament Group's Information Exchange Group (IEG-2) for a six-part study covering environments, sonar performance, fire control and prediction, weapons, system performance, and costs.

The above-mentioned study for The Netherlands was considered to cover the weapons phase; the work done on sonar performance is discussed below in Sect. 12.5. Although a draft final report was written in 1969 covering all phases, it was not fully accepted by IEG-2 and only a more limited report was issued (TR-161) comparing NATO sonars by means of the computer sonar simulation model.

12.5 Sonar Performance Studies

Sonar performance model: A way of calculating relative performance under a variety of environmental and tactical situations is essential to comparison of sonars and weapons systems. In 1967, the OR Group embarked on the development of a detailed sonar-performance model. The simulation model was written in ALGOL for the Centre's Elliott-503 computer and consisted of a number of individual programs covering ray tracing, propagation loss calculation, echo and reverberation level calculation, and detection simulation. Such factors as ship motion, kinematics, and operational degradation were included. The acoustic aspects are described in TR-169, and the probabilistic detection simulation model is covered in a second report (TR-192). The model was used to compare NATO sonars for IEG-2 (TR-161) and to predict sonar performance in MILOC TEST 68 (TR-164). It was also used over the next five years in support of a number of internal studies and was adapted to the UNIVAC-1106 computer for one study in 1975.

RAP Study: The Centre's deep panoramic research sonar project was predicated on the idea that, because of its increased reliable coverage, RAP sonar would find a use in the NATO navies. In support of this concept, an OR study was performed concerning the use of a RAP sonar system in establishing a protected lane for transatlantic reinforcement shipping (TR-122). It was concluded that the ability of RAP to detect submarines reliably at long range made such a system superior to one employing hull-mounted and VDS surface-ship sonars.

Submarine IFF: An important aspect of ASW is the ability to distinguish between friendly and enemy submarines. In support of the NATO Ad-Hoc Mixed Working Group on Identification of Submerged Submarines, SACLANTCEN in 1964 initiated a study to quantify the need for an IFF system and to evaluate a number of possible solutions. The work was completed with the issuance to the NATO group of a collection of eight exploratory papers on various aspects of this problem (TM-108).

Acoustic intercept study: One of the major problems inherent in the use of active sonar is the information that the pings give to an enemy submarine. A submarine is often able to intercept active transmissions at a range greater than that at which the surface ship can detect the submarine. In 1967, the Centre initiated a study of the tactical value to a submarine of "ping stealing", emphasizing methods of obtaining range from such receptions. It was concluded (TR-159) that improved intercept equipments could yield valuable tactical information to a submarine provided countermeasures were not taken. Suggested countermeasures included using a zigzag course, reduced use of high-power pings, and use of long pulses of 1 to 3 seconds. It was also noted that noise radiated by the ship's propellers might be detectable at even longer ranges than the active pings.

12.6 Gibraltar Study

For its part in the Gibraltar Project, the OR group evaluated the performances of a number of possible systems for detecting submarines transiting the Strait, and the effectiveness of two weapons systems that could be used in support of a detection system. Emphasis was placed on the COLOSSUS I system proposed by the U.S. Navy Underwater Sound Laboratory.

Four comprehensive reports were produced, covering the following:

a. Influence of shipping and weather on the performance of a COLOSSUS I system (TR-91).

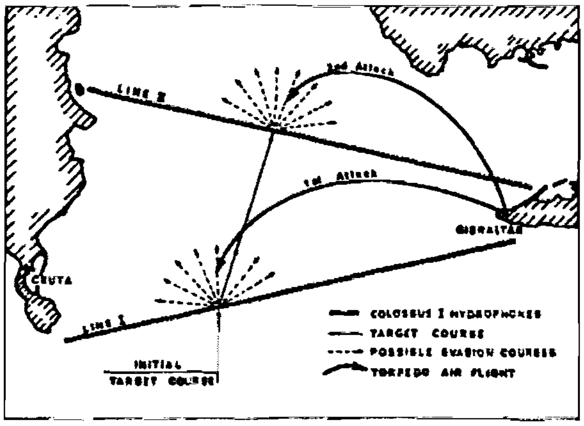
b. Attack systems in support of a COLOSSUS I barrier (TR-99,123).

c. Alternative systems to COLOSSUS I (TR-132).

The last report considered bottom-bounce sonar, bottom-mounted active sonar, passive sonar, and ELF electromagnetic detection; the conclusion was that a combined system consisting of either of the first two augmented by ELF would be feasible as an alternative to COLOSSUS. At the end of the study a short report (TR-135) was issued summarizing the other reports and also listing the acoustic, oceanographic, and ELF studies done in support of the project.

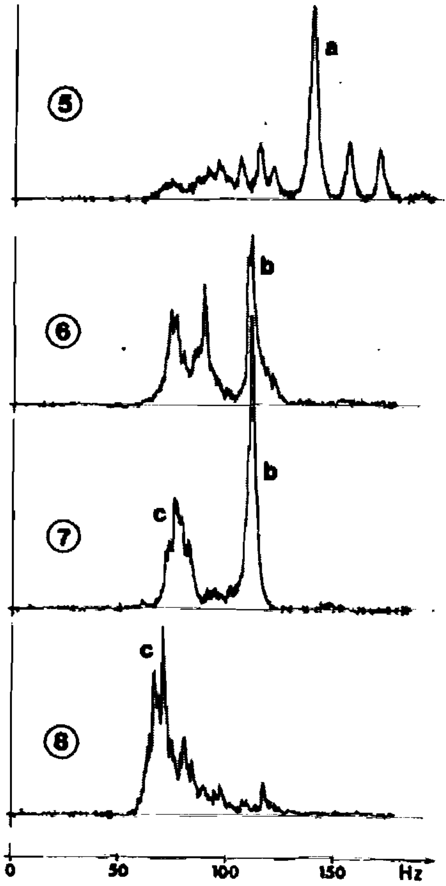
12.7 Preliminary Assessment of Novel Detection Concepts

One of the properties of noise-like, random signals is the number of zero crossings that occur per unit time. Analyses published in the open literature had noted that zero crossings would be a function of the statistics of the signal and that adding a tonal signal to random noise would change the rate. The Special Studies Group at the Centre undertook an investigation of this phenomenon, with the idea that measuring the zero crossing rate might be useful in a simple, low-cost, passive warning system. Both theoretical and experimental studies were made. Theoretical calculations showed that addition of a tonal signal to a band of random noise would lower the zero

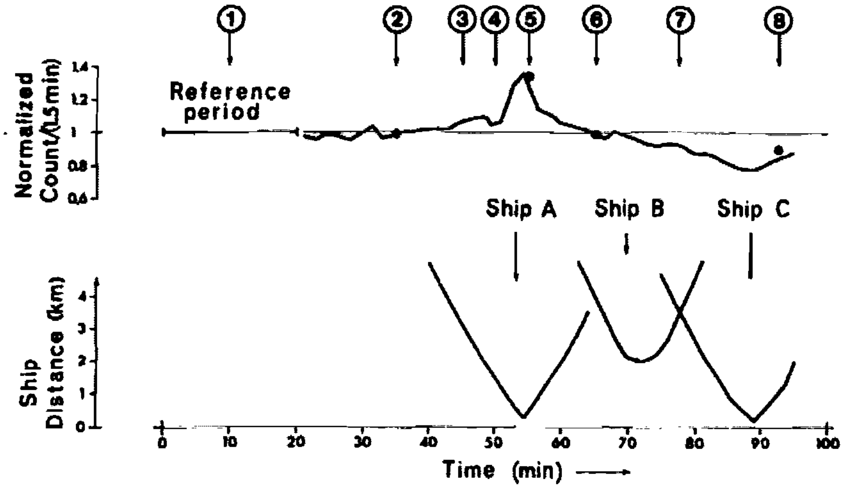


Evaluation of detection and attack systems for the Strait of Gibraltar. [TR-99] crossing rate if the frequency of the tonal were at the low end of the band, would raise it if the frequency were higher than the mean, and might not affect it at all if the frequency were too close to the mean band frequency.

In 1966 and 1967 random background noise and noise during the passage of surface ships and submarines were recorded near Tino Island in the Gulf of La Spezia. The phenomenon was verified, and detection ranges of several kilometres were realized for submarines as well as for surface ships (31) (TR-146). The project was terminated after having demonstrated validity of the concept and prior to demonstrating its value as a development. The idea was not followed up by the nations, probably because other passive systems had been developed that could better distinguish between surface ships and submarines.



Changes in zero-crossing rate as a possible passive sonar detection method. The plots at upper right show typical power spectra of 5-s samples of the ambient noise signal and of the signal during the passages of "ships" A(a), B(b), and C(c), as shown in the lower plots. In plot 5, a submarine (ship A) is approaching on diesel; in 6, it has stopped its engines but a tanker (ship B) is passing, in 7 and 8, the submarine (ship C) is on battery power. [TR-146]



Part. III

Period of Transition

1969 - 75

CHAPTER 13 PERIOD OF TRANSITION (1969-75)

13.1 Introduction

At the beginning of this third period the morale in the Centre was high, and so was scientific productivity. However, this condition gradually changed under the pressures of several adverse factors. Staff expansion ended in 1970, with the imposition of budget restraints. The Centre's one large laboratory building was very much overcrowded and the central computer was rapidly becoming obsolete. The departure of certain key personnel necessitated reorganization, and it was found to be most difficult to match an organizational structure both to programme needs and to existing personnel.

However, the Centre was able to obtain funding for a new building and for a replacement computer, both of which were acquired by the end of the period. The research vessel achieved good results through the development of real-time, on-board, digital data handling systems and the use of the deep research sonar. The Centre also became the focus for an extensive, NATO-wide interchange of information on ASW related topics, primarily through running and participating in numerous working-level conferences.

Transition from one Director (Ir M.W. van Batenburg 1967-72) to another (Dr J.G. Retallack 1972-75). Ceremony in the forecourt.

13.2 Administrative and Finance

During its first ten years, the authorized Civilian Administrative Personnel Establishment (CAPE) had been increased yearly to meet new demands of the research programme. In 1969 there were 224 employees: 210 NATO-graded staff and 14 local wage rate (LWR) employees. A further increase of six support personnel was authorized for 1970, bringing the complement to 68 NATO A grades (including 50 research scientists and 4 programmers), 128 NATO B grades, and 34 NATO C grades (after conversion of the LWR personnel). Except for the temporary addition of eight posts for the duration of the MILOCSURVLANT project, very few changes were made in the following years, and the total was maintained at 230. Even relatively minor position and grade changes were for the most part turned down by the NATO Military Budget Committee (MBC).

The Centre's budget grew during this period at an average rate of about 10% per year. Most of this increase covered salaries, which account for about two-thirds of the total budget and which increase annually due to cost-of-living increases and to progress to higher steps by individuals. The budget rose from about 1950 million lire (3.6 million dollars) in 1969 to 3950 million lire (6.3 million dollars) in 1975. In addition, the MBC during this period appropriated a total of 1400 million lire for non-recurrent special expenses including acquisition of a new building and a new computer.

A major improvement over previous budget procedures was the introduction in 1969 of a special chapter (Chapter XXX) to cover the Programme of Work. This chapter was created for the two NATO research centres to cover all expenses in connection with such items as data processing facilities, ships, other research facilities, and special research equipments. Not including extra funds for two large items, funds for the programme of work increased at an average rate of 6% per year, from 700 million lire in 1969 to 975 in 1975.

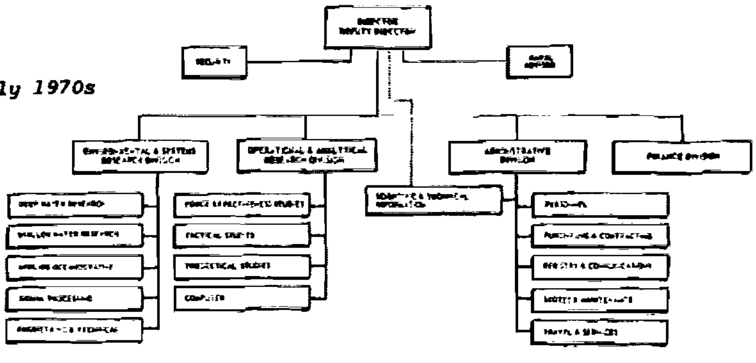
By 1973, rising costs throughout NATO led to a strong move to constrain NATO military budgets. It was proposed by the Military Committee that 1974 and 1975 expenditures be kept at roughly 1973 levels. With rising personnel costs, this would have meant significant cuts in the entire Centre programme. This threat to the programme was discussed at length by the SCNR at its 23rd, 24th, and 25th meetings (October 1973, May 1974, and October 1974). Statements were submitted to SACLANT stressing the severe impact of the proposed budget restrictions on the scientific programme. Individual SCNR members also contacted their national authorities. Eventually, the MBC instructed SACLANT to achieve the required cuts elsewhere in the ACLANT budget, restoring most of the required funding to the Centre's budget. However, the uncertainty as to whether the Centre would be funded at required levels in 1974 and 1975 had a negative effect on morale and productivity during the period of over a year during which the situation was unresolved.

13.3 Organization and Reorganization

At the beginning of this third period, the Centre was headed by Ir H.W. van Batenburg as Director, and Dr Earl Hays of the U.S. as Deputy Director. The scientists were organized into five groups, each having a Group Leader and a deputy. Specialized technical support for oceanographic instrumentation and transducers were within the Oceanographic and Sound Propagation groups. The Computer Section was part of the Special Studies Group. A Head of Technical Services supervised the work of the Design Section, the electronic, instrument and machine shops, as well as the Ship Operations Section, which had been transferred from the Naval Advisor to Technical Services in 1969. Scientific and Technical Information, previously under the Administration, reported to the Directorate from 1969.

In July 1971, Mr A.W. Pryce of the U.S. replaced Dr Hays as Deputy, and in July 1972 Dr J.G. Retallack of Canada succeeded Ir van Batenburg as Director. Later in 1972 a major reorganization was carried out under which the Centre's scientific and technical efforts were concentrated in two Divisions. One, the Environmental and Systems Research (E) Division, was made up of four scientific groups plus the Engineering and Technical Group, in which were oceanographic instrumentation, transducer development, ship operations, electronic and mechanical engineering, and the shops. The other new division was the Operational and Analytical Research (O) Division,

Dr J.G. Retallack
Canada
Director 1972-75



Internal organization in the early 1970s with three study groups and the Computer Group. Dr Roger Prager of the U.S. was appointed Chief of the E division, and Mr T.L. Mack of the U.K. Head of the O Division. The Scientific and Technical Information function was placed under the Administration for management, but with the Head reporting direct to the Director on policy matters.

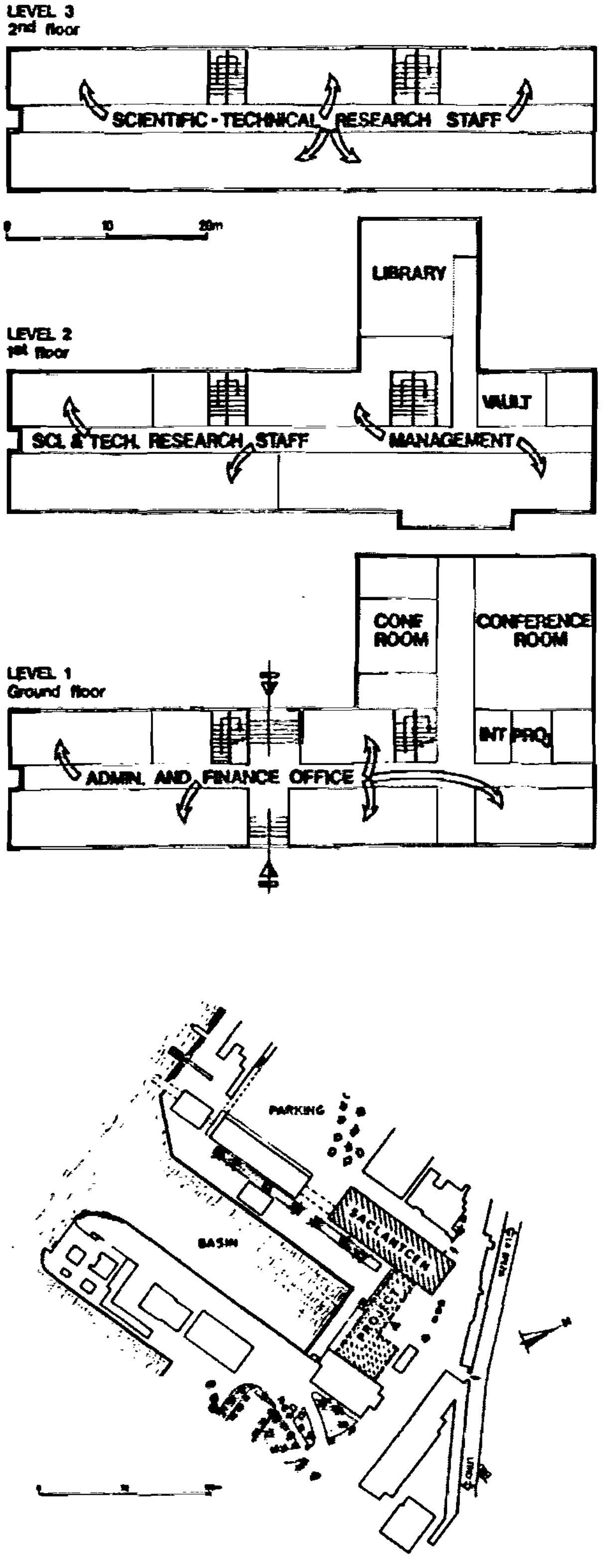
The concentration of all personnel involved in at-sea research programmes within one division proved to be unworkable, and in 1973 the Engineering and Technical Group under Mr K. Rasmussen of Denmark was removed from the E Division and assigned to the Deputy Director. In the same year Ing G.C. Vettori of Italy replaced Dr R. Prager as Division Chief of the E Division. The organization then remained essentially unchanged for two years.

There were a number of position changes associated with the various reorganizations, and a number of internal promotions were made near the end of 1974. Attempts to obtain MBC approval of individual changes having failed, an attempt was made to redefine the Civilian Administrative Personnel Establishment (CAPE) in such a way as to cover those changes already made and to ensure the flexibility required in the management of a research establishment. A new establishment list was generated; this was approved by SACLANT early in 1975, and submitted to the MBC in June 1975 as part of the 1976 budget submission. The MBC rejected the proposed CAPE because it used titles that did not conform to NATO standards. The situation in which the Centre's actual personnel differed from its published CAPE lasted for another 3½ years, only becoming regularized when in January 1979 the MBC approved a list that properly represented current staff and positions.

13.4 Space and Buildings

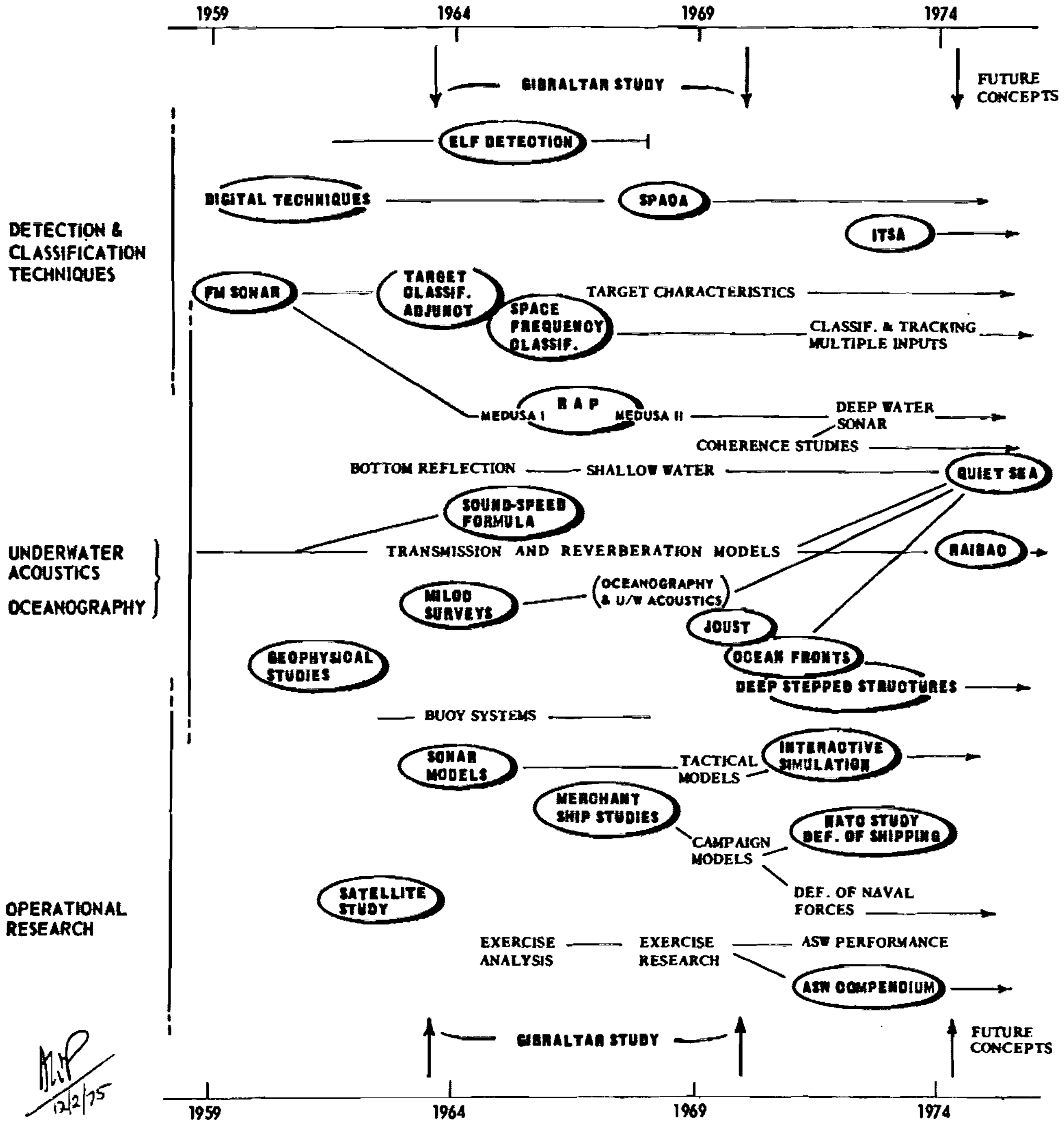
By 1969, even the building of mezzanines above the ground floor was not enough to alleviate the congestion. A detailed space utilization study by SACLANT in August 1970 confirmed that additional space was urgently needed. The Italian government was unable to provide an additional building, but did offer an area of 1750 m^2 immediately adjacent to the original building on which to construct an extension. In November 1970 the MBC authorized 3 million lire for a comprehensive independent engineering analysis and cost estimate.

The study by Ing. Zacutti of La Spezia was accepted by the MBC in November 1973, and 420 million lire appropriated for construction. A contract was awarded, existing small structures demolished, and the building constructed in 1975. It was occupied in January of 1976 and dedicated during the SCNR meeting in May of that year.



1973 plans for extension building; these were later reduced to stay within the budget allocation

PROGRAMME TRENDS & ACHIEVEMENTS



An analysis of SACLANTCEN's programme trends and achievements at the end of the first 15 years [SM-71]

13.5 Replacement of Computer

The Elliott-503 computer obtained by the Centre in 1964 was never fully satisfactory; neither its reliability nor its computing power were as great as required. In 1970, with the backing of the SCNR, the Centre instituted studies and contacts with major computer suppliers with the aim of requesting proposals for a replacement computer; however, the original request for bids was cancelled by decision of the MBC in 1971. The case was then presented to the NATO ADP Committee, which, in November 1971, approved the project. The budgeted amount of 422.5 million lire approved by the MBC for 1972 proved insufficient. After a second set of bids on a reduced configuration had been received, the decision was made in January 1973 to acquire a UNIVAC 1106 computer by a purchase/rental combination. The new computer was installed in December 1973 and, after operational tests, accepted on 20 January 1974. It has proved to be a serviceable unit, capable of increased performance through the addition of memory capacity and various peripherals.

The UNIVAC-1106 central computer as first installed.

The UNIVAC-1106 is used in both batch and time-share modes. For time-share operations, users interact with the computer from Tektronix terminals in other rooms of the building. From the beginning it was recognized that the capability to create graphics at these terminals would be required and software was developed at the Centre for this purpose in 1974-75 (CP-19g). This highly-versitile package, known as UNITEKX, is now being used daily by scientists at the Centre, as well as being available worldwide through the UNIVAC Users Association.

During the period in which the Elliott-503 computer was being replaced, the Centre also acquired three Hewlett-Packard 2116B mini-computers to be used on the research vessel and ashore for acquiring and processing acoustic and oceanographic data.

13.6 Research Vessels

With the exception of the year 1973, when utilization was lower than normal, the MPG was used at sea from 170 to 195 days per year. Although most cruises were short ones to nearby waters, several month-long trips were made: March 1971 to the North Sea; May and September 1972 and February 1973 to the Strait of Sicily; October 1972 and February 1974 to the eastern Mediterranean; and in the summer of 1974 two months to the Barents and Baltic Seas.

In addition to routine maintenance and modifications to enable handling of the MEDUSA system and several other large arrays, the ship's laboratory space was greatly expanded in 1971, and other improvements were made to make the ship suitable for long cruises to remote areas. The ship is available to the Centre under a charter agreement with its owners, and in 1974 the Centre arranged to retain its services until 1980, with a further option extending to 1984.

In many operations the MPG was assisted in its work by the Centre's workboat, the SACLANTCEN 3. This boat had limitations, and in 1974 a larger, more seaworthy auxiliary, the R/V MANNING was loaned to the Centre by the U.S. Government. The 100-ton, 20-metre long MANNING required extensive overhaul of its main engines and auxiliaries and the installation of navigation and safety equipment. It became operational in April 1975, and the old workboat was then restricted to local operations.

13.7 Conferences and Reports

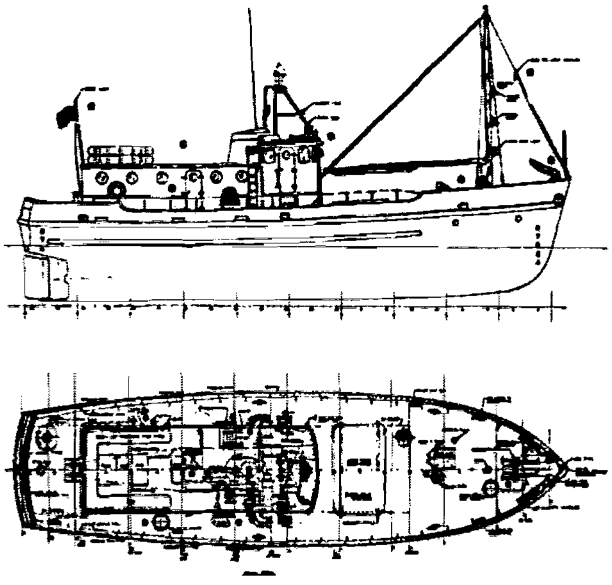
During its first ten years the Centre had concentrated on published reports as the primary means of communicating its work to the NATO nations. Beginning in 1969 the Centre supplemented its written reports with the organization of a series of international working-level seminars to discuss the latest developments in specific fields. These seminars offered two-way communication: the Centre learned of work going on in the nations and it presented its own work to non-Centre experts who would be most able to use it. These working-level conferences were held at an average of two per year, most often in the Spring. It would be hard to overstate the importance of these conferences. They have served the Centre's purposes, and also they have proved to be a major catalyst for co-operation between ASW scientists of the various NATO nations. Some persons have even suggested that the Centre's conference programme is one of its most valuable functions within the NATO community. The proceedings of the conferences have been published in the SACLANTCEN CP- series, which, since 1972, also includes publication (CP-9,-12,-15,-19,-21,-23) of the papers presented by SACLANTCEN staff to the autumn meetings of the Scientific Committee of National Representatives.

In addition to its own conferences, the Centre increased its participation in the NATO committees that deal with various aspects of ASW. Numerous reports were made to these groups.

In 1973 the original series of Technical Reports (TR-) and Technical Memoranda (TM-) were supplanted by new series of SACLANTCEN Reports (SR-) and SACLANTCEN Memoranda (SM-). A bibliography (SB-1) of the TR-, TM-, and Special Reports (M- series) for the 1959-73 period was published that year. This bibliography, being indexed by title-terms (keywords), by citations from other SACLANTCEN documents, and by author and group, provides a flexible means of accessing the literature of that period.

13.8 Anniversaries

In 1973, the Centre's ten years as a NATO International Organization was recognized with the issuance of a brief report summarizing its achievements (SM-13). The occasion of the Centre's 15th Anniversary in May 1974 passed without formal notice, but a summary of the Centre's achievements over the 15-year period was included in the Annual Progress Report for that year.



The U.S. T-boat, R/V MANNING, which replaced the earlier workboat in 1975.

CHAPTER 14 ENVIRONMENTAL ACOUSTICS (1969-75)

14.1 Introduction

During the first half of the 1970s, the Centre devoted a larger fraction of its efforts than before to environmental acoustics and its direct support. In response to pressures from SACLANT and the SCNR to emphasize sonar relevance, environmental projects in both oceanography and acoustics were related to the specific sonar applications of shallow water and of hull-mounted VDS and RAP in deep water. The Centre also attempted to coordinate its projects in the areas of environmental acoustics, active sonar research, and oceanography. The Ligurian Sea, the Levantine Basin, and the Strait of Sicily were areas of joint experiments and of independent study by each of the three groups, leading to a broad knowledge of the environmental factors governing sonar performance, which was then correlated with actual experience using an experimental sonar.

At the beginning of the period, environmental acoustics was for the most part organized into six projects in the Sound Propagation Group. Supporting oceanographic studies were done by the Oceanographic Group, and computer modelling by the Theoretical Studies Group. The RAP active-sonar project also carried on significant environmental acoustics research. Later, in 1972-73, the programme was reorganized, and environmental acoustics research was carried out in two groups, one for deep water and the other for shallow water. Modelling activities were incorporated into the corresponding projects, bottom studies transferred to the Shallow Water Group, and other related oceanographic work done in the Applied Oceanography Group.

Mr R. Laval of France, the Head of the Sound Propagation Group, became the first leader of the Deep Water Research Group. He was succeeded by Mr J. Gerrebout of France for a short period and then Dr W. Bachmann of Germany. Mr O. Hastrup of Denmark was the Group Leader for Shallow Water Research throughout the period.

14.2 Underwater Acoustics Computer Modelling

A major objective of environmental acoustics research is to find relationships between the measured values of propagation loss (TL), reverberation (RL), and ambient noise (NL), and such oceanographic environmental factors as bathymetry, sound-speed profile, bottom characteristics, and sea state. Acoustic modelling is the linking mechanism used to find these relationships. The oceanographic environmental factors are the inputs to the models and the outputs are curves of TL and RL as functions of range, and of all three quantities as functions of frequency. Experiments indicate the relative importance of the various physical factors and also check the accuracy of the models. The objective is to develop models that give accurate results without requiring unrealistically complete oceanographic inputs.

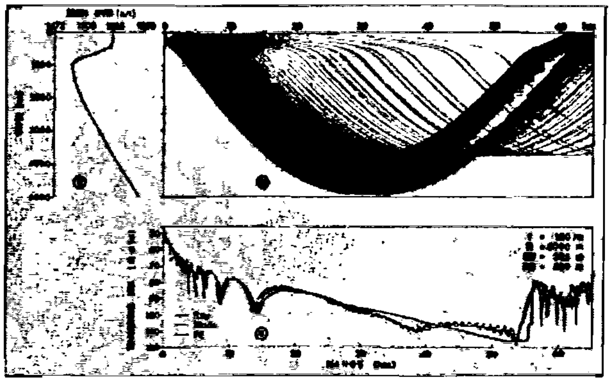
To date no single computer model usable for all possible applications is known to have been developed. If there were such a model, its running cost would be so great that it would have limited utility for that reason alone. Instead, various national activities have developed computer models each with its particular range of utility. The Centre has acquired a number of these, and has also developed models particularly suited to its own needs.

By the end of 1973, the Centre had two propagation-loss models operating on its Elliott-503 computer. One was a ray-trace model (32) (TM-102) written in ALGOL, based on Snell's law, which divides the water column into many layers of constant sound-speed gradient. A range-dependent bottom was incorporated by cutting off ray paths for refracted rays at the shallowest bottom and using the last bottom depth for reflection by bottom-bounce rays. Intensity calculations were made but were inaccurate near caustics. The second model on the Elliott was a normal-mode model (SM-40,-121) applicable only to shallow-water conditions.

With the replacement of the Elliott-503 by the UNIVAC-1106 in 1974, the Centre lost the use of its own ray-trace program but was able to acquire four U.S.-developed models:

CONGRATS	(M-76, CP-5h)
NISSM II	(33,34)
FAST NISSM	(34)
FACT	(35)

CONGRATS, developed at the US Naval Underwater Systems Center, constructs ray diagrams and generates eigenrays using continuous-gradient sound-speed profiles. Bottom profiles serve to limit ray paths; bottom and surface losses are added separately. NISSM II predicts the performance of active sonar systems in terms of probability of detection vs range; it also



Modelling of deep-water, low-frequency propagation. [CP-19j] includes outputs for ray tracing, propagation loss, and reverberation. Its propagation-loss calculations are based on ray theory modified at low frequencies for diffraction effects. FAST NISSM is a shortened version that runs faster. FACT is a U.S. Navy standard flat-bottom, range-independent model.

Propagation model development at the Centre took several paths. The need to incorporate the range dependence of the oceanographic environment was handled by the RDRT model (SM-7, CP-9p), written originally in ALGOL for the Elliott-503. Recognizing the variability of the medium and the tendency of the detection process to obscure details, the RAIBAC stochastic ray model (36,37) (SR-11) was developed; this averages both horizontally and vertically and calculates reverberation as well as propagation. For range-dependent shallow-water propagation, the parabolic equation (PE) method (SM-72) was implemented on the UNIVAC 1106 in 1975. This method is accurate but slow (CP-19j).

For propagation calculations at sea on the HP-2116B minicomputers, the Centre has use of the linear-segment model (SM-49, CP-5d) previously described. Since shadow-zone geometry is important for both surface-reverberation and detection-coverage calculations, the SHADZO program (TM-183), which calculates surface shadow zone dimensions as a function of source depth and sound-speed profile, was also implemented on the minicomputers.

In September 1971 the Centre ran a major conference on Geometrical Acoustics (Ray Tracing), which presented information on computer models and comparisons with experimental data (CP-5).

14.3 Experimental Techniques

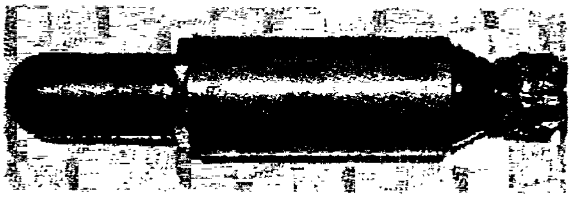
During the period 1969-1975 the Centre carried out extensive at-sea measurements of propagation and reverberation. The programme was particularly effective due to the use of two different experimental techniques, the results of which complemented each other.

Broadband measurements continued to be made using explosive charges as sound sources, analyzed by techniques described in Sect. 8.3. Improvements of these included: calibration of the charges as sources (TM-154); a method to remove the effect of the bubble pulse even in the case of no direct arrival (SM-3); and a special low-noise hydrophone preamplifier for handling pulse signals (TM-158). In order to use arrays to give signal-to-noise improvement independent of frequency, a wideband constant-beamwidth array was designed (TR-205).

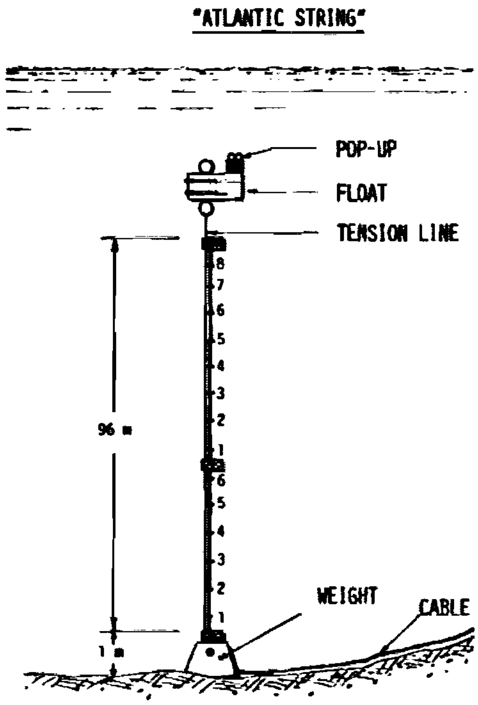
Around 1970, a second-generation digital analysis system, called SPADA, was developed. This uses the HP 2116B minicomputers both for control and analysis functions (M-79c,-80, CP-6j). A variety of signal-processing options was made available through the development of an interactive time-series analysis (ITSA) system (M-79b, CP-6m) that could be used with preprocessed inputs from SPADA. These two systems have formed the heart of the Centre's data acquisition and analysis systems for the past ten years, enabling high-grade work to be done in a most efficient manner.

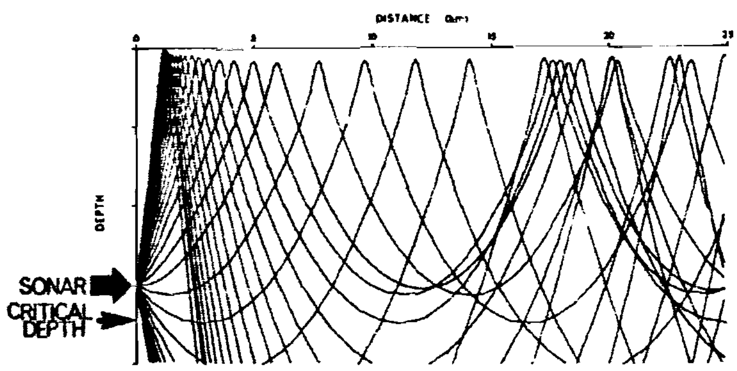
The broadband measurements were supplemented with narrow-band 3.5 kHz pulse signal propagation and reverberation measurements made with the MEDUSA 2000 research sonar used both as transmitter and receiver (TR-223). With the MEDUSA lowered to the desired depth, reverberation could be measured directly (CP-3e), unlike TL which required a transponder to be located at the target's position. When used as an environmental acoustics research tool, the MEDUSA array was calibrated using techniques described in TM-156 and SM-93.

As in prior years, the Transducer Section produced a number of special arrays of receiving transducers, as well as carrying out calibrations of the various hydrophones used for acoustic measurements. Especially noteworthy were two deep vertical arrays employing small (2.5 cm diameter) spherical ceramic hydrophones. These were tested to pressures corresponding to a depth of 4000 m and used successfully in the Atlantic to a depth of 4300 m.



One of the vertical hydrophone arrays produced for at-sea measurements of propagation and reverberation. [CP-21j]





Locating a sonar slightly above the critical (i.e. reliable acoustic path) depth may reduce surface reverberation at the cost of only a thin near-surface shadow zone. [TR-167]

14.4 Deep Water Propagation Research

During the period 1969-1975 most of the Centre's deep water research was carried on in the Mediterranean, primarily in the Ligurian, Tyrrhenian, Ionian, and Levantine Basins and in the deep water area of the Strait of Sicily.

An extensive series of propagation measurements was made in the Levantine Basin in the summer of 1969 (TR-212, CP-10d). Explosive sources were used at five depths between 25 and 2200 m. The signals were received at ranges out to 40 km on hydrophones at 20, 60, 100, and 600 m. A ray-intensity calculation was made for each experiment, using the Centre's Elliott-503 linear-segment ray-trace program. In general, the experimental and model results were in good agreement.

Measurements in the Levantine Basin were also made in October 1972 using the MEDUSA 2000 at five depths between 150 and 2000 m (SM-89). Although propagation models gave good agreement with the data, reverberation calculations were not always successful.

In February 1970, the Centre conducted a joint acoustic oceanographic experiment, known variously as ACOC-1 and JOUST, in the Ligurian Sea. Explosive sources were used at 25 and 180 m depths and the signals were received with hydrophones at 20 to 500 m out to 30 km. Analyses were made for a band centered at 4 kHz. Comparisons of TL curves with the outputs of seven models showed good agreement only with the results for the deepest receiver (TR-215). It was concluded that the models were too sensitive to the input data and that the real sea tended to be much less so.

Further experiments in the Ligurian Sea using explosive sources were carried out in four seasons from Oct 1971 to July 1972. Oceanographic data covering these periods (TM-165, TR-8) were used for the comparison ray tracings and TL calculations, which were made on the minicomputers. The results for ten receiver depths between 10 and 780 m were generally in good agreement with the model (SM-75).

Between April 1969 and November 1970 four sets of propagation and reverberation measurements were made with MEDUSA in the Ligurian Sea. The array was set at four depths between 150 and 1200 m, with the transponder on a submarine at 60 or 90 m depth. The propagation data (TR-222) were generally in good agreement with TL curves calculated with the CONGRATS model. Reverberation measurements made during these trials were also in agreement with model calculations, except in the vicinity of caustics and focal zones (TR-224).

The RAP concept achieves full insonification of the volume when the source is at the critical depth, at which the sound speed equals that at the surface. However, due to insonification of the surface, surface reverberation is high. It was suggested (TR-167) that locating the source slightly above the critical depth would greatly reduce this reverberation, the only cost being creation of a thin near-surface shadow zone. The SHADZO program (TM-183) modelled this concept. A detailed comparison of five models with experimental shadow-zone data showed (SM-69) that horizontal variability and diffraction both cause some penetration of the shadow zone. Reverberation measurements made with the source about 200 m above the critical depth confirmed the predicted reverberation improvement (TR-222,-224). This and other subjects related to the MEDUSA experiments are covered in two review papers (CP-10i,j) presented at the Conference on Deep Active Sonar held at the Centre in April 1973.

14.5 Strait of Sicily

The Strait of Sicily is one of the more important strategic areas in the Mediterranean. Submarines transitting the Mediterranean must pass through this choke point and it is an obvious area for consideration of an ASW barrier. Water depths in the narrowest part of the Strait are less than 400 m and are classified as shallow, but a basin having depths in excess of 1000 m extends between the islands of Lampedusa and Malta to an area directly south of the eastern end of Sicily. Following completion of the Gibraltar studies, the Centre focussed attention on this area and on the neighbouring waters east of Malta. In May 1970 the MPG participated here in MED MILOC 70. Various details were studied for several years thereafter with one to three cruises each year, some oceanographic and some acoustic but most combining the two disciplines.

As discussed further in Sect. 16.2, the Strait of Sicily is an area having complex oceanographic features. The warm, more saline, water formed in the Levantine Basin flows westward at the greater depths, and less saline water flows above this eastward into the Ionian Sea. The result is that in winter the sound channel axis is at the surface, while in summer there is a narrow sound channel centred at about 100 m depth (TM-168, CP-8a). This important effect is clearly visible in acoustic ray tracings (TM-176, CP-8a) made for the deep water area surveyed in May 1970 during MED MILOC 70.

14.6 Effects of Oceanic Variability

Many of the phenomena that occur in the propagation of sound in the ocean may be understood by treating the ocean as a stable medium characterized by a single, smooth, sound-speed profile. However, the ocean is of course not actually stable, and variations that may have significant effects on sound propagation occur both in the horizontal and vertical planes. Phenomena causing these variations include fronts, internal waves, layering (microstructure), and random inhomogeneities. Their acoustic effects may be limited merely to small fluctuations (scintillations) of the received signal or may, in some cases, cause large variations from what would be expected under textbook conditions. Although this is a subject of interest to both oceanographers and acousticians, a review of the literature made in 1972 (TM-184) found "a sad picture of lack of communication" between the two disciplines. The Centre undertook to improve this situation with a number of investigations combining oceanography and acoustics (CP-5a,ag). In September 1975, the Centre hosted a conference in which both large-scale and small-scale phenomena were summarized (CP-17: Pts 5 & 6).

Fronts have been the largest scale oceanic variability considered. During 1970 and 1971 a major front east of Malta was studied extensively. Acoustic measurements as well as range-dependent ray computations showed significant effects of the front on sound propagation (SM-53).

Another phenomenon causing sound-speed variations in both the horizontal and vertical planes is internal waves. The Centre's studies of sound propagation in the Strait of Gibraltar in the presence of internal waves led to a comprehensive report written in 1970 (TR-184). Broadband results obtained under stable thermal conditions were compared with those measured during the passage of an internal wave, the latter being found to contain large amplitude fluctuations of the received signals, even at the lower frequencies.

Layering, or microstructure, also has an effect on sound propagation. Ray-trace computer models assume smooth, continuous, vertical sound-speed profiles. However, detailed bathythermograph measurements have shown that in actuality the ocean is composed of layers of constant temperature connected by high-gradient transitions. This step structure has been found repeatedly in the upper thermocline and also in the deep almost isothermal regions. From ray-trace computations, the Centre found that large spatial fluctuations were to be expected from such "microstructure" (38) (TR-206, CP-15i). Microstructure also causes sound to propagate into what would otherwise be a shadow zone (SM-22).

Fluctuation phenomena are often treated statistically by considering the microstructure to be a random inhomogeneity. Centre scientists made a number of surveys of this approach and reported these in several theoretical treatises (TR-221, SR-8, SM-28).

Work at the Centre relating acoustic results to oceanographic variability ceased for about three years after 1972, and was resumed in 1975-76 with an experiment (AIM) in the Gulf of Lions as part of the COBLAMED international oceanographic programme. This found that complex multiple arrivals are produced by the microstructure (SM-126, CP-19f).

14.7 Surface Scatter and Reverberation

The roughness of the sea surface has two important effects on underwater sound. First, the reflection coefficient for those paths involving surface reflection is less than ideal and its value fluctuates. Second, and perhaps more important, some of the sound energy incident on the rough sea surface is scattered back

Experiment to measure surface reverberation data by means of the MEDUSA sonar. [CP-3e] to the transmitter, giving rise to a dominant component of reverberation. This reverberation effect was of particular interest in the Centre because of its importance to active sonar. The effect of forward scatter on signal coherence was also of interest.

In March 1971 the Centre conducted a conference on surface scatter and reverberation at which nine of the nineteen papers were the work of Centre scientists (CP-3). An introductory review of the literature was followed by papers on theoretical considerations and experimental measurements.

In work relevant to the reflection or forward-scatter aspect of surface roughness effects, the rough sea surface was treated in terms of a filter (39) (TR-181, SR-7, CP-3h,-12g). Other studies treated additional theoretical aspects of this problem (TM-152,-164), particularly the distortion experienced by a sound pulse when reflected from a rough surface. An experimental study of forward scattering using explosive sound sources was carried out between April 1970 and May 1972, covering wave heights of 0.07 to 0.54 m. Results were analyzed up to 24 kHz and showed a slight increase of reflection loss at the higher frequencies (SM-51, CP-3i,j).

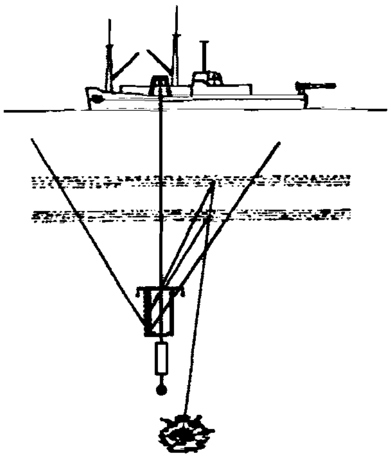
Backscattering due to sea surface roughness is characterized by an amplitude spectrum as a function of frequency relative to that of the signal. This frequency spreading, associated with the wave motion, is important because it limits the effectiveness of doppler reverberation discrimination schemes for slow targets. The Centre successfully carried out both theoretical (TM-170, SR-5, SM-86, CP-17h) and experimental (TM-174, SM-89) studies of surface backscattering. Also, the RAIBAC computer model (SR-11) included the capability of calculating reverberation as well as propagation loss.

14.8 Volume Reverberation from Deep Scattering Layer

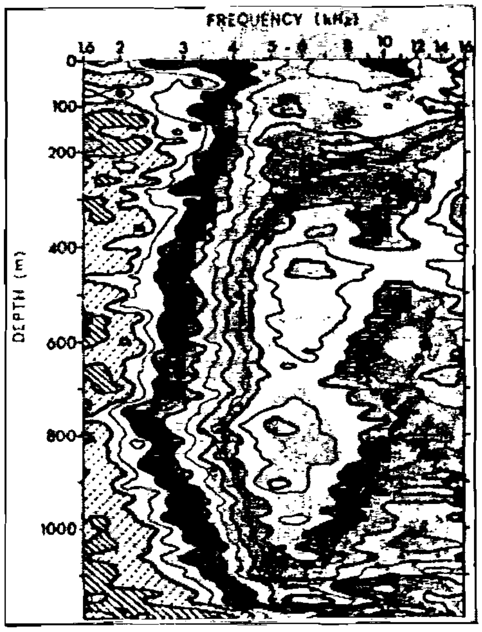
In many ocean areas, reverberation from scatterers within the volume of the ocean is dominated by that from biological organisms having minute air-filled swimbladders. These organisms tend to be concentrated at certain depths and to migrate up and down in response to the amount of light. These concentrations of reflectors, known as the deep scattering layers (DSL), are often observed by echo sounders. They occur frequently in areas of the Mediterranean used by the Centre for its sonar studies, and volume reverberation from these sources was observed frequently in the MEDUSA experiments (SM-89, CP-10j,-12ℓ).

A detailed study of this phenomenon comprised exhaustive bibliographical study and a biological investigation by the Oceanography Group, described in Sect. 16.10, complemented by an acoustic experimental programme using broadband explosive sources.

Most previous investigators had measured volume reverberation at the single frequency of their particular active sonar. By employing its broadband techniques, Centre scientists realized that they would be able to determine the peak frequency of this resonant bubble phenomenon as a function of depth and thereby gain a new understanding of the phenomenon (CP-4a,k). The Centre developed a novel experimental technique involving the use of explosive charges and a receiving hydrophone array located below the scattering layer (40) (TR-225, CP-4a). Measurements were made in a number of different areas in the Mediterranean over a period of several years. The experiments showed that generally the peak of the scattering function occurs at about 5 kHz at depths of 300 to 1000 m and that a second, higher, frequency peak often occurs for depths under 100 m (SR-17, SM-60, CP-9f,-10k).



Volume reverberation from the deep scattering layer measured by means of an end-fire array and explosive sound sources below the layer. The scattering strength (in dB/m) is plotted as a function of frequency and depth [CP-19b]



14.9 Bottom Reflection Studies

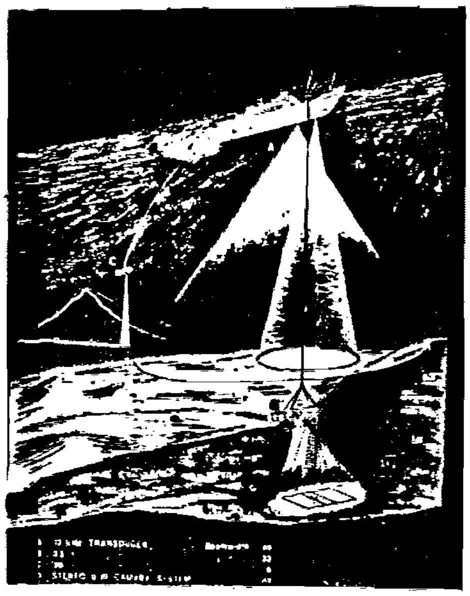
Investigation of the sea floor is another topic that benefited from joint activity by scientists in both the Oceanography and Sound Propagation Groups. During this period the Centre continued to perfect techniques developed prior to 1970 and to exploit those techniques in making new and highly sophisticated measurements.

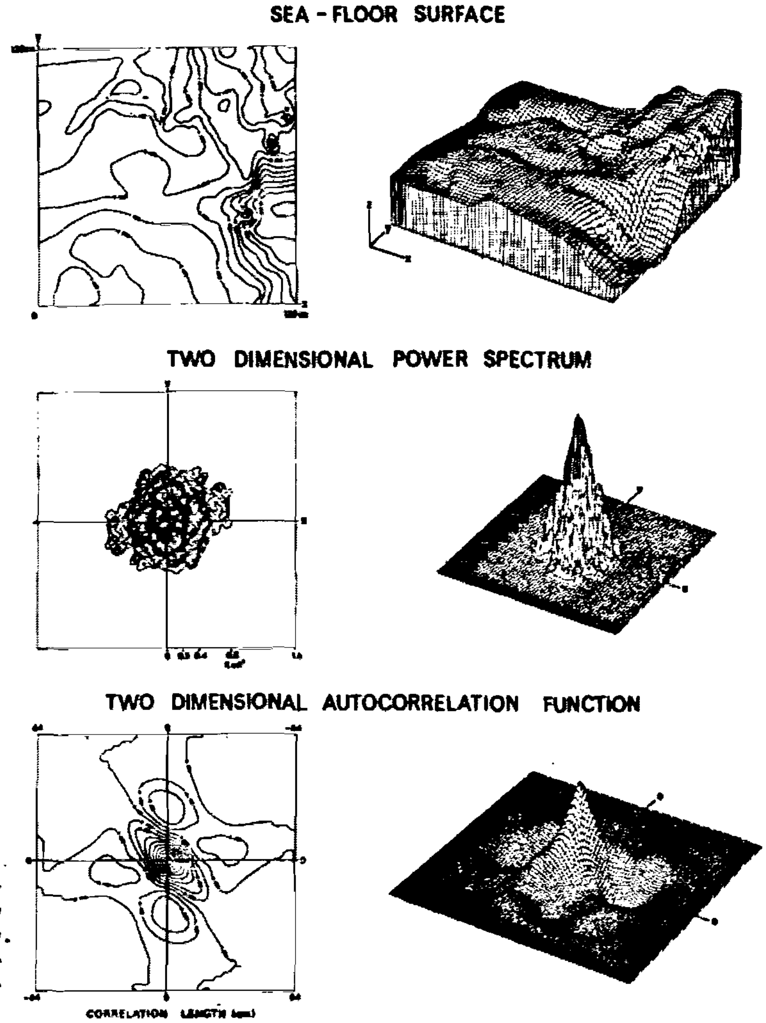
The oceanographic studies of the bottom included bathymetry, cores, and roughness characteristics (CP-14c) in two areas. In the shallow waters south of Elba the bathymetry and bottom structure were measured in great detail (41) (M-82), and similar measurements were performed in the Strait of Sicily (CP-7m,-8c). Bottom roughness characterization studies are reported in (CP-12j).

Most important was the successful correlation of the porosity of the sediments with such fundamental acoustic parameters as relative density and sound speed and also with the reflection coefficient (TR-177, CP-2f).

The Centre's acoustic measurements of bottom reflectivity used explosives, as previously described. During this period the technique was perfected (TR-174, CP-2a) and it was confirmed that the results obtained by using broadband pulses are compatible with those derived from narrowband active sonars (TR-216, CP-9e).

In September 1975 the Centre included a section on the subject of the sea bottom within a conference on oceanic acoustic modelling (CP-17); this served to bring up to date the material presented at the 1970 conference (CP-2a).





Bottom-reflection studies included the measurement of bottom roughness at all scales by means of echo-sounders and stereophotography. Computer methods were developed to analyse and model the statistical properties of the bottom.

14.10 Shallow-Water Propagation

In 1968, a shallow-water propagation project was initiated within the Sound Propagation Group. By 1972, the activity had become large enough for the formation of a separate group under Mr O. Hastrup from Denmark. With the gradual shift of emphasis of the Centre's programme to shallow water, this has become the dominant theme of the Centre's environmental acoustics research programme. Initially, only bottom reflectivity and transmission loss measurements were made; more recently, ambient noise data have also been collected. The overall programme has been characterized by a judicious mix of theoretical and experimental studies tied together through computer modelling.

Theoretical work has been primarily concerned with gaining an understanding of the dominant characteristics of shallow-water propagation and of the proper roles of the ray and mode approaches (TR-187, SM-66, CP-14a,h).

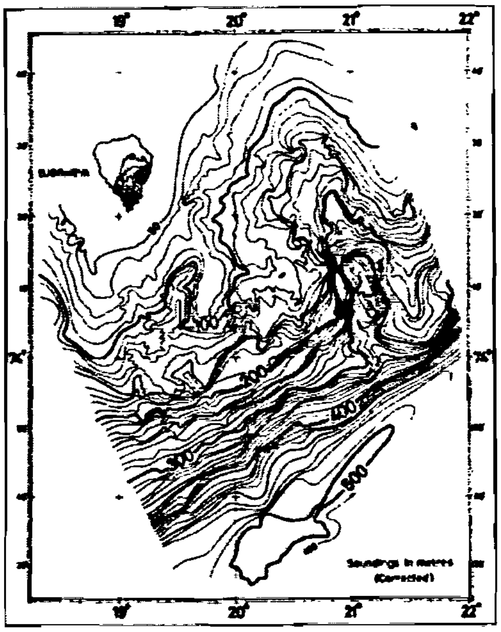
On the experimental side, extensive measurements were made in the test area south of Elba and the results fitted to exponential decay laws (42) (SM-39,-66, CP-12q). Measurements were also made in shallow water in the Strait of Sicily (SM-100).

Because the Elba area has water of near-constant depth, it was considered to be particularly suitable for a semi-permanent test site. The Centre obtained permission to use the lighthouse on the island of Formica Grande off Grosseto as a rudimentary laboratory, and operations using this facility began in 1976.

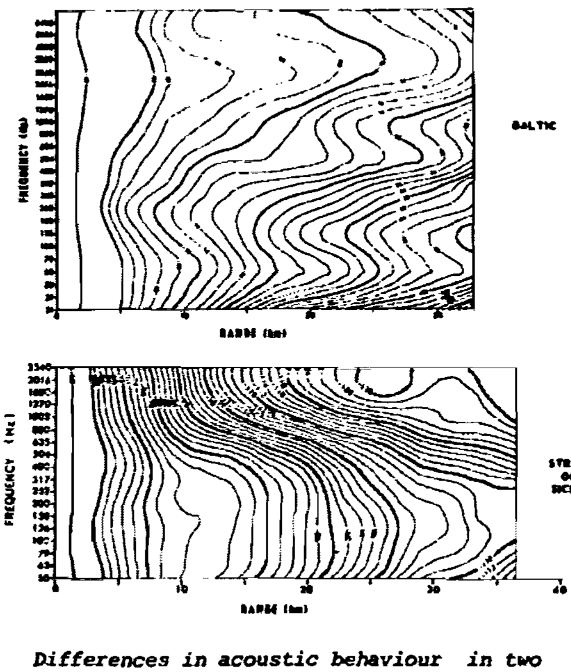
In 1972 planning began for a proposed MILOC oceanographic/acoustic experiment in the Barents Sea (ROUGH START). The Centre's participation included providing the Chief Scientist, oceanographers, and experimental acousticians, and also its vessel, the MPG, for the second-phase experiment carried out in 1975 (QUIET SEA). In the summer of 1974, prior to the full-scale MILOC, the Centre made its own transmission loss and oceanographic measurements (SR-13, SM-67, CP-15f). The specific area investigated included a transition from shallow to deep water, which was known to have a strong thermal front (SM-67, CP-19a). Transmission loss measurements made by the Centre during the 1975 full-scale MILOC are reported in SM-96. They showed distinct differences as a function of geographical position and it was later deduced that the differences for the low frequencies (below 200 Hz) could be correlated with bottom hardness. For hard bottoms there is good coupling to shear waves, resulting in higher losses; for soft bottoms the coupling to shear motions is much poorer.

A limitation to sonar performance in shallow waters is the horizontal spatial coherence of the propagation. This aspect was also studied both theoretically and experimentally (SM-68,-73, CP-14m).

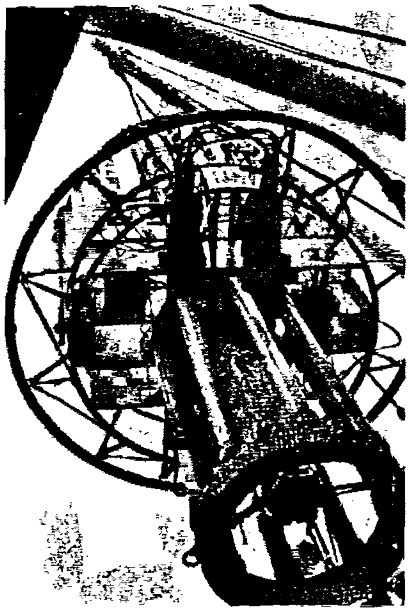
In September 1974 the Centre organized a major international conference on shallow-water propagation attended by thirty eight outside scientists from ten NATO countries (CP-13,-14). It was recommended that the Centre maintain an index of shallow-water experiments conducted in the NATO community, thus acting as a lead laboratory for NATO in the shallow-water aspect of ASW and environmental acoustics.



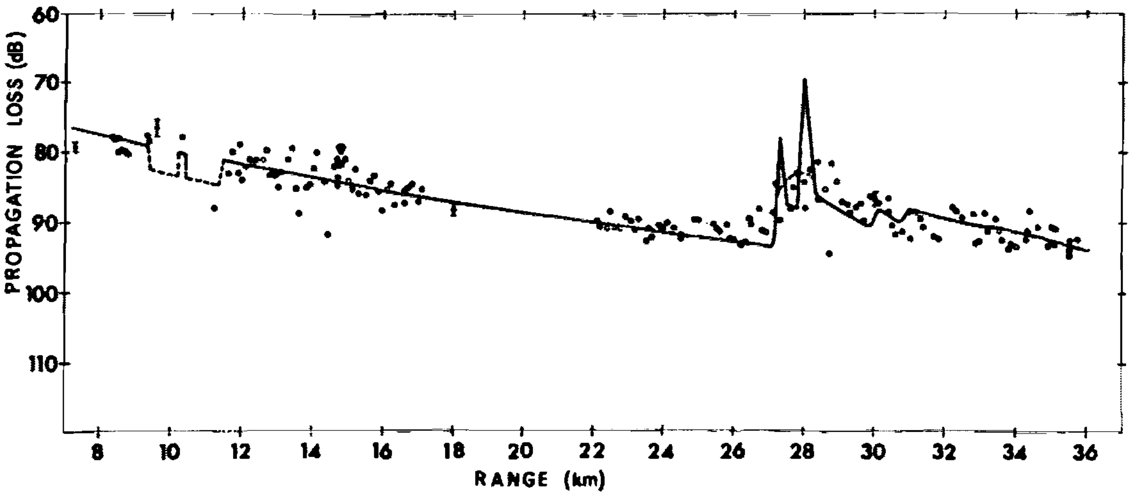
The Barents Sea area of shallow-water studies. [CP-19a]

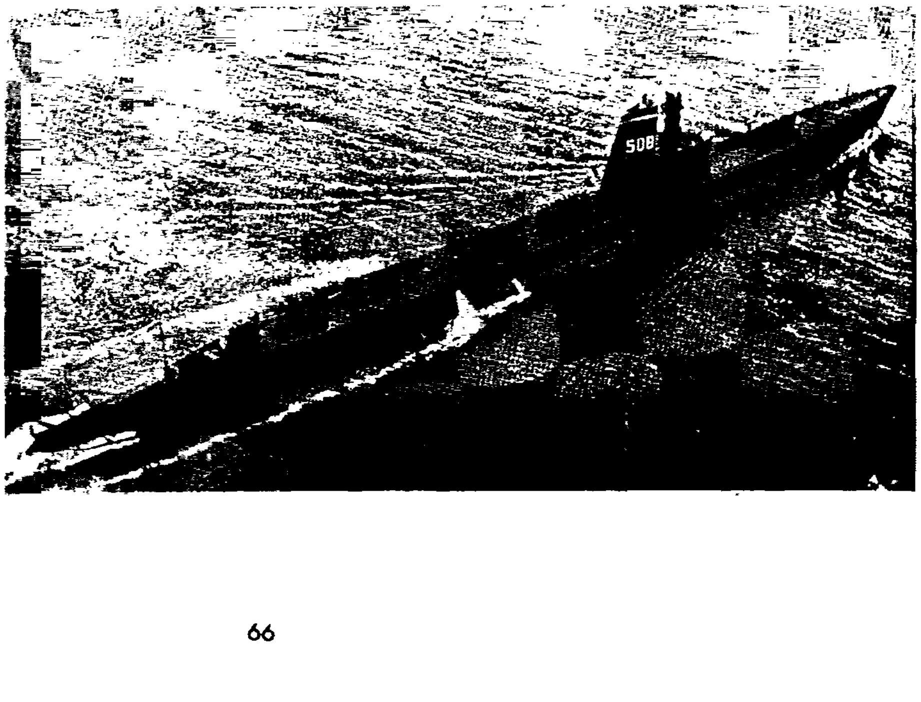


Differences in acoustic behaviour in two shallow-water areas: long-range propagation is associated with much lower frequencies in the Strait of Sicily than in the Baltic. [SR-33]



The MEDUSA 2000 deep panoramic research sonar. One of the many experiments was with the submarine MOROSINI (IT), during which incoherent propagation losses (points on the graph) were measured for comparison with a model's prediction (solid line)





CHAPTER 15 ACTIVE-SONAR RESEARCH (1969-75)

15.1 Introduction

During this third period, the space/frequency target classification project was completed with a demonstration of the technique using a single receiver and also with tests in shallow water. Target classification studies were then broadened to include other aspects of detection, classification, and tracking. The deep panoramic research sonar (MEDUSA 2000) was the focus for a major investigation of deep active sonar, which included the propagation and reverberation studies already described in Ch. 14, as well as detection and classification trials with submarine targets. Work on target echo properties using broadband techniques and employing explosive sources also continued during this period.

At the beginning of the period, in October 1969, the Centre held a conference on active sonar classification (M-55, CP-1), at which it was concluded that increased bandwidths would help substantially in classification effectiveness at some cost in detection range. Problems inherent in shallow-water oper tions were also described, and Centre scientists began to give serious thought to the design of active sonar for shallow-water operations (M-60, CP-14s).

In April 1973 a second conference was held, this time on deep active sonar, at which R. Laval presented an evaluation of the concepts involved (CP-10a). He emphasized the role of digital signal processors and stated the Centre's conviction that deep operation is essential to successful long-range active submarine detection. Members of this conference agreed that support should be given to establishing system parameters for an operational system and this conclusion was presented to the NATO Naval Armament Group's Information Exchange Group 2 at the latter's meeting in September. The IEG requested the NATO Defence Group Panel on the Defence Applications of Operational Research to undertake studies to examine the application of RAP in maritime operations.

15.2 Space/Frequency Classification

By 1969 the space-frequency classification concept had been thoroughly demonstrated, as described in Sect. 9.3. Between September 1969 and November 1970 three sea trials were conducted from which were obtained detailed information on characteristics of the system when the target is near beam aspect (TR-195), and statistics on the accuracy of aspect measurement (TR-198). In addition, a real-time correlator system developed at the Centre was successfully used (TR-200).

Although the original space/frequency concept used a two-hydrophone receiving system and a single ping, it was recognized that the same information might be obtained with a single receiver and analysis of two successive pings. The necessary parallax would be generated by the relative motion between ship and target occurring between the pings. This single-transducer technique could be used with sonar systems already existing aboard operational ships. This theory was tested using tapes previously recorded during the ANDREA DORIA trial (see Sect. 9.1) in which pings had been recorded from an AN/SQS-23B sonar (TR-57). The results confirmed the validity of this important concept (TR-194).

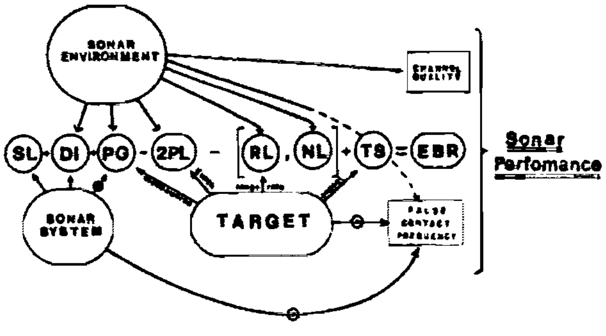
Finally, in March/April 1971, sea trials were performed in shallow water in the North Sea and the English Channel. It was found, as expected, that the performance of the space/frequency technique is degraded in shallow water (SM-30), since the multiple paths confuse the system.

With the writing of the five final reports cited above, work on this specialized aspect of target classification ceased.

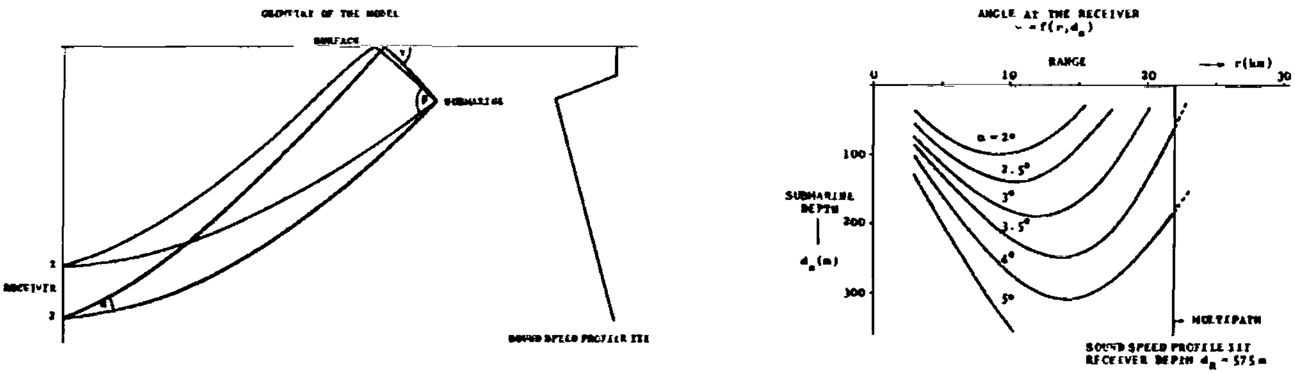
15.3 Submarine Detection and Classification Project

Following conclusion of the space/frequency classification project, the active-sonar detection and classification project turned to methods of extracting classification and tracking information with fewer pings. The emphasis was on the design of more effective transmitted signals (CP-12h). The advantages of multi-ping association were recognized (CP-10s), and the work concentrated on the use of double-pulse methods. A trial was conducted in April 1972 with the submarine CUTLASS (US). This included false target as well as submarine echo results and showed that double-pulse methods yield important classification clues not available from single pings (SR-14, CP-10s), thereby reducing the number of pings required.

The Centre's philosophic approach to active-sonar classification had been established from experience with the MEDUSA 300 research sonar. Classification trials carried out in 1968 and



The sonar equation, showing how the target can deliberately deteriorate sonar performance by changing depth, aspect, or speed. [CP-12]'



Calculating a submarine's depth from a multipath echo field; the angle α between the direct and surface-reflected rays is shown to be related to the submarine's range and depth.[SM-74]

1969 had clearly shown the advantage of multiping processing, that is, of simultaneously presenting the ping-to-ping histories of both the fine-time resolution echo structure and the envelopes of the FM echoes (SM-31,-32).

In an attempt to expedite classification research, the Centre developed a computer simulation of active sonar pulses in which synthetic signals were generated by combining:

- The transfer function of the medium obtained during one-way propagation experiments.
- The submarine's impulse response obtained during experiments to investigate the fine echo structure of submarines.
- The noise and/or reverberation recorded during acoustic trials.
- The characteristics of the sonar system to be investigated (central frequency, bandwidth, waveform of the transmitted signal, signal-processing directivity, etc.).

This research led to a concept for extracting depth information from multipath echo fields. While multiple paths generally degrade sonar performance, the time delay between the signals received is a measure of the extra path length and this can be translated into target depth (SM-74, CP-12k). (This idea has been published by others, using the term CEPSTRUM to describe time resolution analysis).

One other aspect considered during this period was that of signal design for energy detection of a target when fluctuations are being experienced (CP-18k).

15.4 Deep Active Sonar Project

As described in Sect. 9.4, in the second half of the 1960s the Centre initiated a major effort aimed at demonstrating the validity and usefulness of deep active sonars operating either at or near the critical depth. For the Mediterranean in summer, this depth is of the order of 1500 to 2000 m. As a prelude to its work at these depths, a 300 m system, called MEDUSA 300, was acquired and used for reverberation and propagation measurements as well as for detection experiments. For the latter, a digital multi-beam processor (TR-182) was built, producing the results described in SM-31 and 32.

The 2000 m equipment ordered in 1968 was assembled in the U.S. and delivered to the Centre in 1970. The new system was tested and calibrated in the summer of 1970 and used successfully in two trials later that year. The MEDUSA 2000 is described in TR-223. In addition to the MEDUSA 2000, the complete experimental system included analogue receiving channels for linear measurements, a digital panoramic receiver for sonar studies, data acquisition equipments, and a transponder system to be installed on support ships or submarines (CP-10h). The extensive transmission loss and reverberation measurements made with MEDUSA have been described in Ch. 14.

Testing the MEDUSA 2000

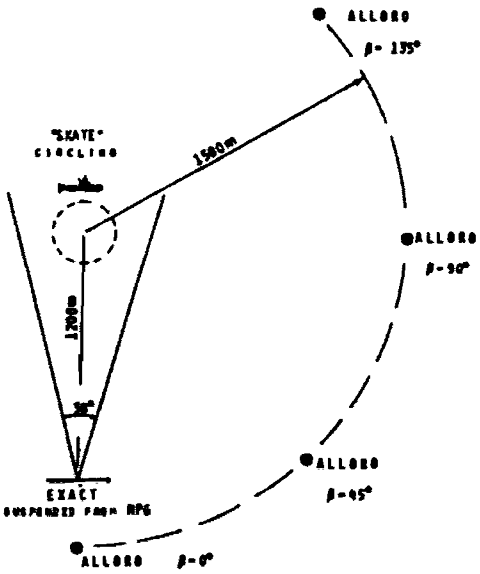
Detection and classification trials were performed in winter conditions in March 1972 with the submarine MOROSINI (IT) (Ex US BALAO class) as target. The experiments used FM pulses of 440 Hz bandwidth and 1.16 s duration centred at 3.5 kHz, and MEDUSA depths of 150, 500, and 1000 m. The longest reliable detection ranges were realized for the greatest depth, with achievement of reliable detections out to 45 km (SM-34, CP-10r). Tests under summer conditions were carried out in July 1973 with the submarine EVANGELISTA TORRICELLI (IT) as target. The advantage of operating slightly above the RAP depth to reduce surface reverberation, as suggested in TR-167, was confirmed (SM-90).

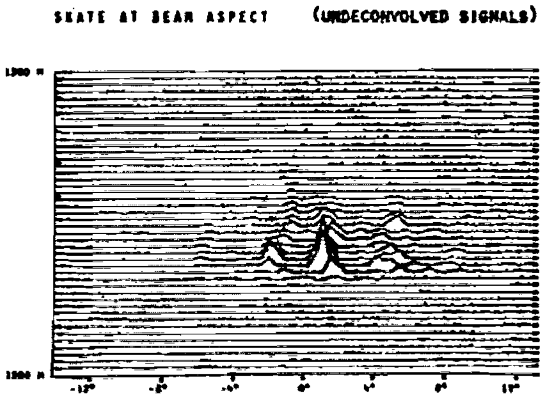
Except for some reverberation measurements, experimental work on RAP sonar was completed in 1973. Attention was then devoted to operational aspects. Predictions were made of maximum ranges under various conditions (SM-84), and thought given to possible bistatic applications (TR-219, CP-10f). By 1975, the advantages of RAP operation had been demonstrated and the next step required was that of engineering design (CP-16s).

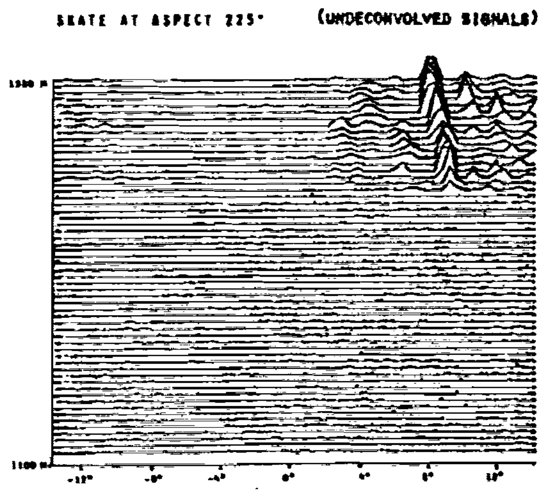
15.5 Submarine Echo Properties

Experimental measurements of submarine echo target strength as a function of frequency, using explosive charges as sound sources, continued during the period under discussion, 1969-1975. Trials with the submarines TRIAIAN (GR) and DAPHNE (FR) in 1969 demonstrated that target strength for off-beam aspects increases with frequency up to about 5 kHz, while that for beam aspect is constant above 2 kHz (TR-193).

Modern sonar signal processors respond not only to the energy in a returned ping but also to its detailed structure. The Centre's investigations therefore included correlation studies of broadband echoes using two closely-spaced hydrophones (TR-209) and vertical coherence measurements using a vertical hydrophone string (SM-36). Several reports summarized research that related the statistical properties of submarine echoes to their detectability by active sonar signal processors (SM-54,-63, CP-12i-18ℓ).

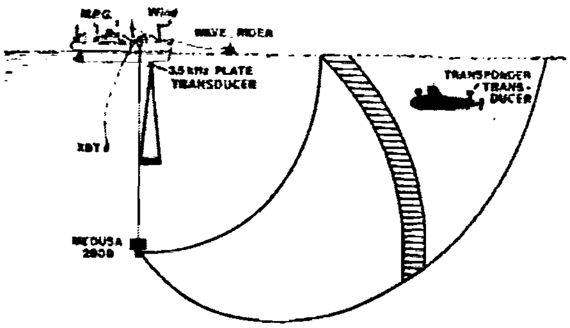


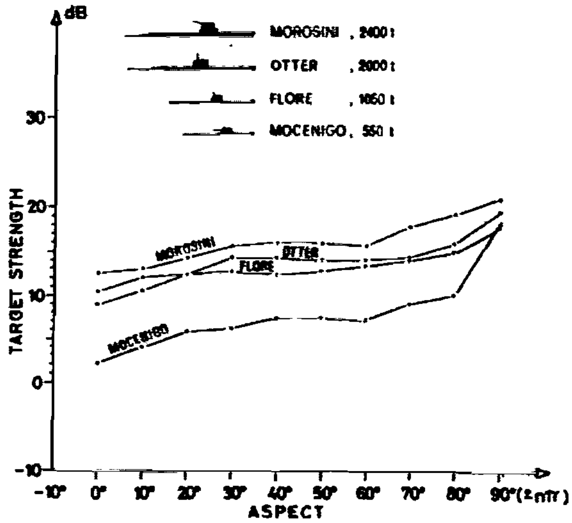




Considerations of RAP applications led to later work on bistatic sonar. This example shows range/bearing displays of explosive pulses reflected from a submarine and recorded on a suspended array.

In 1975 the Centre organized a conference devoted exclusively to papers on submarine echo properties (CP-18). The Centre presented the results of both its broadband studies (CP-18ℓ) and of 3.5 kHz measurements obtained over the years using MEDUSA (CP-18c), the latter showing a correlation of target strength with submarine size. It was suggested that this correlation should be useful for estimating target strengths of Soviet submarines. Conclusions from the meeting, summarized in the 1975 Annual Progress Report, p. 16 included recognition of the need for more information on bistatic target strengths; the Centre's most recent work in this area has concentrated on this topic.





Measurements of target strength. Results, below, relate target strength to the tonnage of the submarine. [CP-18c]

CHAPTER 16 OCEANOGRAPHIC RESEARCH (1969-75)

16.1 Introduction

During most of the period covered in the present section, the activity of the Centre's Applied Oceanography Group was primarily related to environmental acoustics research and/or was in direct support of MILOC surveys: oceanic data were collected for the joint experiment with the Sound Propagation Group (JOUST); measurements of fronts, internal waves and step structure and studies of the sea floor were all related to their acoustic effects; a biological study of the organisms in the deep scattering layer (DSL) was coordinated with acoustic measurements; the Strait of Sicily, the Barents Sea and the North Sea were studied for MILOC; and an area south of Elba was surveyed for the Shallow Water Group.

The Centre's studies of the deep step structure in the Tyrrhenian Sea and of internal waves and thermal microstructure were important contributions to fundamental oceanographic knowledge. The development of a towed oscillating body (TOB) enabled rapid profiling of the oceanic parameters and thereby provided a tool that was later to lead to the development of a technique for separating internal wave variability from thermal microstructure.

Underwater acoustic phenomena are closely related to oceanographic properties and can be fully understood only in terms of a thorough understanding of the oceans. The significant advances at the Centre in environmental acoustics, as described in Ch. 14, were possible because the acoustic phenomena observed by the Sound Propagation Group were correlated with detailed measurements of oceanographic parameters obtained by the Oceanography Group.

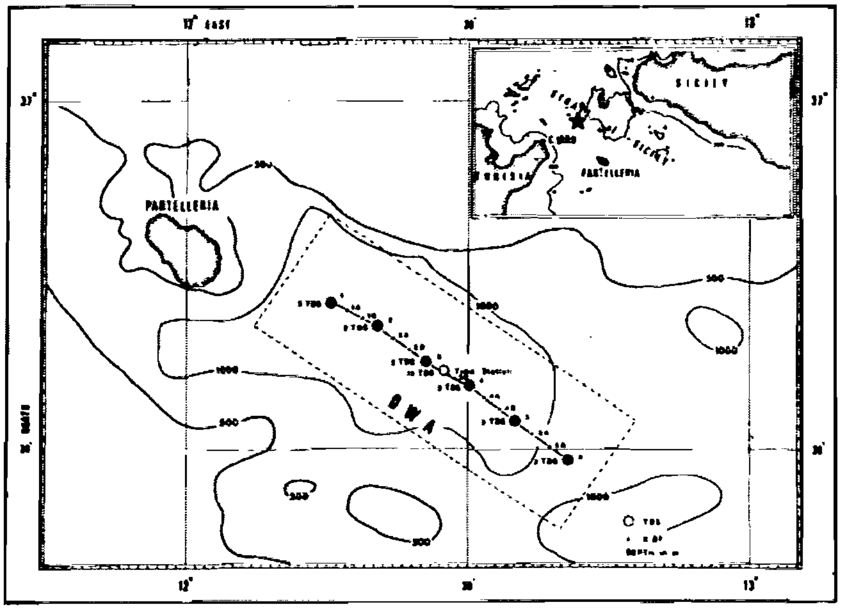
As a result of the Oceanography Group's relationship to the acoustics programme during this period, less emphasis was given to the interfaces and more to properties of the water column, that is, air/sea interaction phenomena and sea floor properties were de-emphasized in favour of temperature, salinity, and sound speed measurements made as functions of time and horizontal position as well as of depth.

16.2 Strait of Sicily

Two MILOC-sponsored surveys were conducted in the Strait of Sicily in the early 1970s. The first of these, MEDMILOC 70, in May 1970, included acoustic as well as oceanographic measurements in the deep water area southeast of the island of Pantelleria. The acoustic studies are described in Sect. 14.5, and the Centre's TDS profiling results are given in TM-168 and CP-7d. In the narrowest passage, between Cap Bon and Punta Stagnone, five moored buoys were used for current measurements in order to establish the flows of the various water types through the Strait (CP-7f).

A second MILOC survey, in May and September 1972, concentrated on variability of the water masses and currents and extended the area covered by the current measurements (SM-65).

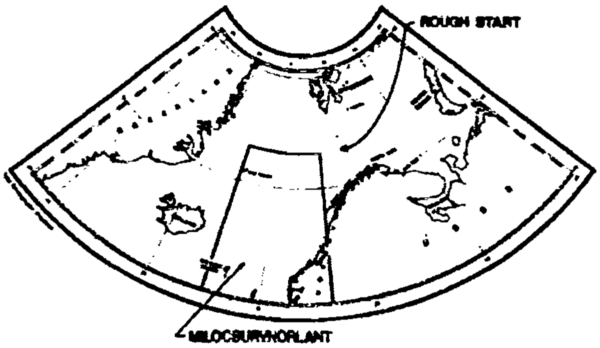
From its own studies, as well as from those of the other MILOC participants, Centre scientists came to have a good understanding of the oceanographic characteristics of this strategically important region. As described in CP-7a and CP-12o, high-salinity water from the eastern half of the Mediterranean flows westward below a counter current of eastward flowing, lower-salinity water. The resultant salinity profile has a marked effect on sound propagation,



MEDMILOC 70 survey of the deep water area of the Strait of Sicily. [CP-7f] creating a strong surface channel in winter and early spring (CP-8a). An estimate of the effects of turbulence on the counter flows through the Strait was attempted by spectral analyses of salinity profile data (SM-59), but it was concluded that higher resolution data were required.

As a part of its further study of this area, the Centre took numerous underwater photographs, bottom samples, deep cores, and echo-sounder profiles (CP-7m,-8c).

High-salinity waters that pass westward through the Strait of Sicily and eventually influence the flow through Gibraltar, originate in the Levantine Basin of the eastern Mediterranean. In February and March 1974 the Centre carried out a study of the Levantine Basin in co-operation with the University of Pisa. It was found that the centre of formation of the high-salinity Levantine water is south of Turkey between Rhodes and Cyprus, near the Bay of Antalya (SM-92).



MILOCSURVNORLANT and ROUGH START/QUIET SEA surveys of the Norwegian and Barent Seas.

16.3 <u>Norwegian Sea (MILOCSURVNORLANT)</u>

MILOCSURVNORLANT was a joint acoustic, oceanographic, and meteorological survey, organized by CINCEASTLANT, carried out in three phases in April, July-August, and October 1970 by ships from France, Germany, The Netherlands, Norway, the United Kingdom, and the United States. Although the MPG was not used, SACLANT arranged funding for a special team of two scientists and six technicians to be set up at SACLANTCEN to collect, collate, and analyze the data. This special project was undertaken in 1971 (CP-12n) and completed in 1974 with the publication of the SACLANTCEN Memoranda cited below.

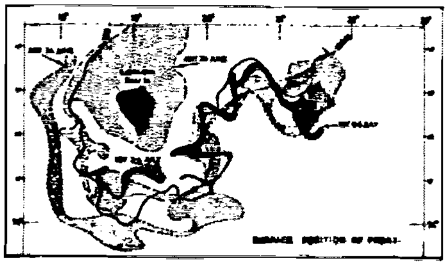
Prior to receipt of the experimental results, the Centre conducted a survey of the literature relating to this area (SM-4,-47). Data were analyzed for oceanography (SM-41,-42), bathymetry (SM-43), and scattering from the DSL (SM-46). In addition, meteorological observations were used to compute heat flow across the air/sea interface (SM-37,-44).

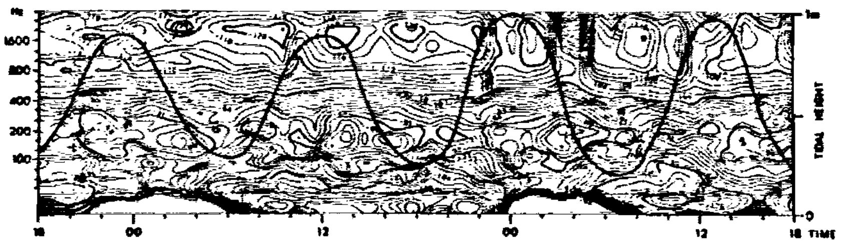
Because it was organized and funded separately from other Centre activities, this potentially interesting project was isolated from the rest of the Centre's programme and was therefore not fully appreciated.

16.4 <u>Barents Sea (QUIET SEA)</u>

As a follow-up to MILOCSURVNORLANT, MOD UK in June 1971 suggested a multi-national, multi-phase MILOC survey of the Barents Sea. The overall project was called ROUGH START and CINCEASTLANT was again the coordinator. The particular area studied for the second, QUIET SEA, phase was located south of Bear Island and characterized by a transition from shallow to deep water marked by a persistent polar thermal front.

The Centre participated fully in the QUIET SEA phase, for which it provided the Chief Scien-





Barents Sea front and its effect on sound propagation through it. Transmission losses are plotted as functions of frequency and time of day; the tidal curve is superimposed. [SR-20] tist and the MPG. The actual experiment took place in May and July 1975. As preparation for this task, the MPG went to the area in July 1974 for a month of pre-QUIET SEA experiments (SM-67, CP-15f). Also useful in planning the trials was a survey of previous observations covering a period of 60 years (SM-52). The environmental data collected during the actual QUIET SEA operation are presented in SM-99; the acoustic results have already been described in Sect. 14.10.

16.5 Military Oceanography Support Project

In addition to its MILOC activities, the Centre has maintained a small project to provide oceanographic information to operational commands and to other Centre projects. This is accomplished primarily from historical data. For the RAP project, Mediterranean BT data were related to predictions of RAP operating depths as a function of season and location (SM-84, CP-10b). The data taken in the Strait of Sicily were used in a study of short-term fluctuations of the RAP critical depth in that area (CP-10c). The ROUGH START project made use of a survey of historical data concerning the polar front south of Bear Island (SM-52).

In the early 1970s, an aborted project studied the surface mixed layer and upper thermocline by obtaining BT and XBT data from naval ships transitting the North Atlantic. No report was issued.

In 1974, installation of the UNIVAC 1106 computer made it possible to establish computerized oceanographic data bases of Mediterranean BT and XBT data and of DSL data from the eastern N.Atlantic and the Mediterranean.

16.6 Ionian Sea Front East of Malta

As discussed in Sect. 14.6, thermal fronts cause the largest oceanic variability and can have a marked effect on underwater sound propagation. Oceanic fronts, found in all oceanic bodies, are boundaries between different water masses and are characterized by rapid spatial variations of temperature and salinity, both horizontally and vertically (CP-8b,-17ab). Their study has increased markedly in the past decade.

Beginning in about 1970, the Centre undertook a study of a major thermal front located in the Ionian Sea east of Malta. The first study, in December 1970, was conducted during a joint cruise with the Oceanographic Group of the U.S. Naval Undersea Center, San Diego (43) (SM-112, CP-5a,-8b). The Centre returned to the area in May 1971 (TM-169, SM-88, CP-7j) to find that the front had migrated westwards into shallow water.

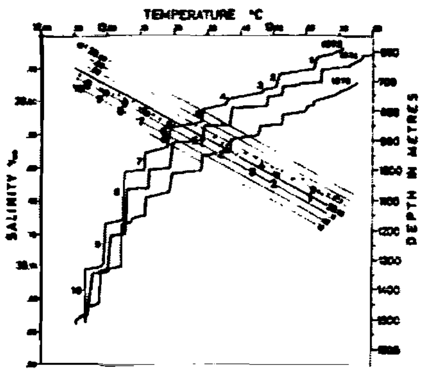
The effects of this front on sound propagation were calculated from the December 1970 oceanographic observations (TR-213, CP-8b). The results indicated that propagation is good from warm toward cold water and may be very poor in the opposite direction, and this was confirmed by acoustic experiments in the area in December 1971 (SM-53). The experiments also showed that range-independent computer programs do not reveal all of the observed features and that therefore a range-dependent ray trace method is required.

The final report on this project showed a need for further work, but the scientists involved left the Centre and the project was terminated. It was hoped that the QUIET SEA experiment would be able to make a contribution; however, the Barents Sea front was unsuitable for a study of this phenomenon.

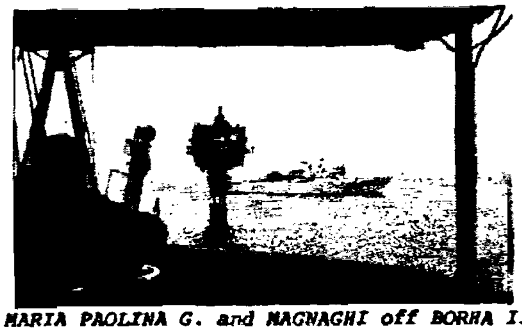
16.7 Step Structure in the Tyrrhenian Sea

During the transit to the area east of Malta in December 1971, deep TDS profiles were taken in the Tyrrhenian Sea. This was an attempt to trace the passage of one branch of the Levantine intermediate water that had flowed westward through the Strait of Sicily. The continuous TDS profile revealed a clearly defined thermohaline step structure between the depths of 600 and 1500 m (44,45) (CP-7j). Three later cruises to study this phenomenon in more detail were made with the MPG in May/June 1972, May 1973, and October 1974. A comparison of the results from year to year revealed remarkable stability of the stratification, which indicated a lifetime in excess of three years and implied steady-state conditions with respect to the transport of heat and salt. Ten steps were found, in which the product of the thickness and the temperature jump between steps was a constant. In addition, the steps were thicker as the depth increased, being of the order of magnitude of 10% of the depth (45) (CP-15i).

As discussed in Sect. 14.6, the major acoustic effect of the deep structure is to cause spatial variations of the sound intensity in excess of those normally expected (TR-206, CP-15i). There is reason to believe that similar step structures exist elsewhere and that some observed fluctuations of long-range sound transmission may be explained by this phenomenon.



Step-like structures of temperature and salinity profiles in the Tyrrhenian Sea in three successive years. [CP-15i]

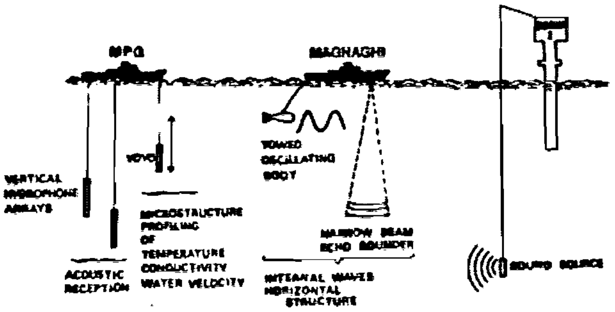


MARIA PAOLINA G. and MAGNAGHI off BORHA II

16.8 Upper Layer Variability

A smooth, range-independent, sound-speed profile is often assumed for acoustic calculations; nevertheless, it has been known for 30 years that spatial variations exist in the thermocline region in the upper layer of the ocean (TM-184, CP-5a). These variations are caused by the two phenomena of internal waves and of layering, the latter often called "microstructure" (CP-17af). Layering in the upper ocean occurs in much thinner steps than in the stable layers of the deep step structure. The upper ocean layering also moves up and down under the influence of internal waves, and keeps its unique characteristics over distances of the order of only a kilometre.

The Centre measured these upper layer variabilities both at the beginning and the end of the period covered in this chapter, in a programme called COBLAMED. The experiments involved cooperative measurements with the French Bouee Laboratoire in the Gulf of Lions, under the auspices of the NATO Sub-Committee on Oceanographic Research. The objective was to study internal waves and microstructure associated with the Mistral winds. Measurements of currents made during COBLAMED 69 in September 1969 were published in (46). By the time of the second study the Centre had developed its towed oscillating body (TOB) (see Sect. 16.12), and simultaneous acoustic measurements were made both in a preliminary experiment in October 1975 and in conjunction with the full-scale COBLAMED 76 in September 1976. The Centre's complementary programme was entitled the "AIM" study: Acoustic propagation in the presence of Internal waves and Microstructure (SM-126, CP-19f).



AIM: a study of sound propagation in the presence of internal waves and microstructure in the Gulf of Lions near the French laboratory buoy BORHA II.

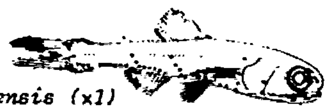
16.9 Air/Sea Interface

The near-surface isothermal mixed layer and the thermocline below it are well known as controlling factors in the performance of hull-mounted sonars. A major objective of military oceanography is therefore the prediction of the depth and temperature of the mixed layer for areas in which naval ships are planning operations. Since a major influence on the surface layer is the transfer of heat energy through the air/sea interface, study of this phenomenon was part of the Centre's oceanographic programme for many years (see Sect. 11.5).

Meteorological measurements were made together with oceanographic measurements during MILOC-SURVNORLANT in the Norwegian Sea in 1970. The results of a study of these data are given in SM-18,-37, and -44. Also, a more detailed statistical study of the correlations between observed changes of sixteen air/sea interaction variables showed that properties of the mixed layer could be predetermined for periods of several hours using data collected over a three-day period.

Surface waves are important not only for their effect on the air/sea interface heat transfer rate but also because of their influence on surface reflectivity and reverberation. A Tucker shipborne wave recorder was used to measure sea surface roughness during the February 1970 JOUST experiments in the Ligurian Sea (TM-172); also a FORTRAN programme was written to calculate the rms displacement of the sea surface from knowledge of the average zero crossing period of the random surface (TM-163).

16.10 Deep Scattering Layer Biology



Ceratoscopelus Maderensis (x1) a sound scattering fish.

The Centre's studies of the biological and oceanographic aspects of the deep scattering layer (DSL) are described in Sect. 11.6. From mid-1969, further work was done on this phenomenon in conjunction with the acoustic measurements described in Sect. 14.8. An initial biological sampling of the DSL in the Ligurian Sea west of Sardinia (TR-148) was followed in September and October 1969 by a more thorough experiment in which a multi-sampling net system (TM-161) was used to capture the small bathypelagic fish that form the layer (TR-189).

Data relevant to the DSL in the Norwegian Sea were collected during MILOCSURVNORLANT; these and other data from the same area are described in SM-52. Finally, in 1975, a previous review of the literature (TM-153) was supplemented by a survey of acoustic aspects (CP-17e), prepared for the Centre's September 1975 Conference on Oceanic Acoustic Modelling.

16.11 Sea Floor Studies

During this period, the Centre's sea floor studies became integrated with its shallow-water acoustics programme. Bottom studies were carried out for the shallow-water areas of the Strait of Sicily (CP-7m,-8c) and south of Elba (TM-162), using the 50 kHz sediment profiler as well as photographs and core analyses. Studies began in 1971 to characterize the roughness of the sea floor by use of Fourier transforms of digitized echograms (CP-12j).

(The Centre's studies of the Mediterranean sea floor, which had been completed in the mid 1960s, were published in (47) and SM-2.

16.12 Oceanographic Instrumentation

The significant progress made by the Centre during the 1970s in its environmental acoustics and oceanographic measurement programmes was facilitated by the successful development of a family of oceanographic sensor systems to be used either deployed from the Centre's research vessels or as long-term, semi-fixed systems. These systems all produce digitized outputs, and in most cases their operation is computer controlled.

By the late 1960s, as mentioned in Sects. 11.3 and 11.8, the Centre had developed a self-recording thermistor and current-meter buoy system. The latter was originally used for the Gibraltar studies (TM-144) and improved for the COBLAMED 69 experiments (46,48,49). The buoy system included a surface float and instrument package, the thermistor string, current meters, mooring cable, and parallel acoustic/time releasers. In addition to use in COBLAMED 69, this buoy was also used for observations of the Maltese front (TM-169). A later version was used in ROUGH START, COBLAMED 76, and other recent studies requiring long-term statistics.

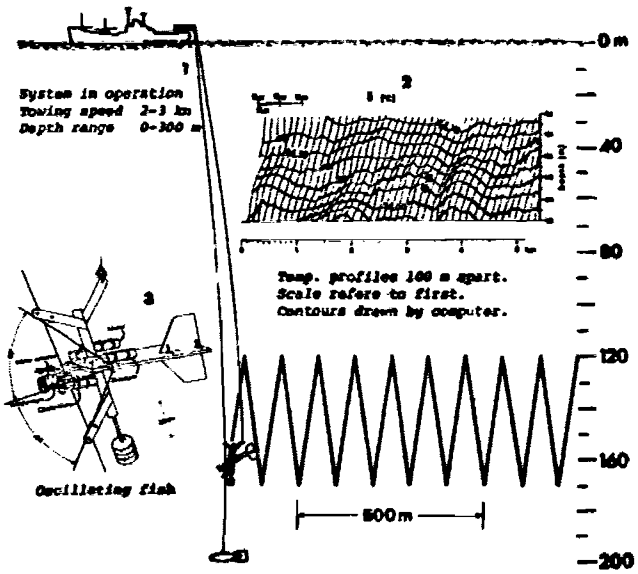
To obtain data about the deep water column from ships, oceanographers had for decades used the Nansen cast system, complemented by BT and XBT measurements in the upper layers. A rapid response temperature/depth/salinity (TDS) profiler (50), developed by Bisset and Berman, made it possible to measure these quantities continuously to a very high precision down to a depth of 6000 m. An early model was adapted to the Centre's HP-2116B real-time computers to become the first fully-digitized shipboard TDS profiling system (SM-9). This system was used to probe the depths of the Tyrrhenian Sea in 1971, revealing the semi-permanent deep step structure. It was also used in MILOCMED 70 in the Strait of Sicily, in the Levantine Basin in 1974, and for other studies of the deep step structure in 1972, 1973, and 1974.

The Centre's computerized real-time environmental data acquisition and processing systems, using Hewlett-Packard 2116B computers, have been documented in a series of SACLANTCEN Memoranda (SM-6,-9,-19,-70,-78). The TDS probe (SM-9), meteorological data (SM-78), XBT temperature profiles (SM-70), and Waverider buoy data (SM-19) are all fully computerized, probably to a greater degree and more successfully than by any other oceanographic research organization.

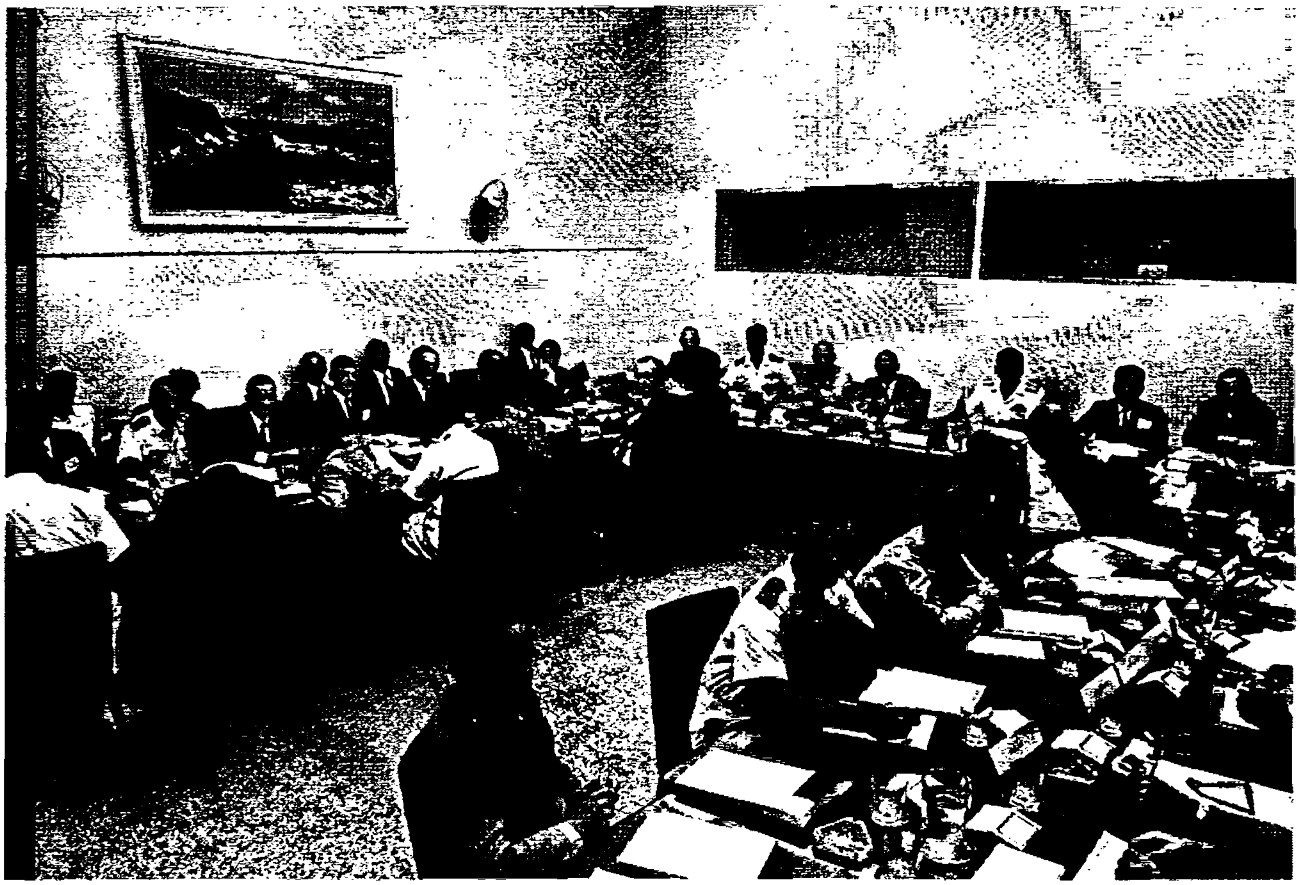
The Centre is also proud of its integrated oceanographic instrumentation calibration system for salinity, temperature, depth, and sound speed sensors. This system provides calibration accuracy greater than that generally required to discern the most detailed characteristics of the ocean environment.

In 1974, the Centre began development of a new controlled-depth, instrumented, towed oscillating body (TOB) to be used to obtain repeated continuous profiles in the upper ocean, as required to study internal waves and microstructure in the thermocline (CP-19h). The first version was used in October 1975 onboard the hydrographic ship AMMIRAGLIO MAGNAGHI (IT) during the AIM pre-COBLAMED cruise. It was used again in AIM in September 1976 (SM-126) and was then improved for a June 1977 investigation of internal waves off the coast of Spain west of Gibraltar (SM-122). As a result of this instrumentation development, the Centre has now been able to separate the effects of internal waves and microstructure in the thermocline.

A yo-yo system to be used from a ship moored on station was also developed for AIM (CP-19h). It has been less useful to the Centre's present programme than the TOB, but, in contrast to the TOB's 200 m depth, it can be used to a depth of 3000 m.



The 'Towed Oscillating Body' designed to measure frequent successive temperature and salinity profiles between given depths A computer-contoured plot of the measurements is shown.



A meeting at SACLANTCEN in September 1970 on the 'Formulation of ASW Requirements'.

CHAPTER 17 ASW STUDIES (1969-75)

17.1 Introduction

During this period, there was a major change of direction in the Centre's OR studies. Following a meeting in September 1970 on the "Formulation of ASW Requirements", chaired by the Deputy Chief of Staff, SACLANT and attended by representatives of all NATO commands with maritime interests, the Centre's major OR effort was directed towards Command-sponsored studies, a policy that continued until 1975. Two major projects and a number of minor projects were undertaken for NATO Commands. In addition, exercise analysis and the development of tools required for a wide range of ASW problems continued. Also studied were broad issues such as energy requirements, stockpiling of resources, and Soviet naval trends.

In September 1969 the Centre ran a three-day meeting attended by representatives of SACLANT, COMCANLANT, CINCEASTLANT, and COMFAIRMED at which ten papers on Centre studies were presented and ideas exchanged on a number of operational problems (M-53). The Centre also continued to participate in operational conferences called by the various NATO commands. In May 1973 it organized a meeting on OR at the tactical level (CP-11).

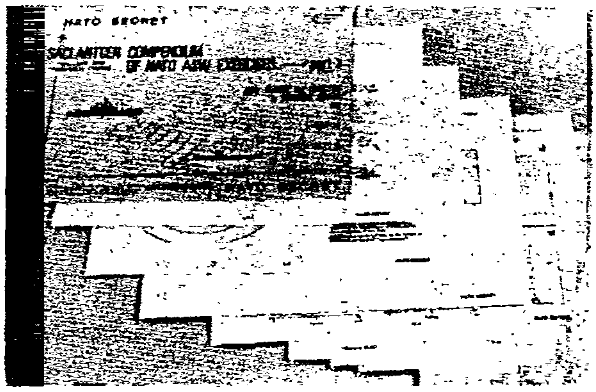
17.2 ASW Exercise Analysis

SACLANTCEN continued its participation in the planning and analysis phases of a number of NATO ASW exercises:

1970	PEACE KEEPER NORTHERN WEDDING GOOD HEART STRONG TIE
1971	RUSTY RAZOR ROUGH RIDE ROYAL NIGHT RUNNING SCRAP
1972	STRONG EXPRESS (SM-14) NIGHT SEARCH PINK LACE
1974	NORTHERN MERGER DAWN PATROL

The nature of the participation in each exercise varied in response to the type of exercise and its relevance to the Centre's interest, as well as to availability of manpower.

By 1972 it was clear that much valuable information from exercise analysis was not being used effectively in the planning of later exercises. The Centre undertook to produce a compendium (SR-1) that would compile ASW information from NATO exercises. Although it was never completed, four parts were issued using data obtained from about forty exercises held during the period 1961-1971. The subjects covered were:



The SACLANTCEN Compendium of NATO ASW Exercises. [SR-1]

ASW search and detection by shipborne sonars.

Classification and attack by shipborne systems.

Detection of hostile forces by submarines.

Classification and attack by submarines.

The compendium was welcomed in some quarters, but certain officers found it at variance with their own experience and others believed that too many diverse data were combined in some of the analyses. Together with reduction of manpower for the Group, these reactions led to termination of the project in 1978. However, its value has been confirmed by the continuing requests from the Commands for the Centre's participation in ASW exercise planning and analysis.

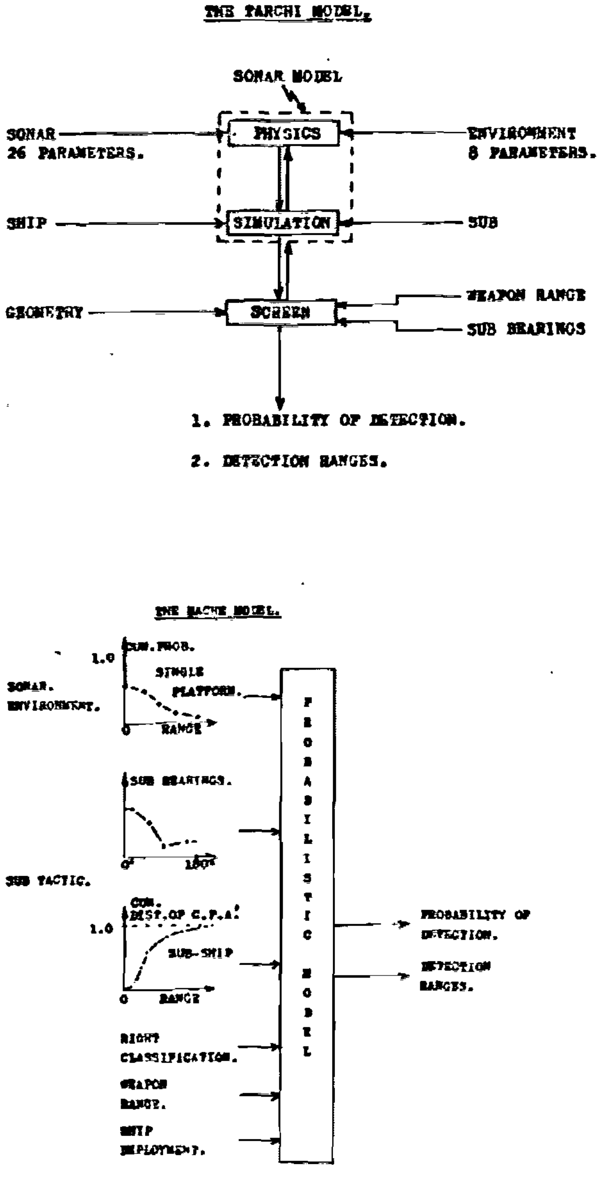
17.3 Tactical Studies

The increased depth capabilities of modern submarines was the impetus for a theoretical study concerning the best operating depth for a submarine for given BT conditions, and for an examination of the options for improving the coverage of surface-ship sonars irrespective of submarine operating depth (TR-211). It was concluded that greater depth capabilities gave the submarine no advantage when attempting to detect a surface vessel but would offer an advantage during the closure phase. (This study made extensive use of the sonar model described in Sect. 12.5).

During this period the OR group developed a large number of computer models, each dealing with an aspect of ASW. Some of the models were developed in response to specific needs of the large Defence of Shipping and Defence of Naval Forces projects, whereas others were developed to fill more general needs.

In 1970 a Centre project analyzed the effectiveness of mixed-nation ASW forces operating in close ASW screens in which ships fitted with sonar encounter torpedo-firing submarines. For this study, a general surface-ship screen model was developed, using as input the sonar model previously reported. The situation examined was that in which a submarine would attempt to attack ships of the main body; the output of the model was the probability of detection of the submarine as a function of range from the main body. In 1972 the model was expanded to include helicopters and maritime patrol aircraft (MPA). This model, called the "Tarchi Model" to distinguish it from other screen models developed at the Centre, is described in SM-25, CP-11h,-12d.

A second screen model, called the "Bache Model" and described in the same papers, was intended to provide inputs to higher-level models. It used exercise data and operational commanders' estimates - based on their experience - for its inputs, and estimated the probability of detection of a submarine by the screen. Being based on actual experience, this simpler model gave



Two models developed to study ASW screens. [CP-12d]

more realistic estimates of screen effectiveness than the Tarchi model, but it was found to be too coarse to perform sensitivity studies of the type that could be done with the more physical, larger model. The two models were used as complementary screen models in larger studies (SM-25).

A major limitation to the usefulness of the Centre's screen models was lack of hard knowledge about submarine tactics. It had been necessary to make gross assumptions about the amount of information available to the submarine, and there was also insufficient information on how the submarine would react. To overcome this problem, the Centre developed an interactive simulation model (SR-10, CP-11u,-12e) with control of the submarine provided by a human operator in an otherwise computerized tactical encounter. Submarine operators were brought to the Centre to participate in canned exercises from which the Centre was able to learn more about real-world submarine tactics. Although the model enabled realistic submarine tactics to be observed, no consistent pattern of submariner reactions was found (SM-81). It was concluded that in the real world the information available to the submariner is often incomplete and/or inaccurate and that therefore it is not possible to predict his responses.

Interactive simulation modelling used to study real-world submarine tactics and submariners' reactions. [SR-10]

Another approach to submarine tactics was a simple analytical model that optimized the operator's screen-penetration tactics by finding the course he would take to minimize the probability of his being detected (CP-15c). The possibility that a deep-diving submarine might penetrate a screen and then hide under the convoy was investigated in 1974-75 with the development of a haven model (CP-15a) to cover this situation.

17.4 Sonar Performance Studies

The sonar performance model mentioned in Sect. 12.5 and described in TR-169 and -192 was used in 1970-1971 in a study to determine the relative importance of approximately thirty five parameters on the initial detection performance of hull-mounted sonars. The parameters studied were those characterizing the environment, the vehicle, the sonar, and the submarine. The results were presented (TR-208) as plots of the 10%, 50% and 90% probability of detection ranges as functions of each parameter. As a base case against which performance changes were evaluated, the study used:

- A typical Atlantic summer environment.
- A 2000 to 3000 ton frigate.
- A 7 kHz hull-mounted scanning sonar.
- The submarine at periscope depth, or below the layer.

The study found that many of the individual parameters have significant effects and that no single parameter is the most influential. Factors singled out as being especially important included:

- Surface-layer depth and gradient.
- Self-noise of the vehicle.
- Directivity index of the sonar array and ability to discriminate against reverberation.
- Operator alertness.
- Submarine parameters such as target strength, aspect, doppler, and depth.

As noted previously, reverberation is a major limiting factor in the ability of active sonars to detect submarines. The Centre carried on extensive fundamental research studies of the various physical mechanisms causing reverberation, as reported in Chs. 14 and 16. In addition, in 1969, following a proposal to IEG2 by the United Kingdom, the Centre was requested to be the coordinating group for a NATO-wide reverberation survey in which national warships recorded reverberation in ocean areas of interest to NATO. In cooperation with the Centre, the UK Admiralty Underwater Weapons Establishment prepared a draft instruction for conducting the survey and a format to collate, check, and compute the results (M-68). This was subsequently issued to the nations as STANAG 4118. Each participating nation had to purchase special recording equipments and install them on its warships. Progress was painstakingly slow; by the end of 1972 only 350 observations had been received. Since it had been estimated that at least 25 000 measurements would be required to achieve the objectives, IEG-2 cancelled the survey in 1973.

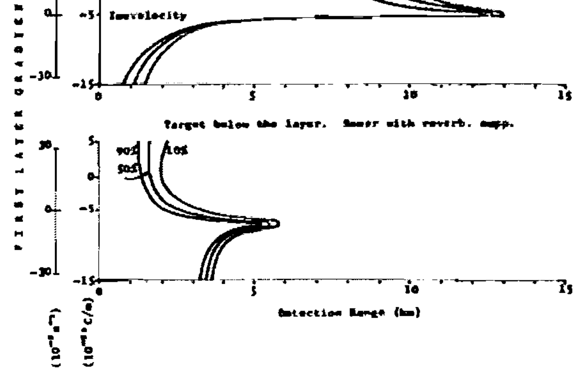
In 1970, the Centre initiated a project aimed at providing the NATO nations with a simple, cheap, and improved means of determining sonar ranges on the spot. The idea was to develop a method for direct measurement of propagation loss, rather than to deduce it from environmental conditions. If this were to be achieved, many of the unknown environmental factors that enter into the computation of sonar range could be eliminated from operational performance estimates. Measurements made with the MPG in December 1970 and September 1971 revealed greater fluctuations of propagation loss in both time and space than had been expected (TR-210). Although no workable on-the-spot ranging system was developed, the project did provide some useful insights concerning propagation and sonar-range fluctuations.

17.5 Force-Effectiveness Studies

Beginning in 1970 and extending through this period, more than half of the effort of the OR Group was devoted to two large studies pertaining to the Defence of Shipping in the Atlantic and the Defence of Naval Forces in the Mediterranean. Originally the two studies were treated as separate projects; in view of the fact that they were similar in approach and methodology, by the end of the period the two became work items under a single project.

Force-effectiveness studies deal with relatively near-term problems facing operational commanders. The questions addressed fall into two general categories: the optimum method of deploying forces allocated, and the necessary augmentation of forces required to achieve a stated military objective.

The Centre's approach was to develop simple analytic methods to assess the value of various options. For each study, the direct defence of NATO formations was simulated in a probabilistic battle model built on a structure of discrete encounters between submarines and various ship formations such as carrier strike groups, ASW support groups, underway replenish-



The effects on sonar performance of parameters characterizing the environment, vehicle, sonar and submarine were presented as probability plots of detection range. The example shows the effects of changes in the first-layer sound-speed gradient when the target is within and below the layer. Similar studies were made for thirty five other parameters. [TR-208] ment groups, amphibious groups, or merchant vessels. The encounter models used input values of relatively elementary quantities describing the performance of both contestants in an encounter, for example, detection probabilities or probability of kill given detection. The outputs gave probable losses on both sides.

The individual encounters were built up into a battle using an encounter-rate model used to determine the mean time between encounters or the probable number of encounters occurring during the course of a battle of limited duration. Inputs were such figures as size of the submarines' patrol areas, frequency with which targets enter these areas, detection ranges for submarines against the formation in question, and the speeds of both. Output values, expressed as a function of time, were the expected number of successful torpedo and missile attacks on important targets, losses of NATO merchant ships, delivery capacity of surviving NATO merchant ships, losses of NATO ASW forces, and losses of Soviet submarines by sinking or disabling.

Details of the specific models depended on the numbers and types of forces deployed on both sides, environmental factors, and the tactical situation specified by the scenario. Some of these affected the structure of the model. For example, a missile-firing submarine required a different form of encounter model from that used for a torpedo-firing submarine. On the other hand, an encounter with a torpedo-firing nuclear submarine was described by the same model as for a torpedo-firing conventional submarine simply by a change in the numerical values of certain of the inputs. Scenario, force level, and tactical inputs were specified by the studies' sponsors and input performance data were the best current estimates as agreed between the sponsors and SACLANTCEN.

Common to many studies was the need for an estimate of attrition rates as a function of force size and battle situation, or scenario. For this type of problem the Centre chose to apply the general model developed by Lanchester in 1916 in connection with air warfare and (51) used by a number of investigators in the 1960s to study problems such as the spread of epidemics, as well as military attrition. A Lanchester model consists of a set of differential equations of the form:

$$\frac{dx}{dt} = r - \alpha xy - \beta y$$

$$\frac{dy}{dt} = s - \gamma xy - \delta y$$

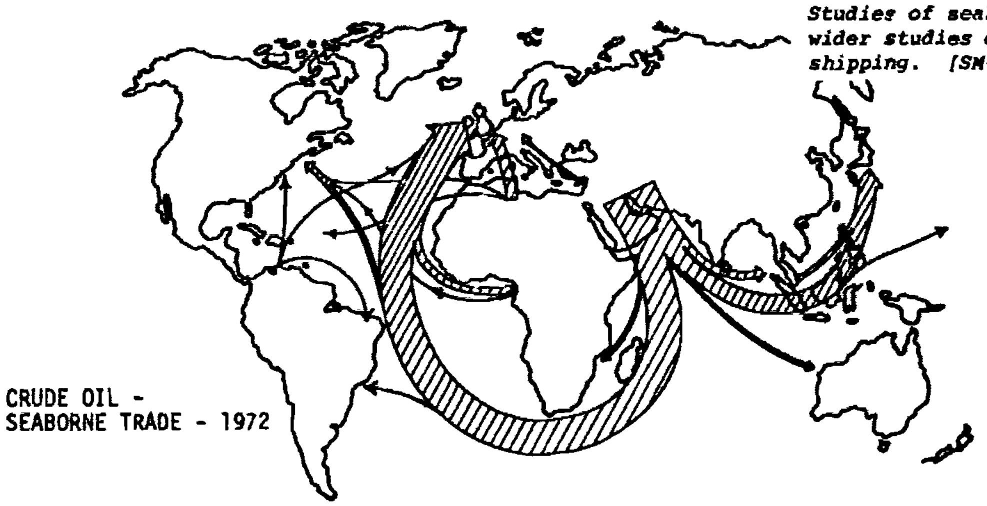
where x and y are the number of units on each side, r and s are replenishment rates, and α, β, γ and δ are coefficients that depend on the scenario and other inputs (CP-11b). Taken as a set, the equations are non-linear. Two approaches were taken to their solution: an approximate solution was found (TR-172) and a computer program was developed (TM-159, SM-5).

A Lanchester model is a deterministic one, in that, for given values of the parameters, it produces a single curve for number of units as a function of time. However, the parameters are not unique and are never known accurately, being subject to some amount of statistical variation. In view of this, the Centre also developed a time-dependent stochastic model (TR-207,-220, SM-1) that yields variances as well as mean values.

Confidence in the Centre's Lanchester model was enhanced when it was successfully applied to a combat situation that had already been studied by a simulation model (TR-202).

17.6 Defence of Shipping Study

As its part of the NATO Defence of Shipping Study sponsored by SACLANT, SACEUR, and CINCHAN, the Centre developed background information and methodology that was then applied to scenarios proposed by the Commands. The study



Studies of seaborne trade contributed to wider studies of the defence of merchant shipping. [SM-50,-61] began late in 1969 and in the first three years consisted of the following tasks:

- Forecasting NATO and world seaborne trade from 1970 to 1985 (TR-176).
- Forecasting NATO and world shipping to 1985 (TR-199).
- Developing and applying Lanchester models (TR-172,-202).
- Developing models for the sailing time of ships in convoys (TR-204, SM-33).
- Developing models for the delivery capacity of convoys and of ships sailing independently (TR-204, SM-56).
- Validating the Lanchester model (TR-202).

In the following years, the various models were applied to additional scenarios: the number of potential shipping routes was expanded, missile firing capability was added, novel forms of surface screens were considered, and more flexibility was assumed for the submarine forces. Work began on sensitivity studies to determine how results would be affected by changes in operational factors and in performance parameters.

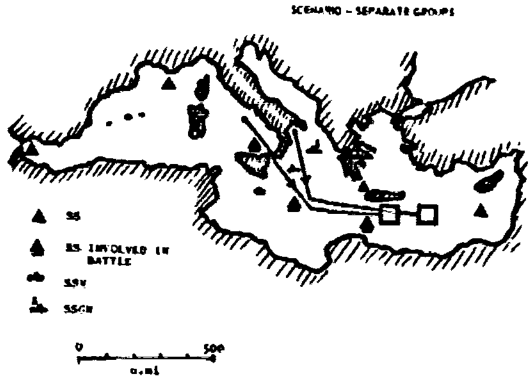
An analysis of convoy screening policies for use when only a limited number of escorts is available indicated that the outcome was highly sensitive to the submarine's ability to discern the escort positions (CP-12c). If the submarine has no information about escort positions, equal distribution of escorts among convoys was found to be the best solution. If, on the other hand, the submarine could be assumed to have good information, then a better option would be to provide high-value convoys with sufficient escorts and to leave the remainder unescorted.

In 1971, as an input for scenarios in periods of interest, a prediction was made of the growth of merchant shipping from 1970 to 1973 (TR-199). In 1974, a comparison of this prediction with actual experience (SM-50) showed that total tonnages of both tankers and bulk carriers had increased at a significantly higher rate than had been forecast. Nevertheless, since the requirement for future scenarios required it, a broad 25-year projection of world energy supplies and shipping was attempted (SM-61, CP-15d,-16e).

The broad-ocean aspect of the Defence of Shipping Study ended in 1974. A related study concerned primarily with the value of fixed ASW barriers in the English Channel was begun in 1975 under the sponsorship of CINCHAN. This study included consideration of a wide range of alternative methods of shipping defence in the Channel area.

17.7 Defence of Naval Forces Study

A new project concerned with the defence of carrier strike groups (CSG) and of underway replenishment groups (URG) in the Mediterranean was undertaken in 1971 under the sponsorship of COMNAVSOUTH and later CINCSOUTH (SR-6). The Centre examined the questions of whether ASW forces should be allocated to direct protection of the CSG or URG, or whether they should be used to patrol Mediterranean entrances and such choke points as the Strait of Sicily.



A study was made for CINCSOUTH in 1971 to determine how Southern Region's maritime forces could be employed to minimize the impact of the submarine threat in the Mediterranean. This included the question of whether forces should be allocated to direct or choke-point defence. (SR-6)

The study was carried out in four phases, as follows:

I. The direct ASW protection of carrier strike groups (M-81, CP-12a).

II. The relative effectiveness of direct versus choke-point defenses (M-83, CP-8g).

III. Optimum distribution of escorts between CSG and URG protection (M-84 and Supp.).

IV. Optimum distribution of ASW resources in NATO's Southern Region (M-85, CP-16p).

For this study, a battle model was developed to treat submarines versus naval task forces (SM-11,-12). Submodels for encounters and encounter rates developed for use with that model are described in (CP-11e).

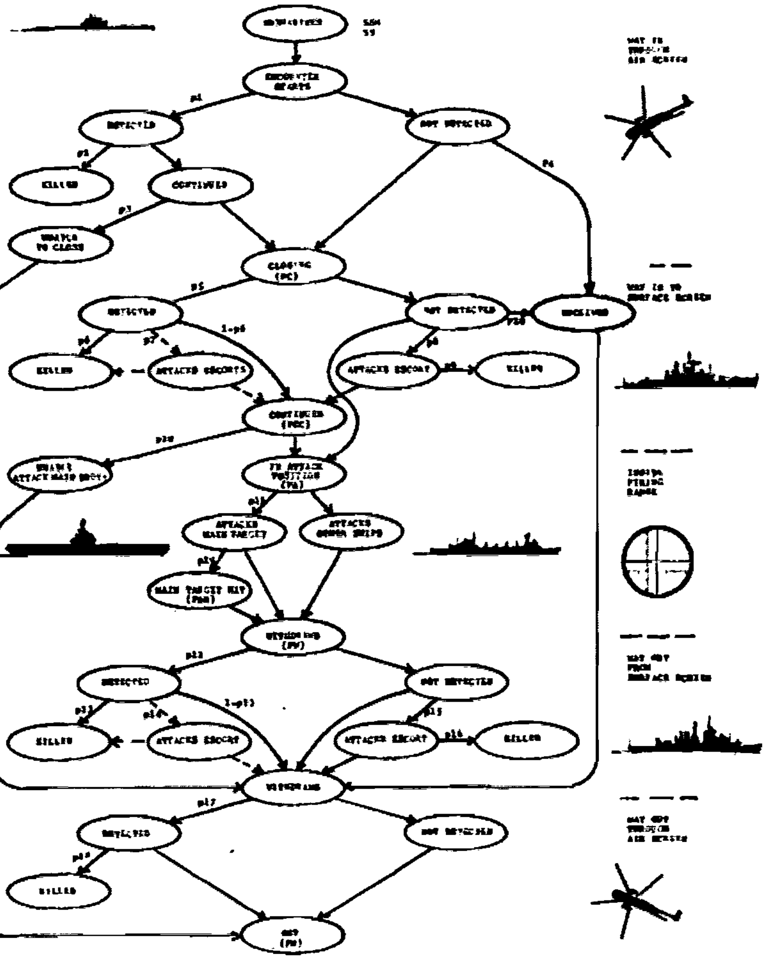
The study first established the level of risk from submarine attack, both missile and torpedo, to which a Carrier Strike Group is exposed during possible strike operations in the central and eastern Mediterranean (M-81). It then went on to show that surface and air ASW forces are more effective in protecting a Carrier Strike Group used in direct defence than when used in choke-point defences (M-83).

The next phase of the study showed that the outcome of a battle is relatively insensitive to the division of escorts between the Carrier Strike Group and the Underway Replenishment Group if the measure of effectiveness adopted is the time that the carrier can continue to operate, neither having been sunk nor having exhausted fuel or armaments. Such a criterion, in a prolonged battle, depends on the survival of the Underway Replenishment Group as well as of the carrier itself.

As a final phase, the Centre in 1974-75 generalized its battle models to develop a methodology independent of the particular scenario (M-85, CP-16p). The technique involved breaking a battle down into individually tractable elements of such size that their models are independent of the broad scenario. This phase addressed the broad question of the distribution of ASW resources in NATO's southern region. It was concluded (M-85) that it is advisable to concentrate ASW defences on groups at risk early in the battle, regardless of priorities.

During the course of the study, it was also concluded that deception tactics could significantly reduce the vulnerability of carriers to submarine attacks (M-81). Further study (CP-15b) showed that evasive tactics could reduce the number of encounters, but that the use of decoys had little effect on the outcome.

At the request of COMSUBMED, a special short-term study was made of the Soviet submarine contact data collected by COMNAVSOUTH for the year 1973 (SM-62).



Encounter models depict the stages in encounters between opposing forces. The example illustrates an encounter between a torpedo-firing submarine and a carrier group. The probabilities associated with each stage allow estimates of, for example, the probability of hits on NATO forces and the probability of the attacking submarine being hit, disabled or running out of weapons.

Part. IV

Period of Reorientation

1975 - 79

CHAPTER 18 PERIOD OF REORIENTATION (1975-79)

CHAPTER 18 PERIOD OF REORIENTATION (1975-79)

18.1 Reorientation of Scientific Programme

In 1975 it became evident that the Centre's scientific programme had gradually lost momentum, as a number of projects had reached a point of diminishing returns and no vital areas of research had replaced them. The RAP deep-water active-sonar project, which had been a major effort for ten years, had arrived at the stage where national development was required. Extensive oceanographic/acoustic investigations of the Mediterranean had been carried on for 15 years, leaving only relatively minor phenomena for further study. Also, the purpose and direction of the operations research programme was being questioned. The problem was to formulate a programme that would not only satisfy long-term and short-term requirements of operational commanders, but would also serve as a bridge between the Centre's environmental research scientists and the operational realities of the ASW problem. The result was a broad mix of studies and a greater diversification of effort than could be readily supported by the limited number of staf.

In mid-1975 Adm. Isaac Kidd replaced Adm. R.W. Cousins as SACLANT and requested his staff to examine the pertinence of the Centre's programme to SACLANT's mission and problems. The SACLANT staff concentrated its efforts on operations research. At the October 1975 SCNR meeting, SACLANT proposed that the OR research programme be expanded from ASW only to communications and all other areas of maritime warfare: electronic, surface, and air. However, the SCNR was cool to this suggestion. A U.S. National Research Advisory Council subcommittee visited the Centre in December 1975; its report to SACLANT, while confirming the value of the Centre's research projects, suggested that La Spezia is too remote a location for a broad programme of OR studies in direct support of SACLANT. SACLANT then proposed a reduction in the scope of the Centre's OR efforts and the transfer of a number of the research staff positions to his Headquarters.

Visit of US National Research Advisory Council Subcommittee, 1975.

After a year of studying proposals and counter-proposals, the NATO Military Budget Committee (MBC) in mid-1977 decided that four research scientist posts held by OR scientists should be removed from the Centre and allocated to SACLANT; this change was subsequently accomplished. These posts all came from the ASW Studies part of the Programme (see Ch. 17), thus severely limiting this activity. The Centre had to refuse a number of study proposals made by various Commands, and the Exercise Research project was terminated in 1978.

During this period the Centre's staff had also been considering its proper role in ASW research. W.K. Grimley, who had previously been a senior ASW research manager in the United Kingdom, proposed (SM-83) that the programme place increased emphasis on:

a. Coastal-water regions
b. Passive sonar
c. System concept formulation.

From these ideas, and with other guidance from SACLANT and the SCNR, the Centre was stimulated to overhaul its entire scientific programme and also to organize the programme along clear project lines.

In February and May 1977 the Centre presented to SACLANT and to the SCNR a revised scientific programme intended to:

a. Give greater emphasis to investigations in the intermediate water depth and slope situations.

b. Initiate work relevant to passive sonar.

c. Conduct more work in the Atlantic and maintain a balance between Atlantic and Mediterranean studies.

d. Expand the frequency band of interest both upwards and downwards.

e. Stress those aspects of operations research that are directly pertinent to the Centre's research programme.

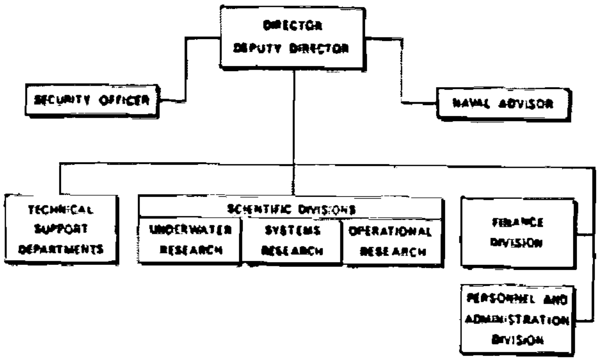
f. Carry out systems studies having the broad objectives of identifying new areas of research on the one hand and of expediting the application of SACLANTCEN work on the other.

g. Investigate non-acoustic phenomena and assess applicability to ASW.

h. Conduct research aimed at improving inter-platform subsurface communication.

The revised programme defined nineteen projects in six research areas. An ASW project was defined as "a study or investigation of significant size, for which a short descriptive statement can be given, and for which ASW relevance can be stated." Sixteen ASW projects, numbered in historical sequence, were proposed for five ASW research areas. A sixth area contained three special support projects required by the Centre in carrying out its mission-related tasks.

SACLANT and the SCNR welcomed the changed format as well as the new project initiatives developed to implement the proposals. Except for the completion of three projects, initiation of one new project, and consolidation of several smaller projects into fewer larger ones, the programme has remained essentially unchanged from 1977 to the present. (For more detailed descriptions of the individual projects, the reader is referred to the Annual Progress Reports beginning in 1977 and to specific proposals for the individual projects in the Proposed Scientific Programmes beginning with 1978.)



Internal Organization in the late 1970s.

18.2 Organization and Personnel Changes

In July 1975, Mr Svend Falck from Denmark replaced Dr Retallack as Director. Soon after his arrival he recognized the importance of ASW systems research and studies and created a Systems Division with Mr Grimley as its first Head. For about a year, much effort was devoted to organizing this Division and formulating its programme (CP-19p,-20c). Following the formal retirement of Mr Grimley in Feb 1977, his place as Division Head was taken by Dr L. Folger Whicker from the United States. SACLANT's Terms of Reference for the Centre were also revised to recognize the Centre's systems studies function.

Mr S. Falck
Denmark
Director 1975-78

Mr Falck also assigned the Deputy Director direct responsibility for the Centre's seven support departments:

- Scientific and Technical Information
- Computer Operations
- Electronic Engineering
- Mechanical and Transducers
- Oceanographic Engineering
- Real-Time Systems
- Ship Operations

The first two of these departments support all of the Centre's work in their respective fields. The other five provide engineering, technician, and procurement support for the Centre's at-sea research.

Except for the loss of one A5 and three A3 scientist posts to SACLANT in 1977, the ceiling for Centre civilian personnel remained constant during this period. However, in January 1979 the MBC approved a new Civilian Administrative Personnel Establishment (CAPE), the first such change in over five years and one which finally recognized the numerous personnel and position changes that had been made in the 1972-74 period (see Sect. 13.3).

In July 1976, the author replaced Mr Pryce as Deputy Director. Mr Falck's term as Director ended in July 1978 and the post was filled in October 1978 by the present Director, Mr Basil Lythall from the United Kingdom. There was also an abnormally large turnover of scientific personnel in late 1975 and throughout 1976, but this has been stable since early 1977.

Mr B.W. Lythall
U.K.
Director 1978 →

18.3 Budget and Finance

The revision of the scientific programme format into clearly defined projects, each with its own allocated resources, greatly aided financial management in the Centre and improved the budget formulation process. As a result, even though the MBC adopted a fully-funded budget concept and eliminated most mid-year requests for additional funds, the Centre has received the financial support to carry out its programme. The MBC agreed to the purchase of certain expensive new scientific equipments, such as towed hydrophone arrays and modern high-speed data processors, and also granted a modest increase in the number of trips covered by the travel budget. On a number of occasions the MBC has granted emergency mid-year additional funding for personnel cost-of-living increases.

18.4 Space and Buildings

The new office building was completed late in 1975 and occupied in February 1976, thus finally relieving the overcrowding that had existed for almost a decade. The building was dedicated in May 1976 at the time of an SCNR meeting. Work then began on a five-year plan of rehabilitation of the space in the original building. A larger conference room was constructed, new accomodation created for the library collection, which had by then grown to over 5000 books, and 10 000 documents related to ASW research, and other offices were refurbished.

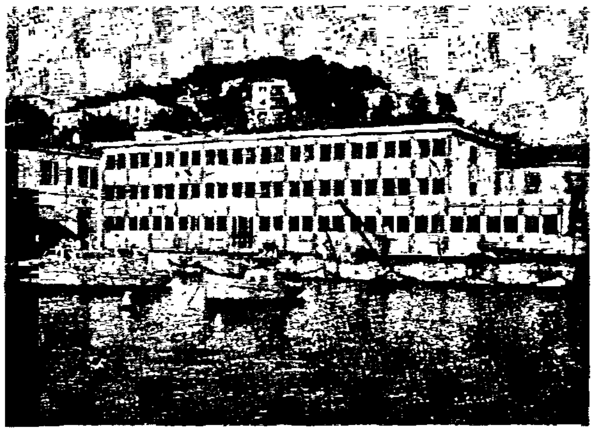
In 1979, funds were obtained to convert a storage building into the additional laboratory and shop space required to handle towed arrays and other large research structures. Also in 1979, the Italian Navy agreed to transfer to the Centre another building suitable for the storage of infrequently used equipments.

18.5 Research Facilities

Throughout this period, the Centre retained under charter the services of the research vessel MARIA PAOLINA G. The major improvement made to the ship was the addition in 1977 of an integrated Loran-C/satellite navigation system. Other moderate improvements were made for array handling, electricity production, and habitability. Use of the ship continued high throughout the period, and the Centre plans to extend the charter to 1984.

The workboat T.B. MANNING proved usable for long periods at sea as well as for local work. Both the MANNING and the MPG were used extensively to install equipments and act as source ships for the Formiche di Grosseto shallow-water test site located southeast of Elba (CP-21j). The main engine of the MANNING became unusable in late 1978 and was replaced by the United States in 1979.

The Univac-1106, acquired in 1974, has proved well suited to the Centre's needs. By doubling the on-line memory, replacing magnetic tape handlers by faster and more reliable units, adding new terminals, procuring a modern, high-speed Calcomp plotter, and adding a graphics terminal microprocessor multiplexer, the capabilities of the system have been steadily improved. Rather than replace this computer, it is now planned to meet growing requirements by augmenting it with a second central processor and additional mass storage and memory units, as well as with such useful peripherals as a colour plotter and colour terminals.



The planned extension to the SACLANTCEN building (see p.55) was completed in 1976.

Improved accommodation for the research staff in the new extension allowed some of the wider rooms of the old building to be enlarged into suitably sized library (above) and conference room (opposite).

The original Hewlett Packard HP-2116B mini-computers, so useful during the first half of the 1970s, became obsolete and were no longer able to meet project demands. The Centre has gradually replaced the 2116Bs with more modern Hewlett Packard 21MX minicomputers with moving-head discs. In addition, a fast array processor (MAP 300) was acquired in 1977 and an advanced programmable beamformer in 1978 (CP-23n).

With the completion of the new library in mid-1978, the Centre achieved a state of excellence in facilities to support its research programme.

18.6 Scientific Projects

It is too early to describe the scientific work done since 1975 with the perspective required for a history. There is therefore no final chapter on scientific projects and, instead, the reader is referred to the appropriate Annual Progress Reports and to the collections of papers presented each year to the Centre's SCNR (CP-19,-21,-23). Complete listings of all Centre publications are given at the back of the annual reports.

18.7 Conferences

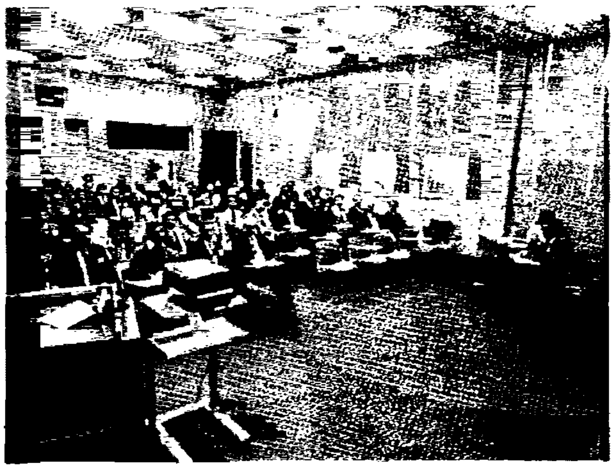
In Autumn 1975, two major conferences were held at the Centre:

Oceanic Acoustic Modelling, Sep 1975 (CP-17)

Submarine Echo Properties, Nov 1975 (CP-18).

Both of these were well attended and each included several Centre papers. No conferences were organized in 1976.

Since 1977, the Centre has continued to organize conferences annually. In March 1977, a Working-Level Meeting on Research for Coastal Waters ASW (CP-20) considered the needs for various types of research, as well as hearing several summary papers on important aspects. This conference served to help the Centre focus its coastal-waters research programme.



In the 1970s, scientific conferences became a regular part of the Centre's activities. A larger and better-equipped conference room was created in 1977.

To help in setting the objectives for research efforts planned for the area southwest of the English Channel (SWAP), in March 1978 the Centre held a conference devoted to ASW operations and oceanographic and acoustic studies of this area (CP-22).

In April 1979, the Centre was the scene for a conference on ASW in the 1990s (CP-24). This was the largest conference ever held at the Centre and was attended by several flag officers as well as other officers and civilians from the Commands and the Nations.

18.8 Twentieth Anniversary

On Tuesday 8 May 1979, preceding its 34th SCNR meeting, the Centre celebrated its twentieth anniversary. Following speeches and the presentation of 20-year certificates to six original staff members, many of the distinguished visitors inspected equipments aboard the MPG during a 4-hour cruise. In the evening the entire Centre participated in a gala party at the Italian Navy Officers' Club.

In his remarks on this occasion the Director expressed his personal evaluation of the high quality of the scientific work that has been carried on at the Centre throughout its twenty years. He took note of the many technical innovations and pioneering researches that have resulted from the efforts of this comparatively small organization. For its size, the influence of the Centre has been great, and it has served as a remarkable example of international collaboration and cooperation.

SACLANTCEN'S TWENTIETH ANNIVERSARY

On 8 May 1979 the Centre celebrated its 20th Anniversary in the presence of the Supreme Allied Commander's Deputy Chief of Staff for Plans, Intelligence, and Operations, Rear Admiral S.A. Swarztrauber USN; Representatives of the Secretary General and other NATO authorities; members of the SACLANTCEN Scientific Committee of National Representatives; Italian military and civil dignitaries; previous SACLANTCEN Directors; and previous members of the staff.

The occasion was marked by speeches and the presentation of 20-year service certificates to veteran members of the staff, by demonstrations in the laboratory and during a short cruise of the MARIA PAOLINA G., by the publication of a souvenir brochure, and by an evening party for all the staff and visitors in the garden of the Italian Naval Officers' Club.

References

The text makes citations in two ways:

- **Citations to SACLANTCEN research publications.**

  These are made by means of the document identifiers as follows:

(TR-)	Technical Report series 1961-73
(TM-)	Technical Memorandum series 1963-73
(M-)	Special Report series 1962-79
(CP-)	Conference Proceedings series 1970-79
(SR-)	SACLANTCEN Report series 1974-79
(SM-)	SACLANTCEN Memorandum series 1973-79

  References and abstracts of these documents are given in SACLANTCEN Bibliography SB-3, which is published as a supplement to the present history.

- **Citations to other works.**

  These are made by the numbers (1) to (51).

  The references corresponding to these citations are listed on the following pages.

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