Engineering the Tools for Science

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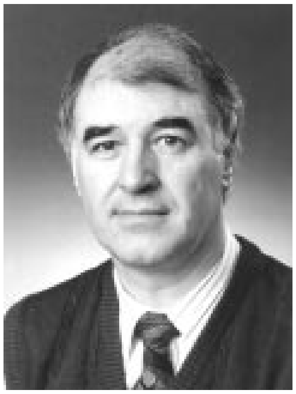
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Introduction

Engineering is often described as the application of science for the benefit of society. Today, fisheries and oceanographic science, like most modern sciences, relies on sophisticated equipment engineered to address specific research goals. In the Scotia Fundy-Region (now the Maritimes Region), it can be convincingly demonstrated that the science program itself depends strongly on engineering technology to fully develop and test the many hypotheses about the ocean and the renewable resources that it contains. Many research and operational programs of the Region look to the engineering and technical staff to design, develop, construct, install, test and maintain unique equipment that cover a broad spectrum of applications for measurement and data collection. For decades, research involving the physics of the ocean and the seafloor has relied heavily on electronic and mechanical engineering. In the past decade, biological research has made increasing demands on these disciplines to address issues related to habitat, to primary production in the ocean and to the fisheries.

The Working Climate

Researchers in fields as diverse as ocean physics and chemistry, hydrography, marine biology, aquaculture, and marine geophysics, all depend on a cadre of engineers and technicians – both in-house and in the private sector – for support essential to their programs. Over the years, technical support personnel have played key roles in creating and mobilizing an array of instruments and devices that have been used successfully to collect, measure, observe, and record all manner of information at the air/sea interface, in the water column, on the seafloor, and in the sediments and strata of the sub-bottom.

The crucible of progress is a collegial approach where engineers come to understand the scientific requirements and scientists come to appreciate the engineering trade-offs; together they face the realities of funding and scheduling. Successful ventures have demonstrated the need for the science and the engineering staff to establish a very interactive, symbiotic relationship in their search for solutions. The relationships that result in the successful development and application of special tools for science tend to be long term. This is an important point, because in the current reality where fisheries and oceanographic research often depend on data collected over many annual cycles, and where the windows of opportunity for at-sea data collection each year are limited, progress tends to be evolutionary more than revolutionary. Thus, the long view is the only realistic one.

The Needs

Scientists are looking for answers to a myriad of questions to help them understand ocean processes. The contributions to this Review outline a number of current studies being undertaken. The impact of human activity on global climate change, the effect of large scale ocean circulation and micro-scale mixing on fish abundance, the effect of deleterious substances in the water and sediments, and the mapping of sub-sea resources are some of the areas where answers are needed. To answer these questions, scientists must have the tools to gather information and make the necessary measurements. Some of these tools, like the conductivity-temperature-depth (CTD) probe - a staple instrument of the physical oceanographer for characterizing water masses - are available commercially. However, many of the unique instruments needed by the science program are not. It is in the latter case that scientists join forces with engineers and technicians to devise the tools for collecting vital data.

Engineers and technicians are an integral part of the scientific investigation. They look for answers to technical issues that, poorly resolved, could jeopardize a scientific program. Often the issues are conceptually, but deceptively, simple: how to keep a moored instrument operating in a mid-water location for a year. In some research programs the technical issues are complex: how to assess the impact of trawling activities in an area like the Grand Banks. Sometimes the issue is measuring a scientific parameter without disturbing the environment: how to measure the average growth rate of fish in aquaculture pens without handling the fish or preventing them from swimming freely.

The oceans remain essentially underexplored, and given Canada's vast coastal zone, its offshore fishing banks, and its Arctic domain, the need for scientific exploration and engineering will continue into the foreseeable future.

The Approach

When researching the answer to a question, the scientist must analyze the relevant information collected either from existing sources, or by known methods, or by means yet to be devised. In the latter case, technology often plays a key role in finding a solution to the data collection problem. The ideal solution will be efficient and cost-effective. Often, the engineering and technical effort will be provided by a team assigned from Management and Technical Services (now Technical Support Services, CCG) and from the client organization - the Region has fostered the concept of a “knowledgeable client” for many years. This team works directly with the personnel dedicated to a particular scientific program to design and develop the necessary equipment. Engineering consultants and contractors play an important role here, as well.

The team often remains on assignment to a project from conception, through the design, construction, and testing phases, and into the sea trials and commissioning. Generally, after it is commissioned, the equipment is operated by the client. It is common for engineering members on the team to take part in some of the scientific expeditions in order to remain aware of scientific findings and the adaptations to their designs that might be required in order to satisfy new needs driven by the findings. This approach underscores the iterative and incremental nature of science and scientific support: new knowledge generally leads to new questions.

Technology Transfer

The need to develop solutions to scientific measurement and data collection problems has naturally led to some interesting and innovative applications of technology. Some of these applications have sparked the interest of companies in the private sector, a fact that has given rise to a number of joint ventures (DOLPHIN Submersible handling system, Tidal Telemetry System) and technology transfers (Pop-Up Float, Moving Vessel CTD, BIONESS towed net system). This arrangement has provided opportunities for Canadian companies to take advantage of the results of research and development by Department of Fisheries and Oceans (DFO) scientists and engineers, and go on to successfully compete on the international scene. In return for the right to use DFO-developed technology, companies return an annual royalty or licensing fee (based on sales) to the federal government. Of course, the companies expect to generate revenue from marketing the licensed product; this creates employment and national wealth, and successful companies broaden the tax base for the government. For these reasons, employees are encouraged to actively pursue patents and licenses under the Public Service Inventions Act.

Some New Tools Developed

Benthic Video Grab System: In order to understand the impact of trawl fishing on the fish habitat, biologists needed sampling equipment that could provide clear images of the sea floor in 300 m of water and retrieve 200 kg benthic samples for quantative analysis. Existing devices sampled blindly and had no means of preselecting interesting or particular areas for sampling. Overcoming this deficiency was of major importance to the proposed study.

The Benthic Video Grab (Fig. 1), together with its deployment winch, was designed to meet the challenge. The grab differs from other similar devices in three important aspects: a) the assembly is landed on the seafloor with the open sampling bucket poised 20 cm above the bottom. By keeping the umbilical cable slack, the grab rests on the bottom, decoupled from ship motion so that the sample area remains undisturbed: b) a high-resolution color video camera above the open bucket gives the operator a real-time view of the seafloor that is about to be sampled; c) the grab can be closed or opened on command from the ship, giving the operator the ability to retain or discard samples. To reduce the disturbance produced by the “bow wave” ahead of the decending unit, the design minimizes the frontal area of the sampler when the bucket is fully open.

Figure 1: The Benthic Video-Grab being deployed from CSS Hudson.

To take a sample, a hydraulic ram slowly drives the grab bucket into the benthic layer using a force of up to 1 tonne, more than sufficient even in relatively hard bottoms. The volume of the sample with full penetration of the bucket is 0.06 m^3 (2.4 ft^3). Essential to the proper operation of the bucket is a lid that closes as the sample is taken. This prevents the fine-grained fraction of the sample washing away as it is hoisted to the surface.

A black-and-white, low-light camera looks down and ahead of the grab as it hangs from the ship on a 30-conductor, kevlar-reinforced cable. This gives the operator a better view as the grab is maneuvered over the seafloor. Lighting is supplied by two 500 watt quartz-halogen lamps. The color camera looks down through the open bucket at the sample area. With focus, zoom and macro remote-control capabilities, the color camera can show remarkable seabed detail. The video information, together with time, latitude and longitude from the differential global positioning system (DGPS), are recorded on Super VHS tape. The sea floor images can be monitored from the shipboard lab. While controlling the grab and the winch, the scientist can direct the maneuvering of the ship as the grab “flies” over the seafloor, look for an appropriate site on which to land the grab, take the sample, and hoist the sample to the surface.

A site on the Grand Banks off Newfoundland has been studied periodically over the past three years by DFO staff from Habitat Ecology, Ocean Physics, and Engineering and Technical Services. Adding pieces to the puzzle of what has happened to the fish on Canada’s East coast demands the intensive effort of people and technology. Assessing the extent of damage to the habitat and organisms caused by trawling, and determining the period required for the area to recover to untrawled conditions may be one key to this puzzle. The final expedition of the Trawling Impact Study took place in July of 1995. The task of analyzing the huge quantity of samples is underway and early results are as yet inconclusive.

Salmon Sizing Video System: The Finfish Aquaculture Section at the St. Andrews Biological Station, in concert with the New Brunswick Salmon Growers Association, were looking for a means of periodically assessing statistical growth rates by measuring the length of fish in aquaculture cages. Researchers and growers have a common interest in the growth of fish as a function of feeding and temperature regimes, genetics, and many other factors. Previous studies that involved the removal of the fish for measuring, placed an unacceptable stress on them and led to dubious conclusions.

Stereoscopic photography combined with geometric calculation (i.e., photogrammetry) has long been used to make accurate spatial measurements. The images produced by two separated, parallel cameras oriented perpendicular to the plane of interest can be analyzed to give point-to-point distances. Photographic film cameras are impractical for this live-specimen application. The operator of the apparatus needs real-time viewing for fish target acquisition and camera orientation. Most importantly, only a few image-pairs of the moving fish will be geometrically useful for analysis. Video cameras provide a promising alternative. With scan rates of thirty frames per second, two cameras can be synchronized for simultaneous imaging.

Figure 2: The underwater portion of the Salmon Sizing System showing the two video cameras, with flotation devices at the top.

By merging the two images using a split screen technique with the "left eye" image on one half of the screen and the "right eye" image on the other, a double image results that is ideal for geometrical analysis.

The operator of the apparatus (Fig. 2) uses a video monitor to ensure that an adequate quantity of good images (same fish in both halves of the image) are acquired at the cage site. VHS recordings of split-screen images are then viewed in a laboratory. Those stereo-pairs that seem promising for measuring are "frame-grabbed" for image analysis using commercially available image-analysis hardware and software (similar to that used in estimating fish age from otoliths). The system is easily transported and deployed, and provides an economical method for the measurement of large numbers of fish.

Sound Velocity Profiler for Multi-beam Ocean Mapping: The Canadian Hydrographic Service is using state-of-the-art multi-beam (MB) sonar technology for mapping coastal waters. (See "New Technologies for Ocean Mapping" in this Review) With the use of multiple oblique beams for measuring depth comes, among other things, the unequivocal need to know the sound velocity profile (SVP) in the water column so that the effects of sound-ray refraction can be removed from the derived vertical depths and from the computed horizontal offsets of the rays. Currently, the survey vessel must stop and deploy a sensor on a wire to measure the SVP. The hydrographer must make an operational compromise between time spent running survey lines and that used for measuring SVPs. Profiles might need to be taken more often than once per hour in those areas where the SVP is changing rapidly with time or tide, or with position in the survey area. It is not until the depth data are partially processed, however, that the full impact of errors due to refraction is apparent. In the end, the error (from all sources) in the charted depths must be less than 0.3 m in water up to 30 m deep, and 1% for deeper water.

The challenge given to a team composed of engineers, technicians, hydrographers and scientists was to improve the efficiency of MB surveys while at the same time decreasing the error from refraction. Due consideration was given to issues such as mathematically modeling the errors and collecting independent, redundant depth data to help identify and resolve the refraction-induced errors.

In the end, an efficient way to obtain SVPs while underway was seen as a common denominator of the solution. An existing science project, the Moving Vessel CTD (MVCTD) system for large ships operating in deep water, provided a starting point for solving the MB problem. However, it was important that the SVP profiler operate from a 10 m-hydrographic launch; three of these boats are now fitted with the Simrad EM3000 MB sonar for bottom mapping in water to 75 m deep.

A design study for a compact, semi-autonomous SVP profiler was coordinated by the team with input from a local consulting company. Finding no existing system that would meet the requirements, a specification was prepared and a contract placed to build a profiler. The design is such that while the launch is underway at 10 knots, the profiler will be able to take SVPs on command or periodically (e.g., every 5 minutes) and transfer the data to the EM3000 sonar for processing and archiving with the hydrographic data (Fig. 3). The construction contract is being managed by an engineer, and the team has a technologist from the MVCTD project as one of its members.

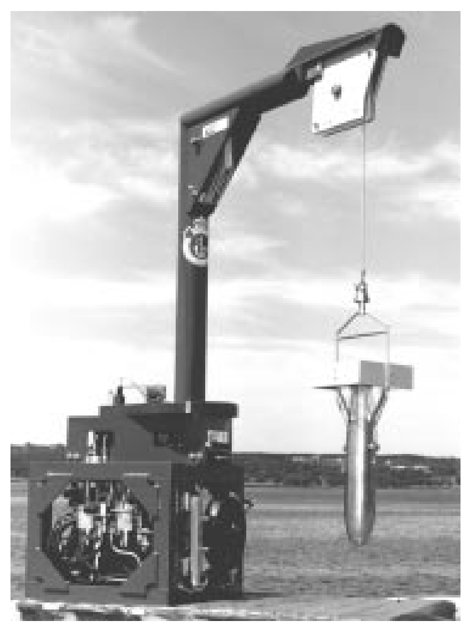

Figure 3: The Moving-vessel Sound Velocity Profiling Winch.

At the time of this printing, the SV profiler is expected to be an operational tool on inshore surveys. Commercial licensing arrangements are already in progress with a local manufacturer, and the company has prospects for sales in several countries.

Opportunities and Challenges: CCG-DFO Amalgamation

The creation of one marine fleet and the imminent decommissioning of older but, nevertheless, capable and important ships servicing the science and CCG programs will create a demand for engineering expertise to reconfigure the remaining ships for tasks new to them. Adding capabilities for oceanographic winching and instrument handling, water and bottom sampling, chemistry, biology and geophysics laboratories, and scientific computing and networking to new classes of ships will need the input from specialists in diverse fields. Fortunately, much of the expertise needed to plan and implement these tasks already exists in the newly re-engineered Department of Fisheries and Oceans and in the commercial ocean sector in the region.

Conclusions

The Department of Fisheries and Oceans intends to remain a world leader in the management and protection of marine resources. Remaining on the cutting edge demands a vigorous application of new technologies in order to meet the challenges that will arise from Canada’s consolidated ocean responsibilities. The partnership of science, engineering, and technical support will be essential to maintaining excellence in such an endeavour.