THE SPINNAKER PROJECT: AN ARCTIC ACOUSTICS TALE

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INTRODUCTION

During the late 1980's, a joint Canadian-American project was initiated to install a hydrophone array on the bottom of the Arctic Ocean and to telemeter the data back to shore over a fiber-optic cable. The array was to be placed near the edge of the continental shelf north of Ellesmere Island, N.W.T., and the fiber-optic cable was to be brought ashore near Canadian Forces Alert, which is on the north coast of the Island (Figure 1).

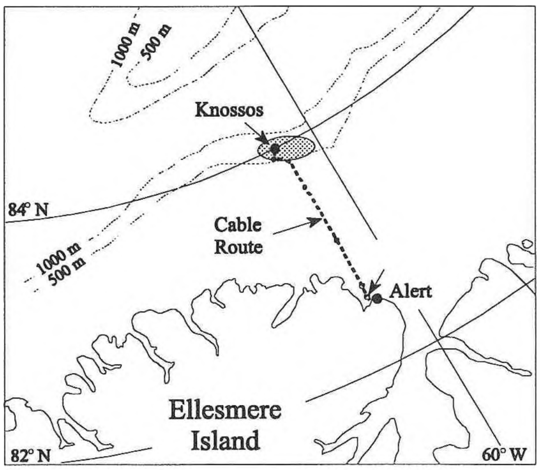

Figure 1: Map showing array site and cable route.

There were three main purposes for this installation. The first was to gather ambient noise and other environmental data in that particular part of the Arctic Ocean. The second was to use the array to prove-out new techniques of analyzing the data gathered from large arrays. The term 'matched-field processing' is generally applied to these algorithms. The third purpose was to develop and demonstrate the technical capability of installing such a complicated system under the heavy continuous ice cover of the Arctic Ocean.

The project was planned and directed by two defence laboratories, the Canadian Defence Research Establishment Pacific (DREP), located in Victoria, BC, and the American Naval Command, Control and Ocean Surveillance Center, Research, Development, Test and Evaluation Division (NRaD), located in San Diego, CA. The work very conveniently separated into two main parts. The Americans built the low-powered hydrophone array and installed it on the ocean bottom. They also designed and installed the hardware to transmit the data along the fiber-optic cable. The Canadians were responsible for laying the fiber-optic cable between the array and the shore, across the shore and into the analysis room in CFS Alert. This involved the design, construction and operation of an autonomous underwater vehicle that laid 180 km of cable under the polar ice. The recording and analysis of the data was a joint responsibility.

Some of the original planning and strategy sessions were held in a well known Victoria pub; consequently the whole scheme became known as 'Project Spinnaker'.

This paper concentrates on the Canadian contribution: the design, testing and operation of the cable-laying AUV, and the installation of the cable in the Arctic Ocean.

THE AUV THESEUS - DESIGN SPECIFICATIONS

Starting in the early 1990's, DREP had a series of contracts with International Submarine Engineering Research (ISER) of Vancouver, BC to design and build a large autonomous underwater vehicle that was capable of laying cable in ice-covered waters. Later, this AUV was known as Theseus - named for the hero of Greek mythology who laid a string behind himself on his way into the labyrinth.

The design constraints on Theseus were severe. The vehicle had to carry (and lay) up to 220 km of fiber-optic cable in an operating area where the ocean is completely ice-covered, mostly by multi-year ice 3.5 to 10-m thick, with ice keels that can dip to a depth of 30 metres or more. Water temperatures are very near freezing, and the currents could be as high as 25 cm/s (0.5 knots).

The navigational ability of the system had to be such that the AUV could pilot itself to a spot 180 km offshore and then 'fly' through a 200-m-wide loop of rope that was suspended from the ice. This ability was achieved by designing the basic navigational system to have an accuracy of about 1% and then updating the vehicle's dead-reckoned position at a series of acoustic beacons that were hung below the ice at known locations. In order to minimize the amount of cable falling through the water column behind the vehicle, Theseus had to follow the bottom (without running into it) at an altitude of about 20 m. Acoustic telemetry was a necessary feature so that communication was possible with the vehicle - especially in emergencies. (Continuous communication with the vehicle was possible as long as Theseus was connected to the shore via the fiber-optic cable.) Since Theseus had to travel both out to the array and then back to shore, it was designed to have an endurance of 450 km. Finally, in order for the AUV to be transportable from the nearest airport (Alert) out onto the ice, it was to be built in modules, each one having a weight less than 1400 kg.

THESEUS - A DESCRIPTION

Figure 2 shows a cut-away view of Theseus, and Table 1 lists the vehicle's principle features.

<u>PROPULSION</u>: The vehicle is propelled by a single 6-hp brushless dc motor and a 61-cm-diameter propeller. Power for this motor (and for all the vehicle's 'hotel' power) is provided by a 360-kWH silver-zinc battery pack, which gives Theseus the capability of a mission at least twice as long as the one described here.

<u>NAVIGATION:</u> Theseus monitors its position by dead reckoning. It uses a Honeywell 726 ring-laser-gyro inertial navigation unit (INU) to provide heading and attitude data. It uses a Doppler sonar to measure the speed over the ground in both the forward and lateral directions. This combination was chosen to provide a position accuracy of 1% of distance travelled, but we found that with careful adjustment the cross-track error could be reduced to about 0.05%. The sonar also measures the altitude above the sea floor,

which is crucial since Theseus is programmed to fly close to the bottom.

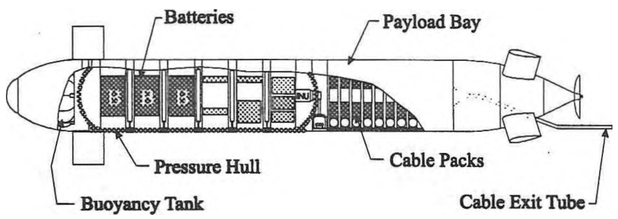

Figure 2: A cut-away schematic showing batteries and electronics in the (dry) pressure hull and the fiber-optic cable packs in the (flooded) payload bay.

Table 1: Theseus's principal features.

Length	10.7 m (35 feet)
Diameter	127 cm (50 inches)
Displacement	8600 kg (19,000 lbs)
Speed	2 m/s (4 knots)
Range	700 km (380 nm)
Maximum operating depth	425 m verified, 1000-m (3280-foot) design depth

CABLE DISPENSING SYSTEM: For 220 km of cable to be stored in a vehicle this size, the cable had to be small - 2 mm in diameter. The cable consisted of a single-mode fiber encased in a steel tube which, in turn, was surrounded by an e-glass wrapping. This was coated with Surlyn plastic. This cable was wound onto eleven spools (of 20 km each) which were stacked longitudinally along the vehicle axis, the appropriate ends being spliced together (Figure 2). The cable, which is pulled from the centre of the spool, is prevented from collapsing into a tangle by gluing the turns together with a special weak adhesive. For simplicity, no active dispensing devices were used; a tension of two to four pounds in the cable was maintained by the glue. The cable leaves the vehicle by way of an exit tube, which keeps the cable away from the screw.

The cable weighs about 2 lb/km (8.9 N/km) in water, and about 200 km of cable were deployed. This loss of 1800 N had to be prevented from affecting Theseus's neutral buoyancy and trim. Surrounding each cable spool is a toroidal ballast tank which is initially empty but which fills with water as the cable is dispensed. This keeps the net buoyancy of each spool/tank assembly near neutral.

ARCTIC CABLE LAYING

Getting Theseus assembled and working in the Arctic involved a lot of very specialized logistics. First, a small village of tents was assembled on the ice of Jolliffe Bay, about 6 km west of Alert. The biggest and most important of these was the tent for Theseus, which was 20 m by 11 m. Inside this tent a hole was made in the 1.7-m-thick ice for Theseus. A hot water drill was used to cut out blocks of ice, each weighing about 4 tonnes. The final hole was 12.2 m by 1.5 m, with extra cut-outs for Theseus's fins - about 70 tonnes of ice.

Two travelling gantry cranes were set up to carry Theseus from its assembly track over to this hole. (Actually, the first job of one of the cranes was to lift the blocks of ice onto the surface.) Next Theseus's assembly track was set up and levelled. Finally, a floor was laid on the ice and two furnaces were installed to heat the tent. Meanwhile, the rest of the camp, which included a mess tent, sleeping tents, a workshop tent and a tent for two Diesel generators was being established.

When all was ready, a Bell 212 helicopter slung the individual vehicle sections from Alert to the ice camp, where they were quickly placed in the warm tent. The next several days were spent loading batteries, electronics and all the fiber-optic cable into Theseus. The cable end was spliced to a pre-laid cable that passed through a hole which had been drilled through the fore-shore in 1994. This hole, which curved upwards, came up into the ocean bottom at a depth of 30 m, deep enough to protect the cable from the largest ice keels. From the beach the cable ran overland to a control centre in Alert. As long as the cable was continuous between Theseus and the shore, the control centre could monitor Theseus's location and health, and, if necessary, take control of the vessel.

Twenty days after it had been slung out to the Jolliffe camp, Theseus was finally ready to carry out its mission. On 17 April, 1996, Theseus left the shore camp, navigated itself through a fairly narrow channel and headed north. At three waypoints Theseus homed-in on acoustic beacons and used their known locations to update its dead-reckoned position. Two more beacons helped Theseus pass through the rope loop that captured the cable. Twenty four hours after departure Theseus successfully completed its first major task by flying through the loop. Once the cable had settled to the bottom of the loop it was pulled to the surface in order to splice it to the cable coming up from the hydrophone array. However, before the cable was cut, Theseus was commanded to return to shore. Note that its return was completely autonomous.

SUBSEQUENT CABLE REPAIRS

The acoustic array worked perfectly for about two months, but on 20 June the data stream suddenly stopped. An Optical Time-Delay Reflectometer (OTDR) at Alert showed no breaks in the shoreward 150 km of cable. Any break would have to be outboard of that. So, in 1997 we returned to Alert prepared both to fix cables and to replace the laser out at the array.

When we arrived we discovered a new cable break 14 km from Alert. Using P-code GPS we set up a camp on the ice over the estimated location of the break and sent down a Phantom ROV to find the cable. It turned out - both here and elsewhere - that the cable was always easy to find because it had been laid with such accuracy by Theseus. The two ends of the break were brought up to two different holes in the ice, and a short piece of connecting cable was slung under the ice between the two holes. Splices were made at the two holes, and the cable was dropped away. A second break was then found at 28 km. It was fixed, and then the laser was replaced at the array. This still left a break, but by this time we had run out of time. More details on this and subsequent repairs can be found in Reference 1.

REFERENCES

1 Verrall, R., Butler, B. 'Testing the Waters: Technologies Converge to Lay Arctic Cable'. GPS World, Vol 10, #5, May '99, pp 23-31.