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HIGH ARCTIC LOGISTICS IN SUPPORT OF THE AUV THESEUS

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ABSTRACT

In 1996 the Department of National Defence laid a 180-km-long fiber-optic cable under the heavy pack ice of the Arctic Ocean north of Alert, NWT. The most important player in this exercise was the large AUV, Theseus, which did the actual cable-lay. However, the success of the mission also depended on specialized logistics support. A 5 x 40-ft (1.5 x 13-m) hole had to be cut through the 6-ft (2-m) ice, and this involved the removal of 65,000 lb (30,000 kg) of ice. A 36 x 60-ft (11 x 18-m) tent was erected to provide heated space for Theseus, and twin gantry cranes were installed within the tent for lifting Theseus into and out of the hole. Theseus had to be slung by helicopter out onto the ice in pieces, moved into the tent and put together on rails. To support this, a small city of tents had to be set up, both at the launching site and at navigational way-points along the route. Transportation for the many people had to be organized. The people of the Defence Research Establishment Pacific (DREP) have had many years of experience in the High Arctic, and this was made evident by the smooth way this all flowed together. This paper discusses the details of getting Theseus ready for its mission.

INTRODUCTION

In the spring of 1996 a joint Canadian-American team installed a 180-km-long fiber-optic cable under the pack ice of the Arctic Ocean. The cable ran along the ocean bottom from a shore station at CFS Alert, Northwest Territories, out to a bottom-mounted sensor array. Figures 1 and 2 show this area north of Alert. This installation, known as the Spinnaker Project, set many world records, e.g., the longest autonomous cable installation, the longest cable laid under Arctic ice, etc. The star of this show was, of course, Theseus, a 19,500-lb (8800-kg) Autonomous Underwater Vehicle (AUV) which had been designed, built and tested during the previous several years. (See also 'The Under-Ice Navigation of the AUV Theseus' in the proceedings of this conference.) Although Theseus did the actual cable-lay and thus deserves top billing, it could not have done the job without a lot of specialized support. Many years of experience went into the development of equipment and techniques that enabled Theseus to be brought to the Arctic, flown out to the ice, put together in a warm environment, lowered through the pack ice, tested, sent on its mission and recovered – and all this without mishap and in reasonable comfort. This paper discusses the logistics and peripheral techniques that enabled the Spinnaker Project to be a success.

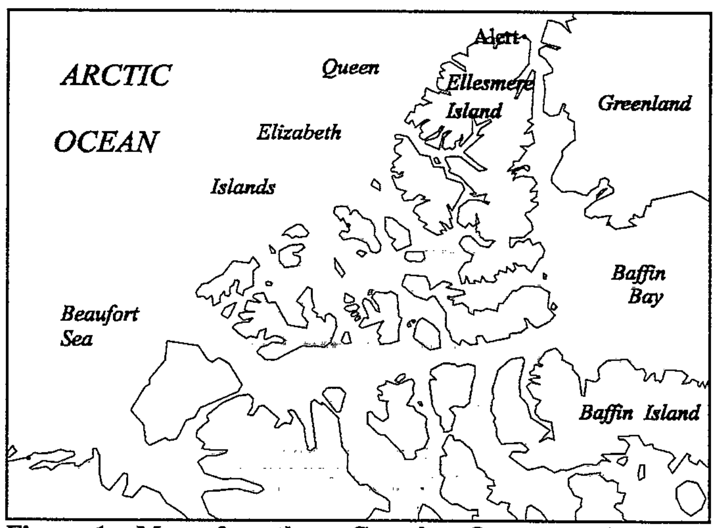

Figure 1: Map of northern Canada. Our area of interest was north of Alert.

CAMP LOCATION:

The location from which to launch Theseus on its cable-laying mission had to be chosen quite carefully. The water had to be deep enough to protect the cable from the scouring action of the ice; the ice had to be smooth enough for a fairly large camp and thin enough to facilitate cutting a large ice hole, and the site had to be close enough to CFS Alert so that the fiber-optic cable could be run overland from the shore site to Alert. Moreover, the beach near the camp site had to have the right shape and be composed of consolidated rock in order that a curved hole could be drilled from the shore out and up into the ocean – coming up in water that was deep enough to protect the cable from the destructive ice.

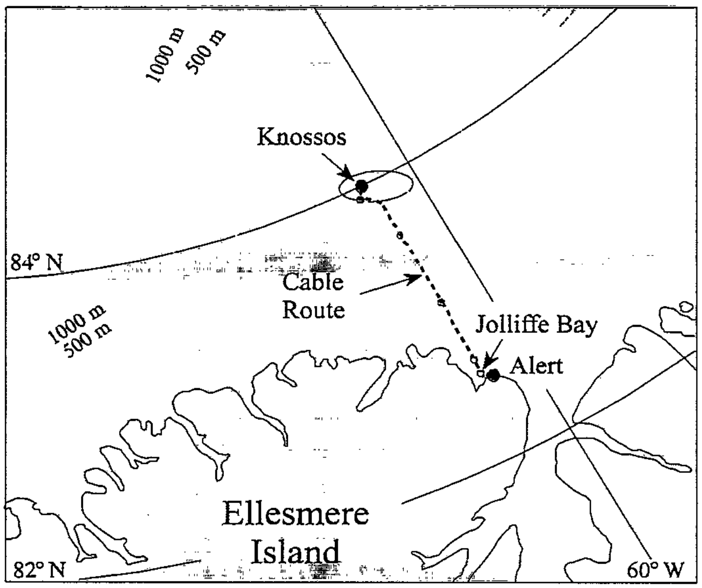

Figure 2: The area of operation north of Ellesmere Island.

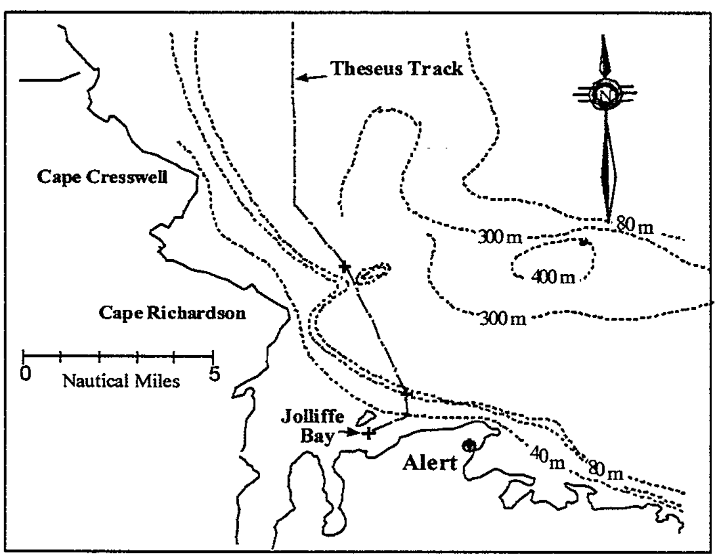

Figure 3: Map showing the location of the launch site. The calbe comes ashore at this location through a curved drilled hole.

These conditions were found in Jolliffe Bay, a small north-facing bay about 6 km west of Alert (Figure 3). The shoreline and the associated rock formation just to the south of the bay were convenient for the curved hole that spanned the dangerous foreshore. This hole was drilled by Foundex Inc. in 1994. Jolliffe Bay's proximity to Alert was very convenient – both for running fiber-optic cable to Alert and for ease of transportation between Alert and Jolliffe Bay. In addition, ice conditions in the bay are generally good. A small island (William Is.) just offshore shields the bay from pack ice being blown south. This means that when the ice solidifies in the fall and early winter the bay is usually covered with first-year ice, which is quite smooth and suitable for an ice camp. The disadvantage to the island is the shallow water around it. Theseus's access to the ocean was through a fairly narrow trench to the east of the island.

HANDLING THESEUS IN THE ARCTIC:

Transportation

The AUV known as Theseus was designed, built and tested by International Submarine Engineering Research (ISER) of Vancouver, British Columbia, in close collaboration with the Defence Research Establishment Pacific (DREP) in Victoria, BC. Figure 4 shows our submarine – painted yellow, of course. Theseus's total displacement is about 19,500 lb (8640 kg), which is much too heavy to transport within the Arctic. Although CF 130 (Hercules) aircraft are available for shipping such large items to the Arctic, the largest practical transport vehicles for off-strip work in the Arctic are fixed-wing DeHavilland DH-3 Twin Otters or Bell 212 helicopters (Twin Hueys). Consequently, Theseus was specified to be dismantlable into pieces that could be carried by either. Later this specification was reduced to remove the requirement that Theseus be transportable by the Twin Otter. The final design had Theseus separable into nine pieces. Figure 5 shows one of these pieces (still in its shipping crate) being slung out to the ice camp on Jolliffe Bay where Theseus was put together. After the crate was placed on the ice, the top cover was removed and the Theseus segment was pushed inside a warm tent. Several of the segments had to be kept reasonably warm since a cold-soaking would damage them. They were taken from warm storage, slung out to Jolliffe bay and put back in the warm – all within half an hour.

Theseus Tent:

The tent had to be large enough to contain Theseus when it was pulled apart into its various segments. Moreover, the tent had to contain the ice hole that was Theseus's access to the ocean. It had to hold the gantries that moved Theseus within the tent; it had to have room for the ROV that tended Theseus underwater, and it had to have enough room for racks of electronics and tables of computers. At busy times the tent housed about a dozen workers and sometimes another dozen tourists from Alert. To fill this requirement, a large tent called the Wide Span Shelter was purchased from Weatherhaven in Vancouver. This tent has the shape of a Quonset or half cylinder, the length of the cylinder being 36 ft (11 m) and the diameter being 65 ft (20 m). Figure 6 shows the four supporting arches being cranked up into place. Most of the tent construction was done with the arches opened up and lying flat on the ice. Figure 7 shows the tent after some days of operation.

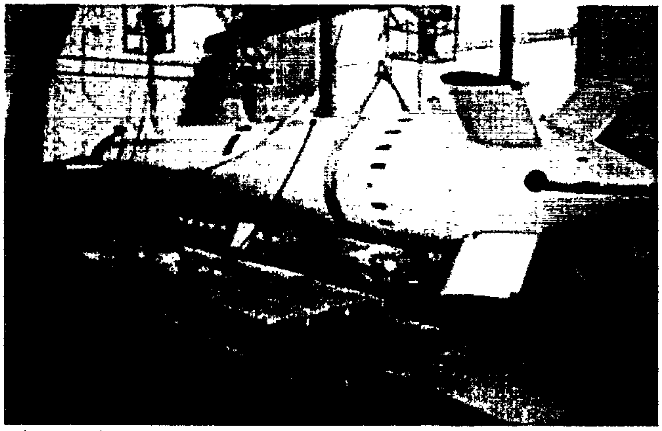

Figure 4. Theseus being removed from the ice hole and placed back on its trolley.

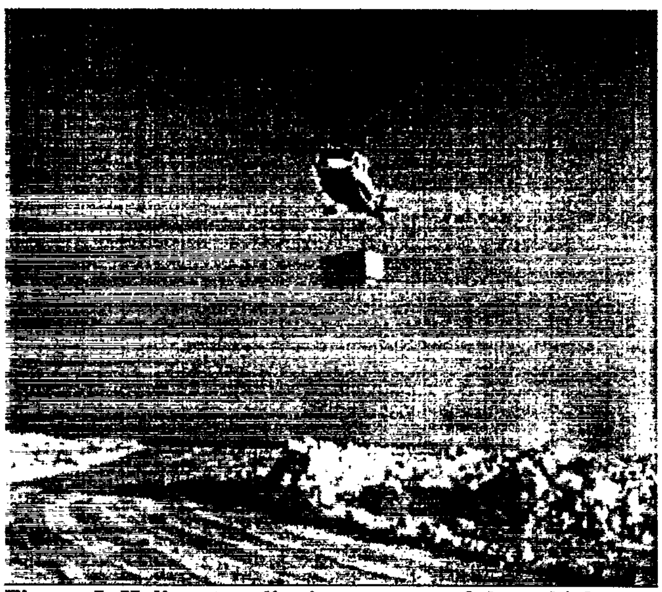

Figure 5. Helicopter slinging out one of the vehicle segments.

The surface of the tent presented an enormous sail area to the local winds. To keep it from blowing away during the spring storms, we needed to guy the tent firmly to the ice. This was done by using ice and snow to good advantage. At the foot of each arch (eight locations in total) two slant holes were drilled in the ice in such a way that they intersected about 18 inches down. This created a V-shaped tie-down point in the ice. A tie-down strap (also known as a Herc strap) was fed through the hole in the ice and then around a solid strut in the metal arch. When the strap was cinched up tight, the leg of the arch was tied solidly to the ice. In addition to these anchors, standard snow flaps were built into the tent by extending the tent's outer skin onto the ice. These flaps were covered with several thousand pounds of snow to help hold the tent in place and to provide 'weather-stripping' (Figure 8). Several severe storms tested out the effectiveness of our guys, and they survived with flying colours (Figure 9).

Figure 6. Wide Span tent going up. Note the four people on the left cranking up the tent with boat winches.

Figure 7. Wide Span tent in place. On the right are the ice blocks taken from the ice hole.

Figure 8. Tent flaps are being covered with snow. The Wide Span tent was similar – only its snow flaps were bigger. Here the Posi-Track was doing one of its many jobs.

Figure 9. Blowing snow creating long drifts. The wind load on the tents is quite high.

Once the tent was in place, we equipped it with everything needed to service the vehicle. Theseus was put together on a track that ran the long dimension (65 ft) of the tent. The length of this track gave plenty of room for working on the various segments of the AUV. We placed the track adjacent to an end wall containing a large roll-up door which gave easy access to the outside. Inboard of the track and parallel to it we cut a long narrow hole in the ice, and we straddled both the track and the hole with two travelling gantries which were to be used for moving Theseus back and forth between the hole and the track. In brief, the order of work was as follows. First, we installed the gantry cranes. We did this first so that we did not have to worry about falling into the ice hole while moving the gantries. An additional reason was that the installed cranes were useful for lifting the ice out of the hole. Next, we marked out the ice hole and cut out the ice. Once the hole was finished, we installed the track for Theseus and then covered the rest of the ice with a plywood floor. Then we installed the furnaces and heated up the tent. Once the tent was warming we brought in the furniture – the tables, chairs, computers, electronics, tools, etc. – everything to be ready for Theseus's arrival.

Let us now look at the tasks in more detail.

Gantry Cranes:

The two travelling gantries were each rated for a 6-ton working load. Each used a 12-in (30-cm) wide-flange I-beam 22 ft (6.7 m) long and weighing 1040 lb (470 kg). A 212 helicopter slung the gantries out to the ice camp in pieces, and we put them together on the ice. To attach the pieces together we stood up the side supports inside the large tent and roped them temporarily to the tent arches. We used a Posi-Track to lift the I-beam to the top of the side supports where we bolted the sides to the I-beams. This operation was not as easy as it sounds since the Posi-Track was not able to lift the I-beam high enough with a single lift. The beam had to be raised in two steps. First, we placed the I-beam on a specially constructed stand, and then we raised the stand plus I-beam to the required height (Figure 10). Then we manoeuvred the legs underneath and held them there until the two sections were bolted together.

Figure 10. The I-beam is being bolted to its legs while the Posi-Track holds the I-beam in place.

Once the gantry was bolted together and stable we could move it with the Posi-Track or walk it over the ice with a crowbar. When it was in the right place we leveled it by jacking each foot with a 'Jack-all' and putting plywood shims under the feet. Even the highest foot was insulated from the ice with a piece of plywood since we had found that an uninsulated steel foot would slowly melt itself into the ice. The I-beam had to be levelled accurately since we wished to pull the 19,500-lb vessel along the beam by hand, and the slightest upward slope would make this impossible. Sometime later, a lighter (2.5 ton rating) transverse I-beam and gantry were slung on rollers from the main beams.

Making the Ice Hole

In order to give Theseus entrance to the ocean, we cut a hole 5-ft wide and 40-ft long through the 6-ft-thick ice (Figure 11). (We made the hole slightly wider where Theseus's fins passed through the ice.) To cut slots in the ice we used the DREP hot water drill. It puts about 300,000 BTU/hr (88 kW) into the 'cutting' water, and this hot water is sprayed like a curtain downward out of holes bored through a piece of pipe into the ‘cutting’ water, and this hot water is sprayed like a curtain downward out of holes bored through a piece of pipe (Figure 12). In general the pipe ‘cookie cutter’ can be made in any shape, but in this case we used straight pipes which melted straight slots through the ice 5-ft (1.5-m) long and about 4 inches (10 cm) wide. The slots were linked up so as to cut out pieces of ice approximately 5 ft by 5 ft by 6-ft thick (1.5 x 1.5 x 1.8 m). A steel cable rigged like a lasso was dropped over the floating ice block, and one of the gantries lifted the block (weighing 7,000 to 8,000 lb (3200 to 3600 kg)) out onto the surface where the Posi-Track pulled it outside into an ice dump. This cutting and lifting process took about a day and a half.

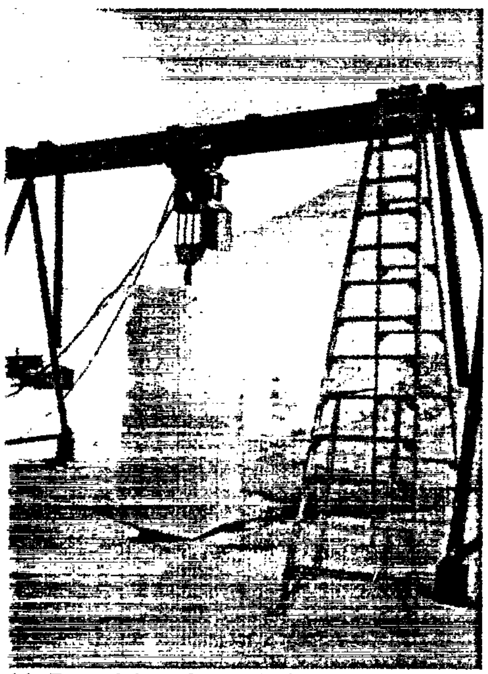

Figure 11. Practising the technique of pulling ice plugs with gantries.

Figure 12. Cutting slots in the ice with hot water.

Completing the Tent Set-Up:

Once we had completed the hole, we set up the track for Theseus. The track was about 50 ft (15 m) long, and, since Theseus is about 36 ft (11 m) long, there is plenty of extra track for pulling apart the various segments of the AUV (Figure 13). The track had to be built straight and level so that the segments could be easily pulled together and joined. Moreover, the track supports had to be insulated from the ice so that they would not melt their way into it.

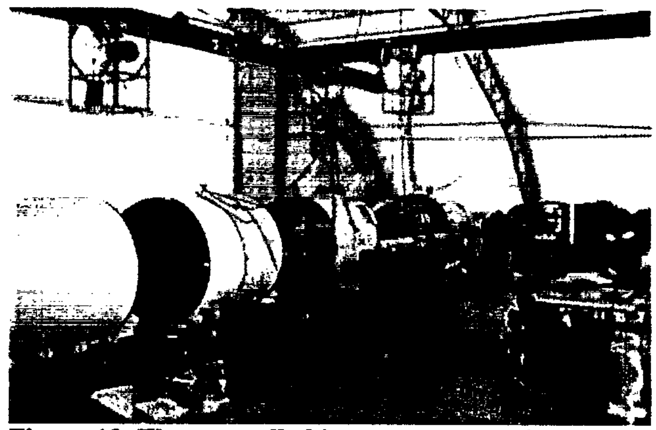

Figure 13. Theseus pulled into segments on its track. Note also the transverse gantry suspended between the two main I-beams.

We covered the rest of the tent floor with wooden panels. Partly this was to level out the irregularities in the ice, but primarily it was because the ice surface would become wet and very slippery when it warmed up. First we levelled the floor by laying ‘sleepers’ on the ice and levelling them reasonably well with wooden shims. The sleepers were long doubled 2 x 8 planks laid ‘on their flats’ 8 ft apart and parallel to the track. On these sleepers we laid 4 x 8-ft panels made of two sheets of plywood screwed to 2x 4’s on 16-inch centres. This gave us a floor that was very stiff. We also laid flooring over the ice hole, but since these panels were often removed and replaced, they were made only 2 ft wide so that they were lighter and easier to handle (Figure 14).

The tent was heated with two oil-burning, 100,000-BTU/Hr (29-kW), forced-air furnaces. They were both placed on the floor near an end wall and vented into the tent. Until the tent was warm they both gave a lot of trouble, and, of course, the tent couldn’t be warmed until they worked. This ‘Catch-22’ situation was very frustrating, and the furnaces soon became known as Satan-1 and Satan-2. If this type of heating were required again, we would put a lot more thinking and preparation into it.

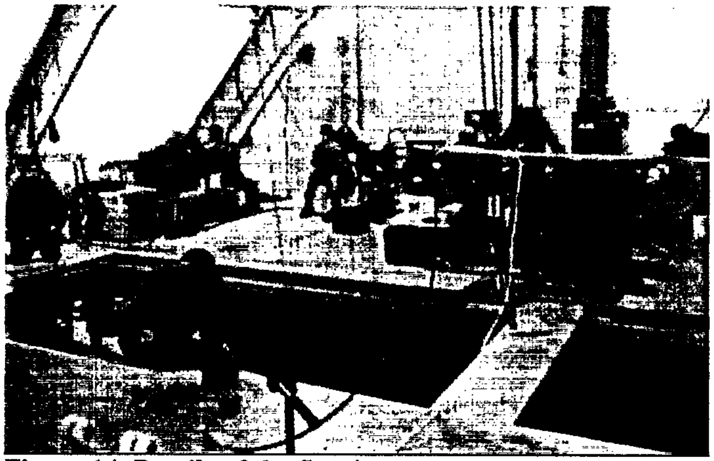

Figure 14. Details of the flooring.

Both furnaces ran non-stop during the coldest periods, but later in April when the outside temperature was higher and the solar heating was significant we were able to get by with just one. We learned that if we were not careful with the hot air blast from the furnace the ice around the open hole would melt and undercut the wooden sleepers running along both sides of the hole. To mitigate this problem, the blast of air was directed away from the floor. Keeping the hole from freezing over was never a problem.

AUXILLIARY EQUIPMENT

Posi-Track

The Posi-Track is a small tracked vehicle that is made by ASV in Minneapolis. We used it both as a front-end loader for moving snow and as a fork lift for such things a unloading helicopters, moving ice blocks, assembling gantries, etc. In spite of its small size it was exceedingly useful; the project would have been much harder and perhaps even impossible without such a workhorse. Figures 8, 10 and 15 show it being used in various ways.

Figure 15. Posi-Track unloading helicopter

Like all Diesels it was hard to start in the cold weather, and it often had to be heated (with a Herman Nelson, for example). We set up a small tent as a garage for the Posi-Track, and even though the tent was unheated and uninsulated it did keep the engine out of the cold wind (Figure 16). When the "Posi' was parked in its garage it would usually start without any external heating. Once started, of course, it was let run all day.

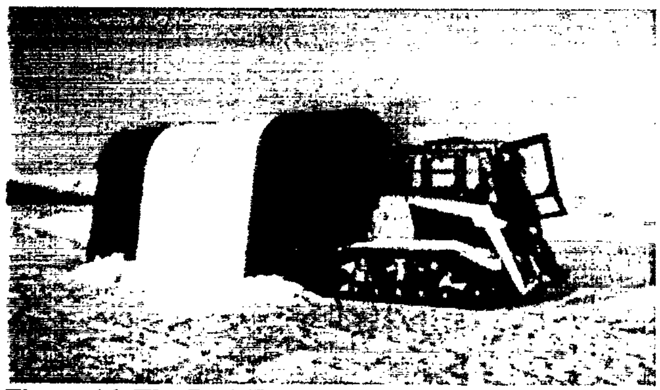

Figure 16. The Posi-Track, kept out of the wind in this thin-walled shelter, would usually start without external heating.

Power Supply

Our power was supplied by two 12-kW 110/220-V single-phase Onan generators. In addition, we had an 8-kW three-phase unit available as a backup. The two 12-kW generators fed separate circuits. One generator provided 'clean' power for computers and general camp requirements, and it was run full-time. The second provided power for heavy electrical equipment like hoists, and it was started only when required. Because of the large voltage spikes introduced into the line when the inductive gantry motors were turned on and off, this was called 'dirty' power, and it was because of these spikes that the two separated supplies were necessary.

The two generators were housed in a separate tent, and their exhaust was fed through a 'sock' in the tent roof. Although the tent was 'unheated', the generators, themselves, produced lots of heat to keep the tent warm. Because they were so noisy, the tent was put as far away as was practical from all the other tents.

Additional Tents

Besides the large Wide Span Shelter, a number of other tents were set up to house and feed the people and to look after the equipment. Figure 17 shows the general lay-out. Two 12 x 28-ft (3.7 x 8.5-m) Weatherhaven tents were set up as bunkhouses, one of them also being used as a clean workshop. A 14 x 32-ft (4.3 x 9.8-m) tent was set up as a kitchen and mess tent. The Warehouse tent contained mostly frozen and dried food. The generator tent and Posi-Track tent were mentioned above, and the 12 x 12-ft (3.7 x 3.7-m) Work tent was used as a warm place for working on engines. The three Octagon tents were additional dormitory tents.

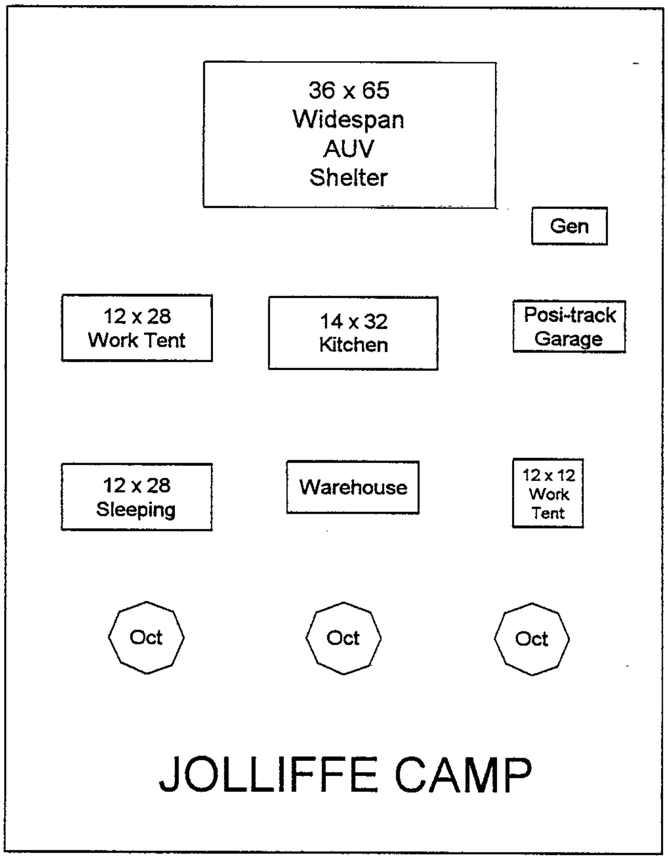

Figure 17. Layout of the tents at the Jolliffe Camp.

Tethered ROV

Another tool that was absolutely necessary for this operation was an ROV (Remotely Operated Vehicle) to act as a 'tender' for Theseus, to recover junction boxes on the ocean bottom and to string lines between holes. We used the Phantom ROV (Figure 18), made by Deep Ocean Engineering, San Leandro California, and we were very pleased with its performance. It was manoeuvrable, easily controlled, and it had enough thrust to go several hundred metres quite easily.

One of its principal uses was to help us recover Theseus when it had parked itself on the bottom under the ice hole. Phantom was sent down with a line, which it attached by poking a hook through a lifting hole on Theseus's back. Phantom then broke itself away from this line and returned to the surface to pick up a second line. Once this second line was attached to Theseus (one being at the bow and the other at the stern), the big AUV could be pulled up and docked in the ice hole.

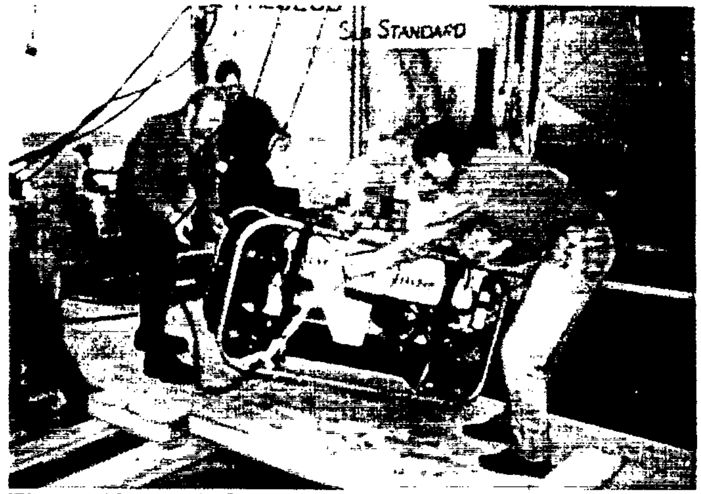

Figure 18. The ROV Phantom being manoeuvred into the ice hole. The transverse gantry was very useful for this.

Phantom was also used for taking underwater videos of Theseus. This, of course, was useful for later 'PR' work, but it was also useful for diagnosing problems when Theseus occasionally got into trouble during its recovery.

SUMMARY:

In 1996, a joint Canadian-American team installed a 180-km-long fiber-optic cable on the bottom of the Arctic Ocean, which, at the time was completely covered by solid pack ice. This record-breaking cable-lay was made possible by the autonomous underwater vehicle, Theseus, which was especially designed for this type of work. It was also made possible by years of experience in the development of workable Arctic logistics and procedures. This paper has discussed this specialized Arctic work. It discussed the various aspects of transporting and assembling a large AUV on the ice. It described the cutting of a large hole for access to the ocean, which involved the removal of 30 tons of ice. It also discussed the equipment that was necessary for handling the 19,500-lb AUV, both in and out of the water.

The fact that the cable was laid successfully on the first attempt is a testimonial to the experience and dedication of all the engineers, scientists and technicians.

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