AD-754 396

PROJECT DEEP OPS: DEEP OBJECT RECOVERY WITH PILOT AND KILLER WHALES

Clark A. Bowers, et al

Naval Undersea Center
San Diego, California

November 1972

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NUC TP 306

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by
C. A. Bowers R. S. Henderson
Undersea Surveillance and Ocean Sciences Department

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ADMINISTRATIVE STATEMENT

The research and development effort reported herein was conducted by the Naval Undersea Center, Hawaii Laboratory, as part of the Advanced Marine Biological Systems Program, U38-12, sponsored by the Naval Ordnance Systems Command.

Program direction flowed from the OPNAV Program Official (OP-098TB) via CNM (03PB) to the Project Officer (ORO-03A) and the Deputy Project Officer (NUC, Code 505).

Work on a whale object recovery system was initiated in August 1969 and was completed, including a simulated operational test, in November 1971.

This report was reviewed for technical accuracy by W. E. Evans, R. L. Pepper, and H. O. Porter.

Released by
B. A. Powell
Bio-Systems Program

Under the Authority of
G. B. Anderson, Head,
Undersea Surveillance and
Ocean Sciences Department

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Undersea Center Hawaii Lab	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

PROJECT DEEP OPS: DEEP OBJECT RECOVERY WITH PILOT AND KILLER WHALES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Project Summary (August 1969 to November 1971)

5. AUTHOR(S) (First name, middle initial, last name)

Clark A. Bowers
R. Scott Henderson

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1972	91	18

8a. CONTRACT OR GRANT NO. Advanced Marine Biological Systems Program, U38-12 b. PROJECT NO P08-0383 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NUC TP 306 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ordnance Systems Command Washington, D.C. 20360

13. ABSTRACT

Two species of whales, killer whales (*Orcinus orca*) and pilot whales (*Globicephala scammoni*), were conditioned to locate and mark for recovery pingered cylindrical objects in the open ocean. The animals were conditioned to boat-follow, wear harnesses with radio backpacks, and deploy mouth-carried recovery hardware.

An automatic direction-finding radio tracking system, originally developed for studies of wild marine mammals, was adopted and transformed to a system which is practical and reliable for day-to-day use with trained whales in the open ocean.

The killer whales dived to maximum depths of 850 feet and 500 feet to deploy practice grabbers. The pilot whale deployed a practice grabber at a depth of 1654 feet and on one occasion apparently made a volunteered dive (without practice grabber) to a depth of 2000 feet.

Float-line recovery devices proved ineffectual, leading to the development of a hydrazine lift system, which was fitted to the operational grabber and is capable of lifting 600 pounds from 1000 feet. The pilot whale aided in the recovery of a dummy Mk 46 torpedo from 500 feet with this device, and during an earlier training session deployed the hydrazine system on the same target at a 1000-foot depth.

DD FORM 1 NOV 65 1473 (PAGE 1)

0102-014-6600

UNCLASSIFIED

Security Classification

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Marine Mammals						
Whales						
Recovery Systems						
Torpedo Recovery						
Orcinum orca						
Globicephala scammoni						

DD FORM 1 NOV 65 1473 (BACK)
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Security Classification

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Frontispiece. Ahab (killer whale) in open ocean with tracking radio backpack.

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INTRODUCTION

At established ocean test ranges the US Navy and Air Force are faced with the regular loss of experimental and exercise ordnance. Objects most commonly lost are prototype and exercise mines, torpedos and air-to-surface missiles, missiles that impact in planned or unplanned areas near their launching sites, and moored oceanographic instruments. A large number of these objects are lost in water deeper than 300 feet. Current recovery methods are subject to certain fundamental limitations.

In waters shallower than 300 feet divers are the common means for recovery. Such recovery is sharply limited by environmental conditions and the physiological effects of depth on man.

In deeper waters manned submersibles are commonly employed for search and recovery missions. To date there are 16 submersibles with operating depths greater than 1000 feet and cruising speeds of less than 3 knots. The original cost of a submersible is very high due to the necessity of providing safety features, life support systems, and high reliability of vital systems. High winds and seas severely restrict or force the cancellation of search efforts involving submersibles. Under high-motion conditions at the air-water interface, the launch, recovery, and support of submersibles are hazardous at best.

Unmanned submersibles, which are generally smaller and less expensive than manned vehicles, still share the problem of dependency on mild sea conditions for efficient deployment. The tethered vehicle CURV (Cable-Controlled Underwater Recovery Vehicle) has an operating depth capability of 2500 feet, with an effective operating radius of 600 feet, and is to date the most common device used to find pingered torpedoes in test ranges.

Surface vessels, which provide support to both manned and unmanned submersibles, are essential to a variety of functions involved in locating and raising an object lost at sea. An acoustic locating device on a surface ship can effectively detect a cooperative target; the position derived from such a detection, however, is not likely to be precise because of the degradation of the target signal as it passes through the water.

Finally, the major problems associated with finding and raising lost objects are difficult and costly to solve. These problems are centered in the following areas:

- surface weather
- surface and subsurface navigation
- effects of current
- bottom topography
- limitation of divers
- underwater visibility
- target classifications

Marine mammals possess certain physiological and sensory capabilities which allow them to function better than man and his equipment in the marine environment.

Several open-ocean studies, deep-dive-training studies, and diving-physiology studies were conducted with marine mammals at Point Mugu, California, prior to the opening of the NUC Hawaii Laboratory in 1967 (Ref. 1–4). Sea lions were trained to wear harnesses and on command to dive to and touch acoustic devices at various depths (Ref. 5). Dolphins were trained to dive to similar acoustic devices and to carry a variety of marking devices to various types of pingered objects. Results of these studies indicated that both dolphins and sea lions could dive to and mark objects below 500 feet.

In an attempt to produce a marine mammal solution to deep ocean recovery problems, Project Deep Ops was initiated at NUC, Hawaii, in 1969. The program was designed to determine first, the maximum deep dive capabilities of trained whales wearing harnesses and carrying hardware and, second, the feasibility of using these animals to mark and recover pingered objects from the open ocean.

From prior knowledge of the diving and feeding behavior of toothed whales it was estimated that killer and pilot whales could be trained to dive to depths of at least 1000 feet and possibly to depths as great as 3000 feet. The basic ability of killer whales and pilot whales to learn fairly complex tasks had been demonstrated in oceanaria and at naval bioscience facilities. Ishmael, one of the killer whales used in the project, had undergone basic training at the Navy Marine Bioscience Facility at Point Mugu, where he had been released several times into a large lagoon and recalled to his pen.

Early concepts for the development of Project Deep Ops envisioned a system in which whales would be trained to mark and recover pingered objects in deep ocean waters. In the final system a whale would follow a support boat from a shore base installation to a work area in the open ocean. There the animal would be commanded to take a device and dive to a pingered target. Upon reaching the target the animal would place the device on the target (torpedo) to initiate the recovery process.

At the inception of the program whales had never before been worked in the open ocean. The success of Project Deep Ops depended largely on the successful training development of conditioned animal behaviors such as open-ocean boat-follow and recall response, deep diving on command, and device toleration and manipulation. Equally important was the development of the associated hardware.

This report will be divided into two major sections: Animal Conditioning and Hardware Development. The first will cover individual animal history, training methods, and some facets of facilities and hardware as they relate to the animal conditioning process. The second will deal specifically with the evolution of animal associated hardware, and will include some descriptions of the animal training that influenced the development of this hardware. Several appendixes are included to provide supplementary material. Appendix A describes whale capture and transport techniques. Appendix B describes the work craft used in the whale training exercises. Appendix C documents the whales' nutrition, health, behavior, and performance. Appendix D presents information about the personnel involved in the Deep Ops program.

BIOGRAPHICAL SUMMARIES

Two killer whales (*Orcinus orca*) and two pilot whales (*Globicephala scammoni*) were procured for Project Deep Ops (Table 1).

Table 1. Whale size, sex, and estimated age at capture.

Name	Sex	Capture date	Age, yr	Weight, lb	Length, ft
Killer whales					
Ahab	M	Oct 1968	9–10	5,500	19
Ishmael	M	Oct 1968	6–7	4,500	17
Pilot whales					
Morgan	M	Oct 1968	6–7	1,200	12
Pip	M	Jan 1970	6–7	1,200	12

Ahab and Ishmael were captured in the vicinity of Seattle, Washington, by the Seattle Public Aquarium and were shipped to Point Mugu, California, where they were used for several months in physiological research studies under the direction of Sam H. Ridgway, DVM.

Ahab was acquired by the Navy on 5 October 1968 and was shipped to Point Mugu on 22 October 1968. By mid-June 1969 Ahab would retrieve an air-filled ring, tow a swimmer, allow handling and brushing, permit his eyes to be covered, and respond to an underwater bridge (2.8 kHz) and a recall buzzer (10 kHz). While at Point Mugu, he was kept in a circular concrete pool having a diameter of 50 feet and a depth of 8 feet. Ahab was shipped to Hawaii on 22 October 1969 for use in Project Deep Ops. He was trained in all system behaviors and worked in the open ocean, where he dove to a maximum depth of 850 feet. Ahab's open-ocean training was discontinued in June 1971 because of behavioral control problems and a lack of time to correct these problems before project termination.

Ishmael was shipped to Point Mugu with Ahab on 22 October 1968 and was also housed in the 50-foot-diameter circular tank. On 19 May 1969 he was transferred to a 40x60-foot floating pen anchored in Mugu Lagoon. Initially he was disoriented and took 5 days to adapt to the new enclosure. Basic training was started on 24 May 1969, and during the following months Ishmael was trained to station, allow handling, respond to a recall buzzer (9 kHz), retrieve an inflated ball with attached ring, swim through a 10x10-foot gate, hold his breath and exhale on acoustic command, and follow a 9-foot outboard skiff.

On 8 December 1969 Ishmael was released into the Mugu Lagoon for the first time. His initial reaction to open water was quite similar to that of smaller trained cetaceans, which when faced with a new situation tend to retreat to familiar territory. Ishmael immediately attempted to return to the floating pen.

Basic training and open bay work was terminated at Point Mugu on 17 December 1969 prior to Ishmael's transfer to Project Deep Ops, NUC, Hawaii. Ishmael was transported to Hawaii on 8 January 1970 and started on a multiphase training program. He was conditioned to perform the majority of the system behaviors and attained a maximum dive and deploy depth of 500 feet.

On 19 February 1971 Ishmael was lost during an open-ocean training exercise. Several days were spent searching for him with surface craft and helicopters. (This event is described in detail later.)

Morgan and Pip, were captured off the coast of southern California in the Catalina Channel. Morgan was caught by Morris Wintermantle, a marine mammal collector working for NUC at Point Mugu. Pip was procured from Marineland of the Pacific, Los Angeles, California.

After capture in October 1968 Morgan was kept in the 50-foot-diameter pool at Point Mugu. During his 60-day stay at the Point Mugu facility some blood chemistry studies were done with him. This work involved stranding the animal by lowering the water level, then drawing blood samples.

Basic training and handling were not initiated with Morgan until after he was shipped to NUC Hawaii on 9 December 1968. Morgan was trained on all Deep Ops system behaviors, and he dove to a record depth of 1654 feet. His training was completed in late October 1971.

Pip was one of seven animals captured by Marineland of the Pacific during January and February 1970. During this period there was an unexplained high mortality rate among these newly captured whales (six died). On 3 March 1970 Pip was shipped to Hawaii, eating and in apparent good health. Basic training was initiated shortly after his arrival, and through the first 10 months of 1970 several phases of basic and intermediate training were completed. His training was hampered at times by his inappetence and lethargic behavior. His abnormal behavior was later attributed to a chronic lung infection which he apparently contracted before being shipped to Hawaii. The animal died on 12 December 1970. The results of a post-mortem indicated that a massive lung infection (*Proteus* sp.) had existed for some time prior to death.

ANIMAL ENCLOSURES

Over the past 5 years a number of dolphins have been housed and trained in fenced bay and lagoon enclosures and in ocean pens. Killer whales captured in the Pacific Northwest have been housed in fenced enclosures for relatively short periods before being transferred into tank facilities. If pilot whales have been kept in floating pens or fenced enclosures, it has yet to be reported.

The majority of all captive marine mammals have been housed and trained in concrete tanks. Because of the extreme cost of constructing and maintaining such enclosures, they are usually built to minimum size and depth. The size of available work space greatly influences the kinds of behavior that the animal can be conditioned to perform.

The housing of marine mammals in fenced ocean pens, as employed at NUC, Hawaii, is a concept common to few biological facilities. Ocean enclosures have been used at NUC, Hawaii, for nearly 4 years with low maintenance costs and excellent animal health. Simplicity and low cost have allowed the construction of very large enclosures. These enclosures, in turn, have allowed the maintenance of pilot whales and killer whales in large, open areas, where normal behaviors are more likely to be exhibited.

For the holding and training of Deep Ops whales, an enclosure complex was constructed from September through December 1969 on the western tip of Mokapu Peninsula (Fig. 1). This complex is located in an ideally situated coastal indentation (known locally as Sag Harbor). Bounded on the north and east by shoreline and on the west by shallow reef, this area of approximately 9 acres opens to the south into Kaneohe Bay and a sea channel. Water depth averages 20 feet and most of the bottom is of coral silt. Water visibility varies from 2 feet to 10 feet.

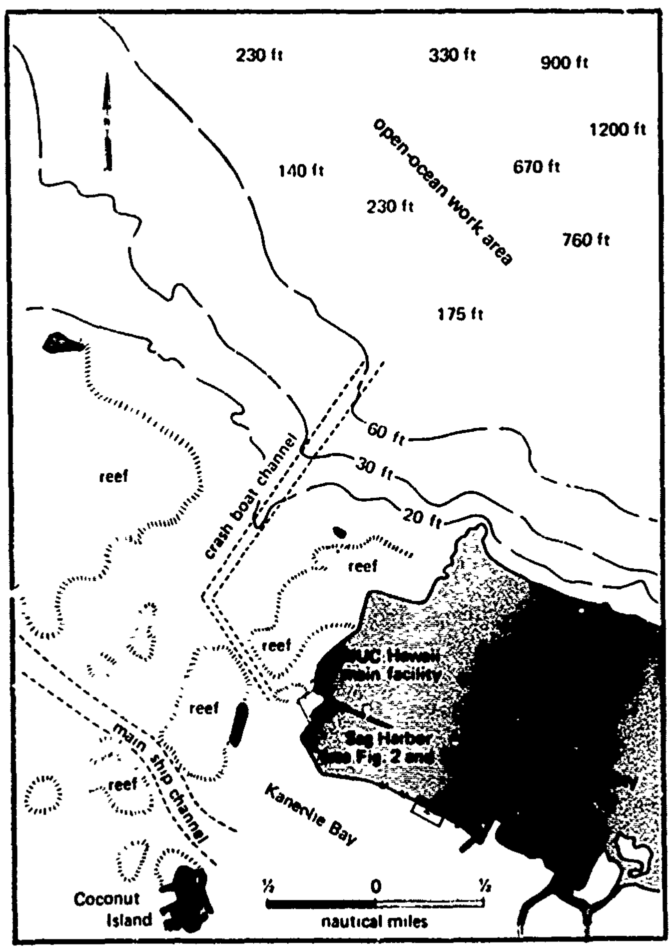

Figure 1. Ocean and bay area surrounding Mokapu Peninsula.

Four 100x100-foot whale pens were built first (Fig. 2 and 3). For fencing supports, 3-inch-diameter pipes were driven into the bay bottom at 15-foot intervals. Galvanized steel fencing (of 6-inch mesh, 11 gauge) was then attached to the pipes to complete the enclosures. At high tide the posts and fence top extend about 1 foot above the water surface.

Figure 2. Whale pens and T-pier at Sag Harbor.

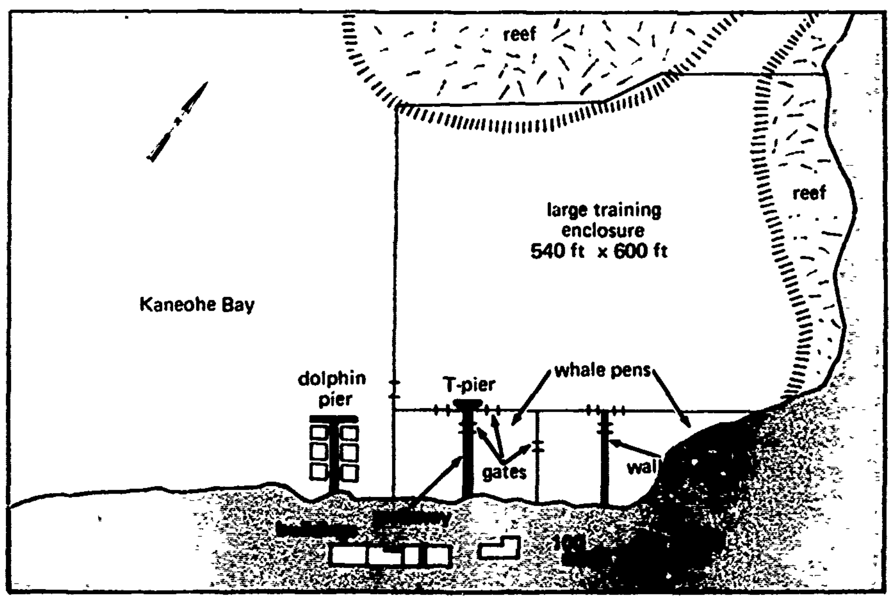

Figure 3. Sag Harbor animal facilities.

Three-foot-wide wooden walkways were built atop the fence posts separating pens 1 and 2 and pens 3 and 4. At the end of one of the walkways, a T-pier was constructed to allow the moorage of small boats.

To facilitate movement of the whales from enclosure to enclosure, 10x10-foot nylon net curtain gates were installed between pens and between the pens and the lagoon area. These net gates opened and closed by sliding up or down on vertical pipes. This style of gate was used for about 1 year until most of them were damaged by the whales "nosing" or chewing on them. After being in place for 18 months, most of the pen mesh was heavily overgrown and corroded, and was replaced. At this time the net curtain gates were replaced with vertically sliding "guillotine" gates. On the new gates a 10x10-foot-square piece of 6-inch mesh wire mounted on a pipe frame replaced the nylon netting. These gates were heavier and required a pulley and hand winch for closure, but were sturdier and less susceptible to biological and mechanical fouling.

In February and March 1970 a large enclosure measuring 540x600 feet was built by enclosing the lagoon area adjacent to the whale holding pens. Fence posts were spaced at 30-foot intervals and 6-inch mesh galvanized wire was used. A large nylon net curtain gate put into the bay side of the enclosure, was large enough to allow the passage of work boats. All four holding pens opened into the enclosure, and the area was used extensively for intermediate and advanced training preceding the open-bay release of the whales.

In the wild, whales and dolphins keep their skin clean by swimming rapidly, by jumping, and by rubbing against one another. When kept individually in captivity they commonly rub against barnacle-encrusted objects. To minimize this problem, heavy ropes were supplied for rubbing. In the center of each pen at Sag Harbor a large float was buoyed tautly to a 2000-pound block of concrete. A length of 5-inch manila hawser was tied on one end to the float and on the other end to a secure object on shore. The use of a heavy hawser minimized the chance of an animal becoming entangled in the line while rubbing.

For water-level access to the animals for training and feeding activities, 9x5-foot floating platforms were constructed by covering six-man balsa wood life-rafts with sheet plywood. The life-raft rings were sealed with fiberglass, and held up well under continual immersion. The low profile of the platforms enabled movement from pen to pen through the low-overhang gates.

In 1969 while Morgan was undergoing basic training he was kept for one month in a floating 40x20x8-foot wire mesh pen adjacent to the Hangar 102 animal facilities (Fig. 4). The 160x100-foot enclosure at this facility was similar in design to

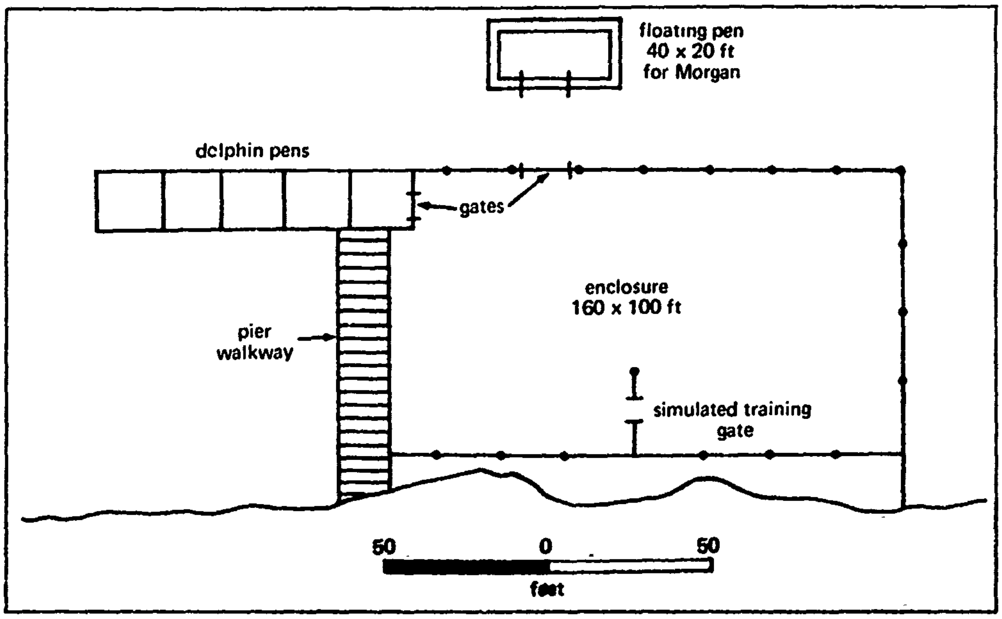

Figure 4. Hangar 102 animal facilities.

the pipe and wire pens being built at Sag Harbor. Morgan was moved from the floating pen to the large enclosure in January 1969, where he remained until October 1969, when he was moved to the Sag Harbor facilities, which were in the final stages of completion. See Steele (Ref. 6) for further details on NUC's marine mammal facilities.

ANIMAL CONDITIONING

Conditioning Techniques

Standard operant conditioning techniques were used to train the Deep Ops animals. The primary reinforcer used to condition each behavior was food (fish). Most of the behaviors were shaped by using differential reinforcement to approach progressively closer approximations of the desirable behavior. Attempts were made to minimize errors by the animal and thus maintain a high positive response level. Successive approximations resulted in a conditioned behavior, such as taking and holding a mouthpiece. Once a basic behavior was attained, it could be chained (linked) with other behaviors until a complex behavioral task was produced, such, for example, as taking a practice grabber, diving to a target, deploying the device, and returning the mouthpiece to the trainer. As an animal gained proficiency in the execution of a chained behavior, the primary reinforcement would be presented, generally only if the chained behavior was completed. If an animal's performance of a specific link of a chained behavior broke down, the reinforcement criterion was temporarily relaxed, and retraining was undertaken until desired performance levels were reestablished.

During preliminary training phases, time-outs (the absence of stimulus or reinforcement) were used to improve an animal's performance. Time-out breaks usually averaged 5 to 10 minutes. On rare occasions, however, when an animal's motivation and response levels were extremely low, his diet was reduced or he was denied food for 24 hours. These deprivations usually produced a higher level of motivation on the following day.

During the initial gate training process, aversive stimuli (crowding nets) were used on two of the whales. A previously conditioned positive stimulus (recall pinger) was presented simultaneously with the aversive stimulus. When the desired behavior was exhibited (gate pass-through), the primary reinforcer (food) was given.

The use of punishment as a conditioning technique was avoided except in one case where mild electrical shock punishment was used to dissuade the pilot whale Morgan from rubbing on boat hulls and channel buoys.

Reward frequency through the preliminary training phases was generally presented on a one-to-one basis (one reward for one properly executed trial). For completion of a particularly difficult task (such as a 1500-foot dive) the magnitude of the reward was commonly boosted. For Morgan a "routine" reward was one or two squid, smelt, or mackerel. A "good" reward was a handful of squid or smelt (5 to 10), or several mackerel (3 to 5).

The killer whales were fed a diet consisting of equal portions of mackerel (with an average weight of 10 ounces each) and bonito (with an average weight of 5 pounds each). Differences in each animal's preference for these two fish provided a variety of reward possibilities. A routine reward for Ishmael might be a piece of cut bonito (1 pound), and a good reward several mackerel. For Ahab, who preferred bonito, a routine reward would be one or two mackerel, and a good reward a whole bonito.

As open-bay and ocean training progressed (and the animals had reached criterion levels on most behaviors) the animals were worked over longer distances, and each task became more time consuming. Under these conditions the periods between rewards were generally lengthened. For example, during preliminary boat-follow training, rewards were given every 30 seconds; during open ocean sessions, boat-follow reward intervals were extended to 3 to 20 minutes. Each dive and deploy trial during the in-pen training was completed in 2 or 3 minutes, and here too the animal was rewarded frequently; for open-ocean dive and deploy in deep waters a complete trial cycle commonly ran 15 to 20 minutes. In this situation the whales were given good rewards immediately after surfacing. While waiting to take the practice grabber for another dive the whales were given routine rewards every 2 or 3 minutes.

Total food averaged 60 pounds per day for the pilot whales and 100 and 125 pounds respectively, for the smaller and larger killer whales. On weekdays it was general practice to attempt to feed each animal his ration of food during or immediately following training sessions. On weekends each animal was fed his daily ration in one midmorning session.

Preliminary Training

The whales' basic training involved several phases of adaptation and conditioning, such as hand feeding, recall training, stationing, in-water handling, enclosure adaptation, boat following, gate training, and harnessing. These behaviors are generally required for most follow-on training programs. Basic, intermediate, and advanced training involved a great number of behaviors, many of which were broken down into subbehaviors (see Table C-3 in Appendix C).

Basic Adaptation. All newly captured animals undergo a basic adaptation phase. This is a period of adjustment to captivity that animals require before they will eat dead food. This period can vary from 1 to 30 days, with the average being 4 or 5 days.

Generally when cetaceans are caught and placed in captivity they are exceedingly vocal. They circle their enclosure at varying speeds, often emitting clearly audible vocalizations. A specific class of these vocalizations is probably distress signals. These signals diminish quite rapidly in 1 or 2 days as the animals begin to adapt. A specific conditioning process begins when the animals have adapted to captivity and eat 100% of their daily ration.

Ahab, the first killer whale to be transported to Hawaii, arrived aboard a C-141 Starlifter aircraft on 22 October 1969. He was off-loaded onto a flatbed truck and taken to Sag Harbor, where a large crane was used to lift the animal and stretcher clear of the transport device and into the water (Fig. 5). Divers detached the stretcher from the lifting bridle and assisted the animal out of the stretcher. The loading, transport, and off-loading procedures were handled much the same with all four whales. Each animal behaved basically the same after being placed in a new enclosure. In general, after being freed from the stretcher they immediately began circling their enclosure. At no time did the animals run into the pen sides in the large enclosure, even though water visibility was very poor. When Ishmael was off-loaded it was completely dark and he circled his pen rapidly, but quickly settled down to "converse" with Ahab, who was in the adjoining enclosure.

Since killer whales do not normally range into semitropical waters, Ahab and Ishmael were brought to Hawaii on separate transports in the event of possible acclimation problems.

Figure 5. Ahab suspended in stretcher.

The first whale to begin training was Morgan. Upon arrival he was placed in a wire floating pen which was 40 feet long, 20 feet wide, and approximately 8 feet deep. The pen adjacent to the Hangar 102 animal facilities, was used as a temporary holding facility until a larger training area could be built. Since there are no records of pilot whales having been housed in wire floating pens, there was concern that he might swim into the pen's sides. Newly captured pilot whales do not appear to be as sensitive or aware of new surroundings or obstructions as dolphins or killer whales, possibly because of visual acuity differences or differing echolocation abilities. Immediately after being placed in the pen, Morgan was stiff and disoriented, and he bumped the sides several times, but after about 10 minutes he was swimming normally. As pilot whales adapt to captivity, their sensitivity to obstructions and environmental stimuli becomes quite acute, equal to and in some areas possibly surpassing the sensory abilities of dolphins and killer whales.

During the time the Hangar 102 training area was being completed Morgan was kept in the floating pen, which was anchored approximately 100 yards offshore. Upon completion of the training area on 26 January 1969, the floating pen was towed in next to an access gate of the new area. The end of Morgan's pen was cut open, but he could not be enticed out of the floating pen, so it was necessary to use a chain-link crowding net to force him into the large enclosure. Once inside, he rigidly swam in small circles in a remote corner of the enclosure. Several times each day a trainer would row a small boat out near the animal's swimming area and toss him food in varying locations to gradually condition him to come farther and farther out of the corner.

Recall and Stationing. Morgan was soon conditioned to the fact that he would not be fed in the corner, and he began moving about the pen more freely. A 100- to 200-Hz recall buzzer had been introduced to Morgan when he was in the floating pen and its use was continued in the large area; the animal was required to bump the sound source with his head when it was put in the water. It took 28 training days before Morgan would respond to the recall buzzer from or to anywhere in the pen. Once recall training became reliable, it enabled more control over the animal. A floating platform was placed in the pen for use as a training station, and most subsequent in-pen training was accomplished from this type of platform.

The next step in training involved getting the animal to touch a recall buzzer and then to hold station for short periods. The natural tendency for animals when first introduced to this type of training is to approach and bump the recall buzzer and then continue moving rather than remain at station.

Several methods were used to establish stationing after the recall buzzer had been touched: (1) the animal was required to hold his head against the recall buzzer until a bridge (whistle) was sounded; (2) the recall buzzer was placed in positions which required the animal to stop to touch it (as in corners or against the side of a pier); (3) the animal's reward after touching the recall was either delayed slightly or

Gate Training. Gate training, as experienced with dolphins, is commonly a difficult and time-consuming process. In their natural environment cetaceans very rarely encounter solid barriers of any sort (such as the shoreline, steep escarpments, thick seaweed growths, and large boats), and their normal reaction when presented with such obstacles is to swim around or under them, not through them. Swimming through a gate is apparently a relatively difficult experience for a newly captured dolphin, and for the first few passes the animal normally needs to be pushed through with a crowding net and rewarded heavily after each such experience. Thereafter, several days and sometimes weeks of training sessions are devoted to coaxing the dolphin through the gate with a recall pinger and fish rewards before he will routinely pass through a gate immediately after being commanded to do so.

In mid-June 1969 gate training was initiated with Morgan at the Hangar 102 training area. A 20-foot section of fence was extended perpendicularly from the enclosure fence in 4-foot-deep water and a 6-foot-wide opening was put in the fence to simulate a pen gate.

Next, Morgan was trained to approach the opening and touch the recall buzzer. On successive trials the buzzer was moved farther and farther through the gate opening until Morgan passed through entirely. Surprisingly this first passage occurred after only 1 hour of training effort. A difficulty of short duration was experienced in the training that followed, for rather than return through the gate on command, Morgan would instead swim around the open end of the fence section to touch the recall buzzer. Eventually, by waylaying and maneuvering him with the buzzer immediately after his first passage, the trainers were able to get him to turn and pass back through the gate without "cheating." Thereafter, Morgan adapted quickly to passing through gates between enclosures and balked only at reentering a floating pen in which he was towed.

This latter reluctance came about in the following manner. In preparation for Morgan's move to the new training area in Sag Harbor, a 20x20 floating pen was tied parallel to the fence in the Hangar 102 training area. Morgan was swimming in and out of this pen in less than 1 day's training. On 24 October 1969 Morgan was called into the floating pen, and the gate was closed. The pen was lashed alongside an LCM work craft and was towed to Sag Harbor. Morgan did not appear too upset by the towing experience; during the following weeks, however, he refused to reenter the floating pen voluntarily. He reentered the pen only when he was tricked into it by various methods, such as when a large amount of fish were thrown in front of him when his head was partially in the pen. Attempts to train him to enter the floating pen voluntarily were abandoned in mid-December 1969. A much larger, deeper enclosure would be required to establish and maintain that behavior.

With the killer whales, gate training was done at the Sag Harbor facility. Since at this location 10x10-foot sliding gates connected the individual enclosures, it was hoped that the spaciousness of the general situation would enhance the gate-training procedure. Both Ahab and Ishmael, however, were very slow in their responses to gate training. Several cumbersome efforts were made to crowd them through the gates with long nets. Often after making a few "volunteered" passes through the gate the animal, on the next day of training, would refuse to go near the gate. Some of these regressions were apparently a result of trauma when the whales scraped their dorsal or pectoral fins on the boundaries of the gates. Approximately 30 days of training were required to establish a reliable level of gate-passing performance for both killer whales.

Ishmael was reported to have undergone gate training prior to and during his releases from his pen in the Mugu Lagoon. This previous experience did not appear to carry over to his gate training at Hawaii. Basic retraining was required, and his progress was at times behind that of Ahab.

Harnessing. Before each whale was released into the open bay and ocean, it was required to wear a harness-pack with tracking transmitter. During open-ocean training sessions it was almost impossible to maintain visual contact with the animals when their range exceeded 200 yards from the training platform. The pack-mounted tracking transmitters permitted the trainers to stay close to the animal if control was lost or reduced during the work session.

The same basic training approaches were used to condition all three whales to wear harnesses and packs. They were first trained to swim into rope loops, which were later replaced by various types of strapping material. From the onset of harness training it was obvious that training the whales to accept harnesses was going to be much easier than it had been training dolphins for the same task. The whales never objected to being touched with ropes or straps; even when the straps were locked on firmly, they did not object. The only problem that occurred with Morgan, although he was always easy to harness, was that he seemed to be severely irritated when packs were placed over his dorsal fin, and he developed a bad habit of rubbing against boat hulls, ropes, buoys, and the ocean bottom while wearing a dorsal pack. Much effort was devoted to the design of a suitable pack for him. A major breakthrough occurred in early August 1970, when a pectoral fin harness was developed which placed the backpack between his blowhole and dorsal fin (Fig. 7). Morgan readily accepted the new harness, and his rubbing behavior was greatly reduced. Morgan's harnessing was accomplished by slipping the harness and pack over his head, rolling him over, and securing the three harness snaps.

The harnesses and packs developed for Ahab and Ishmael were similar except for size differences (see Hardware Development section). A dorsal pack was attached to each of the killer whales with a belly band, which was tightened and secured with a cargo ratchet and locking mechanism.

The harnessing of the killer whales proceeded as follows. A weighted rope was thrown in the water, and the animal swam into the rope loop. The pack's strap was

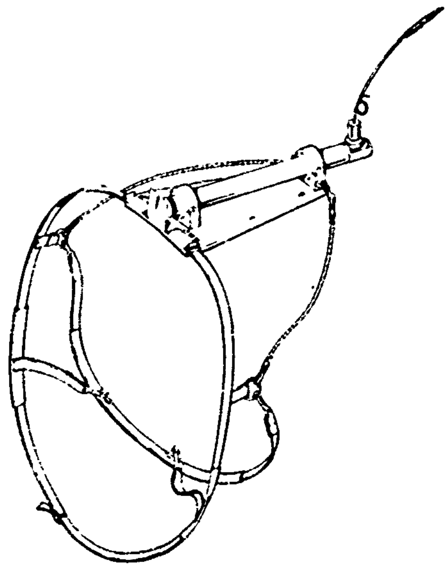

Figure 7. Pectoral fin harness for Morgan. Clamped onto the triangular plate radio pack is a "pig's tail" antenna tracking transmitter.

then snapped to the rope and the pack was slipped over the animal's dorsal fin. Next, the rope and the attached strap were pulled around the animal's girth. After the strap's "free end" was attached to the pack, the cargo ratchet was used to tighten the pack and harness firmly against the animal. The animals were harnessed from their individual training platforms, rubber boats, or the support boat training platforms.

By the time the project was completed it was as easy to harness the whales as it would be to saddle a gentle horse.

In-Shore Dive and Deploy Training

Ring carrying, mouthpiece carrying, and pingered-target marking were also initiated with Morgan at the Hanger 102 training area. Two basic hardware-carrying approaches were tested. The first method required that the animal carry a ring in his mouth and deposit it on a target. Various devices could be attached to the ring. Morgan first learned to carry a ring and deposit it on a surface target. Targets were then gradually lowered to the bottom and planted farther and farther away from his training platform. Morgan had difficulty carrying rings that weighed more than 20 pounds, so alternative hardware-carrying methods were considered.

In the second hardware-carrying method, a mouthpiece was designed which conformed to Morgan's mouth contour and provided a biteplate for the animal to grasp and hold (Fig. 8). After initial mouthpiece acceptance, the animal had to be trained for a new marking sequence. The animal was required to touch the target and return to the trainer with the mouthpiece rather than release it as he had been doing with the weighted ring. This training was accomplished by requiring the animal to hold the mouthpiece, go to and touch the target, and then return the mouthpiece to the trainer. Once this sequence was established, it was a simple matter to extend the range to the target.

Figure 8. Morgan taking first mouthpiece with dolphin nose-cup attached. The white cone separates from the rest of the device when the disc on the tip of the cone is depressed.

It should be noted here that no ring-carry training was given the killer whales, as this behavior had been replaced with mouthpiece carrying of hardware

While at Point Mugu, Ishmael had been trained to stick his tongue out if he was tapped on his nose. This presented a problem during mouthpiece training as each time he started to take the mouthpiece he would stick out his tongue, forcing the mouthpiece away. Special training sessions during which Ishmael was rewarded for not moving his tongue eventually accomplished extinction of this behavior.

Detachable practice-grabber arms were attached to the front of the mouthpiece after the whales had learned the basic mouthpiece-carry chain described above. With detachable arms on the device, the animal had a new task, which entailed orienting the arms around a target and then pressing the device against the target to effect separation of the arms. Orientation efforts were aided somewhat by the use of slightly oversized practice-grabber arms.

The first training target used was a 4-foot-long, 10-inch-diameter aluminum duct pipe. The target was lowered with ropes until it reached the bottom. For training with Ahab, the target was attached to a short section of 3-inch-diameter pipe which extended horizontally from another 3-inch-diameter vertical pipe driven into the bottom. The vertical pipe was bracketed to the walkway on Ahab's pen. The target's elevation was adjustable and could be lowered gradually on the pipe to the bottom as training progressed. A crossbar was attached to the top of the vertical pipe to enable the trainer to rotate the target through a 180-degree arc. This movable target was designed as a training aid to help prevent hardware breakage: when the animal applied enough force to the target it would give rather than damage the arms or locking mechanism on the mouthpiece–grabber assembly.

The major problem encountered while using permanent target positions was that the animals became conditioned to working on specific "routes." Later when a varied locus of targets was used it was difficult to get the animals to make deployments. In the early stages of training with Ishmael much difficulty could have been avoided by first training the animals to touch shallow-water bottom-located targets. However, enclosure size and depth, bottom topography and water visibility prohibited this until training was initiated in the Sag Harbor area in pen 3, which was ideally suited for this type of training. The water immediately offshore was quite deep and the bottom sloped up rapidly to shallow water. The target was positioned on the slope so that the animals could approach and touch it without rubbing their pectoral fins or tail flukes against the bottom (Fig. 9). When Ahab was moved into pen 3 for

Figure 9. Ahab deploying practice grabber on shallow-water target.

deployment training, his performance rapidly improved. As training progressed, the target's diameter and length were increased. Changes in target size made no apparent difference to the animals.

By early March 1970 the 540x600-foot area in front of the holding pens at Sag Harbor was fenced off for advanced training. This area was to be used for large-area training prior to the open-bay release of all animals.

Several hardware breakage problems were encountered during early practice-grab training stages. Although Morgan generally deployed the devices with a minimal amount of force, the forces exerted by the killer whales resulted in continual hardware breakage and forced the redesign of several components.

On early practice grabbers, cam-locks were used as the primary components of the mechanism to separate the grabber arms from the mouthpiece (Fig. 10). In general, the animals' normal target contact would trigger the device and cause separation. They quickly learned that they must separate the grabber arms and floats to receive their reward. Initially, this realization by the animals caused some hardware damage. Ahab, knowing that the floats had to deploy, would occasionally approach the target in an improper attitude and bang away at it until he broke the grabber arms or vibrated them loose. The majority of those incidents occurred before the animal was trained to deploy against a bottom-located target.

Figure 10. Morgan taking CAMLOC practice grabber.

A practice grabber with a new release mechanism was tested with Ahab in March 1970. On this device a quick-disconnect air line fitting replaced the cam-locks as the connecting link. These new fittings were superior in reliability and durability and were thereafter used on all practice and operational grabbers (see Hardware Development section).

A number of training problems resulted from bite-plate changes on the mouthpieces. With Morgan, readaptive training took an hour or two. The killer whales took much longer, sometimes 6 to 8 hours. If the thickness of a bite-plate was changed or if the material used to cover the plate's surface was changed (such as from old neoprene to new neoprene or from soft rubber to hard rubber), the killer whales would frequently refuse to carry it.

Because of this continuing training problem, design changes were frozen on the killer whales' bite-plates. Bite-plate experimentation was continued with Morgan. Neoprene covering tended to crush when the animals dove, reducing its padding effect over the metal. The bite-plate ultimately developed for Morgan was a tapered polypropylene plate with a maximum thickness of ¾ inch. This plate had several improved characteristics. It would not crush under pressure and it provided a good biting surface which was not abrasive to the animal's mouth. Also, the low density of the material added minimal negative buoyancy to the mouthpiece.

As the training targets were moved deeper beyond the trainers' visual range, methods were devised to quickly assess the animals' performance. This was accomplished in two ways. When the device was triggered a float-line was released which was attached to the separated grabber device. This enabled the trainers to detect a deploy (correct performance) before the animal returned with the mouthpiece. On the final practice grabber the arms were buoyant and would come to the surface to reveal proper actuation. Also a "klunk" detector was used to indicate when the animal was at the target. A hydrophone in the target passed the klunking of the grabber arms against the target through a hard-line to an amplifier mounted on the training platform. A circuit for on-off control of the target pinger was also incorporated in the klunk detector lines.

The use of the klunk detector as a training aid was discontinued as training progressed and the floating practice-grabber arms were developed. When the mouthpiece deployment behavior was established on a fairly reliable basis, it was no longer necessary to control the pinger. Even if the target pinger was continually on, the whales would stay near the trainer location until they were given the mouthpiece. This behavior made the use of the more sophisticated klunk detector unnecessary.

When the animals would deploy against the target anywhere in their enclosures, the trainers began using a small boat as a training platform. The animals were required to follow the boat around the enclosure and accept the mouthpiece regardless of whether the boat was moving or stationary.

As the large training area neared completion, boat-follow training was increased in the animals' individual enclosures. Gate training had been completed, and each animal would swim into the adjoining enclosures and return on recall command.

Morgan was released into the large 540x600-foot advanced training enclosure on 9 March 1970, Ishmael on 30 March 1970, and Ahab on 20 April 1970. Ishmael and Ahab took 2 to 3 days longer than Morgan to adapt to the large area. At first they would venture only 20 or 30 yards out and then head back into their pens. When the animals would readily follow the boat around the area the practice-grab deployment ranges were extended. Two 12-inch-diameter, 6-inch long steel cylinders with klunk detectors were planted approximately 100 yards apart and 100 yards from the T-head pier.

In the large area, the animals were trained to follow and work from a 10-foot-long rubber raft, an 18-foot-long Boston whaler, and a 20-foot-long ski barge. In April 1970 a 25-foot-long Luhrs cabin cruiser was modified for use. A great deal of the follow-on open-bay and ocean training was conducted from that craft.

The animals quickly adapted to whatever boat they were required to follow. To aid in this adaptation, a "boat follow cue" was used; it consisted of a 5-kHz short duration tone presented every 3 seconds. The electronics and attached hydrophone were portable, so that the unit could be transferred to whichever boat was to be used. The cue served two functions: it provided a homing signal for the animals, and it helped to identify the boat that they were to follow. Since most of the waters used for open-bay and ocean training were not restricted, pleasure boats and commercial fishing boats would frequently pass close to the work area. Any moving or stationary boat was a potential food source for the animals. Therefore, when other boats passed nearby, recall pingers were used extensively to keep the animal's attention on the work boat.

Open-Ocean Dive and Deploy Training

Open-bay training for Morgan began on 17 April 1970. After his first release, nearly 3½ months were spent training him in different areas in the bay before he was taken out of the channel to the open ocean. (Part of this delay was due to the nonavailability of a reliable radio pack for Morgan.) No difficulties were encountered working Morgan in the bay and channel areas, even where the channel was relatively narrow (50 feet) and shallow (10 feet). On 11 August 1970 during his first ocean release (beyond the channel mouth) Morgan strayed away from the boat for a short period. When he returned to the boat he acted as though he were frightened. He appeared to be disoriented by the fringing reef and shallow water at the mouth of the channel. Except for occasional rubbing sessions on the channel buoys, no major lapses in control were experienced with Morgan during subsequent open-ocean training.

Ahab, the older of the two killer whales, responded better to open-water training than did Ishmael. His behavior was more consistent, and he adapted to changes in environment, hardware, and training more readily. It took nearly 2 months to get Ishmael used to working in the channel leading out to the open ocean. As is true of most higher animals, there were a great many individual differences exhibited between the whales. The stage of maturation and the past experiences of each animal undoubtedly contributed heavily to his behavior pattern.

Pip, the fourth whale to arrive in Hawaii, was never released to the open bay or ocean, since his training never advanced beyond intermediate stages. His training progress was retarded by frequent lethargic behavior and periods of inappetence. During his long illness, medical checks and blood samples were obtained several times after he had been placed in a stretcher on a training transporter. The cause of his illness and resultant abnormal behavior was not determined until he died on 12 December 1970. Postmortem results indicated that 90% of the animal's lung tissue had degenerated as the result of a *Proteus* sp. infection.

Strong trade winds prevail in Hawaii from March through August, and frequent storms occur during the winter months of November through February. Sea-state conditions resulting from these winds are particularly severe off windward Oahu and necessitated the cancellation of many open-ocean training sessions. Even though the animals were capable of operating in seas up to 10 feet, it was dangerous and often impossible for the crew to work from the stern platform of the work boat and handle hardware and training aids in seas exceeding 5 to 6 feet. Unavoidable weather delays in training resulted in an abnormally slow dive training progression. In the training process, unless a regular schedule (5 open-ocean sessions each week) could be maintained, the animals' conditioned response capabilities often regressed, particularly when with each session training tasks became increasingly difficult.

By mid-September 1970 Morgan, Ahab, and Ishmael had all attained open-ocean reliability, and thereafter were taken to sea five times a week for deep-dive and deploy training (Fig. 11).

Figure 11. Morgan following work craft in open ocean.

In the course of a normal training session, the animal was harnessed and released from his pen to follow the work craft to the ocean work area. Once the boat was over the appropriate depth area, the target, with recovery line and buoy, was dropped overboard. The boat and whale then slowly circled the target buoy within a 200-yard radius. A dive and deploy trial would start when the trainer offered the mouthpiece to the whale. After taking the practice grabber, the whale would dive on the target to deploy the grabber (Fig. 12 and 13), and the work boat would continue to circle the target area. After the animal had completed his deployment he returned the mouthpiece to the trainer (Fig. 14) and was rewarded. As soon as the practice-grabber arms surfaced they were recovered by the boat crew and reattached to the mouthpiece in preparation for the next trial.

Figure 12. Ishmael deploying quick-disconnect practice grabber at 30-foot depth.

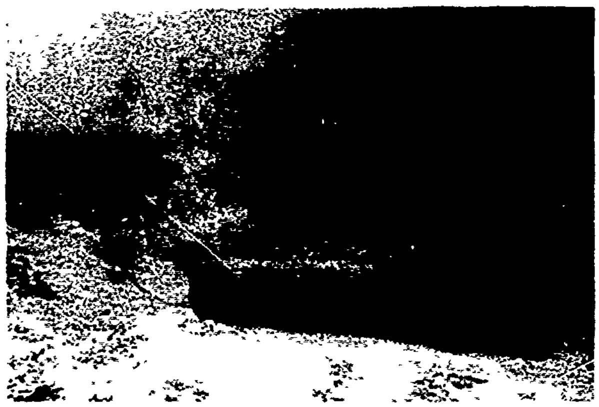

Figure 13. Morgan deploying CAMLOC practice grabber at 60-foot depth.

Figure 14. Ishmael returning practice grabber after successful deployment.

The depth of the whales' dives was determined in two ways: (1) A boat-mounted Raytheon fathometer (model DE-471) was used to locate the various working depths. Once the target was planted, several passes were made by the target area to verify the depth on the fathometer chart read-out. (2) A pack-mounted animal-carried transmitter automatically relayed to the boat, by radio frequency, the maximum depth the animal had attained.

As the work session and open-ocean travel distances increased, it became increasingly difficult to operate from the 25-foot Luhrs cabin cruiser. The sea conditions off windward Oahu generally run 4 to 5 feet, and higher seas of 6 to 8 feet are not uncommon. The average wind velocity is approximately 12 knots. Handling hardware and training animals from the Luhrs in the open ocean was hazardous at best and sometimes dangerous when the swells were above average. A much larger, more seaworthy craft was needed. Therefore NUC, Hawaii, was assigned a 72-foot torpedo recovery boat in November 1970.

Following modifications, the craft was used regularly beginning in January 1971. It took only a few days to accustom all the animals to the torpedo recovery boat. Water flow over the hull created enough pressure to permit Morgan to easily "ride" right behind the stern, under or next to the training platform. The killer whales were too large to get much advantage from the stern pressure wave and consequently had to swim constantly, possibly accounting for their inferior boat-following behavior as compared to Morgan's.

Boat-following speed was governed with the torpedo recovery boat by setting the throttle at 1000 rpm for Morgan and 1000 to 1100 rpm for the killer whales. For these settings, speed varied from 6 to 7 knots, with occasional spurts to 10 knots with following seas and winds. At 6 to 7 knots both species of whale were able to follow the boats for 2- to 4-hour periods with no outward signs of tiring. At speeds greater than 7 knots, the animals (particularly the killer whales) would begin to lag behind. Although killer and pilot whales are capable of speeds far above 7 knots, they will not maintain this speed for sustained periods. Round-trip distances to work sites with 1000-feet to 1200-feet depths were 10 to 12 nautical miles. Occasional boat-following trips were made around Chinaman's Hat Island and Mokumanu Island, where round-trip distances were 13 to 14 nautical miles.

Starting in mid-1970, a four-channel Rustrak chart recorder was used to record animal respiration during open-ocean dive and deploy training sessions. The recorder was mounted inside the boat cabin, and a long wire with four button switches was extended to the stern area of the boat. With this device a trainer who had continuous visual contact with the whale could record all breaths taken by the animal on two channels (one channel for "normal" breaths taken while swimming alongside or lying alongside the boat, and another channel for "induced" breaths taken while surfacing for a fish reward, touching a pinger, or taking a mouthpiece device). The two remaining channels were used to mark the beginning and end of dives or other events, such as the surfacing of floats.

Most commonly, respiratory data were taken 20 to 60 minutes before arriving at a dive work area until about 20 minutes after leaving the area on a homeward track. This interval established average rates of breathing on the way to and on the way back from the work sites (Table 2).

Table 2. Inbound and outbound breathing rates.

Direction	Breaths per minute					
	Morgan			Ahab		
	Avg	Max	Min	Avg	Max	Min
Outbound	3.64	4.98	2.22	2.51	2.92	1.81
Inbound	3.12	4.11	2.31	2.68	3.21	2.21

The outward-bound breathing rate for Morgan averaged 3.46 breaths per minute, and his inbound rate averaged 3.12 breaths per minute. His lower inbound rate was most likely a result of less work being exerted for swimming, as winds and seas are predominantly onshore, enabling Morgan to do a considerable amount of "surfing" on the way in. Also, because his inbound swimming was faster and he was frequently riding waves in positions away from the training platform area, Morgan was generally fed less on the way in and therefore had a lower number of "induced" breaths on the inbound trips.

Average outbound and inbound breathing rates for Ahab were 2.51 breaths per minute and 2.68 breaths per minute, respectively. Ahab's slightly higher inbound breathing rate is probably a result of the tiring effects of the preceding dive and deploy session, more frequent feedings (and therefore more "induced" breaths) on the way in, and poorer ability than Morgan to ride ocean swells and boat wakes.

The first prototype grabbing device was completed in September 1970. Both Morgan and Ahab learned to deploy the grabber without difficulty since very little change in target-approach orientation was required. The task was essentially the same as it had been for practice-grabber trials.

On 26 January 1971 during a practice-grab training session conducted with Ahab in 750 feet of water, the target recovery line snapped and the pingered target cylinder sank to the bottom. It was decided to make an attempt to recover the target using the Deep Ops system. A line pod was quickly fabricated and loaded with 1000 feet of 3/32-inch-diameter line. This pod was attached to the grabber so that when the grabber was deployed a float would pull the line to the surface. Then, hopefully, the training target could be slowly winched to the surface.

Two preliminary shallow-water (100 foot) tests with Ahab and this system against a dummy torpedo worked well. On 3 February 1971 during the actual attempts to recover the lost target, however, two mouthpiece and grabber units were lost. Ahab dived and was down for correct round-trip times, but on both trials he came back with no mouthpiece or grabber. Although the entire device, mouth-piece, and floats were buoyant, nothing surfaced. It was the consensus of opinion of the engineers and trainers that the grabber had locked onto the target, but because of the smaller diameter and "out-of-roundness" of the training target the separating piston was not able to travel far enough to cause the mouthpiece to separate from the grabber. In this situation Ahab would have no choice but to leave the device on the target. It was a mistake to use the grabber on a target having a smaller diameter than the grabber had been designed for.

Another problem was encountered with the grabber on a later operation: the grabber arms could be locked in a closed position prematurely if the arms were bumped off-angle on the target or on the bottom. When this occurred the whale would often continue on with his deployment effort and jam the closed grabber onto the target without affecting a separation of the mouthpiece from the head. This mode of failure was not discovered until the final weeks of the project, when it was observed during tests of the hydrazine lift-grabber system.

Basically this problem could be solved by running more animal trials with the grabber to increase the whales' proficiency at making direct, clean approaches on the target. Grabber units were considerably more bulky than the practice grabbers and were slightly more difficult for the whales to maneuver and place on the targets. However, time limited the number of grabber trials possible.

Another possible solution to premature or nonseparating grabber locks was the addition of a mechanism on the grabber unit which prevented the arms from locking until the separation piston had been depressed far enough to free the mouthpiece. This mechanism was tested and worked fairly well except that added friction from some of its moving parts made the grabber slightly harder to deploy.

Shortly after the unsuccessful attempts to recover the lost training target, Ahab stopped eating. His motivation and food drive remained low for 3 weeks, during which time open-ocean training was curtailed with him. During this same period Morgan's behavior was abnormal. In 1970, from mid-February through March, and through the same period of 1971, Morgan experienced periods of rutting. His rubbing behavior increased, and at times he would refuse food for 1 or 2 days. He had frequent erections and would try to copulate with any large object in his enclosure, such as the rubber raft, the training platform, or the transporter. Several times during these periods Morgan was not worked in fear that in this condition behavioral control might be thwarted by his increased sexual activity and low food drive. Dive training continued with Ishmael, who appeared normal.

As noted earlier, Ishmael was less adaptable and more inconsistent in some of his behaviors than Morgan and Ahab. During early dive training he would often refuse to make over one dive, even at the shallowest depths. Occasionally on the way out of the channel he would turn away from the boat and swim back to his training area. He would, however, always boat-follow well when returning from an open-ocean dive training session. Gradually his inconsistent behavior began to diminish.

During his last training session in February Ishmael made a dive to 500 feet. On the next trial he took the practice grabber, made a shallow dive, and returned to the boat. On a third try he made another shallow dive and spat out the practice grabber. Upon surfacing he was lob-tailing and slapping his pectoral fins in apparent anger or frustration, as he had often done in the past when training pressure was applied. He swam a few hundred yards away from the boat, and the trainers decided to terminate the session. As the trainers began winching in the target they placed the recall in the water and Ishmael headed back toward the direction of the boat. A couple of minutes later, however, Ishmael broke off and started heading towards the mouth of the channel. His back-pack transmitter was transmitting intermittently and its signal was readable only at close range. When it was obvious he was not going to answer the recall and return, the boat proceeded at flank speed in the direction he was heading. Ishmael was last sighted when he was ¼ mile from the boat and ¼ mile out from the channel sea-buoys; at this time the automatic direction finder signal was very weak.

His last sighted position was reached by the boat in a matter of 2 or 3 minutes, and the trainers assumed he had headed for the channel and home. A quick search of the channel and Sag Harbor area, however, showed this assumption to be wrong. The boat was turned around, but contact was never regained. A follow-up search was made for several days using Marine helicopters and several NUC surface craft. No sightings were made.

The Deep Ops staff's firm conviction was that even though behavioral control was lost, the trainers could have approached him, regained control, and returned him to Sag Harbor if contact with the automatic direction finder could have been maintained. After his loss, more emphasis was placed on the reliability of the tracking gear. A back-up transmitter was later installed on Ahab's pack. Although a malfunctioning automatic direction finder system resulted in Ishmael's loss, a functioning system later enabled Ahab's recovery after a 24-hour period.

The seasonal rut that male cetaceans go through may have been partially responsible for Ahab's and Ishmael's behavioral breakdowns, although Ishmael exhibited none of the behavior often evident during the rutting cycle, such as low food drive or high sexual arousal.

When Ahab's in-pen behavior returned to normal on 1 March 1971 (after 1 month of spotty feeding and lethargic behavior), dive and deploy training was resumed with him. It was noted immediately, however, that his boat-follow control and deep-dive ability had fallen off considerably since his 750-foot dive and deploy sessions of January 1971. Several refresher training sessions were run in the shallow waters of the bay and ocean channel. Upon moving to intermediate depth (100 feet to 500 feet) he exhibited behavior similar to Ishmael's, often refusing to dive more than once or twice each session. If training pressure was applied, he objected by lob-tailing or discarding the mouthpiece.

Prior to 11 March 1971 Ahab's swimming speed while diving had averaged 3.5 knots (Fig. 15). After that date his average dive speed dropped to 2.3 knots. The quality of his boat following and diving behavior remained at low levels for the remainder of the program, except for a period of a few days in June 1971 when his performance improved -" ' 'ly. On 4 June 1971 Ahab dived and deployed at a depth

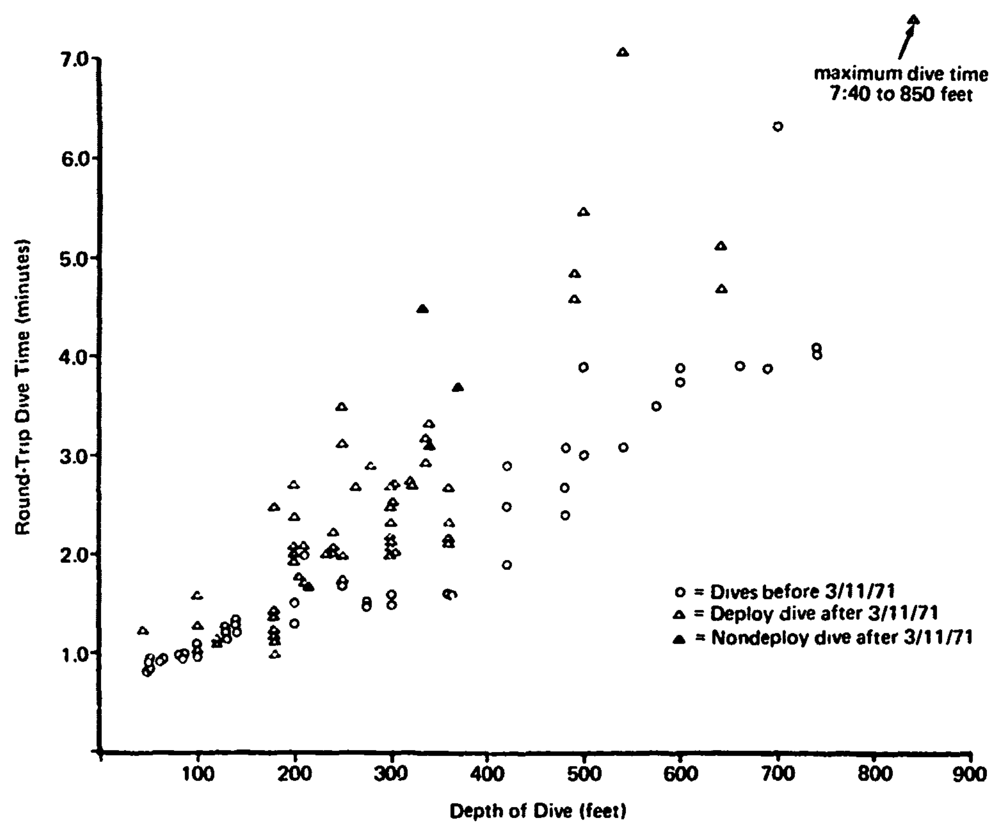

Figure 15. Ahab's round-trip dive time versus depth of dive.

of 850 feet with a down time of 7 minutes 40 seconds. This was his deepest dive and longest breathhold recorded.

On 8 June 1971 Ahab had his last deep-dive training session with Project Deep Ops. He made three dives to 550 feet and then refused to dive when the target was moved to a 750-foot depth. On the way back from the work area, at 1445 hours, Ahab left the boat and began surfing. He disappeared and was picked up on the automatic direction finder heading away from the boat in a northwesterly direction. Through the next 14½ hours he would answer the recall and follow the boat only if the crew's plans followed his. At 0520 on 9 June he began to follow the boat toward home base. After a total elapsed time of 24 hours in which he covered ove: 50 nautical miles, Ahab was finally led back to his enclosure (Fig. 16). During the entire journey the sea was rough, with wave heights of 6 to 12 feet and winds of 15 to 30 knots. If the tracking gear had failed during the 24-hour excursion, the animal would certainly have been lost. Thereafter, dive training sessions were terminated with Ahab for several reasons: (1) An insufficient amount of time rer..ained to correct behavioral problems before the project was to be terminated, (2) A new longer range transmitter could not be fabricated before the project terminated (a necessity to safeguard against future lapses in control). (3) All things considered, it was highly unlikely that Ahab could have equalled Morgan's dive capability in the time remaining.

The last 4 months of Project Deep Ops (June through September 1971) were devoted almost exclusively to Morgan's dive and deploy training.

As Morgan progressed to diving to deeper depths in successive training sessions, the number of trials per session was gradually reduced. From 100 feet to 500 feet Morgan performed an average of 5 to 7 practice deploy dives. Time between dives varied from 1 minute to about 20 minutes, depending upon how quickly the float arms were retrieved or whether the target was moved to another location for the next trial. Between 500 feet and 1000 feet an average of 3 to 4 trials were run, with between-dive periods of 5 minutes to 20 minutes. For dives to depths greater than 1000 feet 2 to 3 trials were normally run, with between-dive periods of 6 to 10 minutes. Long intertrial periods were rare here since only one depth was usually worked during each session, and therefore time-consuming target moves were not made.

In the majority of the sessions when the dives were to be deeper than 1000 feet, warm-up training trials were conducted. A variety of target deployment strategies were tried, such as starting each session 100 feet deeper than the previous day, starting each session at the same depth as the previous day, or conducting a warm-up trial at a much shallower depth. The final strategy adopted was to set the day's deep-dive goal according to the previous day's results. For example, if on the previous day the whale had reached 1400 feet, the next day's trials would be run at 1100 feet, 1300 feet, 1400 feet, and 1500 feet. The number of trials run each session would depend primarily on the whale's motivation and response levels.

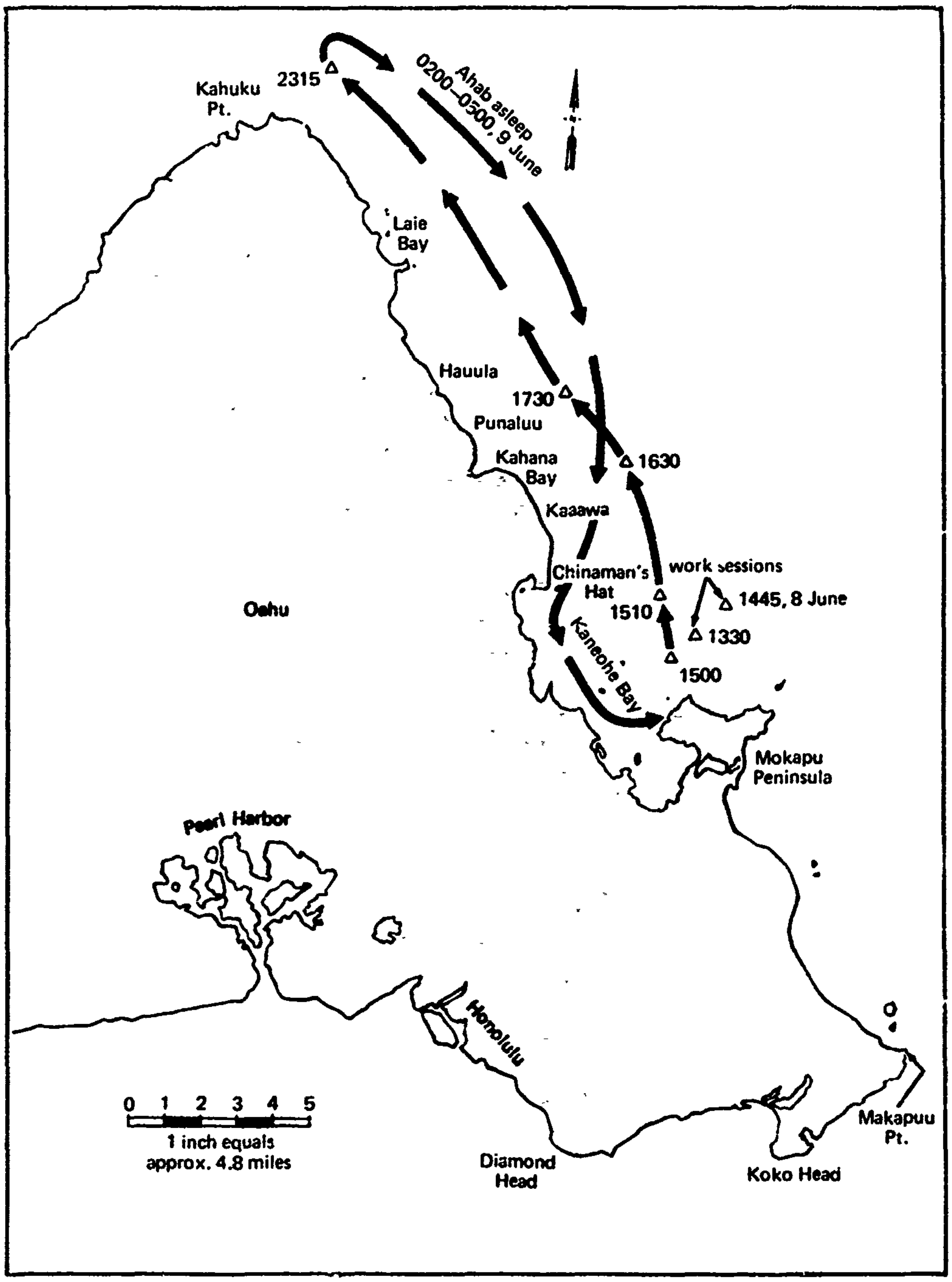

Figure 16. Ahab's track.

Attempts were made to advance at least 100 feet per daily session.

There were a number of behaviors exhibited by the animals that helped the trainer to "read" the animals' response levels. These behaviors included food drive, awareness, boat-follow speed, concentration, and attentiveness. In most cases these often subjective evaluations proved reliable in the field training situation and enabled the trainers to predict performance or to side-step training problems before they became critical.

Morgan's diving speeds maintained a fairly constant average of 2.5 knots through all stages of his dive and deploy training (Fig. 17). On some trials where his down-times were abnormally long, he was possibly delayed by steep target angles which made it difficult to deploy the practice grabber. Irregular bottom terrain and weak target pinger signals may also have periodically affected his time spent searching for the target. On a few trials, while working in areas of irregular terrain (as indicated by fathometer), Morgan had abnormally long dive times and surfaced without deploying the practice grabber. After dragging the target rope for a few hundred yards and then running another trial, Morgan commonly was able to execute a normal deploy dive.

During early shallow-water dive training, Morgan would often make exploratory dives (without the practice grabber) to the target area. At the beginning of a session when the target was dropped overboard, Morgan would frequently follow it all the way to the bottom (as indicated by depth-of-dive readings). Also, at varying points in a session he would refuse to take the practice grabber and would make a dive without the device. Shortly after Morgan began working in depths over 1000 feet, these "volunteered" dives increased in frequency and interfered with practice-grab deploy training. This behavior was apparently Morgan's way of making the dives easier for himself by not having to carry the practice grabber.

From mid-March 1971 through the end of July 1971 he made 50 volunteered dives to depths greater than 500 feet. Forty of these dives were to depths over 1000 feet. Where round-trip times were appropriate, Morgan always made it to the target depth, as verified by the depth-of-dive unit.

During one extraordinary session in June, when the target was placed in 1140 feet of water, Morgan made 9 voluntary dives on the target (Table 3). Also, on 28 July 1971, during a session when the target had just been placed at a 2000-foot depth, he made a free dive of more than 13 minutes, indicating that he probably made it to that depth. The depth-of-dive transmitter was malfunctioning during that session, so the actual depth of the dive was not verified.

Through the month of June 1971 Morgan was worked mostly at depths of 1000 to 1100 feet in an attempt to stabilize his diving proficiency and to eliminate volunteered dives. In early July 1971 he progressed rapidly, diving and deploying the

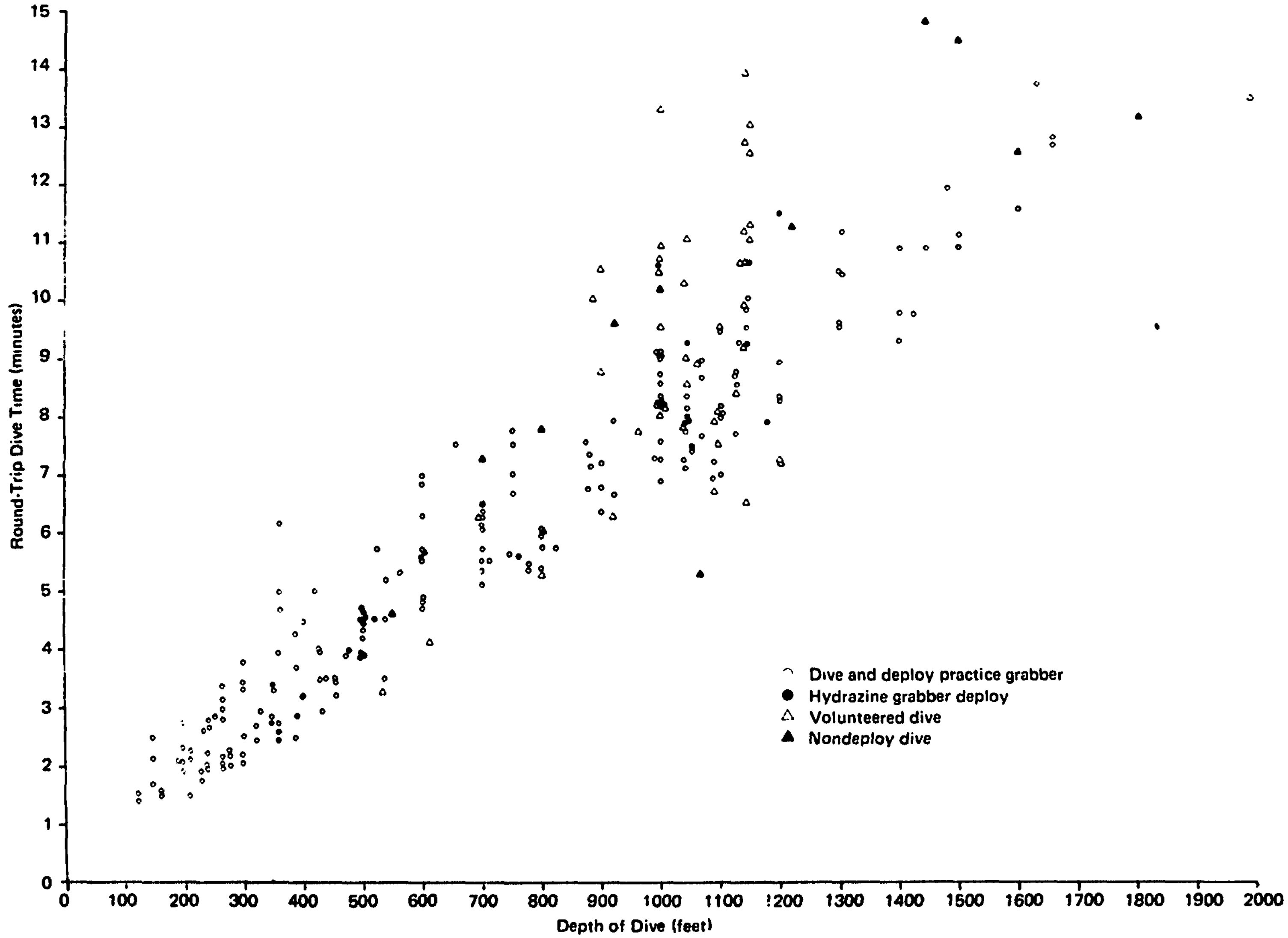

Figure 17. Morgan's round-trip dive time versus depth of dive.

practice grabber at depths of 1300 feet on 1 July, 1440 feet on 2 July, and 1500 feet on 6 and 7 July. (Morgan's longest recorded dive time of 14 minutes 49 seconds was on one of the 1440-foot dives.) On 9 July 1971 Morgan reached his deepest deploy depth of 1654 feet with two dives of 12 minutes 47 seconds and 12 minutes 38 seconds. Except for his possible volunteered dive to 2000 feet (28 July 1971) all attempts to get him to dive deeper were fruitless.

Table 3. Morgan's volunteered dives at a target placed at an 1140-foot depth.

Depth of dive, ft	Dive time	Time between dives
1140	12:45	6:35
1140	9:35	1:30
290	3:15	6:05
438	4:02	2:35
1140	9:15	5:30
215	2:10	6:05
20	0:30	4:45
1135	11:15	7:03
1130	10:36	
Totals	63:23	40:08

Volunteered dive behavior was virtually eliminated by mid-July 1971 by masking the bottom-located 9-kHz pinger with a 9-kHz pinger (held off the boat stern) when it looked as if Morgan was preparing for a noncommand dive. A standard recall pinger was also used to keep Morgan's attention diverted prior to a dive and deploy run. Additional reasons for the practical cessation of volunteered dives were that no reward was given for no-deploy dives and Morgan had possibly become accustomed to deeper diving.

In December 1970 the project had initiated the development of a hydrazine lift system. The hydrazine unit was designed to fit on the existing mouthpiece-grabber units. Before the project undertook the development of the hydrazine lift system, several recovery concepts were conceived, reviewed, and evaluated (Ref. 7). With the exception of the hydrazine system, all other systems involved the use of recovery lines. Those concepts required that the animal carry a line pod down with him. All the recovery line concepts were rejected because of package size, drag effects, or line entanglement hazards to the animals. Additionally the majority of the recovery line concepts would have involved increased adaptation and dive-deployment training time.

The hydrazine system posed minimal packaging problems, did not add significantly to the size or drag of the existing mouthpiece grabber, and presented virtually no hazards to the animals.

The hydrazine grabber lift system was first tested with Morgan in 30 feet of water on 29 July 1971. Although the unit was slightly heavier and bulkier than the training mouthpiece grabber, it made no apparent difference to Morgan. He readily accepted the hydrazine unit ana dived and deployed it on the target, a dummy Mk 46 torpedo (Fig. 18).

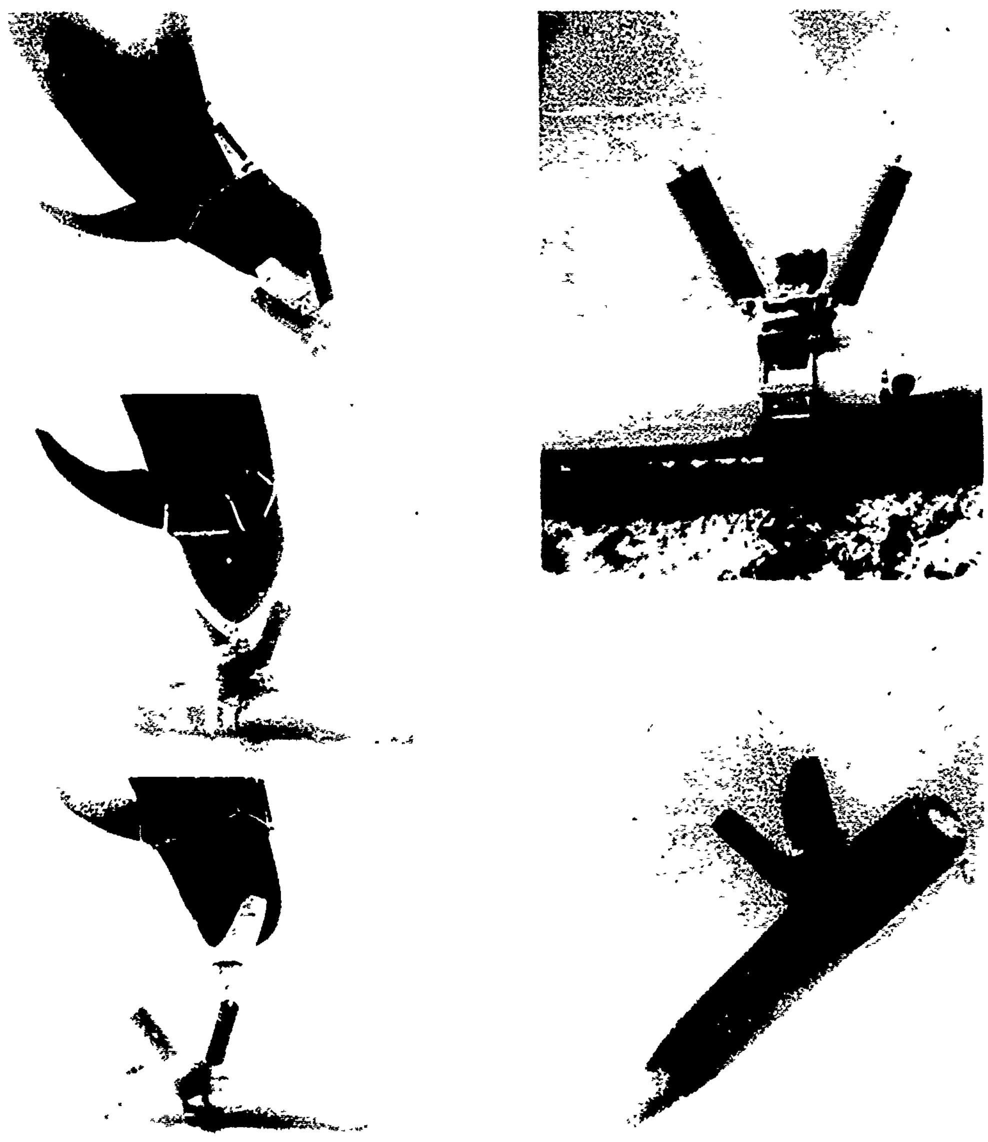

Figure 18. Morgan deploying hydrazine-propelled grabber system on a dummy Mk 46 torpedo.

Morgan was a bit "surprised" when the grabber arms did not float to the surface as the training-model arms normally did. He bumped the fuel pods several times with the mouthpiece, apparently trying to dislodge them so they would surface. The sound produced by the hydrazine gas generation and the associated escaping bubbles from around the lift bag had no influence on Morgan's deployment behavior. He exhibited only minor curiosity when the system was activated.

On 12 August 1971, after initial hydrazine tests were conducted and the project's film documentation was completed, the torpedo recovery boat was pulled out of the water for its semiannual maintenance. The boat was put back into service on 7 September 1971, and dive training and hydrazine testing was resumed and continued through the end of October 1971.

On 15 November 1971 Morgan successfully deployed the hydrazine lift system and effected the recovery of a dummy Mk 46 torpedo in 500 feet of water. The recovery site was approximately 5 nautical miles from Sag Harbor. On one other occasion Morgan deployed the hydrazine unit on a 1000-foot-deep target; however, the grabber did not attach properly. Subsequent attempts were frustrated by inclement weather and heavy seas, and the project was officially concluded on 1 December 1971..

DISCUSSION OF CETACEAN DIVING BEHAVIOR AND CAPABILITIES

In making deep dives, marine mammals must be able to tolerate great pressures and hold their breath for long periods of time. Sperm whales apparently dive regularly to depths of more than 3000 feet, and a Weddell seal is known to have reached almost 2000 feet (Ref. 8). On the basis of stomach content analysis, Cadenat (Ref. 9) suggested that the bottlenose dolphin dives to 650 feet or more in his normal feeding activities. Evans (Ref. 10) attached sensing and telemetry devices to common dolphins (*Delphinus delphis*) and recorded a maximum depth of dive of 845 feet.

Bottlenose whales are credited with being able to remain submerged for 2 hours, and the sperm whale for 1¼ hours (Ref. 11). Daugherty (Ref. 12), without referencing her sources, gives dive times of 15 minutes for the killer whale and 20 minutes for a pilot whale that apparently dived to 1200 feet in the course of being captured by the collecting boat of Marineland of the Pacific. A similar depth-of-dive capability for the pilot whale has been inferred from observed feeding behavior (Ref. 8).

In 1967 at the Navy's Marine Bioscience Facility at Point Mugu, California, Evans and Harmon (Ref. 5) trained a California sea lion and a harbor seal for diving tests; the sea lion reached 560 feet and the seal 90 feet. In 1969, at the same facility, a trained California sea lion was making dives on command to 750 feet.*

In a diving physiology study conducted by Ridgway, Scronce, and Kanwisher (Ref. 13) a bottlenose dolphin named Tuffy made dives to depths as great as 1000 feet. Tuffy's longest recorded breathhold was 4 minutes 45 seconds, but another bottlenose dolphin held its breath for 7 minutes 15 seconds during a pressure chamber experiment.

Many factors are involved in the prolonged diving capabilities of cetaceans. Some of these, as summarized from Scholander (Ref. 11) are listed below:

1. Relative insensitivity to carbon dioxide.

2. Differential vascular control of the distribution of the limited oxygen stores during a dive, keeping mainly the brain and heart supplied with oxygen, whereas organs with little susceptibility to a lack of oxygen, like the muscles, are confined to work anaerobically, or nearly so, during a dive.

3. Ability to incur an oxygen debt which can be paid off later.

4. On deep dives the partial pressure of oxygen increases, enabling full use of the oxygen in lungs.

5. High oxygen capacity of blood; the blood of the sperm whale and some *Phocaena* showed an oxygen capacity of 24% (which is about 30% more than the oxygen capacity of seals).

6. Ability to store oxygen in muscle myoglobin; in larger whales (with flesh weights about 50% of body weight) muscle samples gave off 3% to 8.5% oxygen, representing a very considerable oxygen storage factor.

7. Possible functioning of the retia mirabilia (vascular networks located from the base of the skull and downwards along the thoracic column) in the regulation of circulation during diving; this system may represent an arteriovenous shunt which can allow blood to bypass the muscles.

8. Respiratory and circulatory activity of whales favors the elimination of dissolved nitrogen at the same rate as the solution of nitrogen that accumulates during diving.

9. The maximum length of a whale's dive is assumed to increase with the size of the whale, since the lung volume increases with the body volume, whereas the oxygen consumption increases only with the surface area.

Taking into consideration the aforementioned natural and trained behaviors and the factors involved in diving, it was estimated that pilot whales and killer whales could be trained to dive to at least 1000 feet and possibly as deep as 2000 to 3000 feet.

A depth of 1200 feet probably represents the average "natural" limit to which pilot whales (of Morgan's size) can dive and feed effectively. As indicated by the NUC data, a secondary "trained" depth limit exists somewhere between 1600 and 2000 feet, representing a level to which, under training pressure, the animal will "bounce dive" (that is, dive and make a quick return to the surface).

As noted by Ridgway et al. (Ref. 13), the oxygen level in dolphin expiration drops by 60 to 70% after the first 2 minutes of breath holding (Fig. 19). During the deeper parts of dives, oxygen is supplied 40 times more slowly than it is at the surface. Toward the end of long dives, when the lung and blood stores have been expended, oxygen would presumably be drawn from myoglobin in the muscle tissues. It has been suggested that oxygen drawn from the muscle stores is more difficult to replenish than oxygen drawn from the blood supply (W. E. Evans, personal communication). Therefore, an animal which had incurred a muscle oxygen deficit on a long dive would take a substantially larger number of recovery breaths than an animal that had made a dive on lung and blood oxygen.

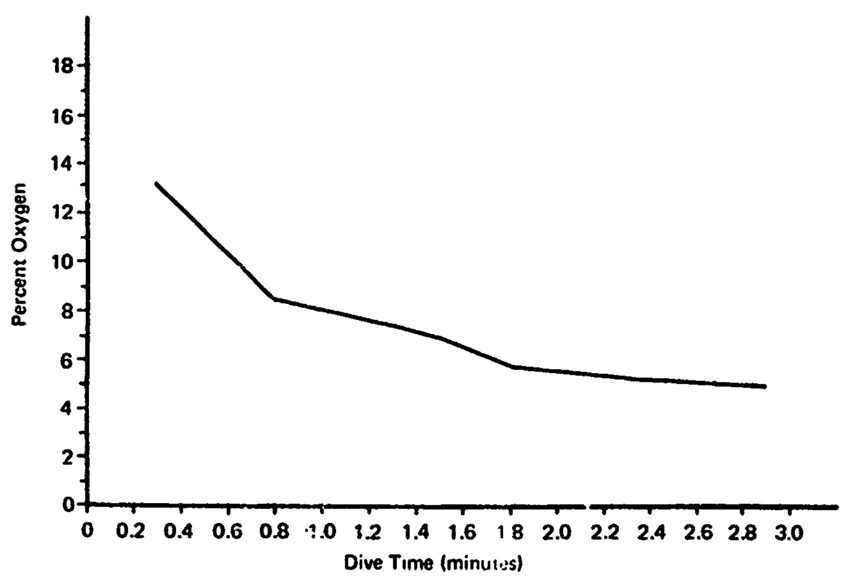

Figure 19. Oxygen level in expiration rate of *Tursiops truncatus* as a function of dive time. (After Ridgeway et al (Ref. 13).)

From breathing data taken during dive sessions, curves were plotted to show the average number of hyperventilation breaths (pre-dive) and recovery breaths (post-dive) versus dive duration for Morgan and Ahab (Fig. 20 and 21). Typically, these periods of accelerated breathing were quite obvious on the chart recordings.

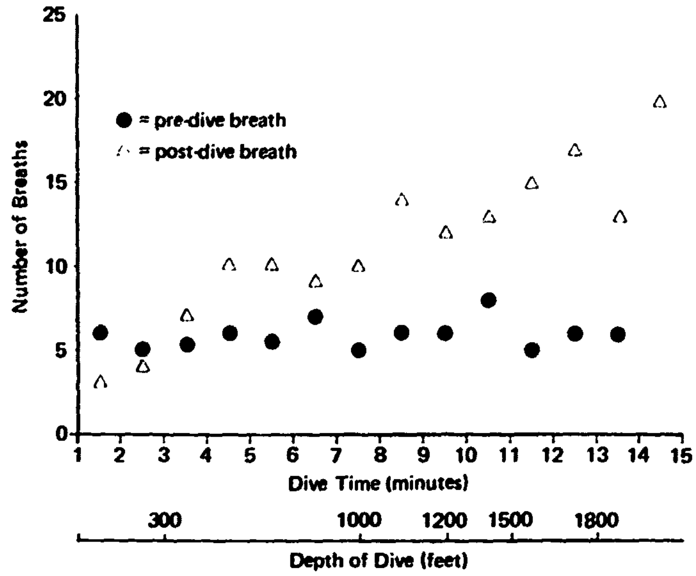

Figure 20. Pre-dive and post-dive hyperventilation breaths for Morgan.

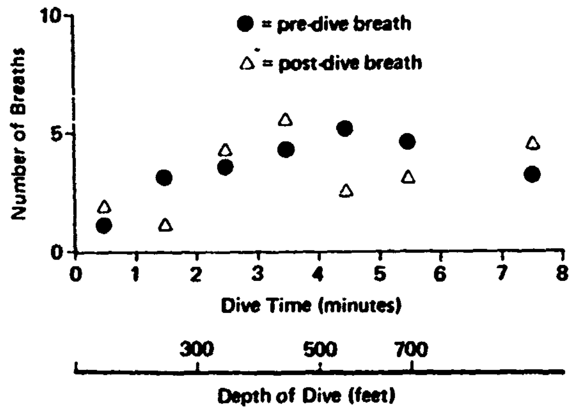

Figure 21. Pre-dive and post-dive hyperventilation breaths for Ahab.

Before diving, the animals normally took several rapid and deep breaths (about 6 for Morgan and 3 to 4 for Ahab), and upon surfacing they took several closely spaced breaths for recovery.

The number of recovery breaths Morgan took after dives increased rather rapidly through the 2-minute to 5-minute dive duration intervals (Fig. 20). The first inflection point at approximately 5 minutes possibly represents the use of approximately 70% of his available oxygen. A second steep increase occurs near 11 minutes and persists through Morgan's maximum dive time of 14 minutes 49 seconds. During this interval Morgan apparently draws on muscle oxygen stores and approaches an upper limit of dive duration (15 to 16 minutes).

With the killer whales, where maximum dive and deploy depths of 500 feet for Ishmael and 850 feet for Ahab were obtained, full dive capabilities were certainly not reached. Ahab initially progressed from shallow-water practice deploying to diving and deploying at 750-foot depths in the relatively short training time of 53 hours over 98 training days (as compared to Morgan's 81 hours over 181 training days). Ahab's progress therafter was seriously hampered by a 6-week illness and several behavioral lapses, which limited his open-ocean work schedule for the remainder of the Deep Ops program. Ishmael was lost in the open ocean in the middle of his maximum depth session of 500 feet.

As illustrated in Fig. 21 Ahab's number of post-dive breaths increased somewhat through the 2-minute to 4-minute dive duration intervals. A large number of those dives, however, took place during Ahab's period of illness when he may have been under stress. Dives longer in duration (4 minutes to 7 minutes 59 seconds) were performed prior to his illness and show minimal increase in hyperventilation or recovery breathing. These data suggest that the killer whales did not approach their full dive capabilities.

HARDWARE DEVELOPMENT

Mouth-Carried Practice Grabber and Training Targets

As best as can be determined, the only apparatus which whales have been heretofore conditioned to carry for mark or recovery functions are weighted rings. In oceanaria shows dolphins and whales are commonly trained to mouth-carry rings to bottom targets. To increase the dolphin's ability to carry and manipulate hardware, NUC developed rostrum (nose) cups as attachment points for lines, small payloads, and recovery grabbers. These nose cups could also be fitted with separable marking heads which were actuated when pressed against an object, sending a buoyed line to the surface.

Although successful with dolphins, the concept of a nose cup device was not applicable to pilot and killer whales because of their lack of a prominently long and narrow rostrum, a characteristic feature of bottle-nosed dolphins. Some thought was given to a "melon cage" that would fit over a whale's head from his snout to some area posterior of his eyes or lower jaw. An apparatus such as this, however, would have been very bulky and might have interfered appreciably with the whale's echolocation and vision.

In early June of 1969 object-mark training began with Morgan, NUC's first pilot whale. Initially, he was required to carry a ring (made of stiff hose) and drop it in a large pingered hoop placed on the enclosure bottom. Within a couple of weeks he was performing this behavior well in 15 feet of water and was carrying rings of 8 inches to 18 inches in diameter. Each ring was weighted with approximately 2 pounds of metal hardware, and in a carrying-capacity study in August, Morgan carried the rings with up to 25 pounds of lead weights on them. During marking exercises the longer weights seemed to cause him some difficulty because they hung below his lower jaw and dragged or snagged on bottom obstacles.

It was decided in early August 1969 to experiment with a biteplate as a structure which Morgan could more efficiently carry and with which he could deploy mark and grab devices. To construct an experimental mouthpiece, it was necessary to first obtain dimensions of Morgan's jaws and dental and gum configurations. To serve as an impression plate, a semiflexible plate of Teflon plastic (1/8 inch thick), bordered on three edges with plywood, was coated with ½ inch of modeling clay. Approximately 3 hours of training was required to get Morgan to carry this impression plate to obtain traces in the clay of his upper and lower gums and impressions of his lower jaw teeth.

After the dimensions were obtained from the impression plate, Morgan's first mouthpiece was constructed (Fig. 22) and was introduced to him on 6 August 1969.

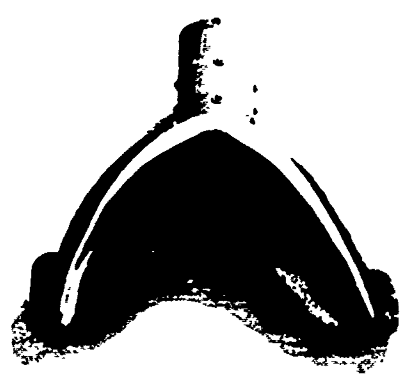

Figure 22. First mouthpiece for Morgan.

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The bite surface of this mouthpiece was made of 1/8-inch- thick nylon plastic and was covered on upper and lower surfaces with ¼-inch-thick neoprene rubber. A nylon skirt, backed with ¾-inch-plywood, was attached around the bite surface perimeter. This skirt fit Morgan's outer lip profile and added ridigity to the entire device.

Morgan adapted quickly to carrying this mouthpiece. A modified dolphin nose cup was attached to the front of the plate (Fig. 8). A plastic cone on the end of the nose cup assembly could be separated from the mouthpiece when a button on the tip of the nose cone was depressed. Morgan was taught to take the mouthpiece–nose cone combination and affect separation of the cone by pressing it against a piece of 8-inch-diameter, 4-inch-long aluminum stovepipe. This stovepipe target was hand-held in a horizontal attitude just below the surface of the water, a short distance away from where Morgan received the mouthpiece.

On 8 October 1969 a second mouthpiece of stouter fabrication and slightly better fit was introduced. Built onto the forward end of the nose cone were two pairs of semicircular aluminum arms having a 12-inch radius. Mounted vertically with respect to the mouthpiece, the arms had to be oriented perpendicular to the axis of cylindrical targets in order for the whales to depress the separation button on the nose cone. This mouthpiece–arm combination served as the first practice grabber.

By mid-October 1969 Morgan was taking the device in his mouth to a cylindrical target and separating the cone with about 25% reliability. After each separation attempt on the cylinder, successful or not, Morgan was required to return the mouthpiece to the trainer. The biggest problem with this first practice grabber was that it frequently misfired or broke during Morgan's experimental bumps on the target; a much sturdier separation mechanism was needed.

Project Deep Ops received its first killer whale (Ahab, a 19-foot, 5500-pound male) from Point Mugu, California, on 22 October 1969. To allow commencement of practice-grab training with Ahab and to continue training with the pilot whale, a custom mouthpiece for each animal was fitted with a nondetachable pair of semicircular arms made of ¼-inch-thick, 1-inch-wide aluminum; a 3½-inch-diameter, 6-inch-long aluminum tube connected the arms to the mouthpiece (Fig. 23). With these temporary devices, the whales could be trained to make oriented contacts on the cylindrical training targets.

In the first week of December 1969 engineering help completed a new design practice grabber which had a separable arm head and a float-line which deployed upon separation of the arms from the mouthpiece. Basically this device consisted of two 4-inch-long aluminum tubes having a diameter of 3½ inches. These sections were held together by four CAMLOC tension latches (CAMLOC Division, REX Chainbelt Inc., Paramus, New Jersey) which were spaced equally around the tube circumfer-

Figure 23. Second mouthpiece for Morgan with nonseparable prongs for "orientation" training.

ence. The arm tube section housed a spring-loaded plunger which protruded approximately an inch into the arc of the arms. Depression of this plunger tripped four L-shaped trigger arms, which in turn tripped the four CAMLOCs which held the tubes together. The prong section would then remain in place on the target while the whale surfaced with the mouthpiece. Also, upon separation of the units, a float line was deployed which had been held in place by an aluminum bar which fit into a slot between the two tubular sections.

By late December 1969 Morgan was reliably deploying the CAMLOC practice grabber on targets placed on his pen bottom at 20-foot depths. On 19 January 1971 an identical unit was introduced to Ahab. After several weeks of training with both animals, several modifications were made on the CAMLOC practice grabbers (Fig. 24). The arms were made of ¼-inch aluminum plate, and large wooden blocks were

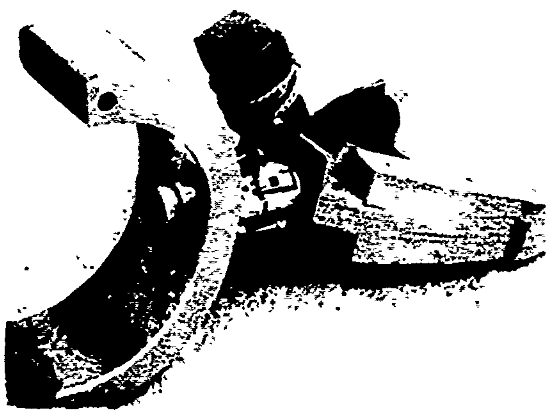

Figure 24. Modified CAMLOC practice grabber.

bolted between the arm pairs to add flotation and strength. Metal blocks on which the CAMLOC's grabbed were raised and made of stainless steel rather than aluminum (these surfaces showed extensive wear as a result of bending actions on the tube when the whales made off-center contacts with solid objects). Small blocks of neoprene rubber were glued under the CAMLOC arms to serve as springs to push the arms free upon triggering. Generally the device operated well in the course of normal training with the pilot whale; however, work with the killer whale brought on numerous failures of the CAMLOCs, and design was begun of a more durable separation mechanism.

By March 1970 Morgan and Ahab both had two custom-fit mouthpieces apiece. The innermost layer of each biteplate consisted of 1/8-inch-thick aluminum which was sandwiched, top and bottom, with layers of 1/8-inch plywood, 1/4-inch neoprene, and 1/16-inch diaphragm rubber. Experience revealed that neither whale would carry a biteplate with a total thickness greater than 1 inch. Also, once a particular shape of plate was introduced to an animal and he had been worked with it for several sessions, it was very difficult to introduce a plate with a different shape without a considerable amount of training. For these reasons, each new mouthpiece for a particular whale had to follow closely the dimensions of the original. On all four mouthpieces, blocks of sugar pine wood were contoured around the outside margins of the Teflon lip fences. These wood pieces, together with the wood blocks between the practice prongs, rendered the entire device positively buoyant in both a separated or unseparated state.

In late March 1970 a practice grabber with a new release mechanism was tested with Ahab. This new device used the same basic tubular sections of the CAMLOC device which fit end to end; however, a quick-disconnect air-line fitting (Flex-O-Matic, automatic coupling, series 66, models 66-1012 and 66-0112, Lincoln Engineering Co., Calif.) replaced the CAMLOCs as the connecting link. The quick-disconnect fitting was mounted inside the 3½-inch tubes. The female link of the quick-disconnect was mounted firmly on a cross-plate inside the mouthpiece tube, and the male link was mounted on the mouthpiece-end of the trigger plunger in the arm-end tube. An external sliding collar connected to the trigger plunger allowed the plunger to be slid backwards forcibly to connect its female connector to the male connector in the mouthpiece tube. A threaded collar located between the sliding collar and the tube juncture could then be screwed outward to tighten the entire connection. Thereafter, the tubes could be separated by pressing the trigger plunger. This would push the quick-disconnect socket sleeve back, allowing a set of pins to drop out of position, releasing the two connector components from each other.

A custom mouthpiece and CAMLOC practice grabber unit were fabricated for training when the second killer whale, Ishmael, arrived. Ishmael and Morgan continued to use the CAMLOC devices until the sturdier quick-release units were completed in May and June 1970. Upon mounting the quick-release units to the smaller mouthpieces of Morgan and Ishmael, it was found that the increased weight of the new devices caused the total device to be negatively buoyant. More buoyancy was required to keep the total device afloat.

Sugar pine wood added to the mouthpieces and arms was found to be inadequate for flotation in deep water. Pressure tests performed on blocks of pine indicated that after 24 hours at a 3000-foot pressure the blocks were fully saturated with water and were no longer buoyant (Ref. 14). Syntactic foam suited for deep use was ordered; however, for temporary flotation at intermediate depths it was decided to use capped polyvinyl chloride tube floats. These tubes had wall thicknesses of ¼ inch and were 4 inches in diameter and 12 inches or 18 inches long. One pair of floats was used with each practice grabber unit. An aluminum V-shaped bar held the floats in positions along both sides of the mouthpiece. A short piece of line originally connected the V-shaped float to the arm head; thus, when the arms were released from the mouthpiece they were pulled to the surface by the floats. Later the aluminum bars to which the floats were attached were simply bolted in place on the arm assembly.

For deep-water flotation of the mouthpieces, syntactic foam blocks (density 0.61, 37 lb/ft^3) replaced the sugar pine wood. The foam blocks were approximately 30% bulkier than the wood material, but the whales generally accepted the greater bulk with little problem. By late August 1970 all animals were working with polyvinyl chloride arm floats and syntactic foam mouthpieces. Between April and December 1970 several other modifications were made to further reduce weight and increase flotation on the total device. The semicircular arm previously made of ¼-inch aluminum was made instead of polypropylene plastic (density approximately 0.9). Besides being slightly buoyant, this material had the added advantage of being very resilient. The aluminum arms were easily bent out of shape by occasional off-target bumps by the animals, whereas the polypropylene arms retained their shape.

On the joining ends of the two 3½-inch-diameter tubes, permanently affixed aluminum collars provided a wide, keyed mating surface for the two sections. As the whales gained experience with the practice grabbers, they made increasingly gentle contacts with the training targets, enabling project engineers to change the mating collars from metal to polypropylene to add more buoyancy to the entire device. The threaded tightening collars were also changed to polypropylene (Fig. 25).

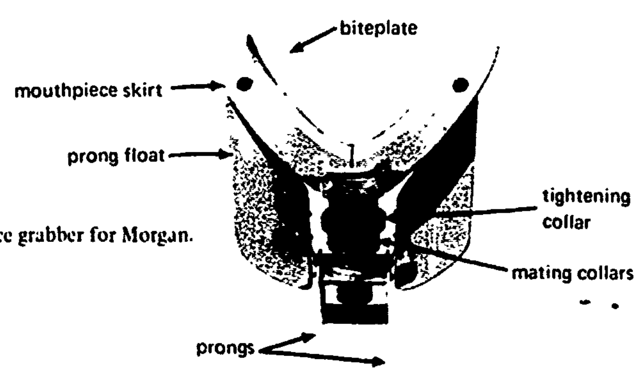

Figure 25. Final model practice grabber for Morgan.

Experimentation with Morgan on acceptance of various biteplates enabled project engineers to replace his aluminum–neoprene–diaphragm rubber mouthpiece with a tapered biteplate made wholly of polypropylene plastic. This plastic biteplate was much simpler to fabricate, added buoyancy to the mouthpiece, and provided a much more durable surface for Morgan to bite on. The rubber surfaces on the older mouthpieces had required replacement rather frequently due to abrasion by the whale's teeth, whereas the polypropylene plate did not scratch or dent readily.

By mid-October 1970 the syntactic foam had still not been received from the manufacturer, and in anticipation of collapse at depth, the polyvinyl chloride tube floats being used on Morgan's practice grabber were filled with ¼-inch-diameter eccospheres. These floats failed to surface during a dive and deploy session with Morgan at a depth of 130 feet. Apparently the tubes had cracked enough to allow the eccospheres to escape. Later, all tube-floats on practice grabbers used in water deeper than 100 feet were replaced with syntactic foam blocks, as was originally planned.

From September 1970 through September 1971 the practice grabbers remained essentially unchanged and functioned well under continual use. Besides daily or weekly wash-downs with fresh water, the only maintenance required was to disassemble the female fitting on the quick-disconnect assembly and pack it with grease. This was done about once every 2 months.

Prototype grabber

In February 1970 the design of a prototype grab device was started. The approach used was to adapt a grabber to the practice grabber release mechanism and mouthpiece. With proper placement and actuation, grab arms were to lock around a cylindrical target and separate from the mouthpiece. A float with a retrieval line would then deploy to the surface.

From several primary designs of varying types, a dual-arm device with distending tubular grab arms was chosen. Fabrication of this grabber (model A-1) was completed in May 1970. Preliminary tests with it indicated problems in the extension of the arms from their tubular sockets. Dissatisfaction with this model prompted the design and fabrication of model B-1 (Ref. 15).

The model B-1 grabber (Fig. 26 and 27) was made of ¼-inch aluminum plate and utilized rotating closure arms rather than distending arms. When pressed against a target and in the proper orientation, the closure arms are forced to rotate and close into circular form and lock into rocking ratchet plates.

This grabber was designed so that the separation-triggering piston cannot be pushed to full activation unless the closure arms are fully closed and locked in

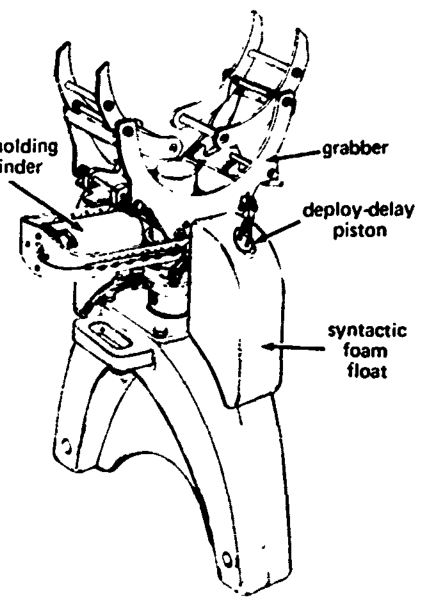

Figure 26. Model B-1 prototype grabber with float and mouthpiece.

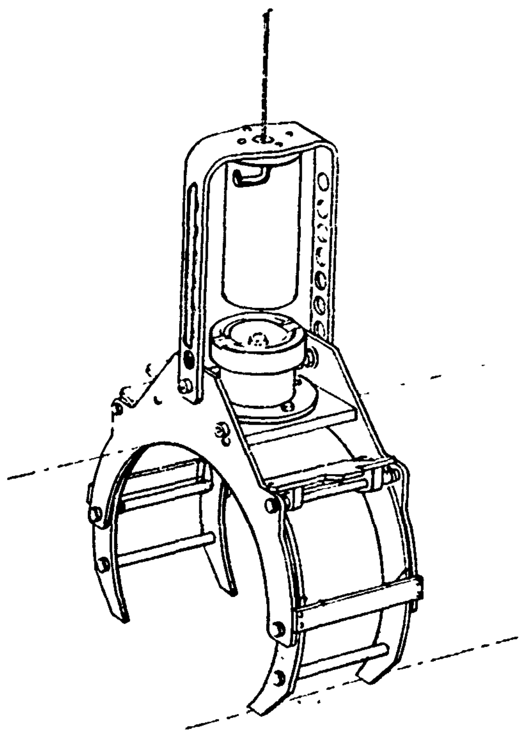

Figure 27. Model B-1 prototype grabber without float and mouthpiece.

position around a target. Thus the grabber must be firmly attached to a target before mouthpiece separation and float-line deployment can occur.

For medium-depth testing, 600 feet of 1/8-inch-diameter nylon line was wound with a shot-line winding device into a cylindrical ball and was fitted into a 3½-inch-diameter, 7-inch-long polyvinyl chloride holding cylinder. The holding cylinder and line snapped into a swiveling aluminum bracket which when not deployed held the cylinder at a right angle to the axis of the mouthpiece–grabber coupling tubes. A float wishbone fit in keyed position between the coupling tubes and pulled the 1/8-inch-diameter line to the surface when the grabber was deployed.

It was hoped that by using the 1/8-inch-diameter nylon line as a travel line, a messenger weight with an attached 3/8-inch-diameter line could be sent down to the grabber. However, tests in the ocean showed that this concept worked reliably in water depths only to 130 feet. Longer lengths of messenger line tended to curve under ocean current conditions, thus preventing proper downward travel of the messenger weights.

Hydrazine Lift System

It was obvious that a float-line method would not work for a system capable of recoveries at depths greater than 1000 feet. In December 1970 development was begun of a hydrazine monopropellant gas generator lift system for deep recoveries. All the components of this system were to be carried on the grab apparatus, and no lines were to be used.

Don Miller, the Navy's leading expert in hydrazine lift systems, was transferred from China Lake, California, to NUC, Hawaii, to design and supervise fabrication of the self-contained lift system. Development began in mid-February 1971, and by early June 1971 a prototype device was ready for testing (Fig. 28).

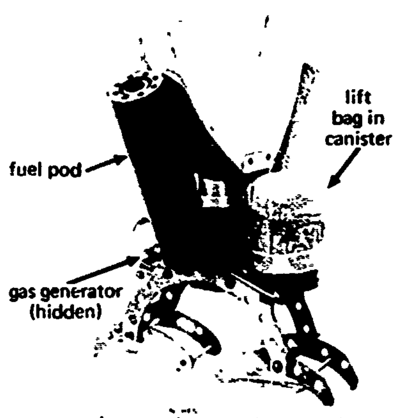

Figure 28. Hydrazine unit.

The basic components of the hydrazine system were designed to match the component configuration of the existing float-line and grabber device. A pair of 4½-inch-diameter, 15-inch-long cylindrical fuel pods were bolted to the grabber, taking approximately the same position and volume as the syntactic foam floats used previously. A 5½-inch-diameter, 6-inch-long canister stored a nylon lift bag and was attached underneath the grabber–mouthpiece junction in place of the line-holding cylinder. Additional hardware, such as high-pressure tubing, valves, and a gas generator, was placed close to the body of the grabber and linkage tubes. The total in-air weight of the entire system with pilot whale mouthpiece attached is approximately 48 pounds. In water and fully fueled, the system is 1 to 2 pounds positively buoyant.

Basically the apparatus works as follows. When the trigger piston is depressed against a target (and the grabber locks on the target), a shaft attached to the piston shears a magnesium pin, opening a spring-loaded fuel valve. With the opening of this valve, hydrazine liquid (N_2H_4) is expelled from the fuel cylinders, passes over a catalyst bed in the generator unit, is converted to gas, and passes through tubes to a baffle chamber built into the bottom of the bag-storage canister. Gas emerging from the baffle then pushes the folded bag from the canister and fills the volume of the bag within approximately 1 minute (Fig. 18). In case of a malfunction, the system will automatically rise to the surface, because the magnesium shear pin which secures the fuel control valve in the closed position will deteriorate after approximately 45 minutes in seawater.

The lift bag is tear-drop-shaped when distended with gas and has a volume of 9.8 ft^3. When inflated with available gas, the bag can lift 600 pounds at a 1000-foot depth, 300 pounds at a 2000-foot depth, and 150 pounds at a 3000-foot depth. It is constructed of 4.6-oz/yd^2 urethane-coated nylon, and loaded suspension is effected by means of 12 straps of nylon (each having a breaking strength of 400 pounds) which pass over the top of the bag and down to the load. The bag was fabricated by Raven Industries, Inc., of Sioux Falls, South Dakota.

Energy for fuel expulsion is provided by storing the hydrazine liquid under moderate pressure within two elastic cylinders. These cylinders have wall thicknesses of approximately 200 thousandths of an inch and are constructed of two layers of ethylene propylene terpolymer material. The inner layer differs slightly in composition from the outer layer and is compatible with the hydrazine fuel. The outer layer of material is of a higher strength and elasticity than the inner layer. When empty, the inside diameter of the cylinders is 1.75 inches; when filled with 4.5 pounds of hydrazine the cylinders expand to 4.10 inches in diameter and fill the inside volumes of surrounding aluminum-protector cylinders. Expulsion pressure is equal to the amount of pressure required to fill the elastomeric cylinders to full capacity, and is independent of ocean depth and ambient pressure.

The gas generator was fabricated at NUC, Hawaii, and consists of a control valve, fuel check valve, shower head injector, spontaneous Shell 405 catalyst bed (composed of approximately 1½ in^3 of iridium-coated alumina-base pellets), body, exhaust tube, and exhaust check valve. When the control valve is opened the hydrazine fuel is expelled from the fuel cylinders through the injector onto the catalyst bed. The liquid hydrazine is then decomposed into gas products (hydrogen, nitrogen, and ammonia) and is exhausted into the lift bag to provide buoyancy.

Hydrazine is a toxic compound which can be quite hazardous if handled improperly. To avoid handling or contacting the fuel at any time during recovery operations, and Deep Ops hydrazine lift system was designed for on-shore fueling. The hydrazine is first transferred from a 55-gallon drum into a high-pressure fuel tank and then into the elastomeric cylinders via quick-disconnect fittings. The charged cylinders can then be stored or transported to the operation location and mounted on the grabber. Each cylinder is attached to the system by the tightening of two wing nuts (Ref.16).

Training Targets

In the early and intermediate stages of training whales to deploy a practice grabber on a bottom target, four sections of steel pipe having a wall thickness of 1/8 inch, a diameter of 12¾ inches, and a length of 6 feet were procured for use as training targets (Fig. 29). To keep the targets from sinking into the soft silt bottom of Kaneohe Bay, they were bolted onto flat plywood bases (¾ inch x 3 feet x 6 feet). Inside each cylinder was placed a 9-kHz pinger (Oceanic Enterprises, model PG-06) and a small listening hydrophone (Clevite Corp., model CH-17). Pingers and hydrophones were linked by long hardwires to control boxes with on and off switches and listening speakers. The listening hydrophones were mounted against the inside walls of the targets and allowed the trainers to hear (at the control box) when the whales made contact with the targets. Sounds that the whales made when approaching the targets were also picked up by the listening apparatus. In the area of the whale pens most targets were left semipermanently in place on the bottom, being moved or lifted from the water only for monthly cleanings or changes of position.

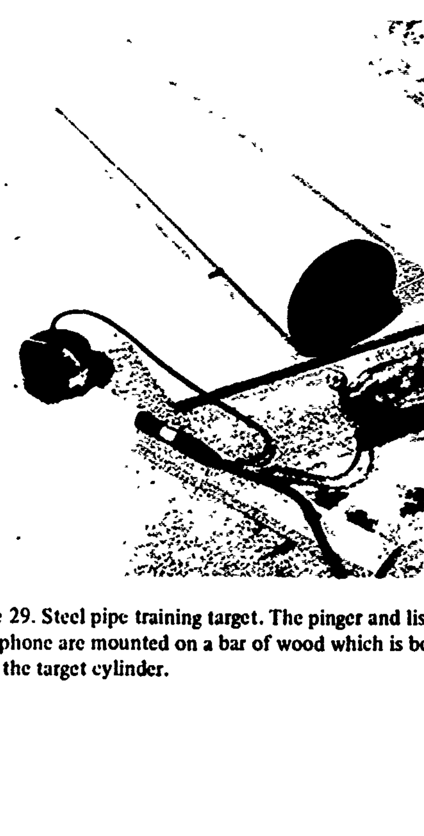

Figure 29. Steel pipe training target. The pinger and listening hydrophone are mounted on a bar of wood which is bolted inside the target cylinder.

During advanced training, when the animals were working in remote locations outside the bay and in deeper water, it became difficult to handle the long lengths of electrical wire involved in the hardwire system. The advanced training target was an aluminum cylinder having the same dimensions as the early-training target. For it, however, a 9-kHz pinger and a battery were mounted inside the cylinder. A rope was tied to a bridle on the conical head of the target, the pinger was turned on by plugging in the battery, and the target was thrown overboard. The surface end of the line was marked and buoyed with a large styrofoam float, and a lead weight was attached to the line about 30 feet away from the target so that some of the line could be laid on the bottom away from the target. The deployment setup for the advanced target is shown in Fig. 30.

Figure 30. Advanced-training target setup aboard the torpedo recovery boat.

Animal Backpacks

At the onset of Project Deep Ops in September 1969, two possible needs were foreseen for animal-carried packages. First, the whales would need to carry radio transmitters at all times while in the open bay or ocean to broadcast direction-finding and depth-of-dive information (tracking and depth-of-dive electronics are discussed in the next section). Second, a backpack surface was a potential attachment point for other types of equipment, such as line spools or flotation devices, which would be used in conjunction with mark or grab operations. Primary requirements of the packs were that they would seat firmly and comfortably on a whale's back for periods of at least several hours, and that they would provide a substantial area of strong material for the attachment of hardware.

The base of the dorsal fin of the whale was originally chosen as an area for placement of the backpacks. This area is above water when the animal surfaces to breathe, satisfying the requirement that the radio transmitter's antenna break surface occasionally for signal transmission. A saddle at the dorsal base also has added advantages of availability to handlers, ease of placement, and nonslip fitting due to the high vertical relief of the whale's dorsal fin.

On 3 December 1969 belt-toleration training began with Morgan. An 8-inch-wide, 90-inch-long band of heavy canvas was used as a training belt. It was wrapped around Morgan's abdomen utilizing a weighted 10-foot cord as a means of pulling the belt under his head, behind his pectoral fins, and then fully around his body. As determined by this belt, Morgan's girth just forward of his dorsal fin was 76 inches to 78 inches. Another belt of rubberized nylon (Dantex) with an 8-inch expandable section of neoprene rubber was used later for belt-adaptation training.

Pliable wire and tape rules were used to obtain relief sections of the contours of Morgan's back at the base of his dorsal fin. From these sections, a three-dimensional model of his back was constructed of plywood and wire cloth. Three layers of fiberglass cloth and two layers of fiberglass matte were laminated over the model. Trimming and sanding resulted in a saddle which was about 1 foot wide and 2½ feet long. The saddle's underside was lined with neoprene foam rubber, and on the upper surface U-bolts were mounted as receptors for belt clips. Saddle and belt-connector modifications were completed on 30 December 1969, and the entire apparatus was introduced to Morgan on that date.

When saddle-wear sessions were conducted in January 1970 with Morgan, the belt, with the expandable neoprene section, tended to stretch too much. At times the saddle and belt slipped entirely off Morgan's body. A new double-belt harness was designed to better secure the pack (Fig. 31). This double-belt harness had four slightly expandable sections made of strands of ¼-inch-diameter bungee cord. A

Figure 31. Fiberglass saddle with double-belt harness.

strap containing a wooden batten connected the two belts along the whale's underside. This stiffened strap kept a 14-inch space between the vertical belts and assisted in maintaining the position of the entire harness. Two cinch straps on each vertical belt were used to tighten the harness where it joined the saddle. Fabrication was completed on 11 February 1970, and Morgan accepted the new harness with no trouble. There was very little slippage of the harness even when Morgan swam at high speed in the pen.

As a prerequisite to Morgan's release into the open bay, a backpack rigged with a direction-finding radio transmitter was required. For temporary use, a radio pack was borrowed from Wm. E. Evans (NUC, San Diego) which he had used to track untamed pilot whales. This pack (Fig. 32) consisted of two heat-formed polyvinyl chloride plastic plates over which was molded a layer of epoxybound ¼-inch eccospheres. An aluminum cylinder containing radio electronics and two batteries was buried in the eccosphere matrix. The entire pack was buoyant, enabling recovery if shed by the whale. To accommodate the double-belt harness, stainless steel plates with keyholes and strap-holding rings were added to the pack. A stainless steel bar was bolted along the pack's length for additional strength, and the pack's underside was lined with neoprene foam rubber.

Figure 32. Morgan wearing Evans' radio pack with double-belt harness. Note expansion of bungee cord sections.

This modified radio pack was used during training sessions for a period of 12 days with Morgan (including 17 April 1970, the day that Morgan was first released into the bay). On 20 April the forward harness strap came loose, and the pack was broken in half when it caught on a gate edge. A stronger backpack with better harness connections was needed.

On 21 April Pip was lifted clear of the water in the training transporter stretcher, primarily for the purpose of taking blood samples. While he was in the transporter, a plaster bandage mold was made of his dorsal fin and base (Fig. 33). From this mold a male cast was made of Hydrostone casting material, and the cast was later slightly reshaped to duplicate Morgan's dorsal contours. It was thought that with the aid of this cast a better fitting saddle could be made for Morgan's back: the first pack had been sloppy in fit because of the difficulty in obtaining detailed morphological measurements.

Over the dorsal cast, a saddle was constructed of several layers of fiberglass cloth (Fig. 34 and 35). A frame of 1/8-inch aluminum was sandwiched beneath the

Figure 33. Making plaster bandage mold for Pip's dorsal fin area.

Figure 34. Second dorsal saddle for Morgan. The metal "U" on the rear of the pack was for the attachment of a colored buoy for tracking the animal if the radio transmitter failed.

Figure 35. Morgan wearing dorsal saddle with "Y" harness. This configuration worked well except that the bungee tended to overstretch, allowing the pack to slip back.

fiberglass for additional strength, and protruding plates attached to the frame provided harness attachment points. A radio transmitter cylinder housed in a piece of polyvinyl chloride tubing was mounted on the pack.

From March through May 1970 Morgan frequently exhibited a habit of rubbing his back against objects such as boats, pipes, ropes, and the ocean bottom. During these rubbing bouts, the rigid antennas on the radios were often snapped off, and the packs and harnesses damaged or shaken free. On 2 June 1970 a waterproofed Hot Shot MD-34 "10" cattle prod was employed as punishment for his rubbing behavior. After being shocked a couple of times while rubbing, Morgan ceased rubbing on objects. Morgan found, however, that he could still free himself of his pack and harness with a combination of swimming at high speed, jumping, and spinning. It was obvious that packs placed on Morgan's dorsal-base area bothered him, and with enough drag applied, the packs could be worked free from his body. Morgan's low and backward- sloping dorsal fin assisted very little in preventing backward slippage of the pack and harness.

During further experimentation, a fiberglass minipack, which fit high on Morgan's dorsal fin (Fig. 36), slipped off entirely during a session of boat-following in the bay. Another pack design, also of fiberglass construction, incorporated a pair

Figure 36. Morgan wearing fiberglass minipack.

of inverted foils in an attempt to hold the pack down (Fig. 37 and 38). This pack worked well in conjunction with a limited-expansion strap: however, Morgan still tried frequently to rid himself of it. A further design was developed which consisted of two parallel polyvinyl chloride tubes held together with a fiberglass cowling. This pack which fit around Morgan's dorsal fin base, met with similar disapproval from Morgan.

Figure 37. Inverted foil pack with single belly strap.

Figure 38. Morgan wearing inverted foil pack.

While the foil pack was being used, experimentation continued with wide belts of stainless steel to hold the packs on. A stainless steel band, 3 inches wide and 1/30 inch thick, was attached on both sides of the pack with rivets. On one side a large adjustable cam-lock allowed closure and tight locking of the band. The rigid nature and fixed diameter of the band kept it from riding back at an angle on the whale's underside; this band worked well, but Morgan continued rubbing with it on.

A major breakthrough in early August 1970 was Morgan's acceptance of a new harness and radio pack assembly (Fig. 7). A triangular nylon plate which fitted onto his back between his blowhole and dorsal fin was used as an attachment surface for radio cylinders. A belt of 1-inch-wide nylon strap was linked to the leading edge of the attachment plate and encircled Morgan's body just forward of his pectoral fins.

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A shorter strap was wrapped behind both pectoral fins and extended up on both sides to clip onto the forward belt. Later refinements included the addition of two small straps between the pectoral fins which connected to the main belt and pectoral fin belt. These small straps kept the pack and harness from rotating on Morgan's body. Also, two lengths of ¼-inch-diameter bungee cord were connected from the rear end of the attachment plate to the main strap, about 14 inches down on either side. These kept the attachment plate from flipping forward and yet allowed some give if a stray rope should become hooked under the rear of the pack. All pressure points on the harness were covered with neoprene foam to prevent abrasion of the whale's skin. The entire assembly presented a very streamlined and lightweight device which Morgan learned, in short time, to tolerate with practically no rubbing or removal action. Radio cylinders were mounted with the antenna heads trailing behind the pack, where Morgan's dorsal fin afforded them some protection. For additional protection, in case an antenna base should be grazed against an obstacle, nylon guards were made which slipped around the antenna break-out area.

This type of backpack has been used with Morgan for 1 year. In this period there has been no loss or breakage of pack or radio (except for a few accidentally severed antennas). Morgan wears the pack for an average period of 3 hours per weekday, traveling 5 to 20 miles per session. During these sessions he has dived frequently over 1000 feet, to a maximum depth of 1654 feet, with no signs of pack shift.

Further experimentation with Morgan resulted in completion of a buoyant model pack on 13 November. The pack was made from a streamlined block of syntactic foam which was approximately 18 inches long, 6 inches wide, and 4 inches high. A 1½-inch-diameter hole was bored through the long axis of the block to accommodate the radio transmitter. As with the nylon plate model, the main strap of the pectoral harness attached to the pack's leading edge, and a ring on the back edge of the pack attached to the two lengths of bungee cord. The only problem encountered with this pack was that it tended to shift about on Morgan's back more than the low-profile nylon plate model.

For preliminary backpack training with the killer whales, a training pack was made of 2-inch-diameter polyvinyl chloride tubing (Fig. 39). This device was

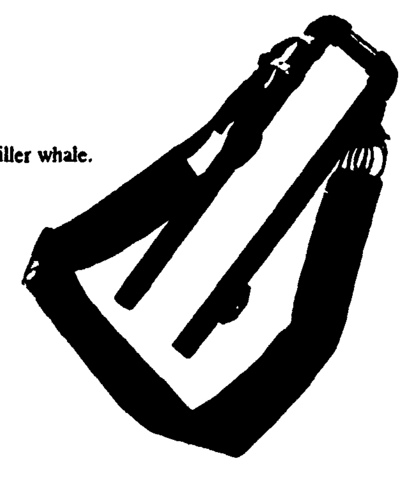

Figure 39. Training backpack for killer whale.

U-shaped with an 8-inch inside width and a 30-inch length. A 6-inch-wide Dantex strap was used as a belly band to hold the pack on the whales. Two 1¾-inch-wide cinch straps were sewn to one end of the belly band and passed through two pairs of brass rings attached to the pack. The other end of the belly band was riveted to the opposite pack side.

In July 1970 radio packs were constructed for both killer whales. These packs were made by joining two 2-inch-diameter polyvinyl chloride tubes with a fiberglassed syntactic foam cowling (Fig. 40). One tube was filled with a syntactic foam cylinder: the other served as a housing for a tracking radio cylinder. With radios, both packs were slightly buoyant.

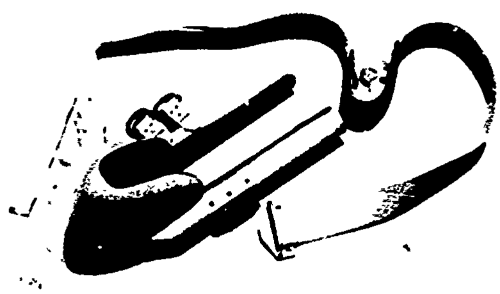

Figure 40. Dual-tube radio pack for killer whale.

To feed the holding straps around the killer whales, a long weighted line was used in a manner similar to that used with Morgan. While both ends of the line were held, the middle section was thrown in front of the whale in a large loop. He then swam into the loop, and the pack was placed on his dorsal base. The loose end of the belly band was clipped to the appropriate end of the feed line, and the feed line was pulled around, bringing the belly band around the whale's underside. On the loose end of the belly band was an aluminum plate with a wide-head peg which fit into a keyhole slot in a plate on the backpack. On the opposite side of the pack, a 1¾-inch wide strap passed through two brass rings for strap tightening. With Ahab (the larger killer whale), 3-inch-wide polyvinyl chloride impregnated nylon material was used for the major length of his belly band. For the total length of the belly band for Ishmael, 1¾-inch nylon strap was used.

Because of the high, nearly vertical dorsal fins of the killer whales, there was practically no upward or backward slippage of the packs. However, there was some difficulty in tightening the belly bands enough so they would not flare and drag against the water. This strap drag seemed to slow the whales noticeably, and in one instance enough force was exerted through the strap to pull the U-shaped pack apart. It was decided at this point to develop a pack of simpler and stronger construction. Also needed were devices for strap attachment and tightening and more area on the pack for the attachment of radios.

In October 1970 a prototype pack which fit the above requirements was completed. First, two elongate plates of ¼-inch-thick polyvinyl chloride material were cut to a length slightly longer than the length of Ishmael's dorsal fin base. Tabs extended below the bottom edges of the side plates for strap-attachment gear. The plates were heat-formed into a slightly concave form, the pilot whale back-cast model being used as an approximate guide. The two side pieces were then "hinged" together by connecting the backs and fronts of the plates with 1/8-inch thick nylon plastic pieces. On early models of this pack, one end of the belly strap was riveted to a tab on the pack. The loose end of the strap fed into a spool on a cargo ratchet. (Aeroquip series M5). A crossbar on the top end of the ratchet could be slipped into a stainless steel "U" bracket mounted on the opposite tab. The bracket was then pressed close and locked with a sliding pin. Once locked in place, the ratchet was then used to reel in the belly band to desired tightness.

While the pack was on a whale's back it was extremely difficult to manipulate the ratchet to release the belly-strap tension for pack removal. Therefore, on later models (Fig. 41) the ratchet was permanently bolted on one side of the pack, and a

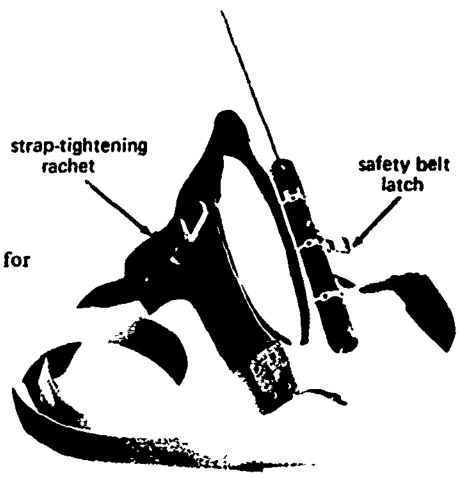

Figure 41. Hinged polyvinyl chloride plate radio pack for killer whale.

safety belt latch was fastened on the opposite tab. With this arrangement the ratchet end of the strap was permanently attached, and the loose end of the strap snapped into the safety belt latch. The strap would then be reeled tight with the ratchet. To remove the pack, all that was required was to pull a piece of cord attached to the release plate of the safety latch.

While Ishmael was being worked in the open ocean on 5 November 1970, his radio pack was lost during a shallow dive. It was concluded that the pack had given way along the riveted seams where the nylon hinge pieces and side pieces of the pack were joined. On subsequent packs all seams were backed with stainless steel plates, and stainless steel nuts and bolts replaced the rivets. Since mid-November 1970, these packs have been used on the killer whales during all open-ocean sessions without loss.

Because of the nylon hinges, the packs are highly flexible and conform well to the contours of the whales' backs. The attachment tabs on which the ratchets and safety latches are mounted angle backwards at approximately 30 degrees. This angle allows the belly strap to slip back on the whale's underside without buckling. With a backward angle, the strap lies well back of the lung and gut area of the whale, on the firmer flesh between dorsal fin and tail. With this strap position, no expandable section was needed to allow for changes in the whale's girth due to breathing.

Tracking and Depth-of-Dive Electronics

When marine mammals are being worked untethered in the open ocean, it is impossible to maintain continual visual contact with them. Under typical surface sea conditions, such as those encountered outside Kaneohe Bay, dolphins and sea lions are practically indistinguishable from the chop and white caps. This situation is essentially the same for pilot whales and killer whales, with reliable visual tracking falling off rapidly at ranges greater than 100 yards in 4- to 6-foot seas.

Normally, dolphins and whales are conditioned to follow their work boats and remain within a 100-yard radius. Occasionally, however, an animal may fall outside of this radius because of the geometry of a work situation (that is, deep diving or long-range recall between boats); because he has been "spooked" by some form of adverse stimulus; or because he has rejected a particular training demand and swum away from the work area. In these situations it is necessary to be able to rapidly assess an animal's location so that proximity and control can be regained. An animal that may temporarily be in an uncooperative mood and not under boat-follow or recall control may nevertheless be tracked and followed until such time as his mood or food drive change for the better.

For tracking the whales during open-ocean sessions it was decided to utilize a radio signal–automatic direction finding system. The basic components of this system were developed, by Ocean Applied Research Corporation of San Diego, in collaboration with Wm. E. Evans of NUC, San Diego, for open-ocean tracking studies of wild dolphins and pilot whales. These studies were funded through independent research and independent exploratory development funds. Work accomplished under this funding was responsible for the demonstration of the basic radio telemetry techniques for marine mammal tracking. Under Project Deep Ops advanced development resulted in a system which was practical and reliable for use with trained animals on a day-to-day basis. In the last 2 years this system has also been adopted by the oceanographic industry for the tracking of numerous "free vehicles" at sea (Ref. 16).

As used by Evans, tracking transmitters and battery packs were housed in narrow cylinders and embedded in the eccosphere–epoxy material making up the sides of animal backpacks. These tracking units fit around the dorsal fin bases of the animals and were held in place with anodized aluminum bolts which passed through the animals' dorsal fins. The bolts were designed to dissolve in 2 to 60 days to release the packs.

For use with Project Deep Ops animals, standard ST206 tracking transmitter units were procured from Ocean Applied Research Corporation (Fig. 42 b and c). These units are self-contained battery-operated radio beacons, packaged in high-pressure cylindrical housings that are capable of exposure to 10,000 psi. The housing cylinders are 1½ inches in diameter and 18¾ inches long. Transmitter input power is 100 mw, and a distinctive frequency shift-keyed modulation is used, making the transmitter signal easy to identify and track. On later models (ST213) transmitter input power was boosted to 500 mw. Five working frequencies are available in the 27-MHz range.

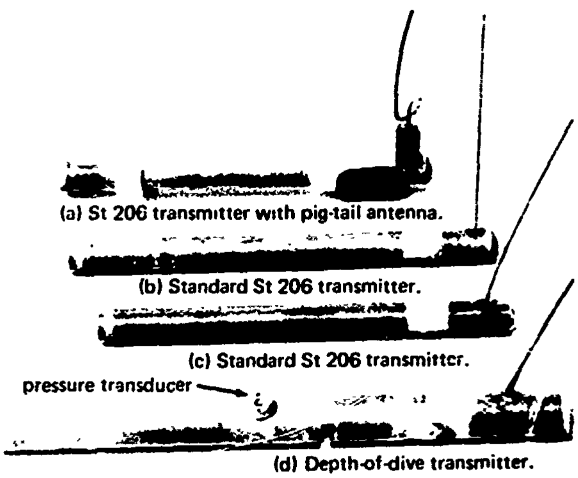

Figure 42. Tracking and depth-of-dive transmitters.

Approximately one-half the volume inside each housing cylinder is occupied by four 1.5-volt size C alkaline batteries. Rechargeable battery units were later obtained for use with one tracking transmitter. A 3-foot-long fiberglass whip antenna is mounted about 1 inch from the front end of the cylinder and angles backward at 45 degrees. When submerged, the transmitter is shut off by a seawater connection between the antenna tip and the transmitter housing. At the surface, the transmitter is activated when the antenna breaks the air-water interface.

Signals from the animal tracking transmitters are received on shipboard through an antenna which consists of a pair of orthogonal loops. Transmitter direction is derived from the sine-cosine amplitude response pattern from the loops which is processed by separate receiver channels and displayed on a cathode ray tube as a spike pointing toward the appropriate bearing on a 360-degree circle. A third channel, received from an omnidirectional vertical sense antenna, eliminates the 180-degree ambiguity. The signal processing and display unit (Fig. 43) measures 14 inches wide, 12 inches deep, and 5 inches high.

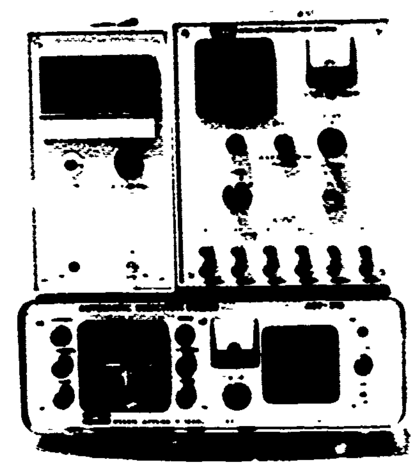

Figure 43. Signal processing and display units for tracking and depth-of-dive information. The upper-right unit receives and processes depth-of-dive data which are displayed in digital form on the screen on the upper-left unit. The lower unit analyzes and displays direction data. A spike of light on the cathode ray screen points to the direction of the transmitter in relation to the axis of the tracking boat. Both systems also emit an audio signal as received from the transmitter.

During Morgan's rubbing episodes, from March through May 1970, it was found that the fiberglass whip antennas were inadequate for use under conditions of rough treatment. Frequent breakage resulted when Morgan brushed the antenna bases against solid objects or tangled the antennas in lines.

In an attempt to solve this problem in mid-1970 project engineers converted to antennas made entirely of 3/32-inch-diameter spring steel. These antennas were 16 inches long and were mounted on the transmitter cylinders at a 90-degree angle. The bottom ends of the antennas were threaded to fit tapped sockets on the radio cylinders, allowing the easy removal and replacement of damaged antennas. Poysulfide casting rubber was used to seal the area around the antenna-cylinder junction.

Because of their extreme flexibility, the spring steel antennas generally fared better under duress than the fiberglass antennas. However, their simple design precluded the use of a seawater connection for shutting off the transmitter while submerged. Instead, a pressure switch which turned the transmitter off at a depth of approximately 20 feet was built into the screw-on end cap of the battery compartment. Unfortunately, the whales rarely dived deeper than 15 feet; therefore, very little battery life was conserved with the pressure switch setup. The spring steel antennas had an adverse effect on signal duration and quality, with a consequent decrease in effective tracking range. Shrink tubing that formed a nonwetting coating on the antennas was continually abraded, allowing antenna–water contact, which contributed to a drop in transmitter performance.

In June 1971 an ocean episode with Ahab demonstrated the inadequacy of the spring steel antennas for long-term use. On a 45-mile 24-hour trip off the coast of Oahu, Ahab was wearing his dorsal saddle with a standard ST206 tracking transmitter and a depth-of-dive transmitter. At the end of approximately 23 hours the spring steel antenna on the ST206 broke off, apparently from continual flexure which occurred as Ahab broke surface and dived in the course of normal breathing and swimming. After 24 hours, the antenna on the depth-of-dive transmitter was close to failure, having worked a weld loose at its screw connections.

In July 1971 an ST206 tracking transmitter was equipped with a prototype of a newly designed heavy-duty antenna (Fig. 42a). The antenna is 14 inches long from base to tip and is made of 3/16-inch spring steel. A 1½-inch-diameter waterproof screw-on connector provides a sturdy antenna-to-cylinder connection and is easily unscrewed with a wrench for antenna replacement. Just above the connector, a 360-degree pig-tail loop was bent into the antenna wire to allow free flexure at that point. A loading coil placed on the upper end of the antenna increased the antenna's diameter to 7/16 inch for a 4½-inch length. This loading coil increased the electrical length of the antenna and boosted the emitted signal range and quality appreciably. To turn the tracking transmitter off while underwater, a seawater connection between antenna tip and transmitter housing was used instead of a pressure switch. For use with Morgan, a protective nylon bumper was mounted on the radio cylinder just forward of the antenna base. This antenna has been used during several open-ocean sessions with Morgan and appears to be superior in durability and performance to all prior antenna types.

To obtain depth-of-dive information during dive and recovery training sessions with the whales, another system was adopted which had been basically developed by

Ocean Applied Research Corporation and Wm. E. Evans. A data-transmitting unit is housed in a 2-inch-diameter, 24-inch-long high-pressure cylinder (Fig. 42d). Power is supplied by eight 1.5-volt alkaline 1/2 D batteries which occupy 9 inches of the cylinder's length. A pressure transducer mounted on the exterior of the cylinder conveys depth magnitude information to an oscillator in the radio transmitting unit. A continuous tone produced by the oscillator is transmitted to a shipboard receiver (Fig. 43), with the frequency of this tone being a direct function of the depth of dive (as conveyed to the oscillator from the pressure transducer). After passing through a shipboard data acquisition unit, the analyzed signal is fed to a digital readout unit (Fig. 43) for display in feet of depth. A pressure switch mounted on the battery compartment cap turns the transmitter off at a depth of 20 feet and also "clears" the oscillator of its previous depth-frequency setting, readying it for a new setting for the ongoing dive.

The depth-of-dive system was put into use in April 1971, and to date has been used to depths of 1700 feet. Transmitter input power is 250 mw; however, the 3/32-inch-diameter spring steel antenna limits transmission distance of depth-of-dive information. In the near future this antenna will be replaced with one of the heavy-duty pig's tail antennas described above.

The continuous tone which is emitted as a carrier of depth-of-dive data is also used as a tracking signal for the automatic direction finding system. After approximately 30 hours of operation, the transmitter batteries are replaced. Although the batteries provide sufficient strength for use as a tracking signal, as the signal becomes weaker the depth-of-dive data become less reliable.

Recall Devices

For early recall training with Morgan, a recall device was fabricated that incorporated an adjustable oscillating circuit and a hydrophone (Clevite Corp., model CH-17M-R) set to "buzz" at 150 Hz to 200 Hz. The electronic components and a 6-volt battery were housed in a 5-inch-diameter, 12-foot long plexiglass cylinder. An external switch at the end of a 3-foot cord allowed on and off control of the buzzer. This apparatus was used with Morgan while he was in the enclosure at Hangar 102 adjacent to dolphins which were undergoing pinger training with high-frequency pingers. It was also used as a buzzer for stretcher training with the pilot whales and killer whales.

At Sag Harbor, where only whales were being recall-trained, standard Burnett porpoise pingers were used which permitted external control of frequency and pulse rate. Normally the pingers were set for 1 to 3 pulses/sec. Through most of 1970 Morgan's pinger frequency was 22 kHz, Pip's was 19 kHz, Ahab's was 32 kHz, and Ishmael's was 19 kHz. By mid-1971 Morgan's and Ahab's pingers were set at 19kHz at 3 pulses/sec: hearing threshold studies with a killer whale indicated that hearing sensitivity in the larger toothed cetaceans may fall off rapidly above 20 kHz (Ref. 17).

Another 19-kHz pinger was made from the oscillator circuitry of a Burnett pinger and a Clevite hydrophone and was powered with four 6-volt batteries (F cells). Circuitry and batteries are contained in a 7½-inch x 6½-inch x 6-inch splash-proof ammunition box. This pinger unit provided a slightly louder signal and longer battery life than were available with the standard Burnett pingers.

In March 1970 a boat-identification signal was added to the workboat. Initially powered by two 6-volt dry cells, an oscillator generated a 5-kHz signal which had a pulse form of 1 second on, 2 seconds off. The output was fed into a hydrophone (Massa Co., New York, model TR-14) which was mounted underwater at the stern of the workboat. Because of the short battery life of the dry cells the unit was later modified to operate on the 22-VDC electrical system of the torpedo recovery boat. The boat-identification signal was operated continuously during all open-bay and open-ocean work sessions and served to distinguish the boat from others in the area; it also provided a homing beacon for the whale after deep dives.

Whale Transporters and Stretchers

During the Deep Ops program, behaviors and equipment were developed that were necessary for the routine long-distant transport of pilot whales and killer whales. The whales were trained to station between a large pair of pontoons and to eventually tolerate stationing over and in stretchers suspended between the pontoons. When training advanced, the animals were progressively lifted to restrained positions in preparation for actual removal from the water and transfer to long-distant transport equipment.

Construction of a preliminary model training transporter was completed on 17 February 1970 (Fig. 44). This device was of a catamaran configuration and utilized

Figure 44. Preliminary model training transporter. Pip is the whale in the stretcher. A later model of this type transporter had higher support arches to allow clearance for the killer whale's dorsal fins.

six 55-gallon drums for flotation. Walkways were made of wood, and galvanized 2-inch-diameter pipe formed three connecting crossbars. A manually operated cable and pulley system enabled project personnel to lower and raise the whales between the pontoons. Because the stretcher was continually exposed to the environment, a training stretcher of plasticized cloth was used. This stretcher was of a two-piece construction, leaving a 2-foot gap for the whales' pectoral fins. Transverse pockets on the bottom side of the stretcher were added to hold sand-filled lengths of garden hose. The weight of these hose sections maintained the stretcher in a "U" shape while it was in the water.

By May 1970 Morgan had adapted to the training transporter very well, allowing himself to be restrained for periods of 2 to 3 minutes in the stretcher. Besides its usefulness for training, the transporter proved to be equally useful for restraining the other pilot whale (Pip) for blood tests and clinical observation. In these situations, the transporter lifted about two-thirds of the whale's weight (or about 900 pounds).

This initial transporter was too small for training with the killer whales. The pontoon-connecting arches were only 2 feet above water level and presented obstructions to the killer whales' dorsal fins as the whales entered the transporter. Also, the vertical cables suspending the stretcher poles were too close together and frequently snagged on the whales' pectoral fins.

Consequently, a second training transporter was launched on 20 July. On this model the connecting arches were made higher (3 feet), and a total of ten 55-gallon drums were used for flotation rather than the six used previously. Also, the stretcher suspension cables were spaced a few inches farther apart.

In April 1970 final design was completed of an operational whale lifter-transporter (Fig. 45). Fabrication by civilian contractor was completed in November

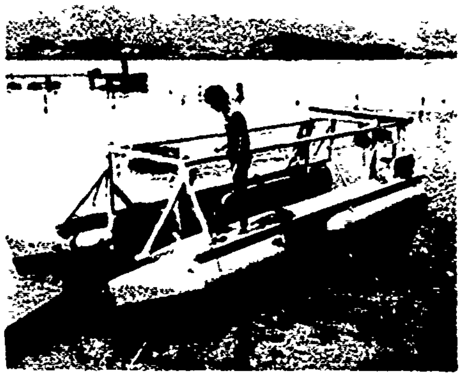

Figure 45. Operational whale lifter-transporter. Morgan is entering the transporter.

1970. The entire transporter is constructed of metal (primarily aluminum), weighs approximately 2500 pounds with empty stretcher, and has a lift capacity of 6000 pounds. With a maximum height of 6 feet a maximum width of 9 feet 9 inches, the transporter can be placed on a 30-inch-high trailer and will fit into the cargo compartment of a C-141 Starlifter aircraft.

In operation, an electric winch on the transporter lifts the stretcher and whale clear of the water. The transporter is then towed to dockside, where a crane lifts the entire device, with stretchered whale, clear of the water. Thereafter, a water-collection bag is placed around and under the whale's body and is connected to the transporter frame; an alternate method is to remove the whale and stretcher from the transporter for independent transport in a separate box lined with waterproof rubberized canvas.

For day-to-day training, a two-piece Dantex stretcher was used in the operational transporter. In June 1971 a stretcher suited for transport use was fabricated. To allow maximal water absorption and cooling for the animal, the body of the stretcher was made of two layers of no. 4 duck canvas. Two-piece configuration left a space between the front and back pieces of the stretcher for the whale's pectoral fins. After the whale was placed in the stretcher, a 38-inch-wide canvas apron with nylon cinch straps and pectoral "windows" could be placed around the whale's pectoral fins and underside. Cargo ratchets attached to the stretcher poles were used to cinch tight the straps on the pectoral apron to support the animal's body in that area. Six-inch-wide straps of two-ply 18-ounce Dantex material were sewn across the stretcher at 1-foot intervals for additional support. On the underside of the cross-straps, an additional layer of single-ply Dantex formed sleeves to hold lengths of sand-filled garden hose (for in-water form-holding).

In the original transport of the Deep Ops whales from California to Hawaii, the stretchered animals were suspended in large pipe-framed wooden boxes. Plastic liners in the boxes held 30 to 50 gallons of water which was circulated by a 12-volt submersible pump to spray-tubing suspended over the length of the whales' bodies. Custom-made terry cloth "jackets" fit over the whales' dorsal surfaces, and terry cloth "socks" were placed over the large pectoral fins of the killer whales. These terry cloth covers are very absorptive and assist in keeping the animals continually moist.

For efficient dolphin transport capability, a self-contained animal transporter (SCAT) was developed at NUC, Hawaii, during the period 1968-1971. In this system, water is pumped by air pressure from a tubular reservoir (which surrounds the base of the box-like transporter) to a spray-nozzle array within an overhead canopy. A battery-powered adjustable timer controls the animal-wetting spray cycle, which is typically set to spray for 8 seconds and turn off for 3 minutes; operational time at that setting is 13 hours. Expended water is caught in the surrounding bag beneath the stretcher. A highly desirable feature of this system is that the water is not reused but is instead rationed by the controlled spray cycle. If more intensive development of a whale transport system were planned, a large-scale version of SCAT could undoubtedly be adapted for use with whales.

A problem which has occurred frequently during the long-time transport of both dolphins and whales is the abrasion of those areas of the animals' bodies which make contact with open edges on the stretchers, particularly susceptible are the pectoral fin "arm pits" and tail base. With pilot and killer whales, pressure on these areas is considerable because of the whales' great weight.

Because of transport abrasions sustained by Ahab (the first killer whale moved to Hawaii), a padded, better-fitting stretcher was made for Ishmael, the next whale to be transported (Fig. 46). The body of this stretcher is of 2 layers of no. 4 duck canvas and is lined on the "whale side" with two layers of cotton blanketing having a length of 15½ feet and a maximum width of 6¼ feet. The pectoral fin openings were made smaller to avoid having a large volume of the whale's body protruding from them. To allow entrance of the pectoral fins to the smaller openings, slits were cut from the outer edge of the stretcher to the edges of the openings. Grommeted lacing straps allowed closure of the slits after the whale was placed in the stretcher. All edges around the pectoral openings were folded over and seamed to provide additional softness. Also, to provide comfortable adjustment of the whale's tail and tail base, the rear end of the stretcher was rigged with four transverse adjustable straps. This enabled the whale's tail to be lowered onto a foam pad on the bottom of the transporter box, removing strain from the tail base, which previously hung over the stretcher edge. Upon arrival in Hawaii, after a 13-hour trip in the new stretcher, Ishmael showed very little damage from stretcher abrasion and drying.

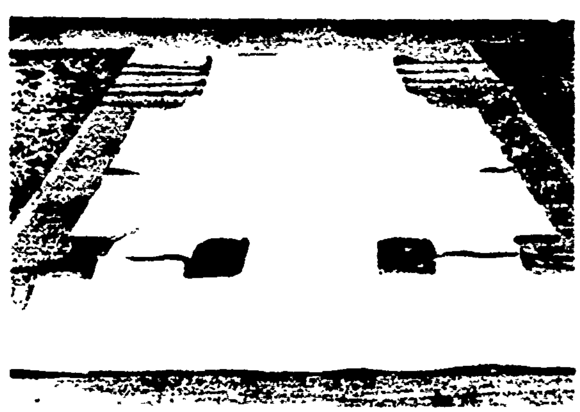

Figure 46. Whale transport stretcher.

CONCLUSIONS

1. Pilot whales and killer whales can be trained to wear harnesses, carry hardware, and deploy grabber recovery devices against bottom-located pingered cylinders. The two species of whale can be worked in the open ocean and held under behavioral control for 3 to 6 hours, with much longer control periods possible.

2. It is possible to boat-follow the whales to an ocean work site if the holding facility is within 10 to 25 miles of the site.

3. Long-distance transport of small whales by surface or air could be effected with existing techniques and equipment.

4. Although both species of whale were trained to perform a variety of tasks in the open ocean, the pilot whale proved more adaptable, responded better to training, and was more reliable and controllable than the killer whales.

5. Whales can be trained to carry and deploy a hydrazine lift recovery system to a 1000-foot depth.

RECOMMENDATIONS

1. Replicate accomplished work with additional numbers of pilot whales.

2. Utilize trained pilot whales in test ranges to recover pingered test ordnance, such as the Mk 46 torpedo, from depths greater than 500 feet.

3. Expand the sensory and behavioral research and open-ocean observation on pilot and killer whales.

4. Investigate pilot and killer whale sonar capabilities, and determine their potential for locating unpingered objects.

5. Expand the training to demonstrate recovery potential when the bottom-located target is vertically oriented in various attitudes through 90-degrees.

Appendix A

CAPTURE AND TRANSPORT

There are two primary methods used to capture pilot and killer whales. The first, used extensively on pilot whales, is the hoop method. A boat modified to support a special pulpit which extends off the bow is used as the capture vessel. The pulpit normally extends 15 to 30 feet off the bow. When animals are spotted, the collector takes his position in the pulpit, and the boat maneuvers into position to put the collector over the swimming animals. The collector uses a capture hoop (of which there are several types) to ensnare the animal. The collector must anticipate the whale's movements and breathing rhythm, provide steering instruction to the boat coxswain, and make his shot at precisely the right moment. At the instant the animal surfaces to breathe under the pulpit, the collector makes a quick lunge, driving the hoop beneath the surface just in front of the animal's head. Forward momentum carries the whale through the hoop, breaking away the attached snare net and rope which is attached to a large float or to a winch on the boat. Thereafter, the objective is to slow the animal and bring him in gently without injury. Once the animal's forward motion is stopped, he can be maneuvered alongside the boat for removal. A stretcher or cargo net is positioned under the animal, and he is then lifted out of the water and placed on a stretcher, mattress, or other cushioning device.

The second method of capture, used primarily for the collection of killer whales and bottlenosed dolphins, is the seine and corral method. Killer whales commonly travel through the relatively narrow inside passage areas along the coast of the Pacific Northwest. It is here that they are normally captured. After a herd of killer whales is sighted in a constricted area, they are encircled with large, heavy-gage salmon netting. Once the animals are confined to a large netted area, additional nets are strung to make smaller "corrals." The whales are then divided into smaller and smaller groups until single animals have been partitioned off. Nets are then raised from the bottom to almost completely restrict the animal's movements so that divers can postion a stretcher under the restrained animal. The whale is then winched clear of the water and transported to a holding facility. Morgan, Pip, Ahab, and Ishmael were all captured by means of the two methods described above.

NUC uses one basic technique to transport both dolphins and whales. Trans-

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port requirements are the same for small and large cetaceans; they must be kept wet, cool, restrained, and as comfortable as possible. If they are transported by air, the aircraft must be pressurized. With few exceptions, cetaceans in general behave much the same during capture and transport: they give up and lie quietly.

NUC has developed transport techniques and hardware that greatly simplify the overall transport procedure. Special stretcher and shipping containers have been built. Animal conditioning techniques have been developed that simplify the handling and loading procedure: for example, dolphins and whales have been trained to swim into and station over submerged stretchers which can easily be winched out of the water (Fig. 5, 45, and 46). Previous methods required a number of people to enter the water, capture the animals in a net, and then wrestle them onto a stretcher. It takes as many as a dozen people to handle an untrained animal the size of Ahab.

Appendix B

WORK CRAFT

From September 1969 through May 1970, only small craft were required to support animal training exercises. Animals were worked from stationary raft platforms, a 10-foot flat-bottom aluminum boat, a 13-foot Boston Whaler, an 18-foot Boston Whaler, and a 19-foot ski barge. When engines were used on the boats, propeller guards were employed. The guards were made either of a single band of metal which formed a hoop around the outer perimeter of the propeller or of metal rod to form a protective net around the propeller.

A 25-foot Luhrs cabin cruiser, available from a previous project, was used for long-distance boat following and practice grab sessions inside and outside of the bay (Fig. B-1). Additions prior to use in June 1970 included a propeller guard, stern work platform, ship-to-shore radio, and larger rudder.

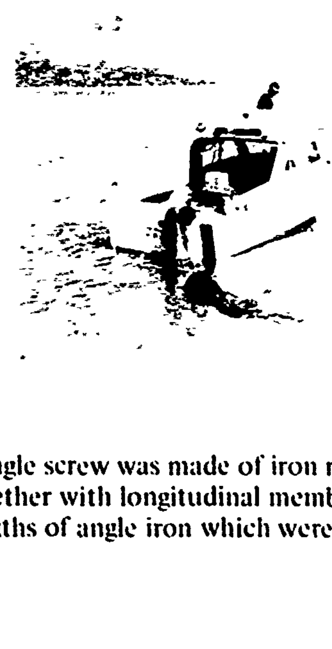

Figure B-1. Morgan being worked in the large training enclosure from the Luhrs craft. This boat was used for 6 months of bay and open-ocean training.

The propeller guard around the Luhrs' single screw was made of iron reinforcing rod. Two U-shaped hoops were braced together with longitudinal members, and the ends of the hoops were welded to two lengths of angle iron which were bolted to the boat bottom.

The work platform, measuring 48 inches by 30 inches, was fabricated of aluminum and wood, and was mounted at water level on the starboard side of the transom.

For target recovery, a gasoline-engine-powered Briggs-Stratton winch was mounted on the port-side deck just aft of the boat cabin. The winch spool is capable of holding 2200 feet of 3/8-inch-diameter line, which can be recovered in approximately 12 minutes.

For the automatic direction-finding system, a 20-foot-high antenna was mounted at midships, just back of the main cabin. All necessary electronics were modified for the boat's 12-volt system and were mounted in the cabin.

The flying bridge on the Luhrs provided excellent visibility for the boat driver, and the boat handled well in the bay. In the open ocean, however, under waves greater than 4 feet, the boat was unstable, making target and equipment handling very difficult.

Later in the program it became obvious that a larger work boat was required, and subsequently a 72-foot torpedo recovery boat was assigned to the Hawaii laboratory (Fig. B-2). Hoop propeller guards made of welded iron reinforcing rod were mounted around both of the boat's twin screws. All electronic and target-handling gear was transferred from the Luhrs to the torpedo recovery boat, and a 3-foot by 6-foot expanded metal platform was mounted at water level off the port stern corner of the boat. On 11 January, Ahab and Morgan were introduced to and began following the torpedo recovery boat. The torpedo recovery boat has proven to be a highly versatile and stable work boat in seas up to 8 feet. Extensive free deck area and the aft-sloping torpedo-recovery ramp make gear and animal handling much safer and more efficient.

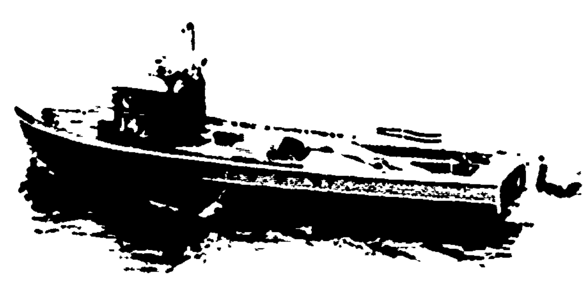

Figure B-2. The 72-foot torpedo recovery boat. Morgan is following the boat alongside the stern platform.

Appendix C

DOCUMENTATION OF ANIMAL NUTRITION, HEALTH, BEHAVIOR, AND PERFORMANCE

Detailed records on all aspects of the whales' nutrition, health, behavior, and performance were required to allow accurate appraisals and summaries of developments in newly researched areas (such as open-ocean control and deep dive-grab behavior) as well as to provide data for the upkeep of standard biographic-medical histories.

In late 1969 a standard Daily Training Log Sheet was adopted for use with the Deep Ops program. This form included spaces for descriptions of training conditions, training results, training times spent on specific behaviors, type and amount of food and vitamins fed, health, medication, and environmental conditions.

In April 1970 a standard Dive and Deploy Session Log Sheet was put into use to enable more detailed on-the-spot collection of data pertaining to the animals' dive and deploy behavior. On these sheets were spaces for the recording of time before dives, duration of dives, time between dives, and horizontal and vertical ranges to targets. Also recorded were environmental conditions, boat and training crew data, start and finish times, and diagrams of training situations.

Summary sheets for daily training times and average daily food and vitamin intake (figures which were calculated monthly) were compiled and added regularly to the animals' standard history forms. Descriptions of the behavior training process and behavioral criteria, along with total hours, training days, and calendar days required to accomplish behavioral criteria with all animals, are presented in Table C-1 and Fig. C-1 to Fig. C-4.

In cooperation with an effort to organize a master record system for all Navy marine mammals (Ref. 18), all of the above described data were transferred to official record forms and are on file at NUC, Hawaii.

Table C-1. Behavior criteria and time to attain criteria for all whales

Behavior	Description of Subbehavior Criteria	Morgan Hours	Morgan Training Days	Morgan Calendar Days	Pip Hours	Pip Training Days	Pip Calendar Days	Ahab Hours	Ahab Training Days	Ahab Calendar Days	Ishmael Hours	Ishmael Training Days	Ishmael Calendar Days
Adaptation	Hand Feed. . To eat 100% of day's food ration from trainer's hand, from any position in pen.	6.3	4	5	11.3	11	12	retrain			retrain		
	Station . . .To eat 100% of day's food ration from a trainer-established locale	116.9	127	127	33.6	29	82	retrain			retrain		
Recall Response	Basic Response. ...To touch a pinger for 100% of trials of one session, in pen.	27.1	28	85	8.3	6	7	14.8	8	10	retrain		
	Distance Response... Same as above, only for distances of 500 feet or greater.	118.2	172	361	not completed			44.0	47	203	4.1	21	60
Gate Pass	On Command .... To pass through gates on command for 100% of trials in a session	32.5	45	201	not started			34.8	26	94	retrain		
Boat Follow	15 Min. ...Follow boat continuously for 15 minutes (food frequent)	14.3	7	65	not started			8.8	10	20	4.6	11	20
	60 Min. .. ..Follow boat for 60 minutes in large enclosure or pen (food frequent to infrequent)	55.9	66	242				18.8	20	154	12.3	17	27
	120 Min Follow boat for 120 minutes outside of pen (food infrequent).	86.7	87	173				109.8	66	114	73.0	84	190
Dive and Deploy	Mouthpiece Carry.. . To take mouthpiece from trainer and carry until trainer takes back.	9.2	7	15	22.0	12	120	5.5	3	3	18.6	17	25

(contd)

Behavior	Description of Subbehavior Criteria	Morgan			Pip			Ahab			Ishmael		
		Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days
	Practice Grab, Suspended Target.....To deploy practice grabber on suspended target, unassisted	60.5	50	114	not completed			77.7	42	99	26.3	22	39
	Practice Grab, Bottom Target.....To deploy practice grabber on bottom target, unassisted	4.3	2	4	not started			17.6	36	70	8.6	8	10
	Practice Grab, 30 Feet.....To deploy practice grabber at indicated depth	37.4*	120	253				36.1*	74	170	29.7*	68	204
	Practice Grab, 100 Feet.	1.0*	2	3				4.1*	7	25	5.7*	12	34
	Practice Grab, 250 Feet.	4.1*	6	11				3.3*	6	30	2.7*	6	30
	Practice Grab, 500 Feet.	32.8*	45	149				2.7*	3	8	6.3*	12	73
	Practice Grab, 750 Feet							7.0*	8	48			
	Practice Grab, 800 Feet	5.9*	8	40									
	Practice Grab, 850 Feet							24.7*	35	129			
	Practice Grab, 1000 Feet	17.4*	20	60									
	Practice Grab, 1100 Feet	17.9*	18	38									
	Practice Grab, 1500 Feet	5.7*	5	8									
	Practice Grab, 1654 Feet	2.3*	2	3									
	Possible Volunteer Dive, 2000 Feet	12.[illegible]*	10	19									
	First Deploy Hydrazine Litter	8.0*	6	12									
Pack Wear	Strap Wear....To tolerate rope or strap around body for session in pen	3.1	6	88	not started			not done			not done		
	Pack and Harness....To tolerate pack and harness for session in pen	5.3	9	28				20.9	19	134	13.4	17	153
Transporter Toleration	Station....To station over stretcher (between pontoons) for 1 minute	0.7	1	1	not started			60.7	36	224	5.7	8	64

(contd)

Behavior	Description of Subbehavior Criteria	Morgan			Pip			Ahab			Ishmael		
		Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days	Hours	Training Days	Calendar Days
	Lift.....To allow restriction (partial lift) in stretcher and to recenter stretcher after that trial.	18.7	23	104		-	–	--	--	–	–		-
Ring Carry	Carry.....To carry ring until taken away by trainer.	9.3	7	7	not started			not started			not started		
	Mark.....To drop ring on pingered target.	4.8	3	6		–	–	–	–	-		–	
	Retrieve.....To retrieve pingered ring and line to trainer.	17.3	11	14	–	--	–	--	–	--	-		
	Carry Weight.....To carry ring with 20-pound weight to pingered target at bottom.	25.5	17	39	--	--	-		-	-			-

* Calculated by dividing by 3 the total length of the open-bay or open-ocean session involved. The quotients obtained are average figures representing the times at the work sites which were devoted to practice-grab training.

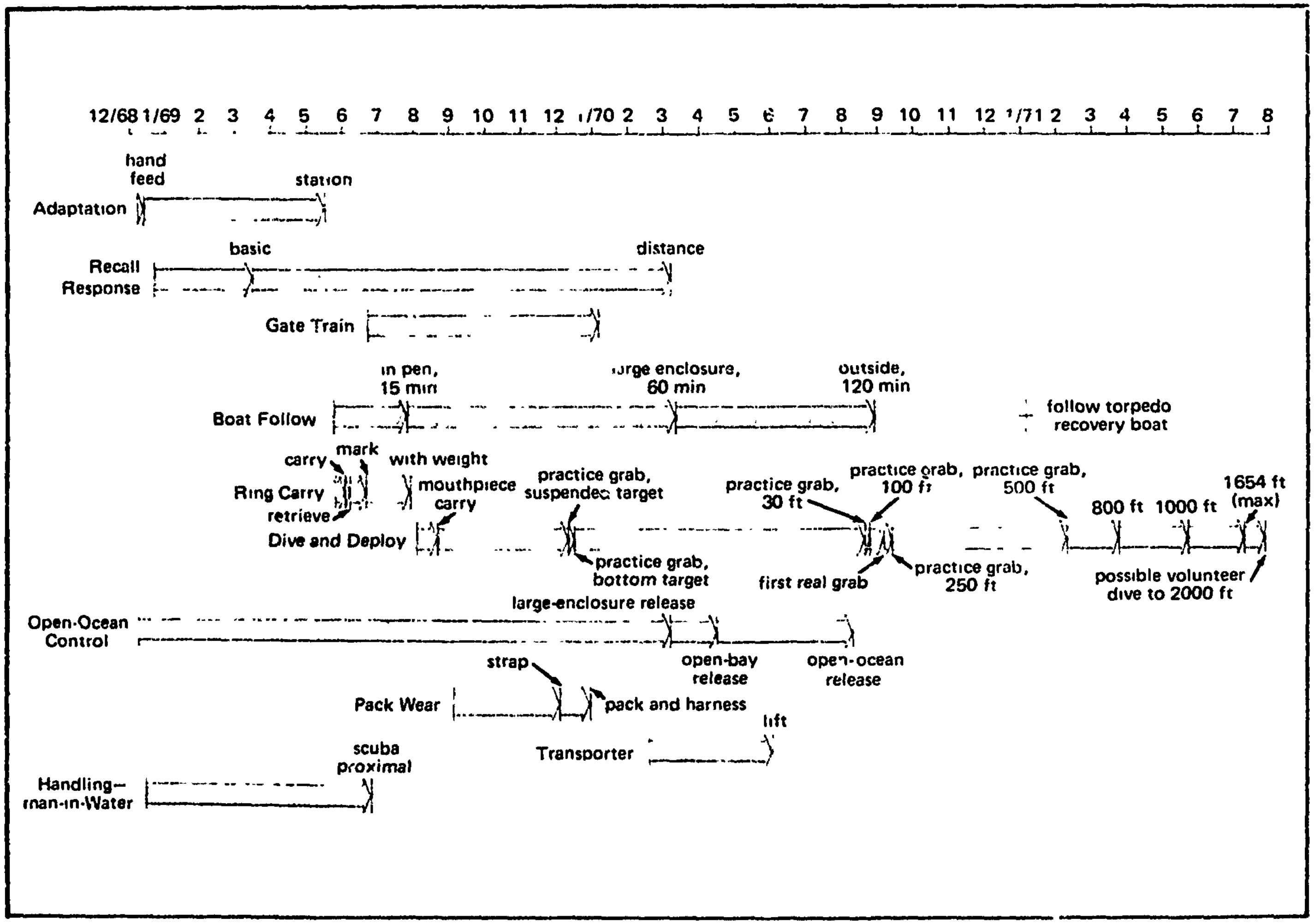

Figure C-1. Flow chart of behavior criteria attainment for Morgan.

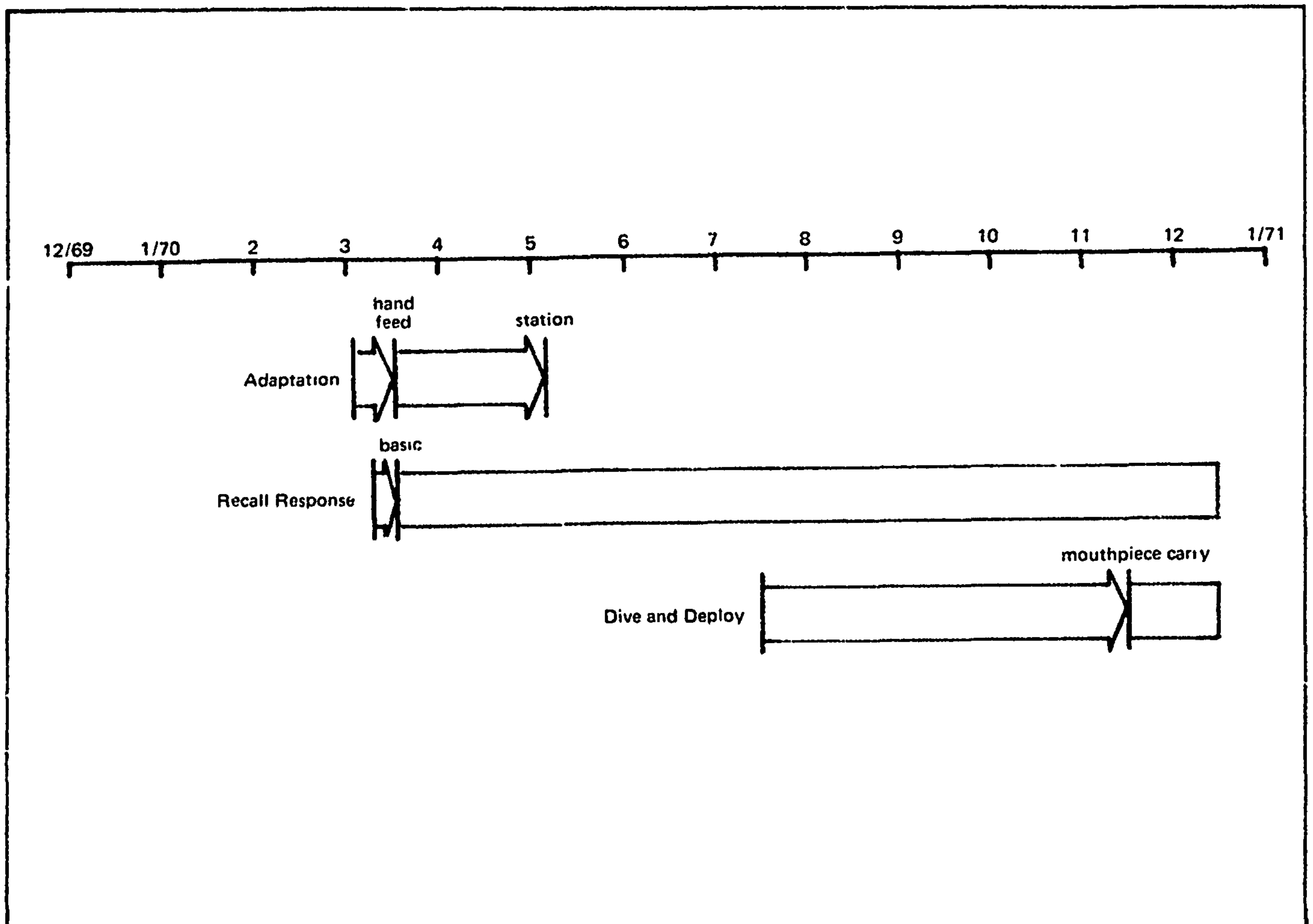

Figure C-2. Flow chart of behavior criteria attainment for Pip.

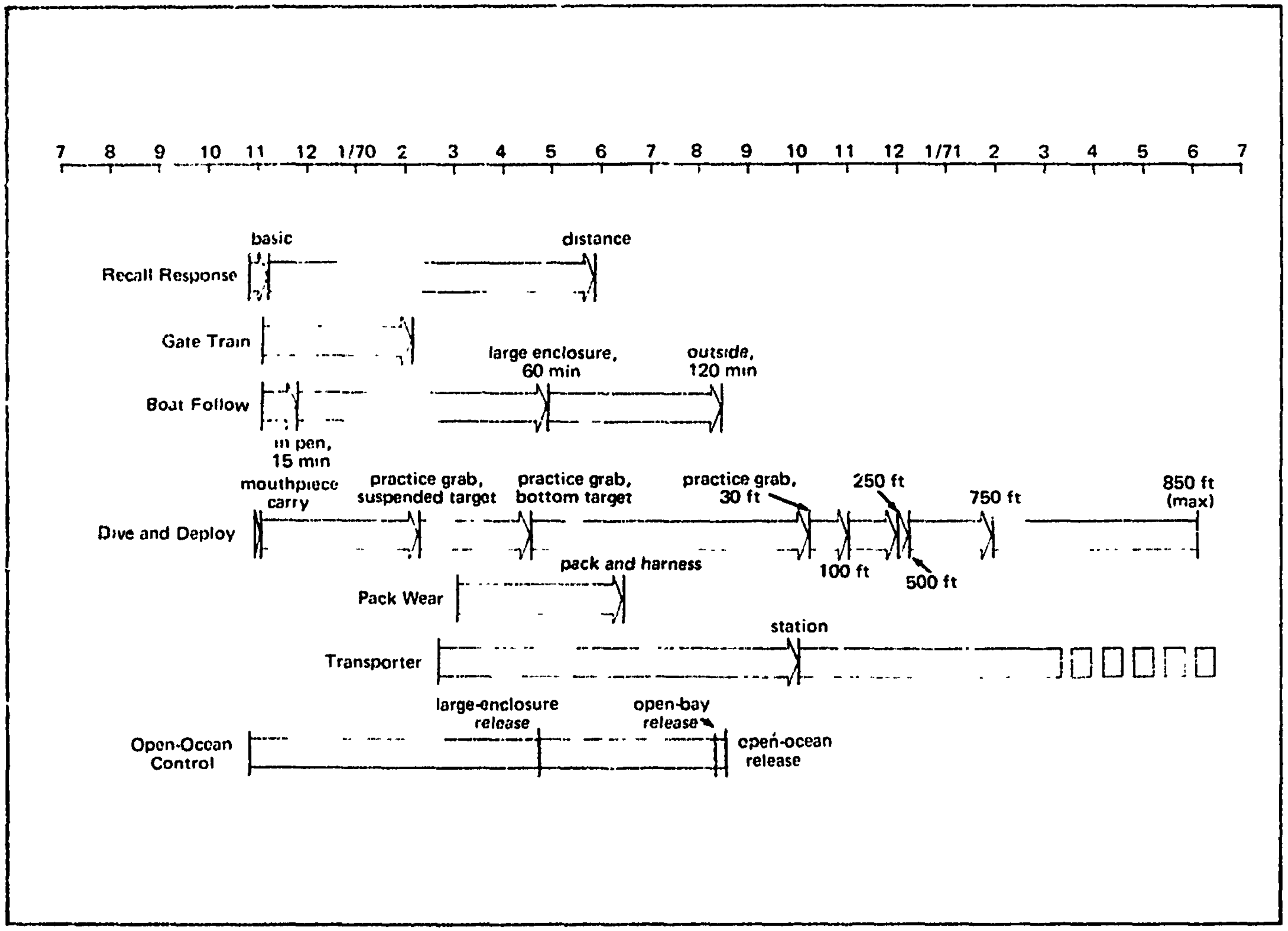

Figure C-3. Flow chart of behavior criteria attainment for Ahab.

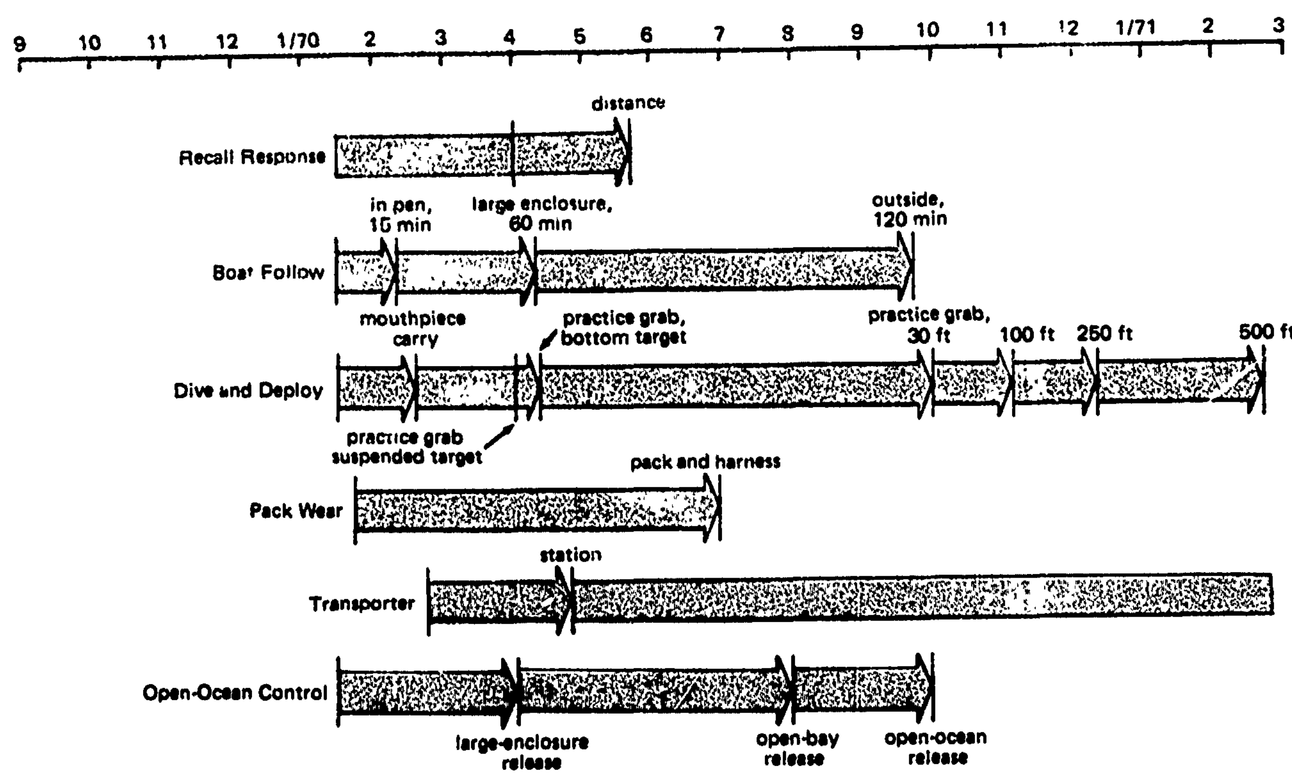

Figure C-4. Flow chart of behavior criteria attainment for Ishmael.

Appendix D

PERSONNEL

PROJECT STAFF

From September 1969 through most of 1970, Project Deep Ops averaged 5 to 6 full-time employees concerned directly with program management and animal training operations. Of these positions, 2 were filled by civil service employees, 2 by Navy personnel, and 2 by B. G. Marine civilian contract employees. In September 1970 the 2 Navy personnel were transferred to another NUC project, and in December 1970 the contractors were released because of termination of the B. G. Marine contract. Thereafter, Deep Ops was manned by an average of 4 full-time civil service employees. Listed below are the names and positions of personnel with over 6 months of project service:

Clark Bowers..........project manager
Scott Henderson .... biologist
Joseph Nolan . biological technician
Milo McManus .... psychologist
Chris Welsh .... biological technician
Richard Pence .... chief, Navy
Art Turnbough ... bosunmate, Navy

FACILITIES PERSONNEL

The Facilities Support Branch of the Bio-Systems Program under the supervision of J. W. Steele and Harold Joerding provided services primarily for the design and fabrication of animal holding facilities and associated training structures. Through the last year of Project Deep Ops, this group also supplied much needed personnel for boat driving, equipment handling, and boat-engine maintenance. All of these activities were essential to the open-ocean training. Labor for facilities support amounted to approximately 1½ man-years per year. Special thanks go to all of the below mentioned:

J. W. Steele ...... engineer technician (supervisor)
Harold Joerding . engineer technician (supervisor)
Paul Jones .... laboratory crafts aid
Larry Landis ... laboratory crafts aid
Paul Tam .... laboratory crafts aid
Rick Kahikina . laboratory crafts aid
Pete Makalii .... laboratory crafts aid
Adam Camara.. laboratory crafts aid

ENGINEERING PERSONNEL

A major portion of hardware design and fabrication was accomplished by engineers of the Ocean Systems Division. In particular, Homer Porter provided supervising services and designs for whale transporters and some grabber components; Gerry Ching designed and supervised fabrication of the operational grabber; and Doug Murphy was largely responsible for the application of the quick-release link to the grabber. Also, Don Miller designed the hydrazine lift system, and with much assistance from Warren Staples (of the Bio-Systems Program), fabricated the system and fitted it to the existing grabber. Engineering services amounted to approximately 1½ man-years per year. Others who contributed directly to the Deep Ops hardware development effort were:

Harry Chalmers ...... general physicist
Norm Estabrook .... mechanical engineer
Floyd York .... design technician
George Vota .... engineer assistant
Ron Seiple .... research analyst

OTHER PERSONNEL

For all operations with the torpedo recovery boat, the Navy boathouse crash crew (based at Kaneohe Marine Corps Air Station) provided an engineman for underway as well as pierside engine maintenance. Electricians from the Ocean Systems Division designed and maintained recall devices and other electronic gear. Day-to-day repairs and maintenance of boat engines were essential tasks ably performed by Francis Nakamitsu.

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