S E C T I O N I

IN SERVICE APPLICATIONS
OF AIR CUSHION TECHNOLOGY

THE USE OF ACVs IN SEARCH AND RESCUE - A PROVEN ROLE

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ABSTRACT

This presentation will outline Canadian Coast Guard search and rescue operations using air cushion vehicles.

The functional aspects of the CCG West Coast Hovercraft Unit will be discussed and the type and scope of operations will be reviewed, supplemented with movie film coverage.

The advantages and also limitations of the Coast Guard's existing air cushion vehicles will be highlighted.

The paper will conclude with a presentation of suggested improvements that the author deems desirable for 2nd generation search and rescue ACVs.

In Vancouver each year the Canadian Coast Guard expects to handle at least 3000 rescue calls. Every year a consistent, relentless increase of 10% is experienced. Contrary to popular belief the high incident time is not on winter nights when winds are blowing and rain is rattling on the windows, but is instead, usually on a holiday weekend when the sun is shining and a high percentage of the population of Vancouver are barreling around in their pleasure craft, desperately seeking diversion.

On such days anything can happen - children fall off cliffs, passengers are overcome by carbon monoxide fumes, scuba divers fail to surface and proud owners of new boats are wondering why their boats will only go at two knots at full power, being blissfully unaware that they are in only eighteen inches of water.

Summer is hectic. Fewer incidents occur over the winter months, but the degree of severity is increased. There is no time of the year when our rescue service can stand down and relax.

A study of incidents resulting in death has indicated that many such cases have started off as trivial boating mishaps. A pleasure craft runs out of gas. The anchor fails to hold. The craft drifts up against a breakwater. Tide and current sweep the now damaged craft over the breakwater into shallows. Hours have passed - no one has been advised - no radios on the boat. The occupants become irrational as darkness nears. They try to walk ashore and all are swept away by rising tides and perish.

The objective of the Canadian Coast Guard is rapid resolution of SAR (Search and Rescue) incidents. Nip them in the bud. Do not allow the situation to deteriorate. Many rescue incidents appear to be non-dramatic and mundane, but such incidents are highly successful as the problem has been solved and danger cancelled before lives were jeopardized.

We are only too well aware that no single type of equipment can do all our work for us. Life would be easy if such equipment existed.

In the Vancouver area certain conditions must be met and at this time the operational requirements for an inshore SAR unit are:

Speed	Amphibious Capability
Endurance	Nightsearch Capability
Power	Versatility
Cab Space	Manoeuvreability

At this time the hovercraft, or ACV fulfills these requirements.

The movie which we will now show, is about three years old. It shows a simulated medical evacuation from the Pt. Grey area. Before ACVs were used this operation took hours. Over the past ten years nearly a hundred casualties have been removed from this area by hovercraft. Each operation taking less than half an hour from start to finish.

To operate ACVs effectively it has become very obvious that certain conditions must be met. Pilots must be well trained, competent personnel who can operate the vehicles under the most adverse conditions. In the Canadian Coast Guard, pilots are selected for basic training who are either graduates of CCG College with at least two years sea experience or hold an equivalent commercial license. Flexibility, enthusiasm and confidence being vital factors for selection. After twenty-five hours of basic training, if certain skill levels are reached and written exams passed, the individual is then considered suitable for additional training. After approximately one year of operational experience the individual is regarded as being suitable for a command position and again, has to pass stiff written tests and operation checkouts before being qualified.

At 0100 hours on March 17th, an ACV left the CG base at Vancouver Airport. It navigated at full speed through a fishing fleet of over 800 vessels - avoiding not only vessels but also net lights. Shortly after the vehicle proceeded up a narrow channel and landed on a rock-strewn beach only twenty feet deep and forty feet wide. Two seriously ill patients were taken from the island and forty minutes later were in hospital. The vehicles operate at high speed in the same plain as many dangerous obstacles and hazards. Good training is essential.

Vehicle maintenance is the most critical factor in the effective operation of ACVs. Without good maintenance, the operation reverts quickly to a shambles. We must all ask ourselves - how many vitally important ACV operations have failed in the initial stages due to the crippling combination of poor pilots and faulty maintenance? How much irreparable damage has been caused through these failures?

THE FUTURE

Whereas present generation ACVs do a good job, areas for improvement certainly exist. The machine of the future as we see it should have -

Size:	About 50 feet long
Speed:	Engines should be of higher power to give greater speed. Speeds of 80-100 knots should not be impossible and training techniques are underway which will allow competent control of vehicles at such speeds.
Comfort:	The tapered skirt shows great promise and should be incorporated in all future vehicles. During medical evacuations it is essential that speed be maintained but not at the expense of comfort.
Control:	Twin shrouded props give good control and low noise level.
Cabin Space:	Is essential for SAR and a cabin with less space than the SRN6 is unacceptable.
Electrical Power:	At least 400 amps at 28V/DC

CONCLUDING REMARKS

We await new developments with confidence and in this part of the world can say that the ACV has become a well respected member of the community. Many people are alive today because of the ACV and its capabilities and on behalf of those people and on behalf of my colleagues, who are proud to be associated with such vehicles, I would like to thank everyone here who has played a part in the development of the ACV.

THE UNITED STATES ARMY MAGIC CARPET

John F. Sargent
LACV-30 Project Engineer
U.S. Army Mobility Equipment
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GENERAL

Figure 1 (LACV-30 with Swing Crane) - The magic carpet of Arabian Nights fableland has materialized into a true transporter for the U.S. Army with the introduction of the U.S. Army LACV-30. Early efforts by the Army in the mid-50's to exploit the air cushion principle were premature, since the technology had yet to mature. Subsequently, when Cockerell introduced the flexible seal system to trap the air under a platform, it was only a matter of time until the concept would move into commercial marketplace. That movement began when England led the world by introducing the SRN-4 into plying the English Channel circa 1968. Now, in 1977, the U.S. Army is evaluating the Lighter, Air Cushion Vehicle, 30-ton payload (LACV-30) for amphibious logistical resupply. This is a major deviation from prior wheeled amphibian concepts which fundamentally began with the WW II DUKW and is currently represented by the inventory LARC-V, LARC-IV, and LARC-LX. It is intended that the LACV-30 will replace the LARC-V and the LARC-XV. Although designed primarily for the logistical mission, it could support secondary missions of coastal, harbor, and inland waterways roles, search and rescue, and medical evacuation. Figure 2 (Craft Description).

MISSION

For the military amphibious ACV, there appear only two firm missions which it could support; the first being an amphibious assault mission, and the second a lighterage or logistic ship-to-shore resupply mission where there are no fixed port facilities. The former is a U.S. Naval function, which is beyond the scope of this paper, and the latter is one of the fundamental U.S. Army missions in which, after the beachhead has been secured, the supply of beans and bullets becomes an extremely important part of the operation, even a critical part. It is the latter mission which the LACV-30 must satisfy.

As the student of military history knows, the success of a sustained amphibious operation is founded on the resupply phase. The mission of the U.S. Army logistical amphibian addressed that part of the resupply operation consisting of movement of cargo ship-to-shore and inland. The scenario for this mission envisioned the loaded cargo ship as standing offshore up to a 5-mile distance (a 1-mile distance was the usual offshore distance). The beachhead was assumed to be secured and a marshalling yard for cargo transfer inland followed the assault units. This

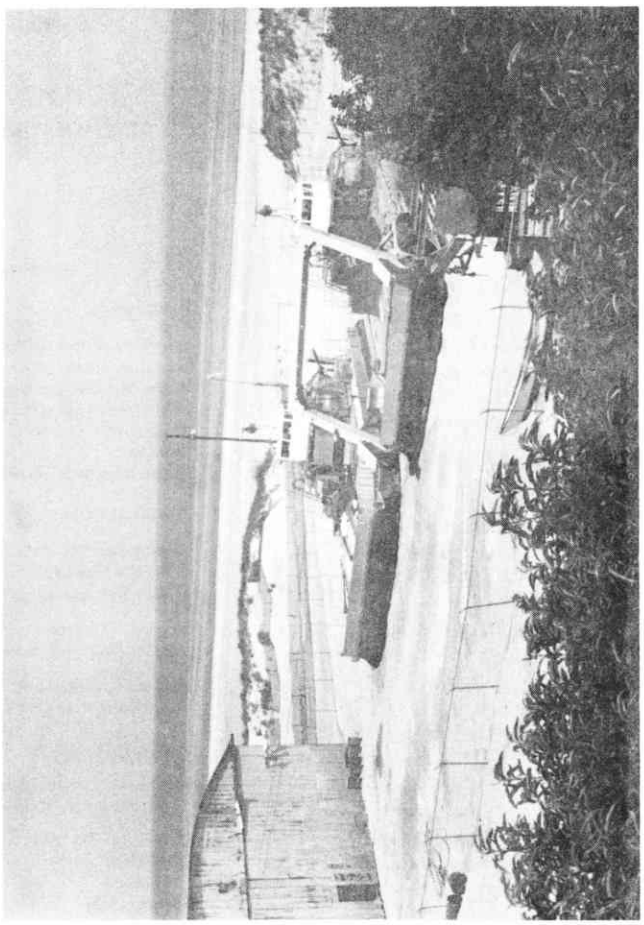
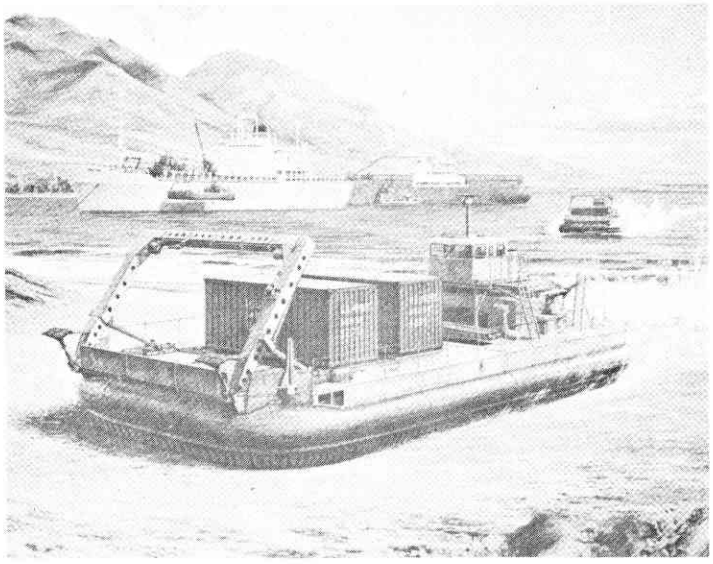
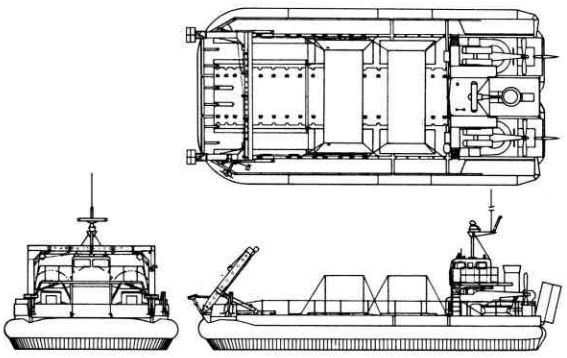


FIGURE 1 - LACV-30 with Swing Crane





LACV-30

The Bell Aerospace Model 7467 LACV-30 (Lighter, Amphibian Air Cushion Vehicle - 30 Ton Payload) is a fully amphibious high-speed craft designed to meet the U.S. Army requirement of transporting military cargo payloads in support of the logistics over-the-shore (LOTS) mission.

The LACV-30 is a hardened version of the standard commercial Bell "Voyageur" Model 7380 air cushion vehicle which is in production and already operating in a number of remote area cargo haul applications.

The LACV-30 is intended to replace the LARC-5 and the LARC-15 vehicles by 1980. The LACV-30 will provide the U.S. Army logistical system with a rapid lift capability to move cargo and equipment over water, marginal areas, beaches, ice, and snow. It will be capable of carrying military cargo consisting of cargo containers, wheeled and tracked vehicles, engineer equipment, pallets, nets, barrels, and other general cargo. It will be used primarily in the LOTS mission as a lighter in combat service support operations and will support secondary missions such as coastal, harbor, and inland waterway roles, search and rescue, and medical evacuation. The craft can be given self-unload capability with the addition of an optional bow-mounted swing crane.

PAYLOAD AND ENDURANCE CHARACTERISTICS			
	Configuration and Payload		
Cruise Endurance	Drive-On Cargo	MILVAN Cargo	Self-Unload MILVAN Cargo
2.0 hours	30.0 tons	30.0 tons	26.5 tons
5.0 hours	27.3 tons	27.3 tons	23.5 tons
9.1 hours	23.7 tons	23.7 tons	20.2 tons

SPECIFICATIONS

DIMENSIONS

Length, overall (on cushion)	76.25 ft
Beam, overall (on cushion)	36.33 ft
Height, overall (on cushion)	24.33 ft
Height, overall (off cushion)	21.50 ft
Height, skirt (nominal)	4.00 ft
Cargo deck	51.5 x 32.5 ft
Height, cargo deck (off cushion)	4.00 ft

POWER MODULES

Powerplants - Two UACL/Pratt & Whitney Twin Pac ST6T gas turbines (maximum rating 1800 SHP - normal rating 1400 SHP per unit)

Propellers - Two Hamilton Standard Model 43D50-363 three-bladed variable pitch

Lift Fans - Two Bell/BHC 7 ft centrifugal, 12-bladed, fixed pitch

FUEL SYSTEM

Fuel Type - Standard aviation kerosene (Jet A-1, JP4, JP5 or light diesel fuel oil)

Main Fuel Usable Capacity	2,365 gal.
Fuel Ballast/Emergency Fuel Capacity	1,584 gal.
Estimated Fuel Consumption at Cruise	260 gal./hr

ELECTRICAL SYSTEM

Starter Generators - Four gearbox driven, brushless, 28 vdc, 200 amp (each)

Batteries - Two nickel cadmium, 28 vdc, 40 amp hr (each)

PERFORMANCE (ESTIMATED)

Standard day, zero wind, calm water

Gross Weight 115,000 lb

Normal rating	47 mph
Maximum rating	57 mph

FIGURE 2 - Craft Description

fixed the routing for LOTS (Logistics Over The Shore) operations, viz., the amphibious movement of supplies from cargo ships standing five miles or less offshore to a cargo transfer point up to five miles inland. Beach barriers of surf, sand bars, and long, shallow water approaches to the beach threaten to deny landing craft a successful landing; if landing craft are stranded, then materials handling equipment (MHE) must work in treacherous surf. Immediately inland of this are assumed sand dunes with associated drainage areas behind them attendent with swamp areas. The forte of the amphibian is its capability to through-put its cargo to an inland transfer point; non amphibious craft such as landing craft, barges, etc., must transfer their cargo at the beachline which invariably results in a beach buildup of cargo presenting a lucrative target and contributing to beach congestion which hamstrings the entire operation. Attendent to this environment are the most hostile elements of all for machinery - sand and salt water. These mission requirements for Army amphibians impacted less severely on wheeled amphibians than on air cushion vehicles conceptual design, yet, the decision was made to prosecute the air cushion concept. Rationale for this seemingly paradoxical approach was indirectly predicted on commercial acceptance of containerized cargo. For the U.S. Army must rely on commercial shipping for wartime support, and commercial shipping has within the past eight years aggressively developed huge containerships capable of carrying thousands of 20 and 40 foot containers. The advent of containerships threatens to eclipse break-bulk cargo ships and their slow rate of cargo discharge. That slow cargo transfer rate was dictated by break-bulk cargo handling of sling loads, pallet loads, and in recent years the 5-ton CONEX container. At best, the cargo discharge rate for break-bulk ships in a LOTS operation was approximately 720 tons per day for planning purposes; with containerships it appears this rate can be increased to 6,000-7,000 tons per day. Historically, the concept of containerized cargo is not new, but through-put of this type freight is, which, coupled with the pilferage protection it offers, promises a latitude in amphibious assault tactics and strategy never available before. Selection of the air cushion vehicle as a candidate for the LOTS amphibian was based on its performance. Design experience with wheeled amphibians having a cargo payload in excess of eight to ten tons indicates it suffers severe degradation in performance, especially in speed, manoeuverability, and mobility. Thus, with the requirement to transport a 22-ton container, an ACV with open, flat, cargo deck was dictated.

VOYAGEUR MILITARIZING

So in 1972, the tests of Off Shore Discharge Of Containerships (OSDOC II) conducted in the Fort Story, Virginia, area, evaluated the Voyageur ACV as a logistical amphibian. The craft favorably demonstrated this capability despite several mechanical shortcomings. These shortcomings were addressed in subsequent feasibility analysis and consisted of the following:

1) Increasing payload to 30 short tons.
2) Strengthening deck to absorb container load impacts.
3) Inclusion of turbine air intake filtration system.
4) Adequacy of negotiating eight foot plunging surf.
5) Installation of communication-navigation equipment; including a collision avoidance radar system.
6) Substitution of dieselized for turbanized power.
7) Noise suppression.
8) Self unloading capability.
9) Incorporation of a bow ramp.
10) Land directional control.
11) Craft fendering.

All of the above items except substitution of dieselized for turbanized power and land directional control were incorporated in the LACV-30 design concept. Substitution of diesel engines and incorporation of hull wheels were not incorporated because of the associated complexity and cost involved. A summary description of the adopted items of the "hardening" study follows.

Increased Payload - The Voyageur 6000 series aluminum hull was stretched eleven and one-half feet amidships after model tests and structural analysis indicated no adverse affects. (Figure 3, Stretch).

Deck Strengthening - A particular concern in transported the loaded containers was structural adequacy of deck to accept the box during loading asea. In any kind of running seas, the container is expected to strike the deck with one corner of the box as it pendulates into position. The obvious solution of strengthening the entire cargo deck would have penalized the craft weight adversely; consequently, load spreader pallets were fabricated to act as doublers for the box to land on. (Figure 4, Load Spreader Pallets).

Filtration System - It was recognized that the turbine would be forced to operate in a hostile environment of sand, salt water, ice, grass, etc. Abetting this was the spray generated by the cushion air which tends to recirculate the contaminents. Consequently, a filtration system was designed to protect the turbine air intake. The system was powered by a small 150 hp auxiliary power unit driving an axial fan which draws in air about 12 feet off the deck level. This air is then split to the port and starboard turbine flowing through an inertial separater, a tortuous path water separater, and a barrier filter prior to reaching the engines. The ducting carrying this air is pressurized with a minimum of 2-inch head of water at the turbine air intake; by pressurizing the ducting, outside contaminated air is prevented from leaking into the system downstream of the filters. (Figure 5, Air Management System).

Surf Protection - to comply with the military requirement to negotiate 8-feet plunging surf, the hull was evaluated for surf compatibility. It was determined that a surf fence was required on the bow to protect cargo from the 20 psi surf impact pressure when proceeding out to sea. In

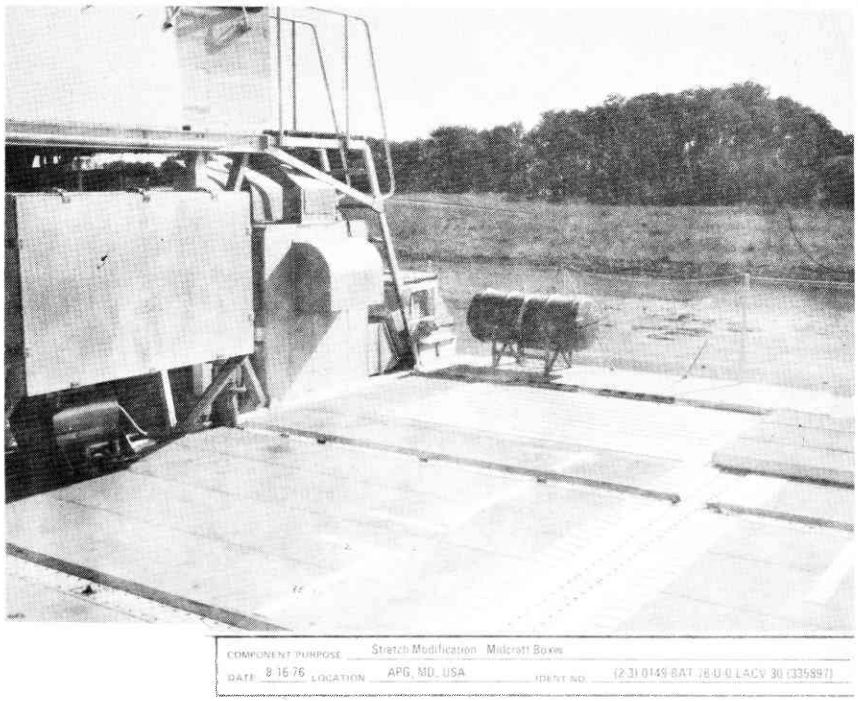


FIGURE 3 - Stretch

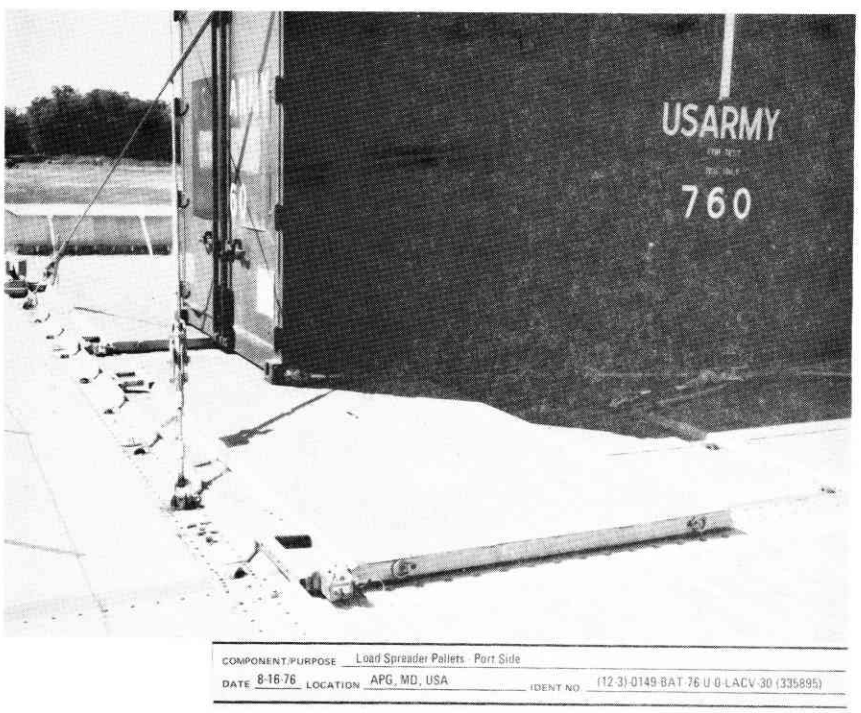


FIGURE 4 - Load Spreader Pallets

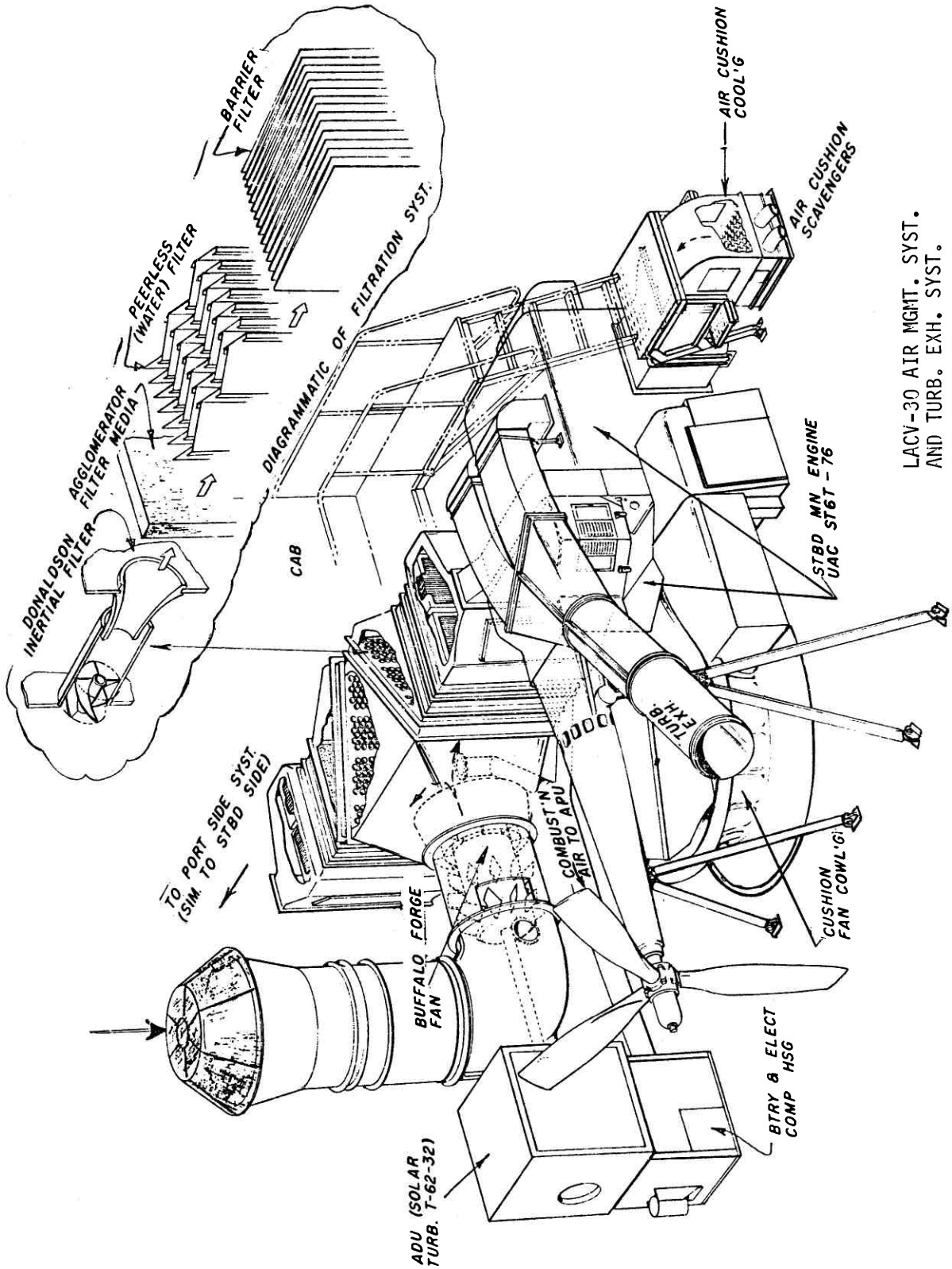


FIGURE 5 - Air Management System

approaching the shoreline with following surf, it is planned to surfboard the breaker to the beach and quickly scramble for high ground to avoid the disaster experienced by the SRN-6 in Africa.

Model surf tests were conducted on the 1/7.5 model and when following surf was allowed to envelope the stern of the craft, it was dissipated by the cushion and propeller action. Only full scale field tests will determine the validity of this observation.

Self-Unloading Capability - In early deployment of the LACV-30 during a LOTS operation, it is expected the craft may have to operate without field materials handling equipment (MHE). Consequently, a means was needed to unload the containers off the LACV-30. Of the various configurations evaluated, the most feasible method was a swing crane, bow mounted, hydraulically operated; to avoid overstressing the hull bow when the crane is loaded, outriggers were incorporated to transfer the swing crane loads to the ground. To move the containers under the crane for lift, they were skidded on the pallets discussed above by operating the swing crane over centre with a tagline to the pallets and repeating as necessary to centre the box for lift. (Figure 6, Swing Crane).

Bow Ramp - Finger ramps manually emplaced were also incorporated. Also, load spreader tracks are provided with ramps to bridge the deck from the ramp to the pallets now used as vehicle load spreaders. A davit equipped with a hand winch is provided to handle ramps and tracks. (Figure 7, Bow Ramp).

Communication-Navigation - The incorporation of specific communication-navigation equipment was also analyzed. A VHF marine radio telephone, a tactical FM VHF radio, an intercom for both internal and external (deck hands) craft communication, in addition to a collision avoidance type of radar were included in the cab design. (Figure 8, Cab Interior).

Dieselization - Analysis of five candidate diesel engines for possible substitution of the gas turbines currently installed was conducted. Excessive weight of the diesel power plants and associated systems required to replace the current turbines indicated this approach to be infeasible.

Noise Suppression - The external power sound level of the basic Voyageur craft at the hull side was measured to be approximately 150 dBa. Prior experience of the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) with air boat noise suppression of air propellers had been ineffective, so it was considered more feasible to insulate the cab and its occupants from this sound intensity. A target of 84 dBa was set for the noise level within the cab by insulation and acoustic treatment of the cab.

Land Directional Control - In recognition of the difficulty of ACV negotiation over land, especially in gusty winds or on a side slope, an analysis for land directional control for the LACV-30 was conducted. To

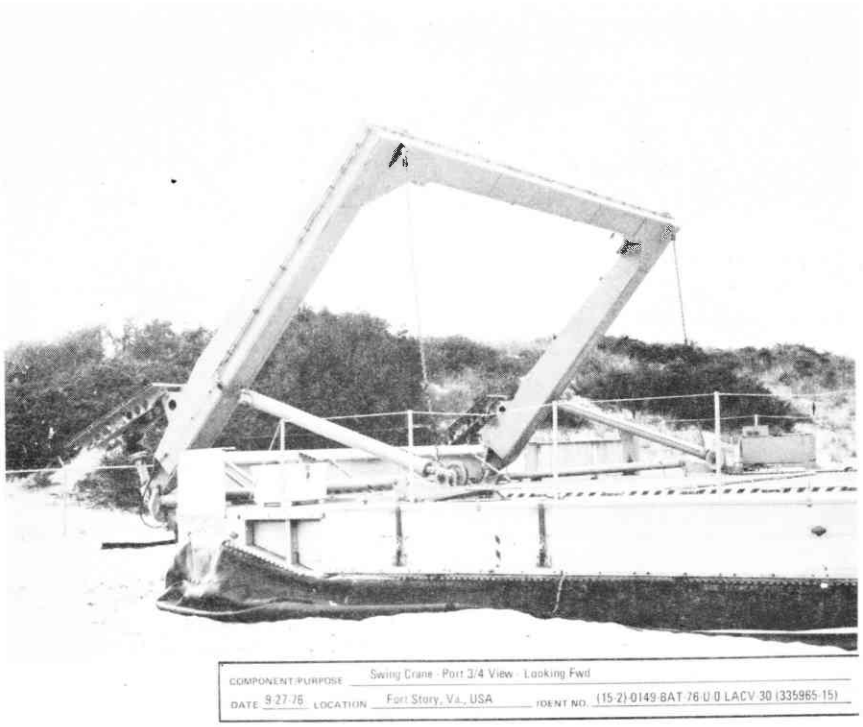


FIGURE 6 - Swing Crane

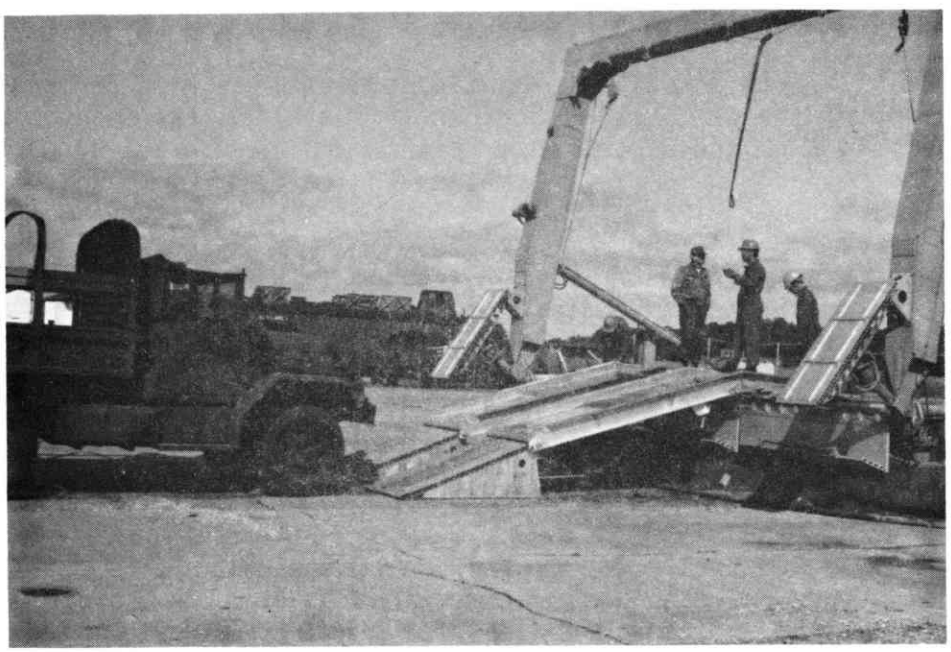


FIGURE 7 - Bow Ramp

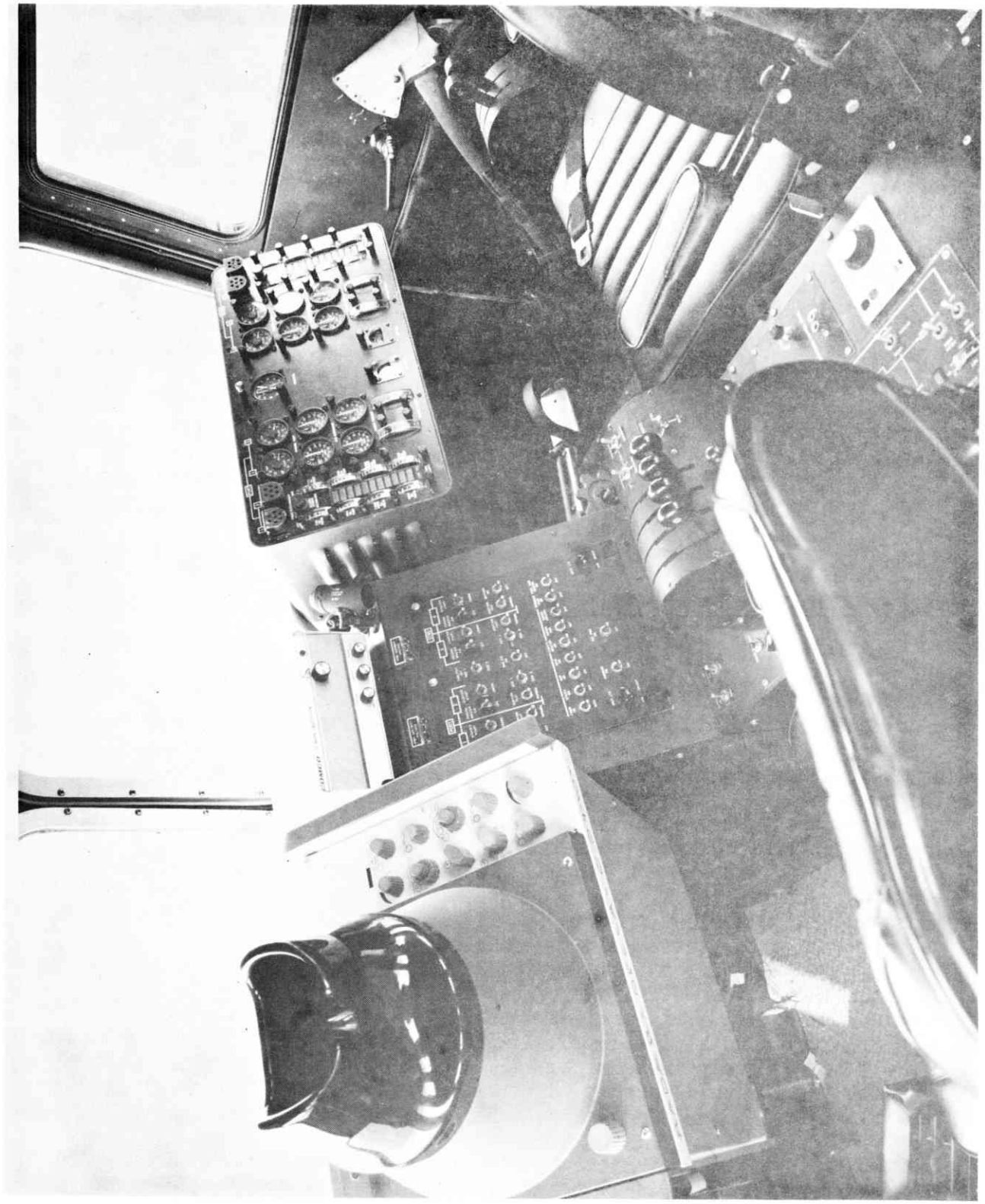


FIGURE 8 - Cab Interior

simplify the concept, a retractible pair of oversized wheels installed approximately amidship under the cushion was considered. However, the complexity of land drag and retraction was too severe a penalty for incorporation and the concept was deferred.

Miscellaneous - Both the hull stretch and surfing performance were model tested at the Bell Aerospace ACV test tank. Other improvements over the Voyageur craft included a newer version of the original turbine which boosted its power from 1,700 hp to 1,800 hp per twin-pac for burst conditions and a higher activity factor propelled to absorb the additional power. Furthermore, to improve performance of the 11½ foot stretched Voyageur craft, an investigation of the lift system was conducted. The net result was the incorporation of lift fan volutes in the discharge plenums and an improved stern seal which would reduce cushion leakage and increase bag-to-cushion pressure ratios.

In addition to the above, fendering, cargo tiedowns, hull fittings, and a tapered skirt were considered for the LACV-30. The latter was rejected due to costs and the lead time for development. These feasibility studies transpired over a two year period, 1973-74, due to very austere funding and a low priority lead time.

LACV-30 CONSTRUCTION AND TRAINING

In late 1974 when the U.S. Army TRANS-HYDRO Study was gaining visibility, the air cushion vehicle candidate for amphibious resupply of cargo started receiving attention. Although concepts were prepared in-house for the candidate, it was in response to a proposal from the manufacturer that a contract was awarded in March 1975 for a modified Voyageur craft, based on the program schedule generated with the above feasibility analysis. The award addressed the procurement of two LACV-30 craft complete with software, parts, training, and support equipment. The purpose of obtaining two craft was to provide a test unit for each of two different test programs to accelerate evaluation. These two test programs were development test program (DT II) which addressed craft performance quantitatively, and an operational test program (OT II) which was a mission oriented tests. The latter test was to be conducted at Fort Story, Virginia, the home of Army Amphibious Training and Testing. The DT II was scheduled to be conducted in four different test sites: 1) Aberdeen Proving Ground, Maryland, for initial instrumented tests including rail hump tests; 2) U.S. Naval Coastal Systems Laboratory, Panama City, Florida, for water performance on their instrumented sea range; 3) Eglin Air Force Base, Florida, for the cold chamber tests; and 4) Monterey, California, for heavy surf tests.

The two craft were constructed at the Bell Aerospace Textron Canada site in Grand Bend, Ontario, and were outfitted at Bell Aerospace Textron's Wheatfield plant near Buffalo, New York. Due to the need for a realistic water and land test site where possible, acceptance tests would be conducted at the manufacturer's site, but the remaining tests would be

conducted at the government test site where the true marine environment would be realized. After the first craft, LACV-30-1, was completed at Grand Bend, preliminary sea trials were conducted in Lake Huron to validate model data on performance for both the stretched craft, as well as lift system and filtration system effectiveness. Water performance using local police radar tracking (no tickets were given) did confirm model test predictions, so the craft was then shipped to Wheatfield, New York, for outfitting and land acceptance tests in a very benign environment.

At this time it is important to note the preparation by the government to merge the availability of a crew with craft availability. In the summer of 1975, a screening process was initiated to facilitate selection of a 15-man military crew for each craft. (Of these 15 personnel, 3 were supervisory, 2 administrative, 2 were deck hands, and 4-2 operators and 2 navigators-were operational; resulting in a total of four direct craft maintenance personnel.)

The crew size was kept large since each unit would have to be self-supporting during isolated tests. After the teams (Team A for OT II and Team B for DT II) were selected, and their military tour of duty stabilized to insure availability during the entire test, a training program was initiated within the constraints of funding and yet sufficiently effective to facilitate contractor turnover. This program addressed training of each maintenance skill required for the craft by classroom, by sub-contractor, manufacturer, and by on-the-job-training. For the operators and navigators, a total of 100 hours "stick-time" as a minimum was required for each operator and a total of 35 hours "stick-time" required for each navigator; each operator and navigator was given a comprehensive solo test before being certified by the contractor. Approximately the first half of training was conducted at the U.S. Naval Coastal System Laboratory (USNCSL), Panama City, Florida, in the Fall of 1975 by Bell Aerospace Textron using their Voyageur 001 craft. The second half of the training was conducted at respective LACV-30 test sites by each crew on their own LACV-30. It should be noted that the USNCSL is the most advanced air cushion vehicle testing facility in the world; it is located in a moderate climatic area, with two radar towers located up to 12 miles off shore which establish a tracking range, with sea and weather conditions plotted on each test tracking printout. Shore installations include a modern hangar with one end that can be opened to berth the large 80-90 foot U.S. Navy Amphibious Assault Landing Craft and with parking facilities which permit easy access to the sea. This is clearly one of the most outstanding test facilities ever seen by the author, and anyone who has had to establish a speed curve by repetitive test runs over a measured mile course will appreciate the "instant" recording on a graphical printout of not only speed, but acceleration, turning circles, crash stop distances, etc., all complete with weather and sea conditions.

The "stick-time" of 100 hours for the operator was arbitrarily specified by the government on the basis of United Kingdom and Canadian certification requirements, and due to funding constraints. Prerequisite

for operator selection was a marine license approved by U.S. Coast Guard. The U.S. Coast Guard at that time had no regulations controlling certification of ACV operators; consequently, it was delegated to Bell Aerospace due to their considerable experience in operating their Voyageur craft. The concern of the government in specifying effective operator training was predicted on the high speed performance (50 mph) of the LACV-30 as compared with the relatively slow speed displacement craft (8-12 mph) which Army operators were used to handling. Considering this performance differential when operating in highly trafficed seas, the chance for a catastrophic accident becomes a distinct possibility. Furthermore, to insure the navigator could take over in an emergency, he was given operational training within those constraints of time and funding with the intention of subsequent on-the-job-training by the Army to qualify the navigator as a certified operator. Additionally, of course, the navigator had to be qualified in marine navigation as well as being a qualified radar operator. So, at Panama City, Florida, Army operatory and navigator training commenced, with emphasis on water operation initially.

Concurrently, the maintenance trainees were diligently occupied keeping Voyageur 001 operational, as its age was beginning to reflect the wear and tear of prior years of use. As the training progressed, the students were advised of the difference between the Voyageur and the LACV-30 so as to be prepared for the LACV-30 when delivered to the Army.

Following introductory training on the Voyageur craft, the military teams were instructed on operation and maintenance of the LACV-30 following delivery to the government test sites. The transition training under Bell's supervision went well except for two accidents occurring on the OT craft. One occurred when negotiating a sand dune grade with full load, a decision to come off cushion prematurely when veering off course allowed the craft to slam into the dune. The other resulted in more severe damage when a decision to come off cushion was late and the slow cushion decay permitted the craft to crash into a concrete block at the beach edge. Land training was conducted at Aberdeen Proving Ground, Maryland, while the APU failures were being investigated on the other craft. During the land training conducted on a tank test area, the area's heavy grass stirred up by the cushion clogged the filters in the cushion air-to-engine-coolers and had to be manually cleaned. Flow diverters and screens provided some protection, but the problem was not believed serious, since this terrain was not typical of a marine environment. However, another condition which was also not typical of a marine environment was believed more serious and that was the harsh cinder-type surface of the DT craft test site. This was to cause reduced skirt life, as discussed in more detail in the section on Panama City, Florida, testing. Training, however, was eventually completed without either operator or navigator washouts; all four operators were certified. To date, these operators have done well as a team with their navigators, and promise a strong capability for future Army transition training. Likewise, the maintenance teams showed their grasp of the craft design by innovations and applications which kept the craft operational under adverse conditions.

TEST INTEGRATED WORKING GROUP (TIWG)

Training was only a part of the preparation required for the Army to evaluate the pilot craft LACV-30. One especially salient organization formed for the LACV-30 program was the Test Integrated Working Group chartered at higher headquarters. This organization was formed specifically to co-ordinate all test activity scheduled for the craft to insure co-ordination as well as to avoid duplication of effort. The TIWG was formed of representatives of both the DT and the OT testers and evaluators in addition to the developer, contractor, and future user. It is a sizable group which addressed major determinations of testing and the procedures as how to obtain that data in the minimum of time and cost. The TIWG convened a number of times prior to craft delivery to address, among other subjects, Reliability, Maintainability, and Availability; Test Determinations; Scoring Criteria; and Scheduling. The TIWG was chaired by the developer and each meeting was documented for concurrence. As with any committee action, control was difficult and priorities had to be established to order that control. The TIWG was successful, however, in formulating a plan of test and associated schedule for both DT and OT. Also, scoring criteria were established for infant failures, major failures, and compounding failures; this criteria became the basis for scoring conferences subsequently held on all craft failures and shortcomings, each and every one of which was formally reported.

INTEGRATED LOGISTICS SUPPORT WORKING GROUP (ILSWG)

A unique organization peculiar to the LACV-30 program was formed to plan logistics supportability for the craft. This was the Integrated Logistics Support Working Group (ILSWG). The group consisted of experts in logistics field.

The group addressed the nine elements of logistics, following, which are part of the management science technique in acquisition of new material:

1) Maintenance Plan
2) Supply Support
3) Support and Test Equipment
4) Transportation & Handling
5) Technical Data
6) Facilities
7) Personnel and Training
8) Logistics Support Resource Funds
9) Logistics Support Management Information

Assignments were made with the ILSWG for implementation and deadlines for these elements. The target date for starting tests of the craft established priority for task completion preparatory to receipt of the craft. A brief description of each task follows.

The Maintenance Plan - A maintenance concept was agreed to, predicated on deployment experience with prior Army amphibians, wherein the craft were envisioned as operating in an isolated mission without support maintenance. The concept addressed a company of twelve craft potentially

capable of operating separately in three platoons of four craft each, wherein the company must provide all maintenance and repair within its expertise and tools furnished. This implied a two level echelon of maintenance, organizational and depot. A 30-day level of supply had to be maintained and a pipeline for resupply had to be estimated. As required, complex machinery or components would be returned to the depot or manufacturer for repair with complete unit replacement.

Supply Support and Test Equipment - Typically of most acquisitions, a list of spare parts was drafted as a "best estimate" for the LACV-30. Mortality rate of the parts, including revisions to the list would be determined by actual test use; in that regard the OT simulated and rigorously adhered to a realistic LOTS scenario, comprehensively documenting all maintenance action taken complete with parts used. Both DT and OT teams maintained similar records which were extensively used during scoring conferences, cost effective analysis, and as a basis for stocking the pipeline. Although the lack of funding dictated selective procurement of parts and tools initially, those parts not available were obtained by cash buys while machine tools and diagnostic equipment were rented and operated by the craft crew.

Transportation and Handling - During TIWG action, it was agreed that movement of the DT craft would be by various modes - land, sea and air - and documented complete with analysis. Long term storage of inventory craft was also considered.

Technical Data - A running account of changes required for operator and technical manuals, performance specifications, and drawings were recorded for subsequent updating.

Facilities - A fuel farm and fresh water storage facility was entered as support facilities required for the LACV-30. Also, a motor park optimized for the sea and surf environment was defined complete with materials handling equipment, electrical and compressed air support.

Personnel and Training - Prerequisites for the craft operating and maintenance was described in detail, including the need for cross training. The transition of training from manufacturer to the Army (U.S. Army Transportation School) has already been initiated with formalized program of instruction and the necessary qualifications for the school to provide their own certification of craft operators.

Logistics Supply Analysis (LSA) - This is an action to analyze and record select maintenance functions for developing quantative and qualitative logistics resource requirements.

Reliability - In today's military environment, after performance, reliability is the most important characteristic of an item. In the LACV-30 no goals were set, since it was agreed that tests would establish the criteria. Guidelines from Canadian and United Kingdom usage were utilized, but in acknowledgment that the environments were not the same as that for LOTS.

Material Fielding Plan - A Material Field Plan is under preparation. This is a user-oriented document which contains all plans, schedules, and procedures necessary to successfully deploy and sustain the item being turned over to the military. An element of the plan is Project Hand-Off. In essence, Project Hand-Off has the objective of commitment, or warranting by the developer of new equipment to the soldiers satisfaction. This is accomplished by a transition period in which the developer provides a field team to backup both physically and psychologically the using agency during initial deployment of the commodity. This is implemented by assignment of the design engineer living with the initial deployment, and by using a quality assurance team to protect the government's interest.

TESTS

During early conceptualizing of the LACV-30, additional total cushion lift (115,000 pounds loaded displacement) was needed beyond that offered by the Voyageur craft (88,000 pounds loaded displacement). Although weight control of the LACV-30 during design was rigidly maintained, the additional components and systems required to militarize the craft made the concept heavier. Incorporation of surf fences, container pallets, swing crane, and air management system were, among others, responsible for the increased craft lifting weight.

To satisfy the need for additional cushion lift, a hull stretch of 11½ feet was added amidship and the cushion pressure was raised from about 50 psf to about 56 psf. In addition, the stern seal of the cushion was improved by incorporating fitted cones of approximately 50% decrease in airflow exit area. When the efficiency of the fan lift system was improved by the addition of volutes or scrolls in the plenum of each fan to improve airflow. These were all successfully model tested in Bell's ACV model tank.

In addition, the twin-pac engines were upgraded from 1,300 hp continuous to approximately 1,500 hp. Higher activity propeller blades were also incorporated to absorb the additional power. The intent of these modifications was to retain the high performance capability of the Voyageur despite the greater displacement of the LACV-30.

The basic craft were constructed at Bell Canada in Grand Bend, Ontario. They were then trucked to Bell Aerospace at Wheatfield, N.Y. for final outfitting. The lack of access to a water test site in Wheatfield raised concern over the ability to test LACV-30 basic performance with the hull stretch and modified cushion while under direct control of Bell, and prior to shipping the craft to a government test site.

Fortunately the proximity of Lake Huron to the Bell Canada plant offered that water test site. Through the courtesy of the Canadian Government, we were allowed to use that water site. So in the Fall of 1975, the tests were conducted on Lake Huron that successfully confirmed the model tests. The tests were quite simple - a few speed runs, land and water hover, a three-hour endurance run, and a few beachings.

Following tests, the craft was trucked, sectionalized, to Wheatfield, N.Y. for final outfitting, including installation of the bow mounted swing crane. Subsequently, limited land tests were conducted at a nearby airport. Shop tests were conducted on the swing crane, consisting of the movement of a fully loaded container from an aft position on the cargo well deck to a position under the crane and then lifted off the craft to the ground. The rate of container movement was deliberately slow (approximately 15 minutes to unload the box as described above) in order to control the heavy lift, so the crane design appeared crude and simple. In answer to criticism of these apparent shortcomings, it was explained the rate of movement could be increased, but only at the risk of a 20-25 ton load getting out of control. Also, the simplistic design of the crane was defended on the basis of austerity and of the poor reliability experienced with the preferred electrified swing crane in the LOTS environment. Crane tests did point out a shortcoming, however, which was the need for incorporation of small hydraulic cylinders which insured the outrigger's contact with the ground when the load was swung over center forward. This change was found necessary when during tests, it was observed that the outriggers lifted off the ground during swinging the load over center forward, shifting the pivot point to the aft landing pads. If the craft were on a slope, it was possible the craft could pivot on these aft pads and allow the load to get out of control.

Following completion of Wheatfield tests, March 1976, the first LACV-30 was trucked to the Fort Story, Virginia, government test site for final contractual acceptance. The purpose of using this site was to immediately expose the craft design to a LOTS environment. Initially, the test integrated working group decision was contested, because both the craft and the test site had been selected for operational tests, a test which should sequentially follow DT since DT provides the safety release based on acquired performance data. However, the DT craft was scheduled to be shipped to Aberdeen Proving Ground, Maryland, for initial required tests and, furthermore, could not be completed until two months later. One of the reasons for the staggered delivery was a test integrated working group agreement to incorporate a Data Acquisition Package in that craft for recording data from approximately sixty sensors. (Figure 9, Data Acquisition Package Recorded Channels). However, that decision was successfully defended on the basis that there was an urgent need to determine the adequacy of the air management system (turbine air intake filtration) in that environment, and that the burden of cost was unwarranted for shipping the sectionalized LACV-30 DT craft to Fort Story, Virginia, and then to have to trans-ship it to Aberdeen Proving Ground, Maryland. Consequently, the OT craft was subjected to acceptance test first. It should be noted that even MERADCOM design engineers in their fourth iteration of amphibious development failed to fully appreciate the hostility of the LOTS environment to an air cushion vehicle. (Figure 10, Sand Clouds).

Particles were in the range of 20 to 100 microns. Efforts to reduce hover-generated sand spray included wet-soaking of the parking area over an inch thick, but cushion hover escape air quickly broke up that crust.

CHANNELS	PARAMETER	RANGE	SENSOR
1-4	Power Turbine Temp	0-1200°C	Engine Pickup
5-8	Gas Generator rpm	0-100%	Engine Pickup
9-12	Power Turbine rpm	0-100%	Engine Pickup
13-16	Engine Torque	0-60 psi	Engine Pickup
17-20	Air Intake Temp	0-200°F	IC Thermocouple
21-29	Engine Bay Temp	0-400°F	IC Thermocouple
30-35	Prop Blade Angle	-	Rotary Potentiometer
36-37	Prunk Pressure Peripheral	0-75 psf	Pressure Transducer
38	Keel Trunk Pressure	0-75 psf	Pressure Transducer
29-40	Stability Trunk Pressure	0-75 psf	Pressure Transducer
41	Rear Trunk Pressure	0-75 psf	Pressure Transducer
42-45	Cushion Pressure	0-75 psf	Pressure Transducer
46	Pitch Attitude	±30°	Attitude Gyro
47	Roll Attitude	30°	Attitude Gyro
48	Roll Rate	60°/sec	Rate Gyro
49	Pitch Rate	60°/sec	Rate Gyro
50	Yaw Rate	60°/sec	Rate Gyro
51	CG Acceleration Vert	±5g	Accelerometer
52	CG Acceleration Lat	±5g	Accelerometer
53	CG Acceleration Long	±5g	Accelerometer
54	Bow Acceleration Vert	±10g	Accelerometer
55-58	Air Management Pressure	± 1 psi	Pressure Transducer
59-60	Air Management Temp	0-250°F	Thermocoupler
61	Air Speed	0-100 mph	Cup Anemometer
62	Wind Directional	± 170° off	Wind Vane
63	Event Marker	-	Switch
64	Time Code	IRIG B	
65	Intercom		

FIGURE 9 - Data Acquisition Package
Recorded Channels

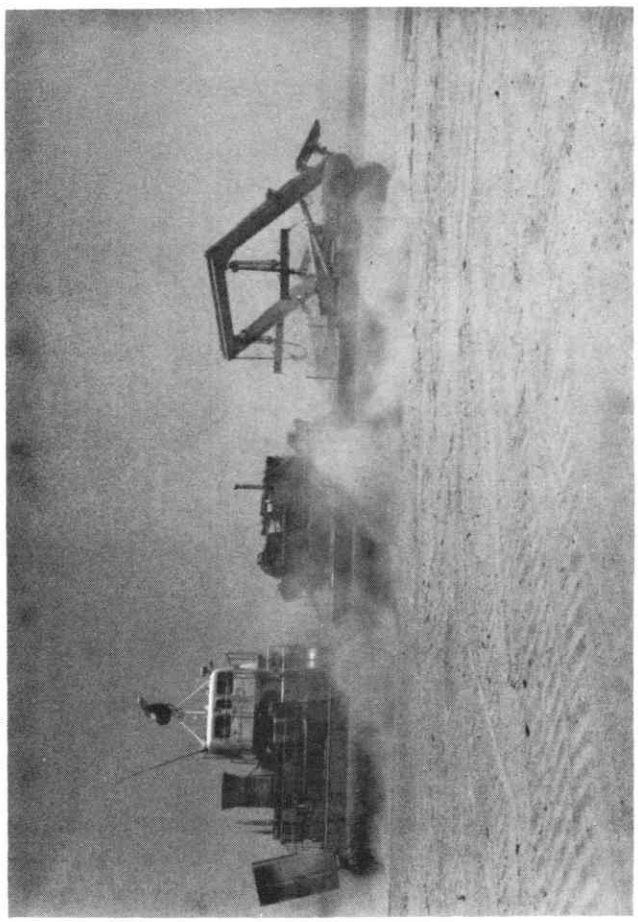


FIGURE 10 - Sand Clouds

It was obvious that if successful, the air management system promised to be a major breakthrough in protecting an exposed turbine operating in the sand and salt water environment.

However, two major deficiencies were revealed by the Fort Story, Virginia, exposure. These were: 1) auxiliary power unit (APU) failures, and 2) a vacuum experienced at the turbine air intake. Addressing the APU failures first, it should be recognized that this APU which powers the fan energizing the air management system, is successfully used in a number of military operations. However, in the first LACV-30 installation, six failures were realized. Confounding the problem was the successful operation of the APU installation on the second LACV-30, after an initial infant failure. A task team dedicated to solving the APU problem ultimately isolated and corrected the problem. A 250 Hz vibration detected in the power section of the APU while on the manufacturer's test stand was found to be controlled by grounding the exhaust of the turbine. Analysis revealed that the problem arose in the LACV-30 installation due to using only a straight, cantilevered tailpipe exhaust, whereas on other successful military installations an exhaust system with muffler was grounded to the APU structure. In short, the APU problem was resolved by fitting the exhaust with a pre-loaded bellows fixture.

The other deficiency experienced was the inadequacy of the air management system to pressurize the turbine air intake. The design intent of pressurizing the turbine air intake is to discourage leakage of impuritives downstream of the filters into the turbine, e.g., a vacuum at the turbine intake ducting encourages a flow of any impurities through leaks in the downstream air ducting. Again, a dedicated team resolved the problem by: 1) introducing a diffusor at the fan discharge to recover some of air energy lost due to ducting geometry, and 2) by deleting the machinery cooling function originally designed into the air management system. That cooling function was provided successfully by an independent cushion air bleedoff. As a final precaution, a barrier-type filter was incorporated as a fourth stage filter just ahead of the turbine air intake. That intake pressure is now protected by an alarm which alerts the operator when the pressure falls below four inches of water, signalling a dirty filter. An isokinetic sampling system testing the filtration efficiency indicated 97% of contaminents introduced through the intake duct were filtered out.

Other relatively minor, but annoying, deficiencies were detected, such as turbine air dump valves to reduce air intake temperatures, and watertight integrity of the electrical system. These were resolved on a case basis, which were time consuming, but in October 1976, after transition training was completed, the DT craft was accepted and in January 1977, the OT craft was accepted. The respective tests commenced immediately thereafter. Craft performance data cited in the following have not been formalized by test reports yet, so I have taken the liberty to generalize.

OT II

Operational Test II was conducted in total at Fort Story, Virginia. These were mission oriented tests conducted entirely by a military team previously trained for that mission. The test site is located on Hampton Roads, Norfolk, Virginia. Simulated missions carrying containers were conducted between Fort Story, Virginia and Fort Eustis, Virginia, which is on the James River; a distance of about 45 miles. Also, behind the beach were sand dunes which were negotiated for gradability tests. This was the only craft fitted with the swing crane.

The OT test site was a brutal selection due to the shifting sand and lack of adequate berthing. However, this was the testers perogative since they felt it was a typical locale. Although this environment took its toll of machinery life, it was relatively benign to the skirt system. It is expected to obtain over 600 hours with the OT II skirt fingers and cones. But, on the other hand, a maximum of 300 hours is all that can be expected with the propellers based on bollard thrust performance (fatigue life is unknown at this time). At the end of the 375 hour inspection of the OT craft, a bollard pull test was conducted; with new propellers the craft could exert a pull of over 6,000 pounds with about 1,800 pounds in reverse, but with these worn propellers, only a pull of 2,700 pounds was experienced. Now perhaps a fourth of that loss can be blamed on engine performance loss - heat, compressor blade erosion, etc., as engine data recorded at that time indicates. Bollard pulls conducted on the DT craft with approximately the same amount of operational time logged on the craft yielded a pull of 5,060 pounds. The difference in environmental effect was obviously radical.

DT II

Development Tests II were conducted at four test sites, Aberdeen Proving Ground, Maryland; U.S. Naval Coastal Systems Laboratory, Panama City, Florida; Eglin Air Force Base, Florida; and Camp Pendleton, California. At Aberdeen Proving Ground sufficient performance data was generated to permit a safety release for the OT craft. Additionally, rail hump tests, human engineering, radio interference suppression, and instrumented operations were conducted. The craft was then rail transported to Panama City, Florida; this movement was part of the transportability tests, and was successfully conducted except for minor hull cracks from entrapped water frozen during the movement due to improper loading. The Army leased from the U.S. Naval Coastal Systems Laboratory the use of their magnificent ACV hangar and concrete ramps. While at that site, continuous operation on the tracking sea range was conducted and printouts of each run were provided for analysis. While being tracked by the U.S. Navy radars, the craft data acquisition package was time indexed with the tracking printouts so that range performance (speed, acceleration, etc.) could be correlated with craft operation (power, fuel consumption, cushion performance, etc.). (Figure 11, NCSL Tracking Range Printout).

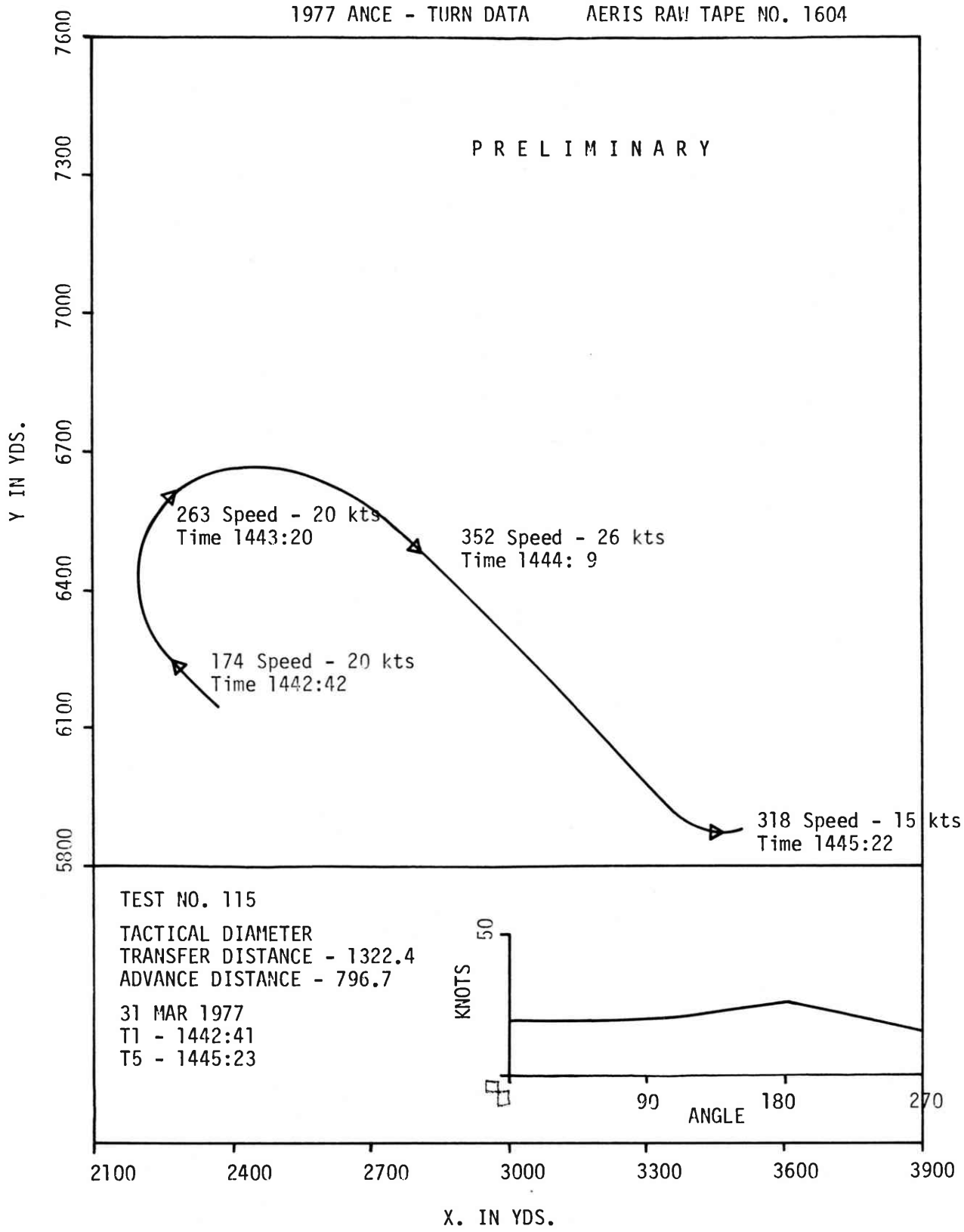


FIGURE 11 - NCSL Tracking Range Printout

It should be noted, however, that prior to use of either the Voyageur or the LACV-30 in the Panama City, Florida, area, an Environmental Impact Statement had to be prepared and approved. This was an intensive report in which Canadian experiments with ACV passes over vegetation without damage were cited. The statement was finally approved, which paves the way for other ACV operations in that area. However, we learned the hard way that although noise is objectionable, people will tolerate it unless it is generated early in the morning. In our anxiety to avoid the mid-day heat in Florida, we changed the schedule to operate early in the morning - about 0430-0500 hours. The response was immediate and vociferous - the craft noise would not be tolerated in those early hours, so we changed back to our original schedule.

Upon delivery of the LACV-30-2 to U.S. Naval Coastal Systems Laboratory, Florida, the rail transportability tests were completed. In general, dis-assembly of the craft required about two weeks including any packaging needed. To reassemble the craft at destination, takes about three weeks including a run-in trial, assuming the necessary support gear is available.

Some of the problems encountered by the DT craft included skirt wear, temperature compensators, and the 400 cycle generator driven by the APU. The skirt fingers and cones endured about 350 hours of operation with the wear confined to the aft half of fingers and cones; this could be associated with new operators technique of keeping the craft under control while over land by dragging the stern for braking the craft. (Figure 12, Skirt Wear of LACV-30-2 (350 hours))

The cone extensions of the stability truck were badly worn as were the rear cones and side fingers. Also, the keel blade of the keel trunk had to be replaced. These were replaced in total, but local abrasions on the trunks were patch repaired. (It should be noted that the National Research Council formed an AD Hoc Group to study skirt durability. The U.S. Navy has a study group addressing this problem, as has the contractor, Bell Aerospace, and the Materials Laboratory of U.S. Army Mobility Equipment Research and Development Command. Ten of the U.S. Naval experimental fingers and five of Bell's experimental fingers have been installed on the LACV-30-2, along with the conventional material installed to replace the worn skirt components. At about 300 hours of operation, a comparison of wear will be made). Craft speed performance only improved about 15% after skirt finger and cone replacement.

The temperature compensators for the main turbines are devices which bias the individual turbine temperature (the maximum operating temperature of each turbine differs so to permit each temperature indicator on the dashboard to read the same and simplify the operator's work the indicators are biased). These temperature compensators have failed frequently (at a cost of about $1,000 each) reportedly due to a high voltage spike in the electrical system. The "spike" appears to occur when the puff ports are actuated by an electrically operated hydraulic pump. Initial suppressors installed in the electrical system to contain the surge were unsuccessful; consequently, the crew preferred to operate without temper-

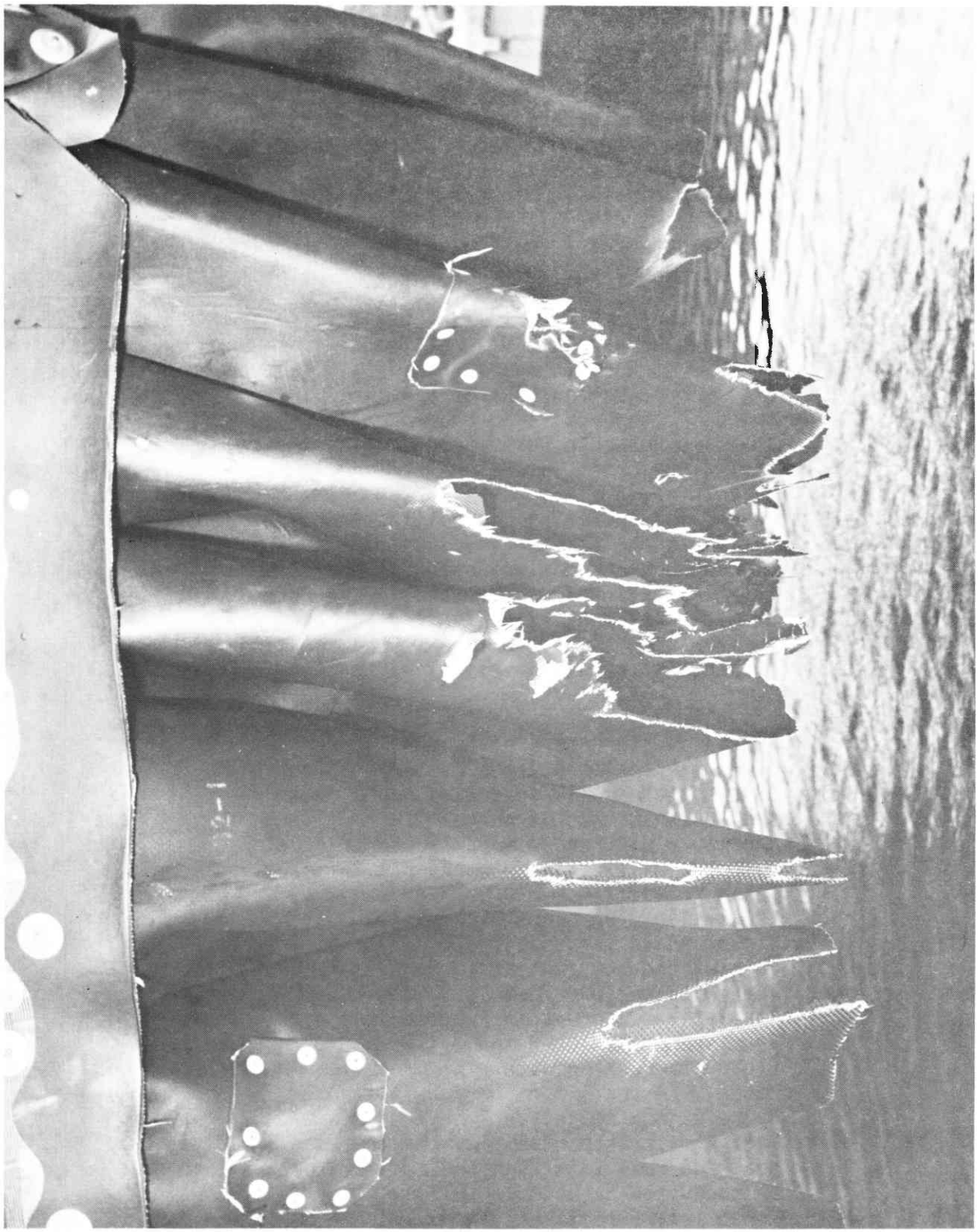


FIGURE 12 - Skirt Wear of LACV-30-2 (350 hours)

ature compensation, but the upper safe temperature limits used by the operator penalized turbine power. So, a larger capacity suppressor will be installed for evaluation.

The high frequency alternator driven by the APU failed twice, but only on the LACV-30-2. It was determined that the alternator enclosed in the APU housing had overheated. Inspection of the air supply to the turbine revealed cloth filters installed in the ducting for the Aberdeen grass contamination had become clogged, and during propeller reversing, the APU exhaust was being blown back into the housing. The filters were removed and the alternator temperature is being monitored.

Near the end of the Panama City, Florida, phase of tests in June 1977, the decision was made to have the DT craft participate in the Joint LOTS Tests in August 1977 at Fort Story, Virginia. This impacted on the Eglin Air Force Base cold chamber tests as it permitted only the month of July 1977 to move to Eglin, conduct cold chamber tests, and move to Fort Story, Virginia. The schedule was met by driving the craft to Eglin Air Force Base, placing the craft in the chamber and immediately reducing the temperature to a -40°F. After some brief tests at that temperature - starting, hovering, and operating controls - the craft was driven to Mobile, Alabama, for a Challenger-type ship lift to Norfolk, Virginia. The craft was loaded on a Monday, unloaded in Norfolk, Virginia, on Saturday, and 50 minutes later was berthed in the Fort Story, Virginia, test site, a 30 mile distance, ready for a mission.

Performance characteristics determined by DT testing included the following:

1. Attain a water speed of 50 mph
2. Clear vertical obstacles at least 3 feet high
3. Cross ditches 6-12 feet wide and 9 feet deep
4. Transport 30 tons of cargo
5. Accommodate three 20 foot ISO containers
6. Operate in climatic categories 1-6 inclusive (down to -40°F)
7. Cruise for five hours with maximum payload
8. Use standard military fuels
9. Turn within 500 feet at 10 mph
10. Turn within 2,000 feet at 50 mph
11. Completely stop within 7-12 seconds over water from speeds of 20-50 mph
12. Float off-cushion with maximum payload while in water
13. Operate in a sea state 3 sea
14. Meet Army transportability requirements of motor, sea, and rail (air transportability tests are to be conducted in October 1977)
15. Rehability (Preliminary)

    MTBF = 14 hours
    Maintenance to Operating hours ratio = 7

JOINT LOTS TESTS

This was an Army, Navy, Marine Corps joint effort conducted in August 1977 to evaluate various concepts of ship to shore resupply of containerized cargo. It was a three week test, the first week of which only the Army was involved in a bare beach scenario, the second week the U.S. Navy and U.S. Marine Corps were jointly involved, and the third week all forces were involved.

Unfortunately, the weather and sea were benign. Virtually no surf existed and at the best 3-4 foot waves were encountered. The weather was hot - at least 100°F with little wind. With these calm sea conditions, the advantages of a flat open cargo deck, such as the LACV-30 offered, were not fully appreciated. There were other factors such as poor loading, lack of priority when alongside ship, containership too close to shore, which also penalized the LACV-30. The important point is that the two LACV-30 craft did not miss a mission called on, and that the two craft transported 31.9% of the containers moved during the bare beach test.

CONCLUSIONS

It is concluded that the LACV-30 performed up to expectations.

It is also concluded that the LACV-30 is expensive to operate - probably in the range of $1,000. to $1,500. per hour.

It is, therefore, concluded that if the craft is managed well - high payloads, long water legs, and a scenario which allows it to move the cargo inland - the craft will be most cost effective.

HOVERCRAFT MINE COUNTERMEASURES WITH PARTICULAR REFERENCE TO SR.N4

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INTRODUCTION

Two decades have passed since the British Armed Forces first showed an interest in the military potential of the amphibious hovercraft. This interest has led to many studies for craft to meet a wide spectrum of operational roles. Projected craft have included a DUKW replacement, an air cushion assisted tracked vehicle, several '90 knot frigates' and a whole range of logistic support craft.

Early naval interest arose largely because of the hovercraft's high speed dash capability and its ability to operate from unprepared bases. More recently the focus of interest has moved to the possible exploitation of the amphibious hovercraft's low underwater signatures and near invulnerability to underwater explosions which result from the air cushion support. These features immediately suggest use of the craft in the mine countermeasures role.

The SR.N4 is particularly suitable for use in this role because -

i) The basic craft has been fully developed in nine years of commercial service.

ii) It has a powerful control system for accurate track keeping in all likely weather conditions.

iii) It is large enough to be able to carry, deploy and use all known, existing and projected, mine countermeasures equipment.

THE SR.N4

The design and development of the SR.N4 commercial passenger car ferry, Figure 1, has been covered in References 1, 2 and 3 (and only a few salient details will be repeated here).

The SR.N4 Mk.1, which first entered service on the British Rail Hovercraft Seaspeed cross-channel route in 1968, is 40 metres long overall, 25 metres wide overall, has a maximum all-up-weight of 190 tonnes and can carry up to 32 cars and 254 passengers. It is powered by four Rolls-Royce Marine Proteus 15M/529 gas turbines each driving a 3.5 metres diameter lift fan and a 5.8 metres diameter propeller.

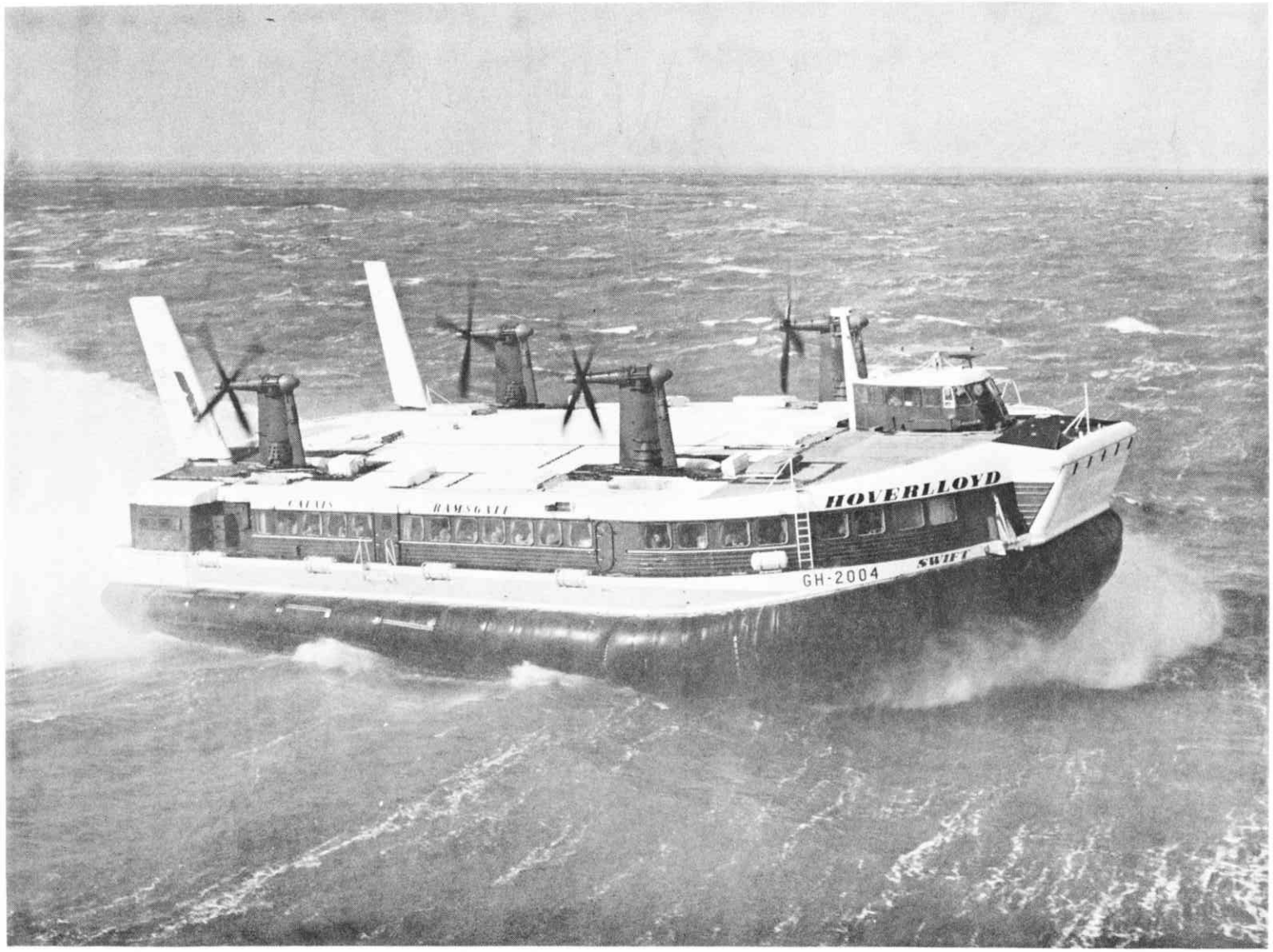


FIGURE 1 - SR.N4 MK.2

37 CARS 280 PASSENGERS WEIGHT 200 TONNES LENGTH 40m

The SR.N4 Mk.2 is generally similar but has a maximum all-up-weight of 203 tonnes and, within the same overall dimensions a larger cabin, enabling it to carry up to 37 cars and 280 passengers. A total of six of these craft have now been built and currently five are being operated on services across the English Channel, four SR.N4 Mk.2s by Hoverlloyd and one SR.N4 Mk.1 by Seaspeed. The sixth, Seaspeed, craft is now in the Company's works at Cowes where it is being converted to the SR.N4 Mk.3 version which involves a 'stretch' of 16.8 metres, Figure 2. It will be able to carry up to 58 cars and 400 passengers. This conversion is programmed to be completed in the Spring of 1978.

Collectively the SR.N4s have accumulated over 56,000 hours of operation at an average rate of some 1,500 hours per craft per year. They have carried some eleven million passengers and one and three quarter million vehicles.

Of particular interest is the craft's service reliability, Figure 3. In 1975 and 1976 engineering reliability reached 99%. Weather cancellations were of the order of 3% and each craft was available for commercial service on some 290-300 days of the year.

MINES AND MINE COUNTERMEASURES

An indication of the severity of the mining threat can be gauged from the 802 British ships lost to mines in World War II. Present mines can be divided into two main categories, moored mines and ground mines. Whilst only moored mines can be activated by contact both moored and ground mines can be activated by ship influences which can be magnetic, acoustic, pressure or some combination of these.

Moored mines can be swept using a mechanical or wire sweep which cuts the mooring wire; typical wire sweeps include the British Wire Mk.3 and the American helicopter-towed Mk.103. Influence sweeps which produce ship type acoustic and magnetic signatures, are used to sweep influence mines. Typical influence sweeps include the British Magnetic Minesweep Mk.11 and the Osborn acoustic sweep (usually towed together) and the American helicopter-towed Mk.104, Mk.105 and Mk.106.

Mines that cannot be swept, and at present this includes those with pressure influence activation, must be located and neutralised or destroyed. Location is currently achieved using a towed or hull mounted sonar, and disposal by explosive charge placed by a remotely controlled vehicle such as the PAP 104 or by divers.

MINISTRY OF DEFENCE TRIALS AND STUDIES OF HOVERCRAFT IN THE MINE COUNTERMEASURES ROLE

During the last few years the British Ministry of Defence has undertaken or has funded a series of trials and studies including -

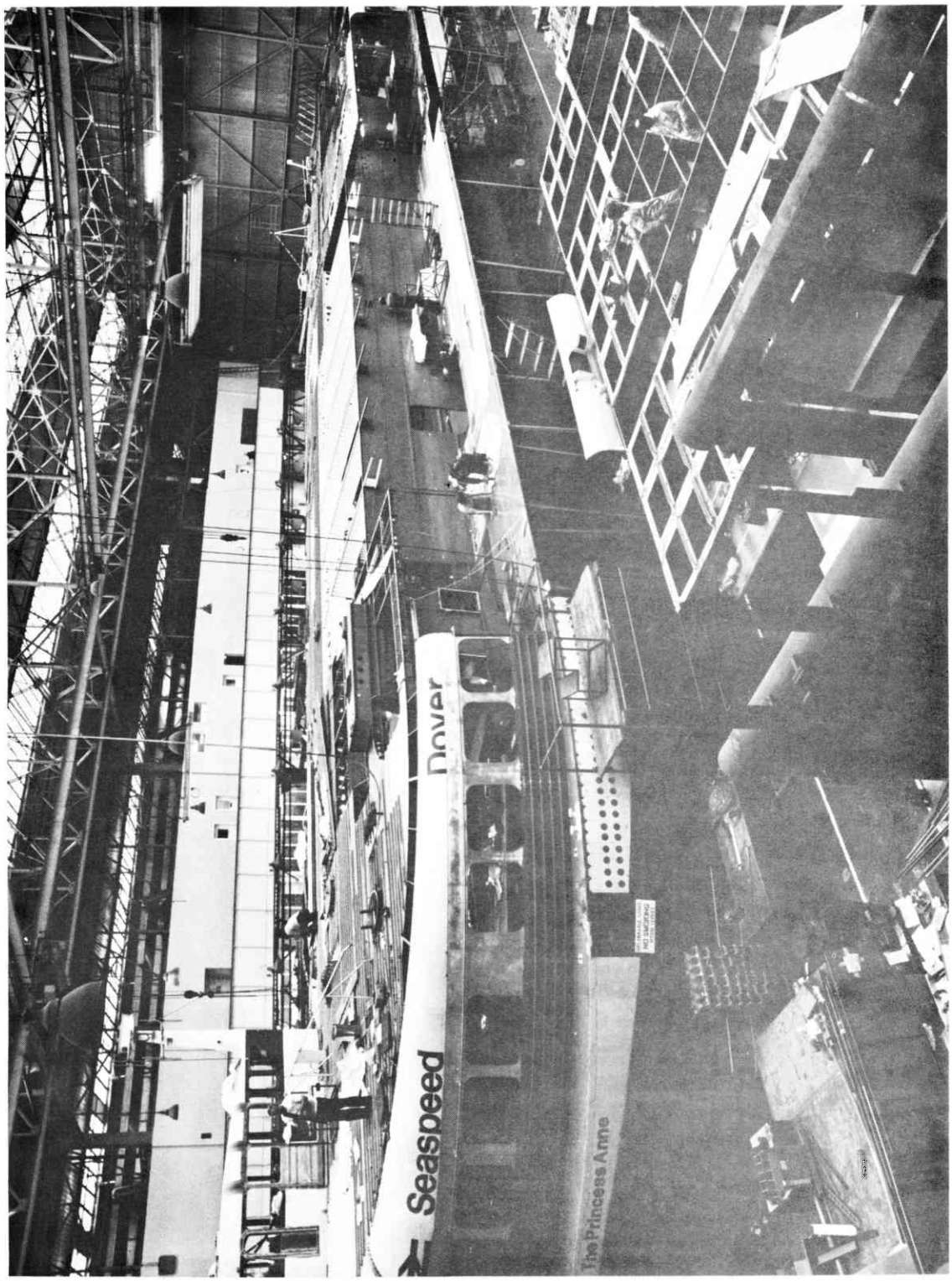


FIGURE 2 - SR.N4 Mk.3 Under Construction

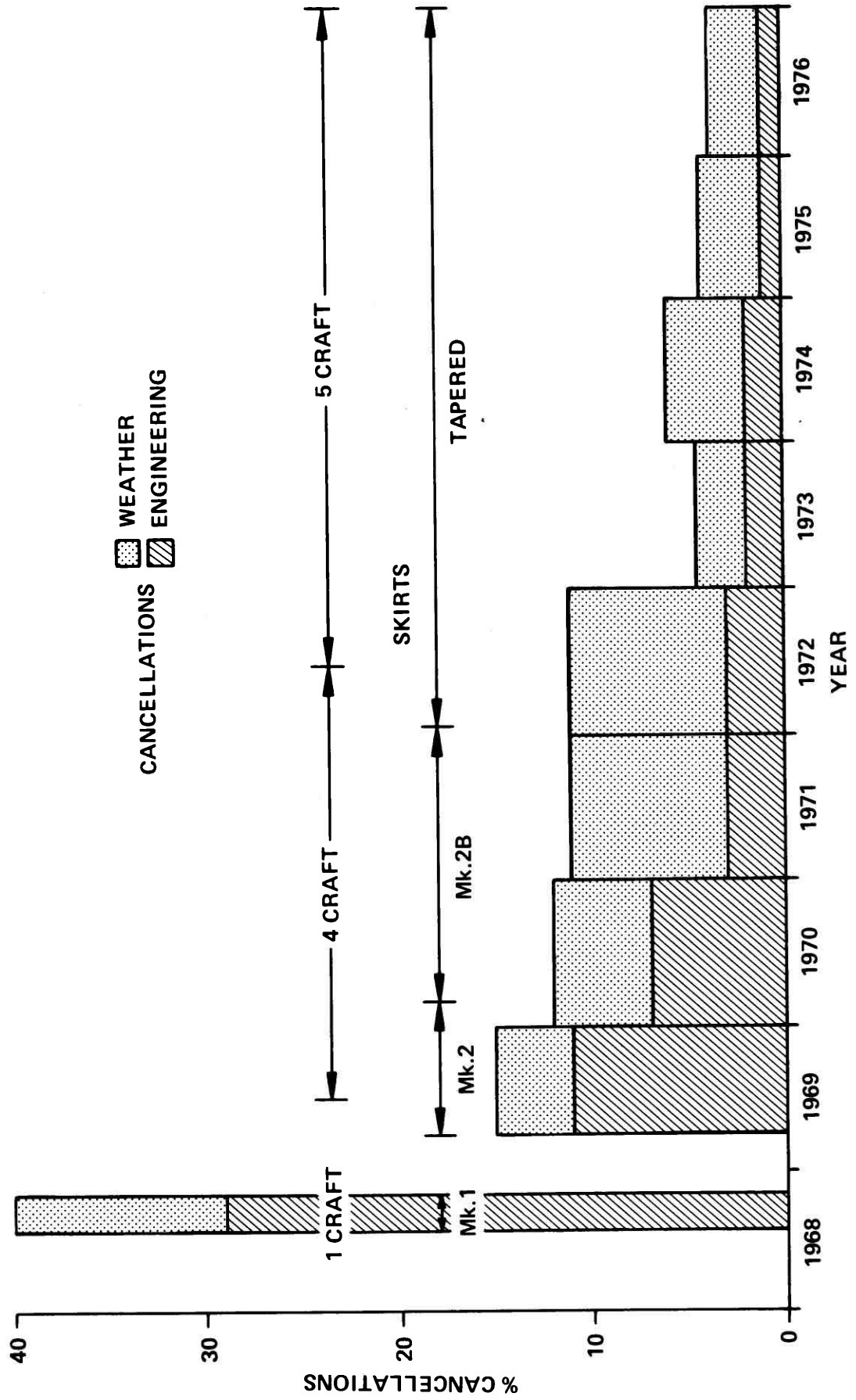


FIGURE 3 - SR.N4 Service Reliability

a) Underwater Signature Measurements
b) Towing, Controllability and Track Keeping Trials
c) Equipment Trials
d) Explosion Trials
e) Craft Design, Systems and Life Cycle Cost Studies

Underwater Signatures - acoustic, magnetic and pressure, have been measured on several amphibious hovercraft, in particular SR.N6, BH.7 and SR.N4. Because of its air propulsion and air cushion support, the acoustic signature of SR.N4 in its commercial form is quieter than any MCMV, (Figure 4), and its noise level does not increase when turning or when the propeller is damaged as is the case with the MCMV.

The magnetic signature of the commercial SR.N4 without treatment is similar to that of an existing MCMV. Trials have shown that the ferro magnetic signature is halved when hovering and the method of construction keeps the eddy current contribution low, (Figure 5).

Pressure signatures are low and the measured pressure signature of SR.N4 is below that required to activate any known pressure mine.

Towing Controllability and Track Keeping Trials - have been made with SR.N6, BH.7 and SR.N4 using simulated sweeps. The control of BH.7 (see Reference 4 for details of the control system) when towing in up to Force 6 winds was found to be satisfactory. In Force 6 winds BH.7 could maintain its track to within a standard deviation of 25 metres. Because of its fore and aft control system, the control of SR.N4 is superior to that of BH.7. In particular, using the standard control system (Figure 6) the SR.N4 can maintain a track defined by HIFIX to within 3-5 metres standard deviation in Coastal Code 5. This is considerably better than expected from conventional ships. A sample track keeping record is shown in Figure 7. It was also concluded that the control of SR.N4 with one engine dead was acceptable for mine countermeasures work.

Equipment Trials - BH.7 has been fitted with a 'sweepdeck', hydraulic winches and a derrick, for use in sweeping trials. Equipment that has been tried includes the U.S. Mk.103 and the U.S. Mk.104 sweeps, the U.S. Shadowgraph side-scan sonar and wire sweeps. No major problems were experienced in deployment, sweeping and recovery.

Explosion Trials - Some tests were undertaken with VA.3, the first hovercraft to be used commercially, in the late 1960s. More recently the SR.N3 was subjected to a series of increasingly severe mine explosions which were intended to destroy her. These failed completely and the craft was able to return to base under its own power (Figures 8, 9, 10 and 11). Based on these tests, it was concluded that an SR.N4 and its strapped-in crew could withstand the explosion of a mine only a few metres from the craft.

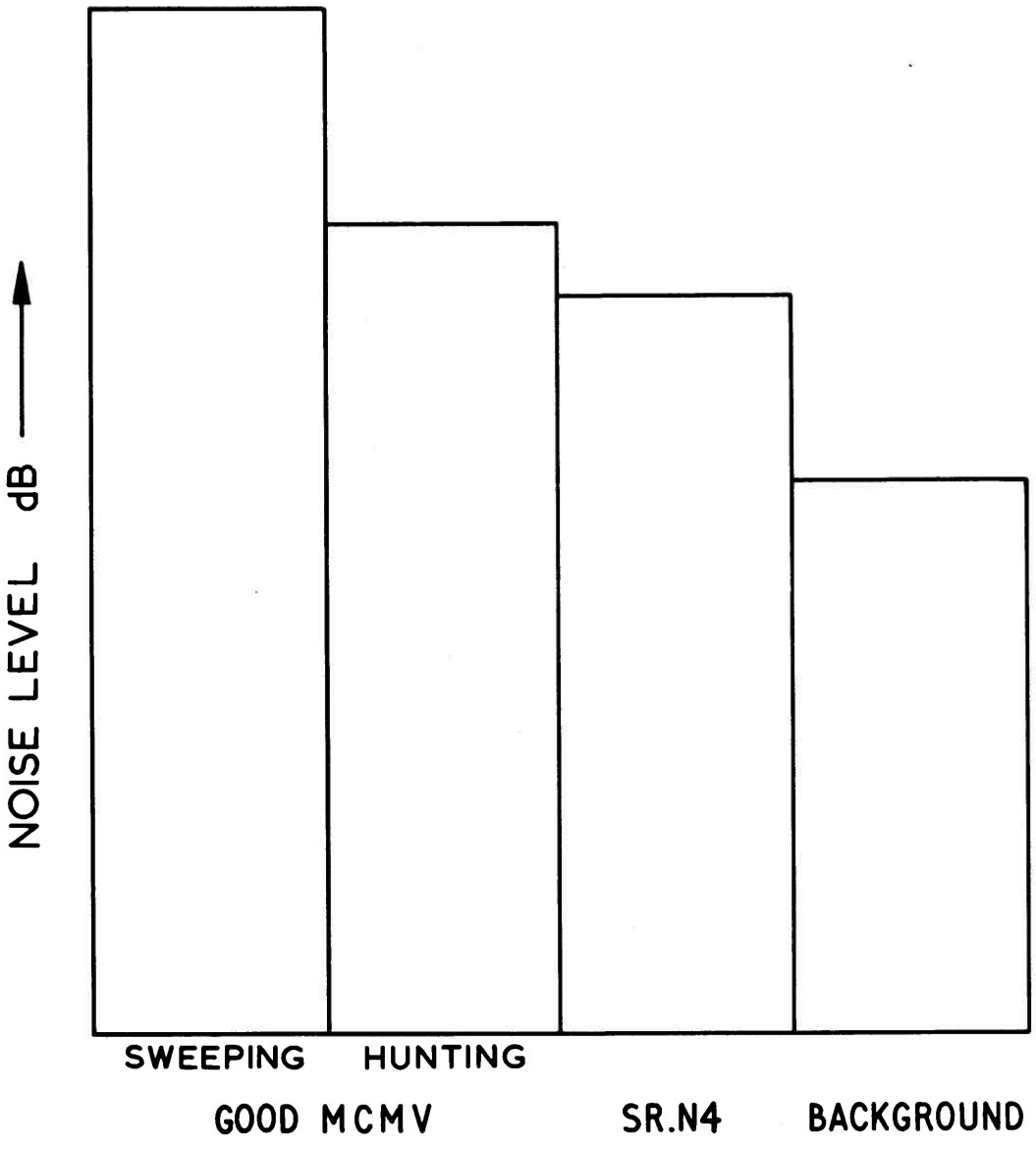


FIGURE 4 - Acoustic Signatures

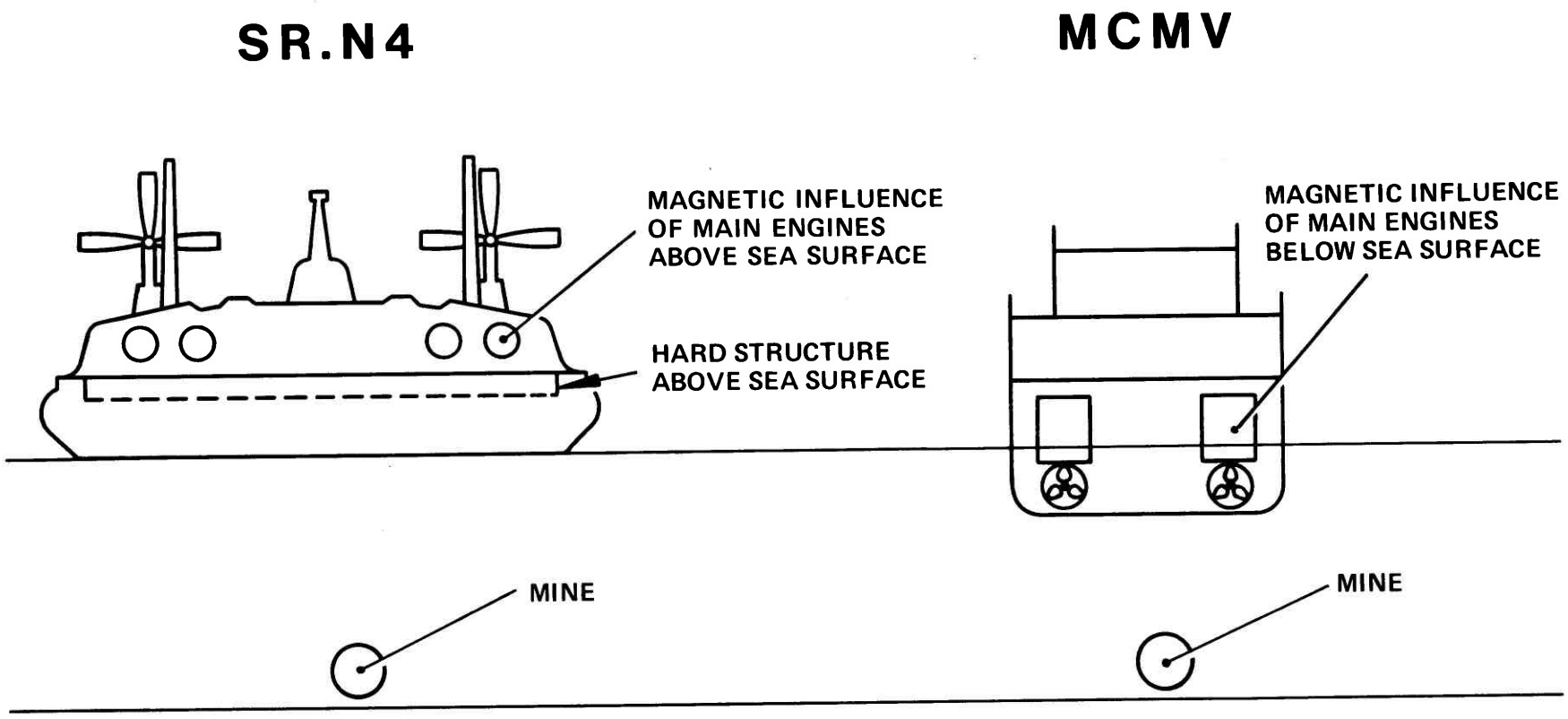
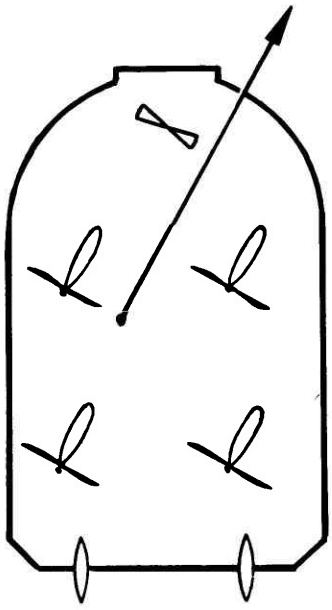
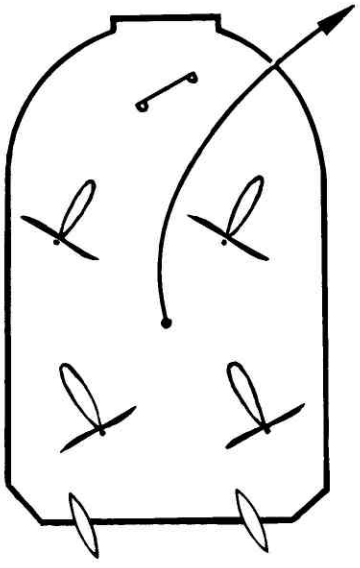


FIGURE 5 - Magnetic Signatures



YOKE CONTROL
ROTATES PYLONS
COLLECTIVELY TO
PRODUCE VECTORED
SIDE FORCE



RUDDER BAR CONTROL
ROTATES PYLONS AND
FINS ABOUT CRAFT AXIS
SO AS TO PRODUCE
TURNING MOMENT

FIGURE 6 - SR.N4 Standard Control Mode

CONTROL MODE	:	STANDARD
TURBINE SPEED	:	9000 R.P.M.
TRIM	:	0-¼° BOW UP
SEA DIRECTION	:	QUARTERING
WAVEHEIGHT	:	1½ – 2m
WINDSPEED	:	22 kt
WATERSPEED	:	9.9 kt

SORTIE : 7
RUN : 5

STANDARD DEVIATION = 4.1 m

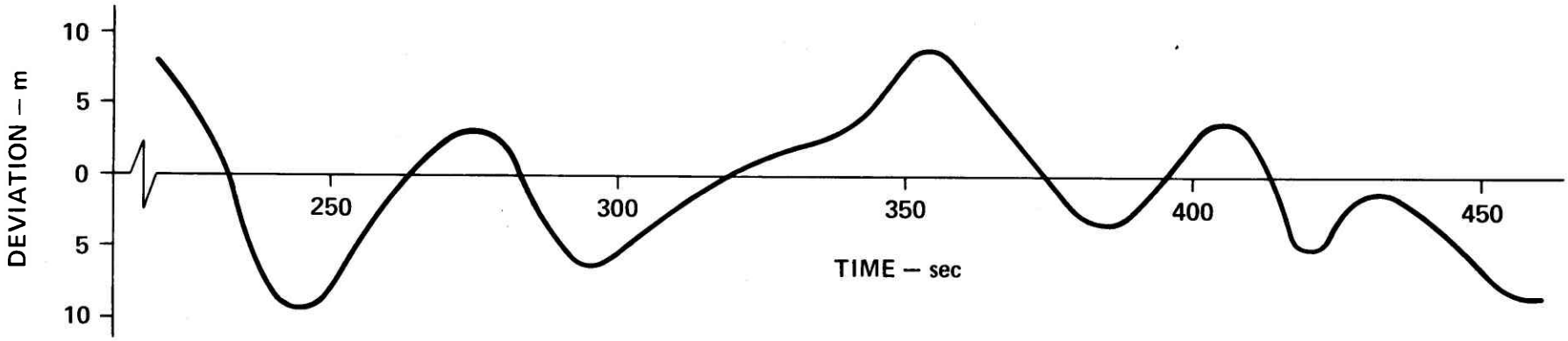


FIGURE 7 - SR.N4 Assessment Trial -
Sample Track Keeping Record



FIGURE 8 - SR.N3

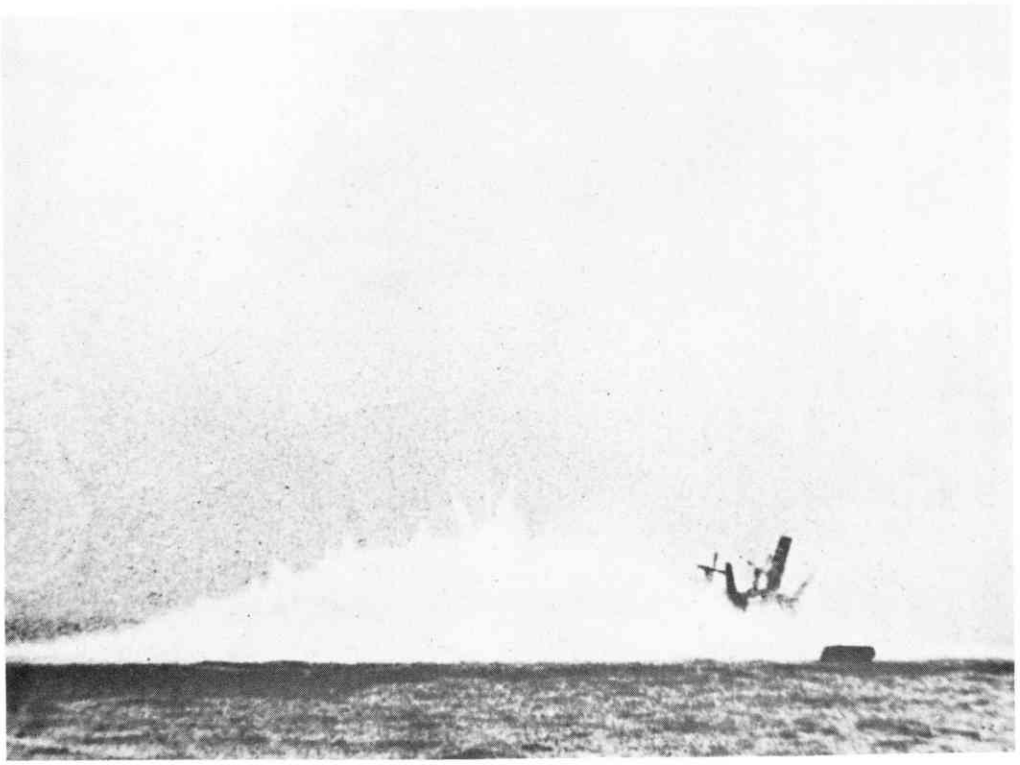


FIGURE 9 - SR.N3 Tethered and Hovering Unmanned,
within the Shock Dome

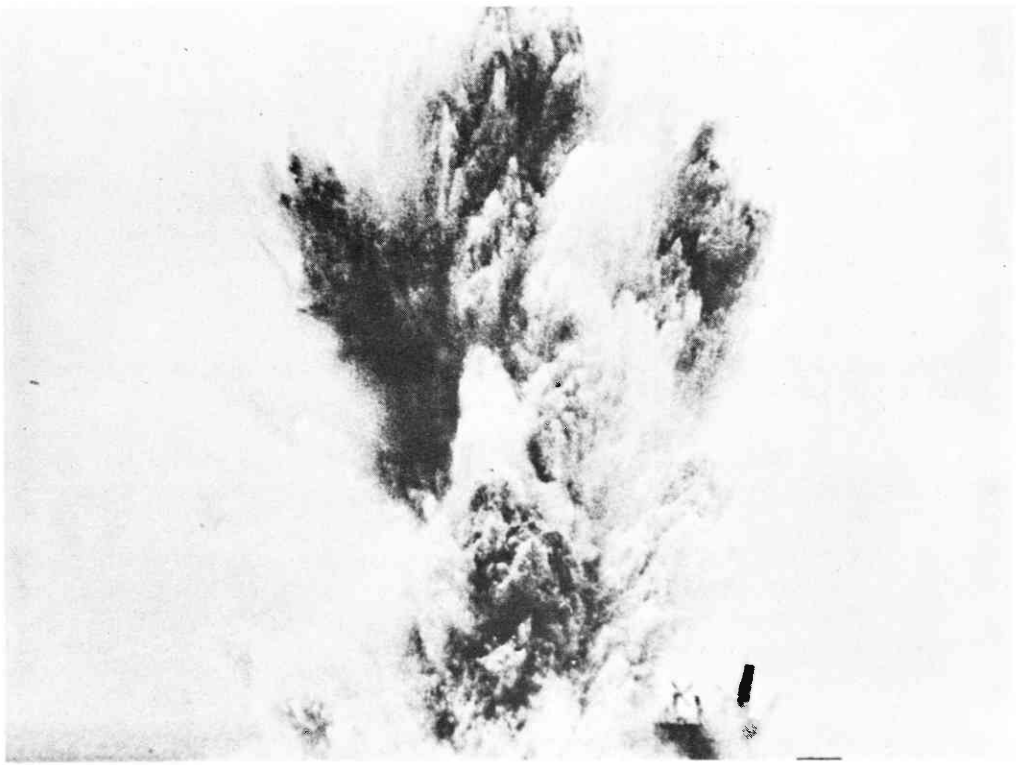


FIGURE 10 - SR.N3 Tethered and Hovering Unmanned,
in Mine Explosion Plume



FIGURE 11 - SR.N3 Hovering after Explosion and able to return to Base
with Engines Running,
Radar Operative and Minor Damage to Hull and Skirt

Craft Design, Systems and Life Cycle Cost Studies - were undertaken covering -

a) Craft Design
b) Control
c) Navigation and Action Information Organisation (NAV/AIO)
d) Life Cycle Costs

The design and control studies were carried out by a joint B.H.C. and Vosper Thornycraft team for the Ministry of Defence and both new and existing designs were considered.

As a result of the studies it was concluded by the Ministry of Defence that the SR.N4 was the craft best suited to the MCM role.

The SR.N4 is relatively cheap because no prototype and no development are required. It has good seakeeping qualities and is large enough to carry the same MCM gear (wire, magnetic and acoustic sweeps) as an MCMV of the Hunt class.

THE SR.N4 MINE COUNTERMEASURES HOVERCRAFT

As a result of the conclusions drawn from the series of trials and studies discussed above, B.H.C., in conjunction with the Ministry of Defence, have designed a mine countermeasures version of the SR.N4 Mk.1/2 craft known as the SR.N4 MCMH.

Operational Capability - Because of its size and installed power levels, the craft will be capable of carrying, deploying and operating a complete set of the mine countermeasures equipment that will be fitted to the new Royal Navy mine countermeasures vessels. Alternatively, any known existing or projected equipment for minesweeping, mine hunting and mine disposal may be carried. The particular suite of equipment proposed for the SR.N4 MCMH gives the following operational capability.

(a) Wire Sweeping (Figure 12)

For wire or mechanical sweeping of buoyant moored or tethered mines, the craft will be fitted with the standard Royal Navy Wire MK.3 sweep, as used in the Ton and Hunt class vessels, or its Mk.8 derivative complete with all wires, floats, kites, otters and cutters.

Alternative wire sweeps include the Royal Navy Mk.7 and the U.S. Navy Mk.103 helicopter-towed sweep. These sweeps are lighter than the Mk.3 but less robust and in consequence have a lower operational life.

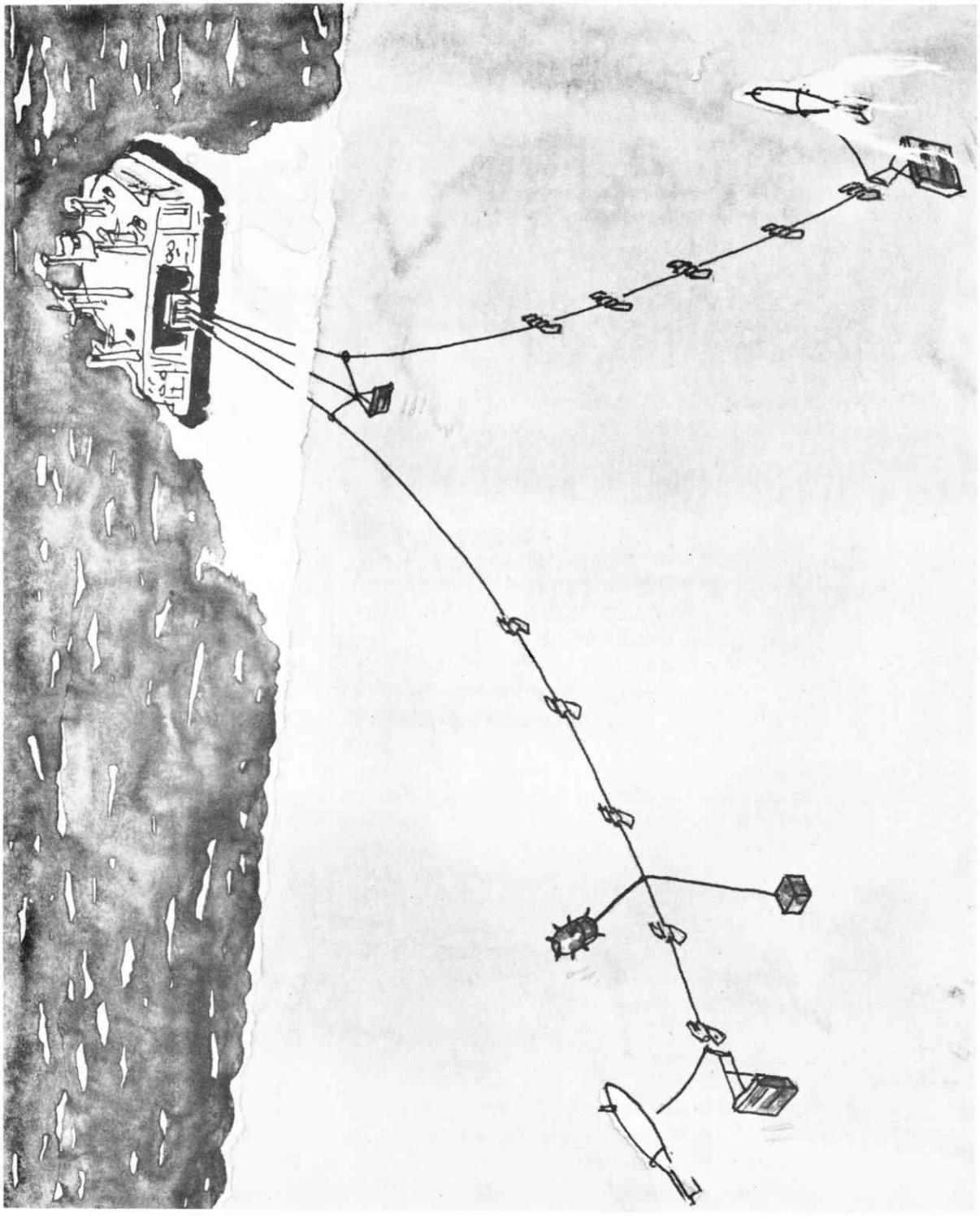


FIGURE 12 - SR.N4 MCMH Towing R.N. MK.3 Wire Sweep

(b) Influence Sweeping (Figure 13)

For influence sweeping of acoustic, magnetic or combination mines, the proposed fit includes the standard Royal Navy magnetic mine sweep Mk.11, powered by an on-board generator driven by a gas turbine, and the new Osborn acoustic sweep complete with acoustic generator, hydrophones and acoustic monitor.

Alternative equipment again includes the U.S. helicopter-towed sweeps, in this case the Mk.104 and the Mk.105. The Mk. 105 sled can be readily towed by the SR.N4 MCMH, but if this sweep system were to be used it would be more efficient and more cost effective to mount the generator on the hovercraft and stream the conductor wire in the usual way.

(c) Mine Hunting (Figure 14)

As noted earlier in the paper, mines that cannot be swept using mechanical or influence sweeps must be hunted using a sonar or, in very shallow waters, divers. To hunt, locate and subsequently classify mines, the SR.N4 MCMH will be fitted with the Royal Navy standard Plessey 193M sonar deployed on a mounting from beneath the craft. Preliminary simulation trials have indicated that there will be no insoluble problems in installing and operating this sonar.

In addition, or as an alternative to the 193M, it will be possible to deploy a dunking sonar from the stern of the craft.

(d) Mine Disposal (Figure 14)

When the mine has been located and classified it must be neutralised, destroyed or otherwise disposed of. Unless the mine is required for study this is customarily achieved by destroying it using an external charge.

Three disposal systems are proposed for the SR.N4 MCMH; the French PAP 104 remotely controlled 'fish', the Sperry Cat and a Gemini dinghy with divers. Each of these systems gives the ability to place a destructive charge adjacent to the located mine, the first two by remote control from the craft. If the Gemini is used the charge may be lowered or alternatively placed by divers. For deep diving operations a small decompression chamber is carried on the craft.

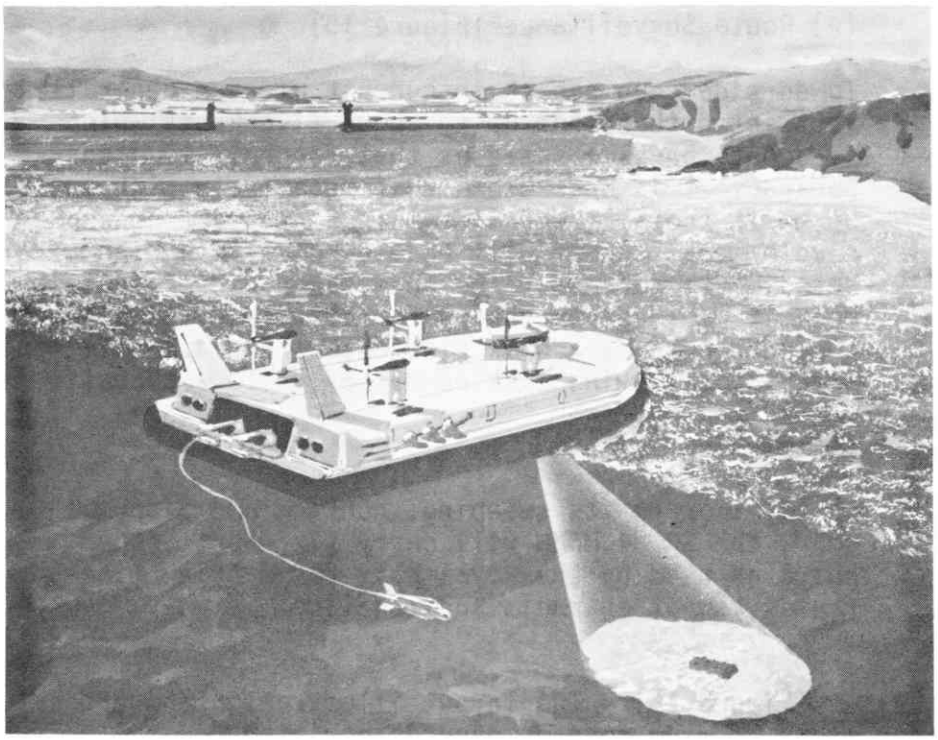


FIGURE 13 - SR.N4 MCMH Towing R.N. MK.II Magnetic and Osborn Influence Sweeps

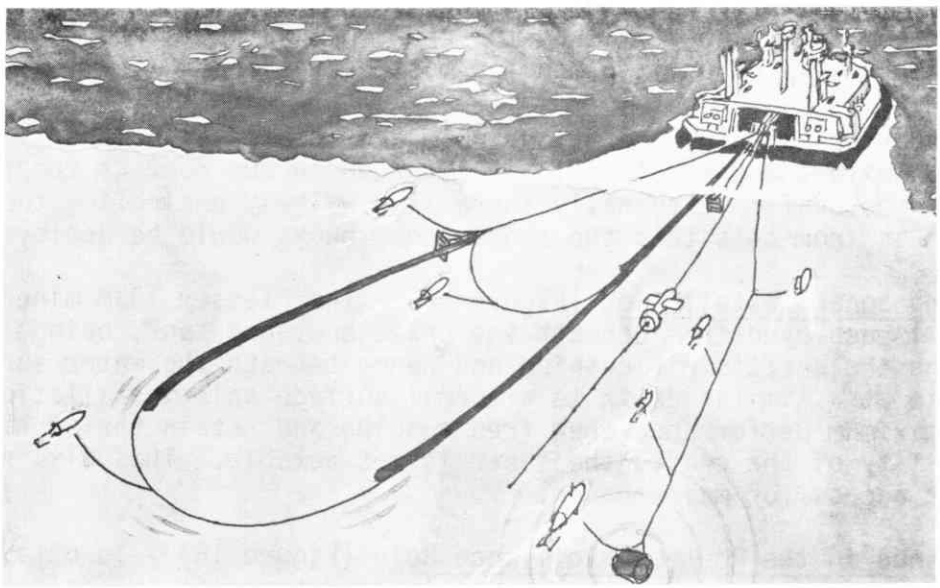


FIGURE 14 - SR.N4 MCMH Hunting with R.N. Plessey 193M and Directing PAP 104 'FISH'

(e) Route Surveillance (Figure 15)

Towed side scan sonars in current use are generally restricted to speeds up to about five knots which is about the same speed as that for hull mounted sonars. It is understood that relatively high speed, up to 20 knots, towed side scan sonars are now under development. These will enable relatively high speed route surveys to be undertaken. Used in this mode it would be necessary for all mine-like objects located to be marked or plotted, with classification and disposal being carried out by follow-up craft.

(f) Marking

In addition to its sweeping, hunting and disposal gear, the SR.N4 MCMH will carry six short scope buoys as used by the Royal Navy for marking mine-fields, swept channels and the like.

Craft Layout (Figure 16) - The layout illustration shows the location of the major items of mine countermeasures equipment on the main deck, together with the winches and davits necessary for deployment and recovery. This figure also shows the overhead rail system for transferring equipment to the stern. All the large items of equipment are palletised to facilitate removal and subsequent rapid conversion of the craft to other roles.

The spaciousness of the sweepdeck will be apparent from the illustration, this being approximately 35 metres long and 10 metres wide (i.e. 350m^2 in area). Even when fitted with all the equipment required for wire sweeping, for influence sweeping and for hunting and disposal, there is ample room for access to it by the crew. It is envisaged that the crew complement will be only 15 men for most operations.

Crew quarters and the operations room are located along the sides of the craft, while the control cabin is situated on the roof at the forward end of the craft. Externally there is a walkway encircling the craft and it is from this that the short scope buoys would be deployed.

Hunting Sonar Installation (Figure 17) - The Plessey 193M minehunting sonar is deployed from beneath the craft buoyancy tank, being lowered through the craft's air cushion and hence beneath the water surface to operate at a similar depth to a normal surface ship installation. To give maximum performance when free running and retain the amphibious capability of the craft, the sonar is retractable. This also provides better access for maintenance.

Endurance in the Route Surveillance Role (Figure 18) - To obtain long endurance for extended route surveillance duties, it is desirable to increase the craft's fuel tankage. It would be possible to do this by

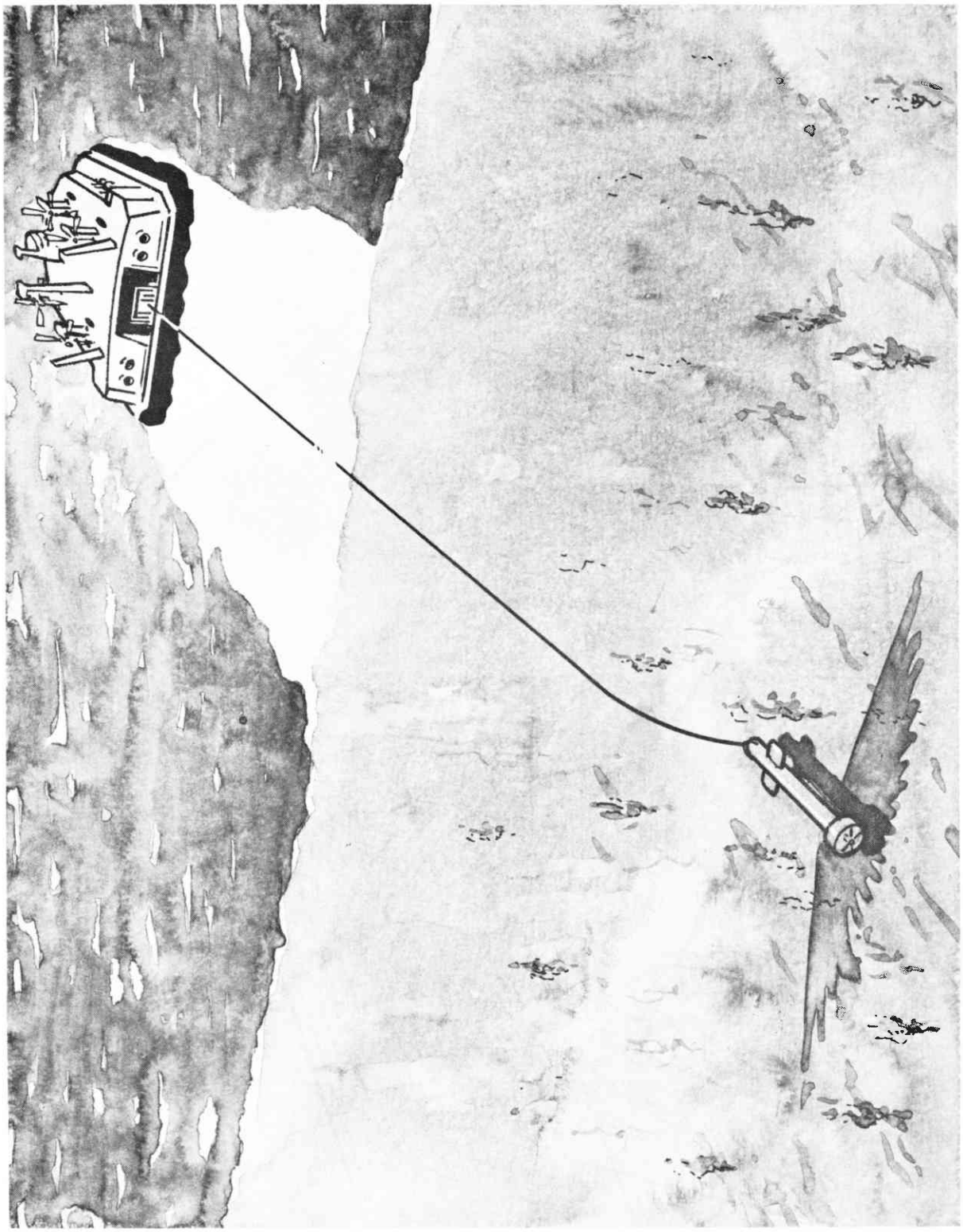


FIGURE 15 - SR.N4 MCMH Route Surveillance with Side Scan Sonar

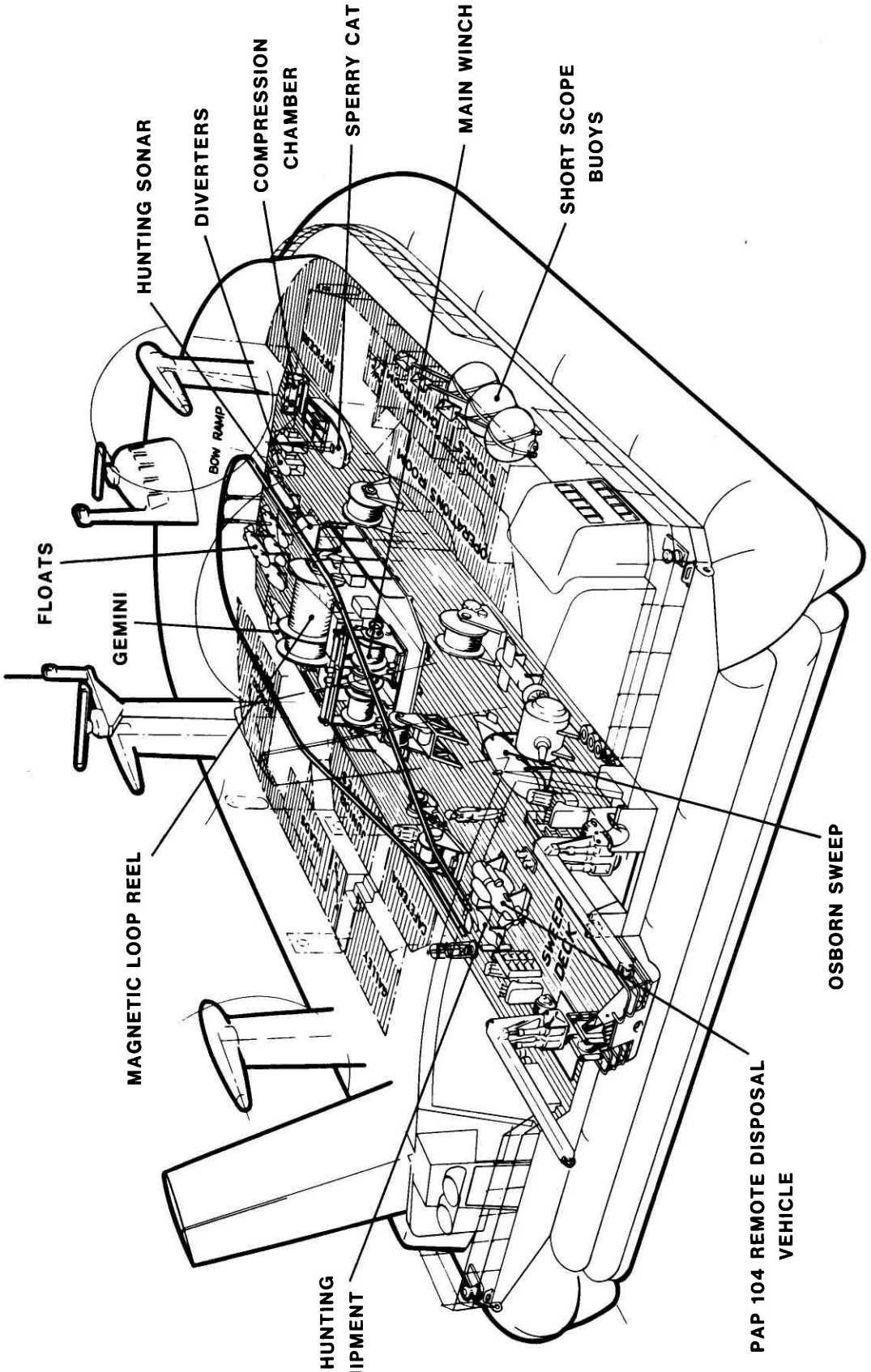


FIGURE 16 - SR.N4 MCMH Sweep Deck Equipment

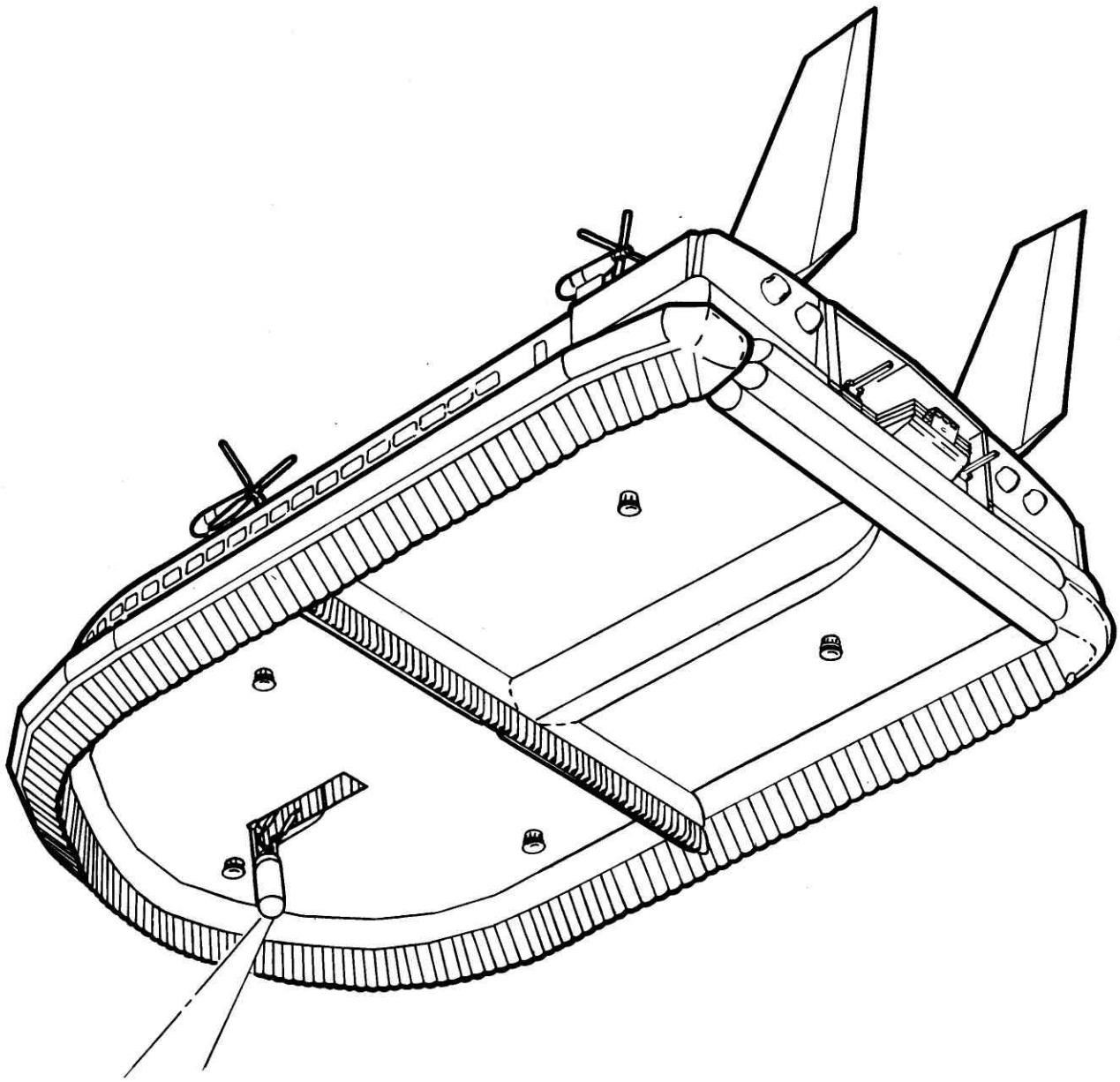


FIGURE 17 - SR.N4 MCMH Installation of
Plessey 193M Hunting Sonar

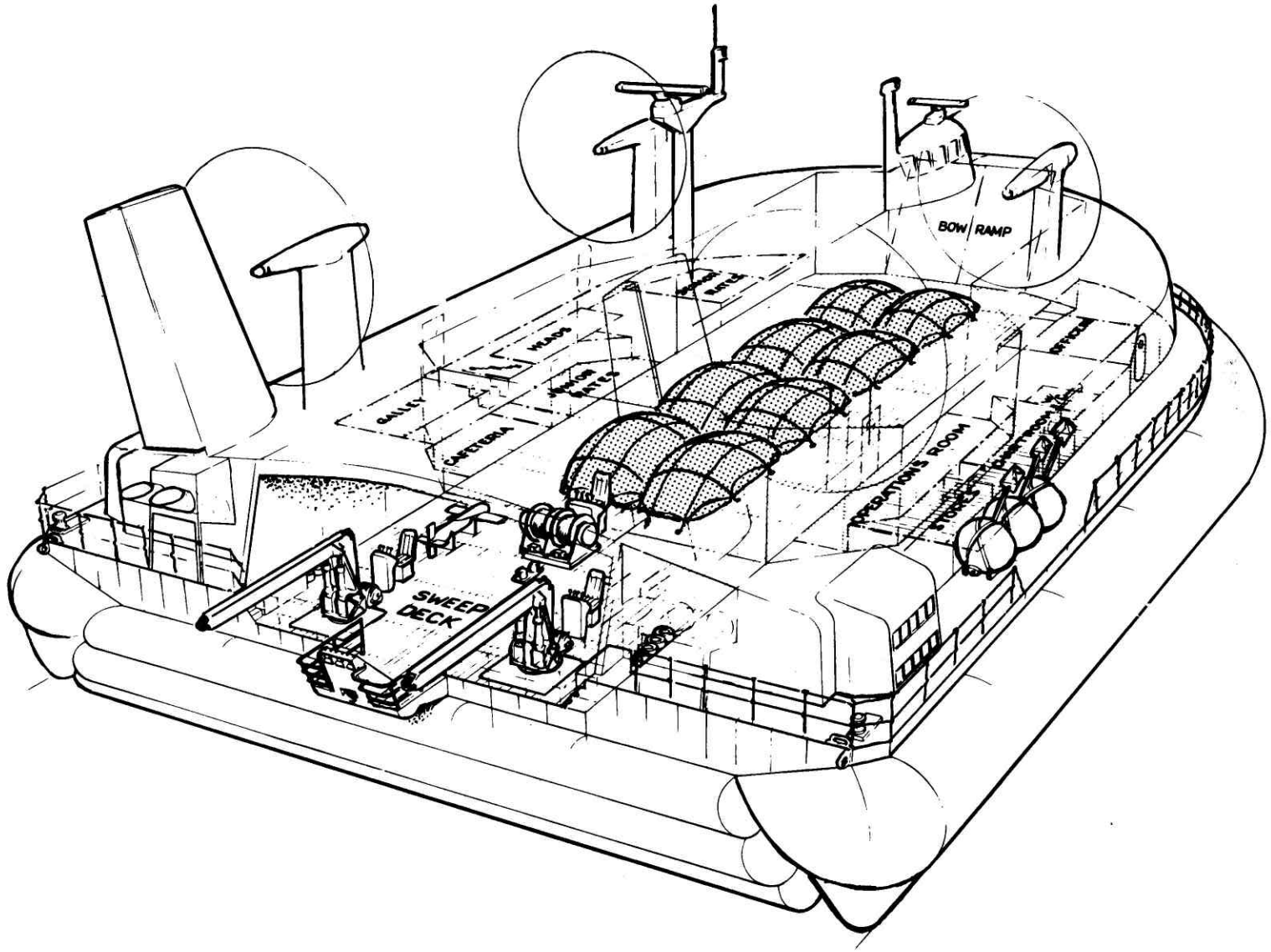


FIGURE 18 - SR.N4 MCMH Route Surveillance Role -
Additional Pillow Tankage for 24 Hours Endurance

removing the palletised MCM equipment and substituting a series of flexible pillow tanks. In this way the endurance could be raised from the proposed standard of ten hours to 24 hours at the full maximum continuous power rating of the engines.

Minesweeping Performance - The potential performance of the SR.N4 MCMH in the minesweeping role is quite impressive, the craft being capable of exerting a static drawbar pull, or towing force, approaching 175 kN (18 tonnes). This reduces to 135 kN (14 tonnes) when towing at a waterspeed of five knots in conditions corresponding to a 13 knot headwind and a 1m significant waveheight.

This towing force enables the SR.N4 MCMH to tow all existing and projected sweepgear in weather conditions up to the limits imposed by the gear itself or its handling. These limits correspond to 11 knots for the Wire Mk.3 sweep, nine knots for the combined influence sweep and up to 20 knots for the side-scan sonar.

Free-Running Performance (Figure 19) - In the free-running mode the SR.N4 MCMH would have substantially the same performance as its civil counterpart but without the commercial limitations. At normal operating weights this is as follows -

Maximum Speed in calm	70-80 knots
Waterspeed in 12 kt headwind and 1m sea	50-65 knots
Waterspeed in 20 kt headwind and 2m sea	35-45 knots

Regular cross-channel services have proved that the craft is capable of operation in Force 8 conditions without difficulty.

Alternative Roles - In addition to undertaking all tasks in the mine countermeasures field the SR.N4 MCMH can serve a useful function in a number of other roles:

(a) Recovery Vessel (Figure 20)

The SR.N4 MCMH can be used for the recovery of damaged ships from minefields and if necessary the rescue of their crews. In this role the craft has sufficient drawbar pull to tow comparatively large ships such as those of the U.S. Navy's 'Spruance' class. It has the further advantage that, by virtue of its amphibious capability, it can tow over shallow water and beach the towed ship at little risk to itself.

The feasibility of a hovercraft towing a conventional ship has already been demonstrated by the successful towing of a 'Ton' class CMS by an SR.N6.

(b) Logistic Support Craft (Figure 21)

The craft can also be used in the craft replenishment and logistic support roles. By removing some, or all

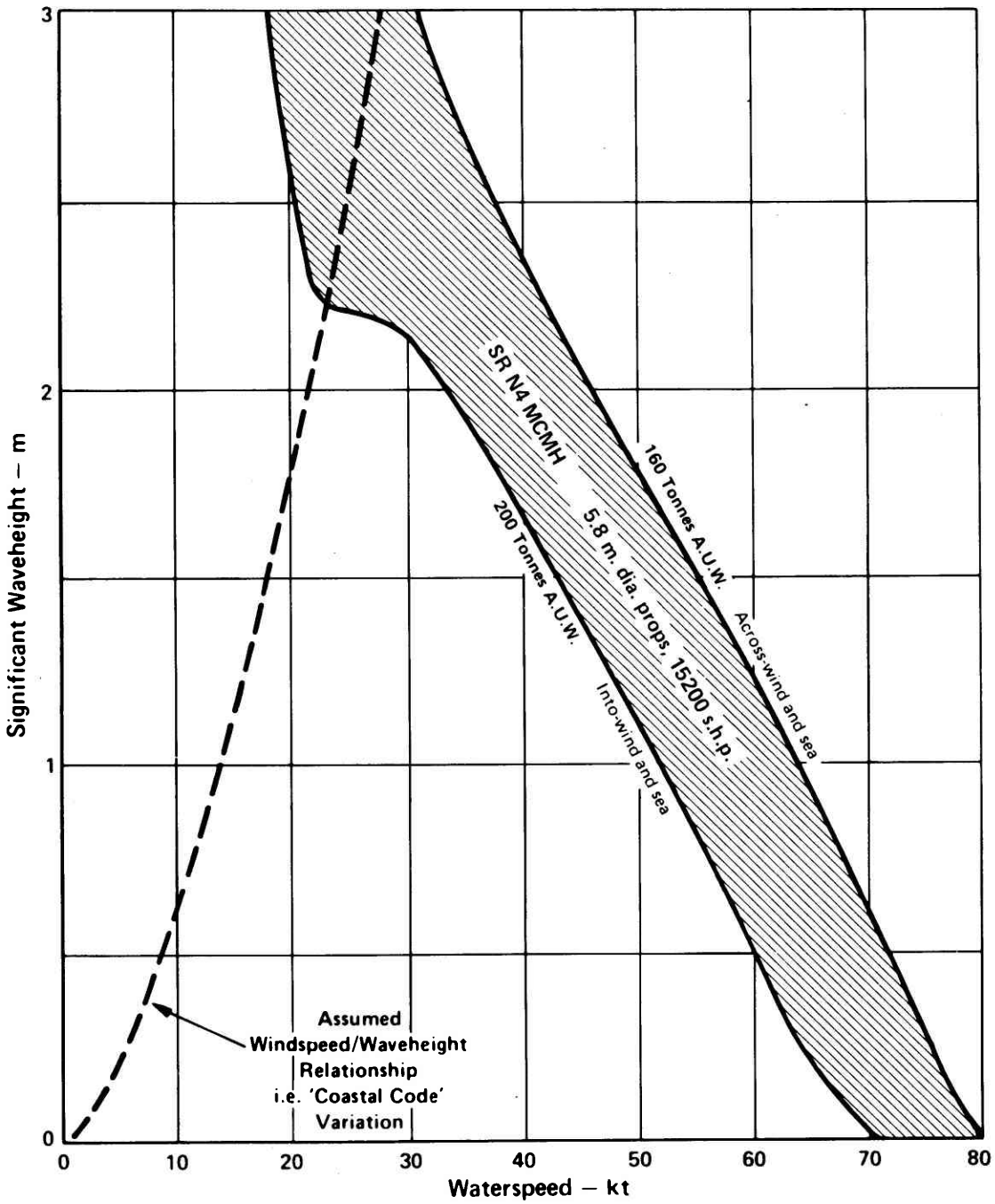


FIGURE 19 - SR.N4 MCMH Free Running Performance

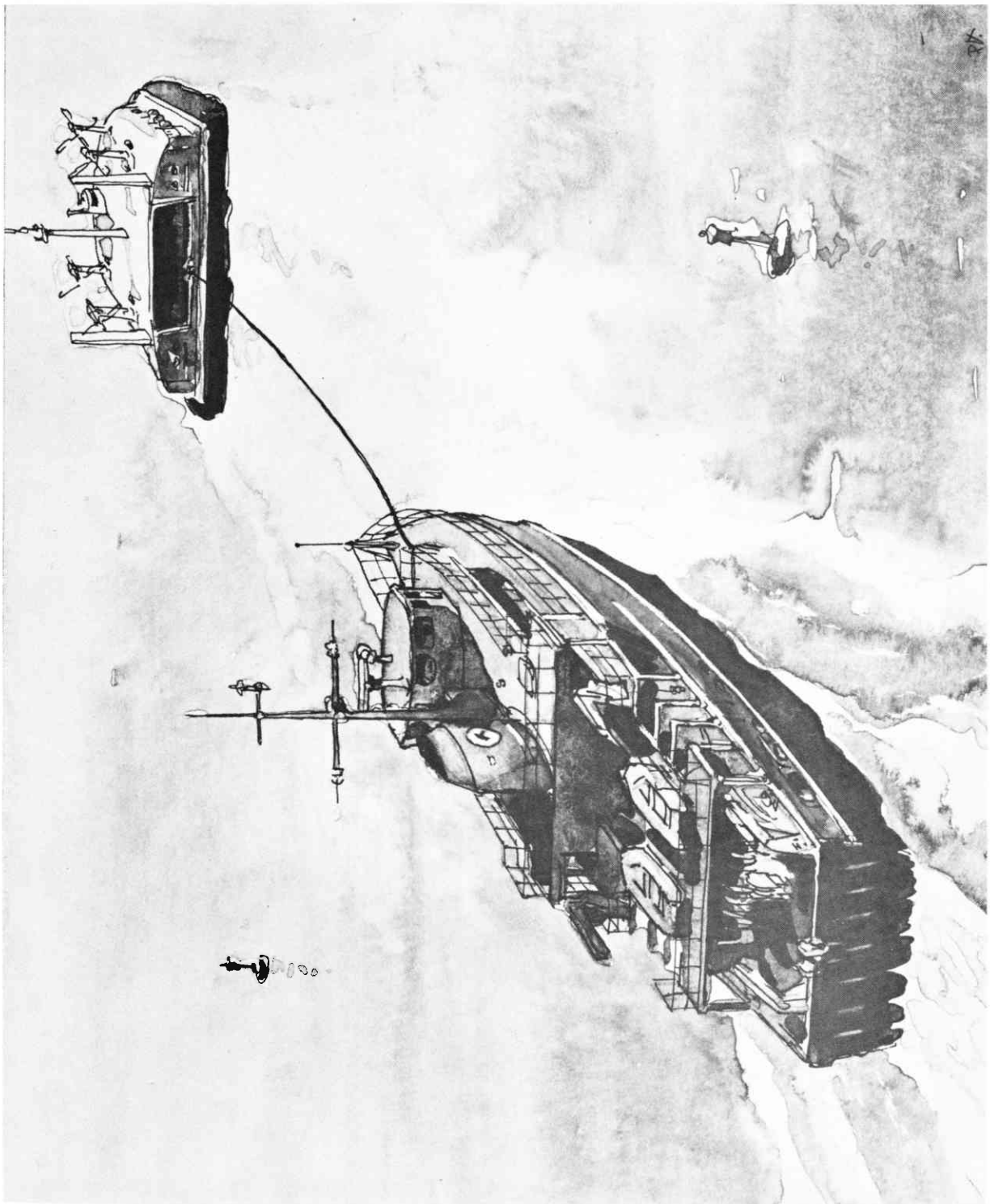


FIGURE 20 - SR.N4 MCMH as a Recovery Vessel

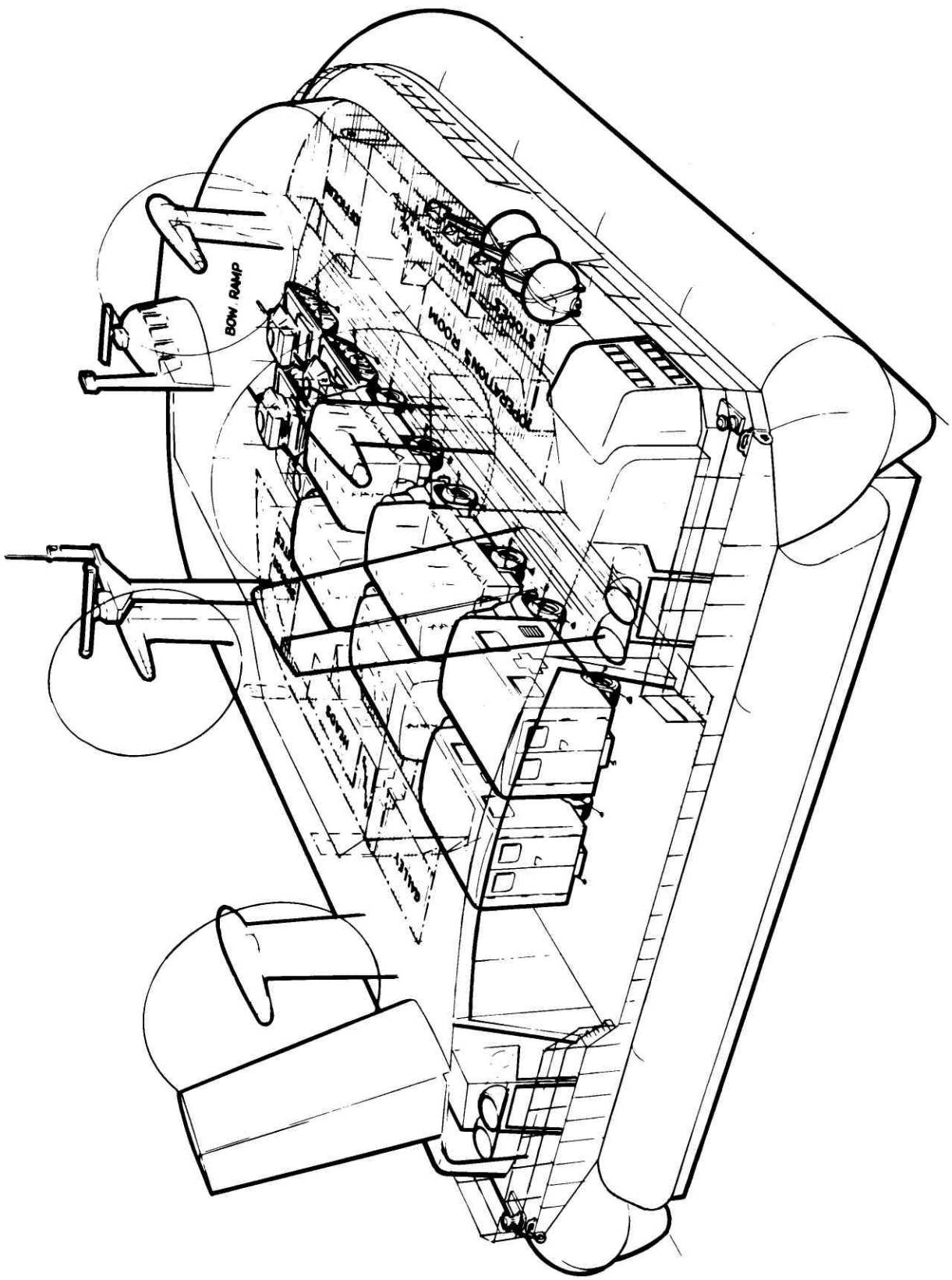


FIGURE 21 - SR.N4 MCMH Logistic Support

of its palletised MCM equipment, it can carry stores, spares and fuel to ships and other hovercraft and be used as a military logistic support craft.

Typical payloads in the logistic support role include up to 800 troops, soft and armoured vehicles and equipment to a total weight of 90 tonnes. With suitable deck reinforcement the SR.N4 MCMH could carry and put ashore a main battle tank such as the Chieftain.

(c) Minelayer (Figure 22)

With the removal of the MCM gear and the addition of mine rails, the craft can become a very effective minelayer. In this role its large deck area, high speed and ability to negotiate shallows can be used to advantage. The illustration shows a typical load of 120 ground mines, each of which weighs approximately 0.5 tonnes with its trolley.

Comparative Deck Areas (Figures 23 and 24) - It is of interest to compare the sweepdeck areas of the SR.N4 MCMH with conventional minesweepers. The figure shows the comparative areas of the SR.N4 MCMH, the Royal Navy 'Ton' class CMS and the 'Hunt' class MCMV, from which it can be seen that, in addition to its other virtues, the SR.N4 MCMH has a larger sweepdeck or more convenient proportions than these conventional sweepers. It also has the advantage of having its sweepdeck completely covered in.

CONCLUSIONS

Summarising, it is maintained that the SR.N4 MCMH would be the most cost-effective mine countermeasures vehicle, offering the following main features:

i) Lower underwater signatures combined with invulnerability to underwater explosions.

ii) A powerful control system for accurate track-keeping.

iii) The ability to operate as a multi-role craft carrying the full range of sweeping, hunting and disposal equipment.

iv) Palletised equipment allowing rapid conversion for MCM force support and logistic support duties.

v) Proven engineering reliability.

vi) A very high transit speed combined with amphibious capability.

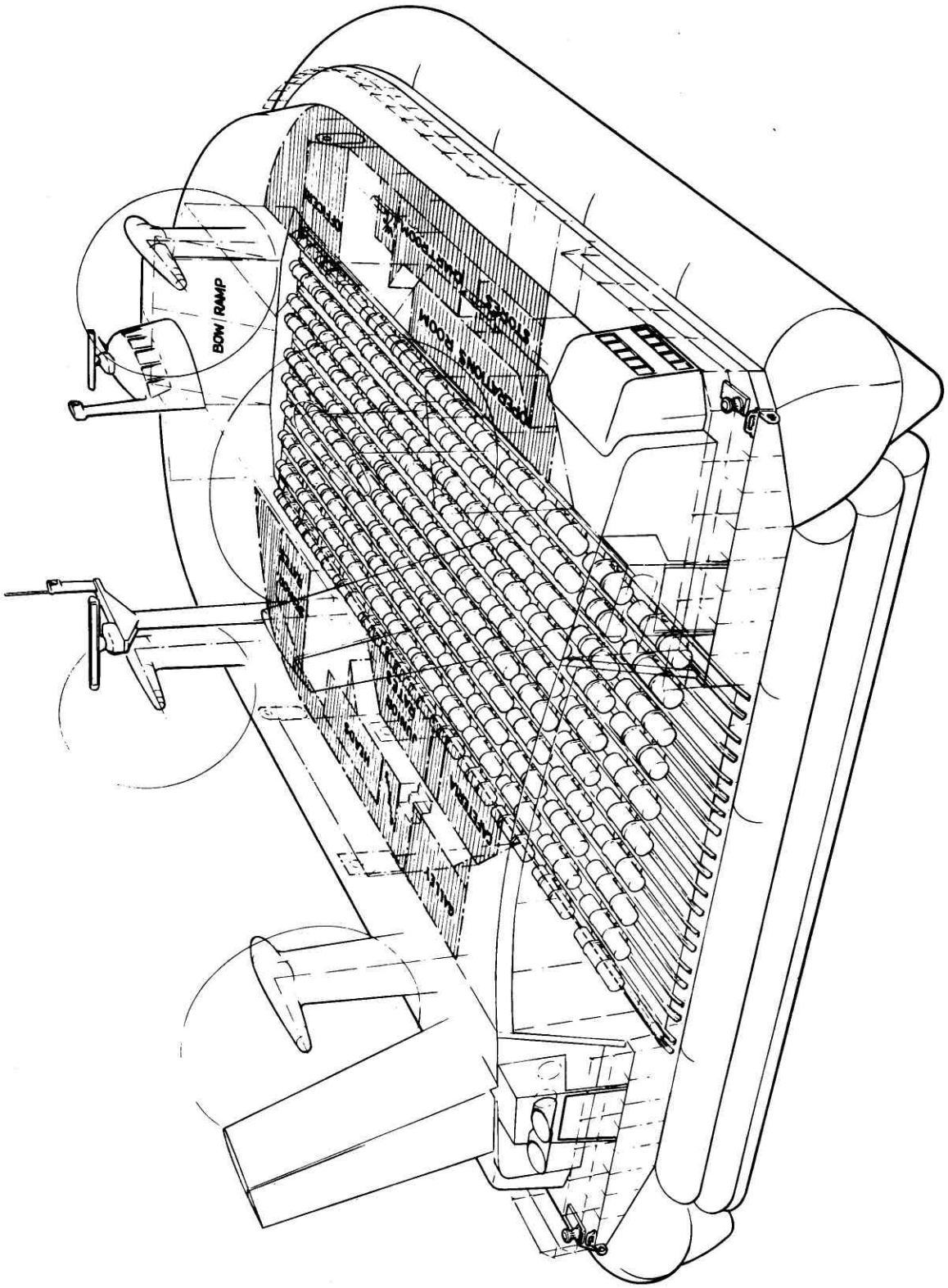
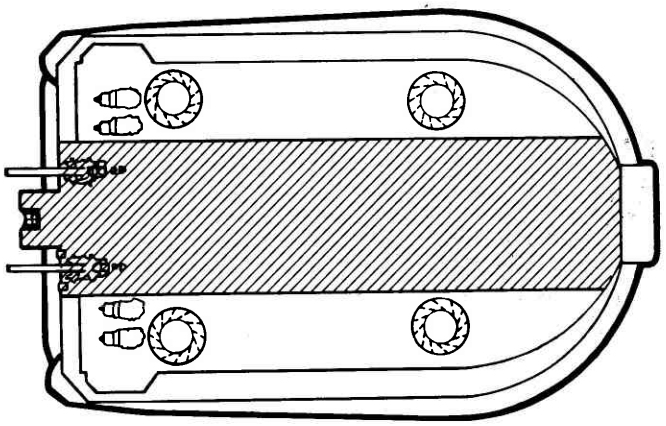
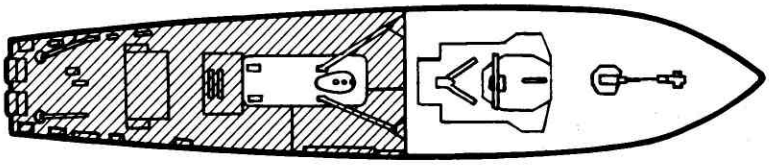


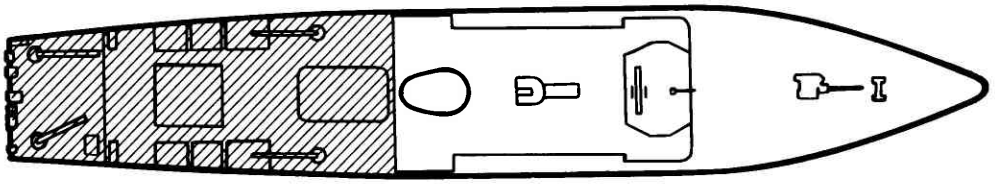
FIGURE 22 - SR.N4 Minelayer



SR.N4 MCMH

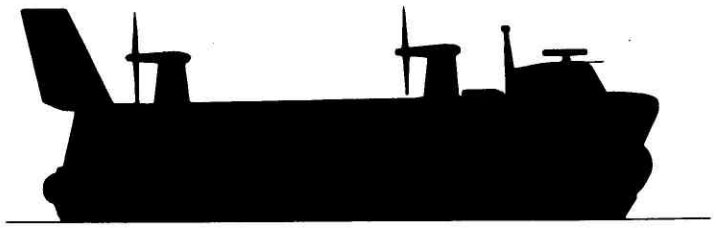


CMS TON CLASS

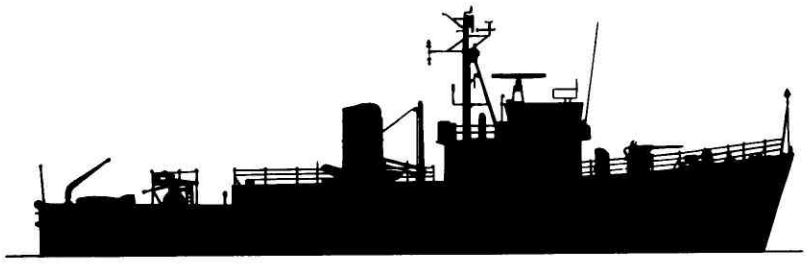


MCMV HUNT CLASS

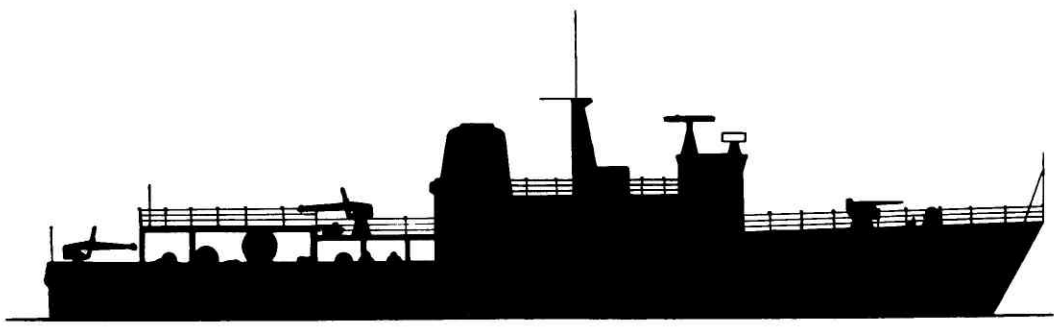
FIGURE 23 - Comparative Sweep Deck Areas



SR.N4 MCMH



CMS TON CLASS



MCMV HUNT CLASS

FIGURE 24 - Mine Countermeasures Craft Comparison

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THE NEW HM.2 HOVERFERRY - IN-SERVICE

Edward F. Davison
President, Hovermarine Corporation
Pittsburgh, Pennsylvania

INTRODUCTION

The first HM.2 Hoverferry was launched in 1968. In early 1974, addressing an AIAA/SNAME Advanced Marine Vehicles Conference, Captain Michael C. Davis of the U.S. Navy's Surface Effect Ship Project Office described HM.2 as "the Volkswagon of sidewall SES" (Reference 1), an analogy as following remarks attest intended to define HM.2's worldwide use, and high reliability; and one which all in his audience would immediately realize. Thus did HM.2 develop in its first six years - remarkable, considering the fact that the sidewall "concept" preceded the first HM-2 launching by only a few years.

The HM.2 which was launched in 1968 was a "Mark I", a 50 foot craft capable of carrying 62 passengers at speeds to 35 knots in relatively limited seas. The craft which Captain Davis referred to was a "Mark III" and, in particular, a then-standard production model which, after having been heavily instrumented, had recently completed a trials program covering more than 2,000 test runs for the U.S. Navy's SES Project Office. The trials were conducted over 450 operational hours in all kinds of weather and seas, and Reference 1 credits the craft with an engineering reliability of 96%. The test results contributed significantly to the Navy's SES data bank (Reference 2). Production of the 50 foot Mark III craft continued through 1976, and 40 of these craft are now in operation around the world - in 18 different countries and on every continent.

In late 1976 Hovermarine launched HM.2 "Mark 4", its "Rabbit" version of the Volkswagon. "Mark 4" is a 60 foot HM.2, designed to carry 84 passengers (92 passengers in certain configurations) with improved comfort. The Mark 4 development was based upon the almost 250,000 hours of operational experience gained by Hovermarine with previous models of HM.2. At this writing, four of these craft have been delivered and a further five are in production. This paper discusses the new Mark 4, presents the technical and economic rationale for its introduction, and describes its yet still brief, but highly successful in-service history to date.

WHAT IS A HOVERMARINE?

The Hovermarine as shown in Figure 1 is a rigid sidewall type of non-amphibious hovercraft, which employs an air cushion to lift the main body of the craft above the water. After "lift", thin longitudinal catamaran-type side keels are the only portion of the hull structure which remain in contact with the water surface and, therefore, the hull

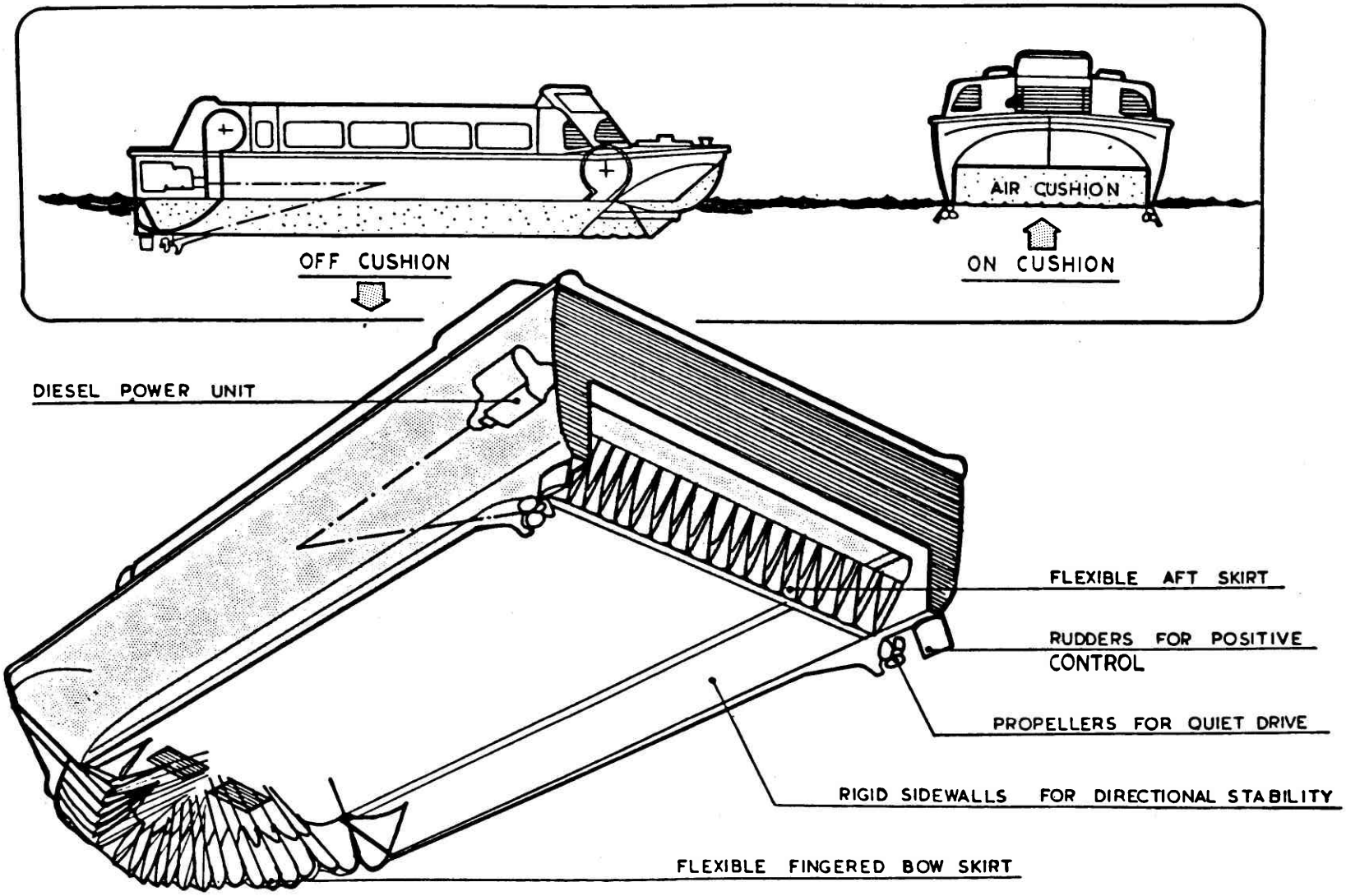


FIGURE 1 - The Hovermarine Principle

resistance or drag is greatly reduced, allowing a given payload-speed requirement to be met with reduced power.

The air cushion which is provided by engine driven fans is maintained or sealed longitudinally by the thin keels called "sidewalls", and at the bow and stern by flexible skirts which are resilient to the sea surface.

The sidewalls provide the craft's excellent stability features and house the drive train for the waterscrew propulsion system, which provides positive directional control under all operating conditions. Diesel engines are employed to drive the water screws.

The Hovermarine thus benefits performance-wise from the hovercraft principle, but maintains those normal marine features so familiar to boat operators throughout the world. Operators with displacement craft experience take immediately to the Hovermarine since its water screws, water rudders and diesel engines are familiar to mariners everywhere. The "feel" of the craft is that of a high-speed displacement craft since the hydrodynamics of the sidewall-propeller drive produce positive directional control - there is no skid or sideslip. Yet the craft is extremely manoeuverable, inherently performing tight co-ordinated turns at high speeds and manoeuvering within its own length at low speeds. Thus from the operator's viewpoint, the Hovermarine is a marine vehicle which can be integrated easily with existing fleets of conventional marine craft. No specialized people or facilities are required.

The Hovermarine principle is well known to the industry technicians by other terminology, including principally "sidewall hovercraft" and "surface effect ship"; but to our operators around the world it is a "Hovermarine". The descriptor is becoming generic, and is utilized just as is the noun "submarine".

WHY A HOVERMARINE?

All successful concepts/designs and resultant hardware employ trade-offs to various extents to achieve the desired end, and the Hovermarine is no exception to this axiom. In any work-productive transport system the designer and operator want to carry the desired payload, usually as much as possible safely, at the highest speeds at the lowest cost in terms of both employed capital and operating expense. The passenger (if that is the payload) wants a comfortable, convenient ride - also at a competitive fare level. Any system designed to bring the two together must be based on physical laws, basic economics, the property of materials and builders capabilities. Failure to apply all of these has prevented many concepts from realization, for although gains are certainly being made in the latter two areas, the former two are sometimes ignored.

Hovermarine employs all of these criteria while using (usually at no cost) waterways to haul people and goods, and perform other work functions at moderately fast speeds, economically - an efficient over-water transport vehicle.

In a since-famous work presented in 1950 (Reference 3), von Karman and Gabrielli developed a concise method of answering the question "What price speed?" The non-dimensional parameter "specific power" was devised to compare all forms of transport (from pedestrians to the highest speed aircraft then existent) in terms of the power required to perform useful work at various speeds. The authors produced achievement level limits - boundaries to which existing transport concepts had been extended. There was a large gap in these limits between, say, 25 and 100 mph over water, i.e. there were no efficient transport media having speeds between that of the merchant ship and the airplane operating over water.

Since 1950 the achievement levels have been extended by super-tankers on the low speed end, by jet aircraft on the high end, and many types of vehicles including the hydrofoil, amphibious hovercraft and Hovermarine, none of which were then-existent in a meaningful form, having aimed at filling the over-water speed gap.

The inverse of the von Karman/Gabrielli expression, that is the product of weight and speed as a function of installed power, has come to be known as "transport efficiency". Defining transport efficiency as follows:

$$\text{Transport Efficiency} = \frac{WV}{P}$$

Where $W = W_p$, Payload Weight

V = Maximum Operating Speed

P = Total Installed Power

produces an expression which is a true comparison of vehicle transport efficiency given equivalent range criteria.

Figure 2, adapted from Reference 4, compares this measure of transport efficiency for existing marine transport vessels at speeds up to 100 knots. Displacement ferry efficiencies which are high at the low speeds, decrease rapidly at speeds above 20 knots. From that speed up one progresses through the catamaran in the mid-20 knot region to Hovermarines and hydrofoils in the 30-40 knot region, and on to amphibious hovercraft which have speeds to over 60 knots. An envelope has been placed on Figure 2 which defines the "achievement level" limits of these existing vehicles. There are gains to be made but, while designs and concepts exist which transcend this envelope, they have yet to be brought to the dock.

Based upon this criteria, Hovermarines are the more efficient means of transport in the 30-40 knot region by a factor of 1.5 to 1.75. While the WV/P expression relates only to operating costs, it will be shown later that the HM.2 is also a very cost-effective transport mechanism on a total cost per seat-mile or ton-mile basis.

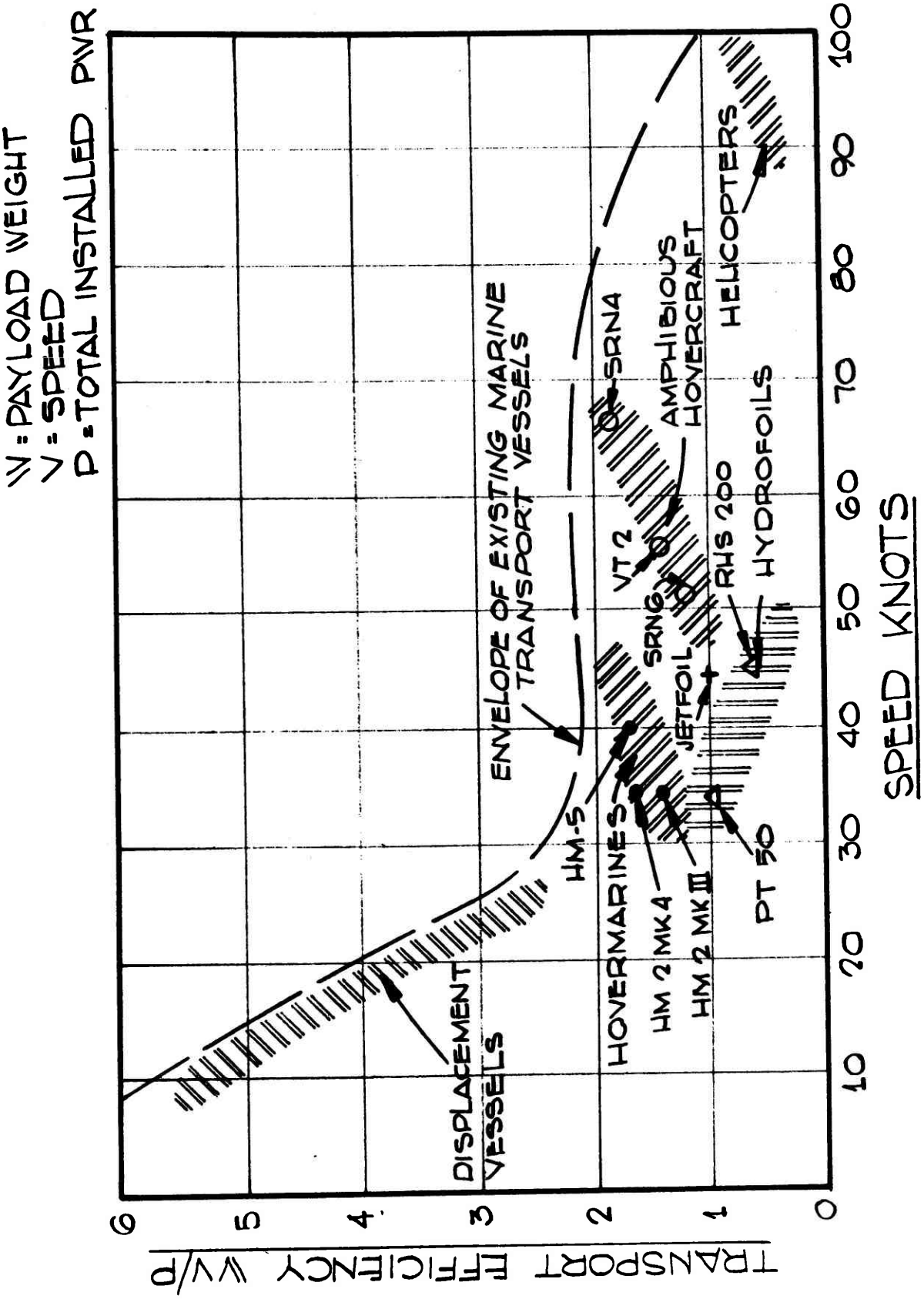


FIGURE 2 - Overwater Vehicle Transport Efficiency Comparison

BACKGROUND TO THE MARK 4

Figure 3 is a photograph of the first HM.2 Mark I, taken shortly after its launching in 1968. The prototype craft achieved its speed/payload performance goals, but early models including the Mark II (which employed a small skirt system change) did suffer some system problems which, from a reliability standpoint, would not have warranted the "Volkswagon" designator. Additionally, sea state performance of the early version was not all that its designers planned for nor all that its operators wanted, even though at 50 feet in length it was always recognized that HM.2 was intended to operate in relatively sheltered waters. Systems improvement work was completed in 1970 when the first Mark III entered service. All of the Mark III improvements excepting one were internal, the basic hydrodynamic surfaces and exterior remained untouched. The external feature which changed was the bow skirt, and (as shown in Figure 4) the new bow loop "wave impact attenuator" certainly changed HM.2's appearance. As will be shown later, this new feature, extending up over two-thirds of the former hard structure bow, permitted a significant improvement in the HM.2's ability to maintain speed in a seaway at increased passenger comfort levels.

The Mark III remained Hovermarine's "standard" for some six years, although many additional improvements and passenger amenities were incorporated as production expanded. These latter features included "airline-type" seating and interiors, air conditioning and stereophonic tape decks - the Mark III evolved into a luxury "Hoverbus".

No vehicle can remain stagnant in design and yet grow consistently in acceptance (for very long anyway), and so Hovermarine continuously sought a major improvement in HM.2. The worldwide inflationary economy which we have been living under in recent years really served as a dictatorial foundation for the three major criteria on which the Mark 4 was based: 1) a significant increase in disposable load with attendant reduction in seat-mile costs, 2) minimum possible cost (both capital and operating) increases, and 3) as near zero technical risk as was possible - with minimal associated development costs. There were, of course, attendant performance goals, but simple economics edicted the Mark 4 which is shown in Figure 5.

The Mark 4 certainly resembles the Mark III and except for a 10 foot increase in overall length, externally she is unchanged, maintaining exactly the Mark III bow features. The discerning eye will note the addition of a fifth window in the saloon which is the main distinguishing external feature. This feature would probably go un-noticed unless a Mark III and 4 were observed operating alongside each other, as is the case in two current services. We believe the Mark 4 however, to be a better looking craft - better proportioned for the increased length.

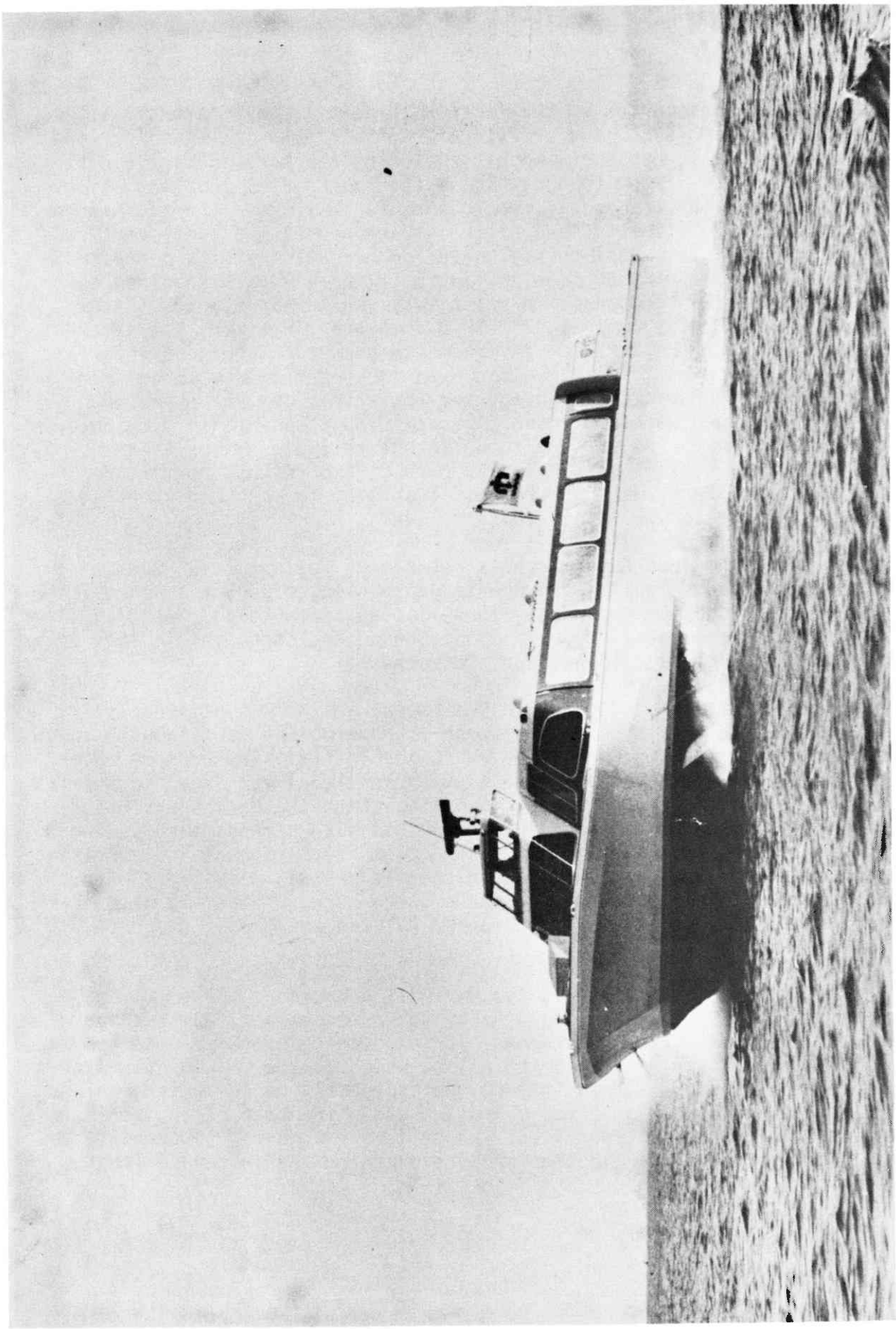


FIGURE 3 - The Hovermarine HM.2 Mark I



FIGURE 5 - The Hovermarine HM.2 Mark 4

DESIGNING THE MARK 4

As stated, the Mark 4 is a design compromise amongst the inter-woven technico-economic factors previously discussed. It is in essence the result of a "Hovermarine only" analysis of the question "What price speed?" A "stretch" was an obvious consideration in meeting the design criteria, but "how much stretch" was an attendant question. The answer to both questions finally evolved around available power plants, and the determinant was in the end the advent of the newly available General Motors' V92 series engine in marine models. The 8V-92 engine in the Hovermarine duty rating meant 380 bhp per engine, an increase of 80 hp per shaft over the Mark III installation at the sacrifice of approximately 500 pounds in increased weight. Additionally, the 8V-92 would be employed in naturally aspirated form at the 380 hp rating, whereas the Mark III engine was turbocharged. The changeover was about a stand-off on a specific weight basis at 8.6 pounds per horsepower and, yet, the 8V-92 will shortly be available in turbocharged form at 450 bhp in the Hovermarine duty rating. The performance of the 8V-92 as installed is shown in Figure 6.

The available power increase was assessed as to stretch length, as it in turn impacted structural weight and drag vs. resultant payload gains. Various alternatives with regard to the passenger saloon were also integrated into the stretch considerations. These factors were all traded-off against speed. The analysis resulted in the decision to add eight feet at the waterline, equivalent to four transverse frame spaces, and an additional 18 inches at the transome to improve passenger flow. In effect, therefore, HM.2 went from 50 feet to 60 feet in overall length.

The results of the trade-off on HM-2 performance are shown in Figure 7, which is a plot of the resultant HM.2 speed drag characteristics with the selected 8V-92 powered propeller-produced thrust overlayed thereon. The top end speed is down only a knot or so from the 35 knots achieved by the Mark III. Yet because of the increased length, added power and larger propellers employed, the cruise speed, as will be compared later, has actually increased by a knot or two.

Structurally, the Mark 4 "stretch" was catered for by an extension to the existing tooling and the structure is an integral one as was Mark III, that is, the eight feet was not added on, it was built into the mold. Structural modifications were of course required, particularly due to the increased bending and torsional loads resulting from the increased length. The side decks and lower sidehull sections were thickened and a number of shear members reinforced. The basic hull structure, however, remained unchanged and modifications were made only where the increase in loads dictated. As shown in Figure 8, the hull shell is a single grip molding. The bottom skin is stiffened between transverse frames which are spaced every two feet, and which transmit floor loads to the sidewalls which are considered longitudinal beams in which the skin and stringers are the effective bending material.

8V-92 (5)

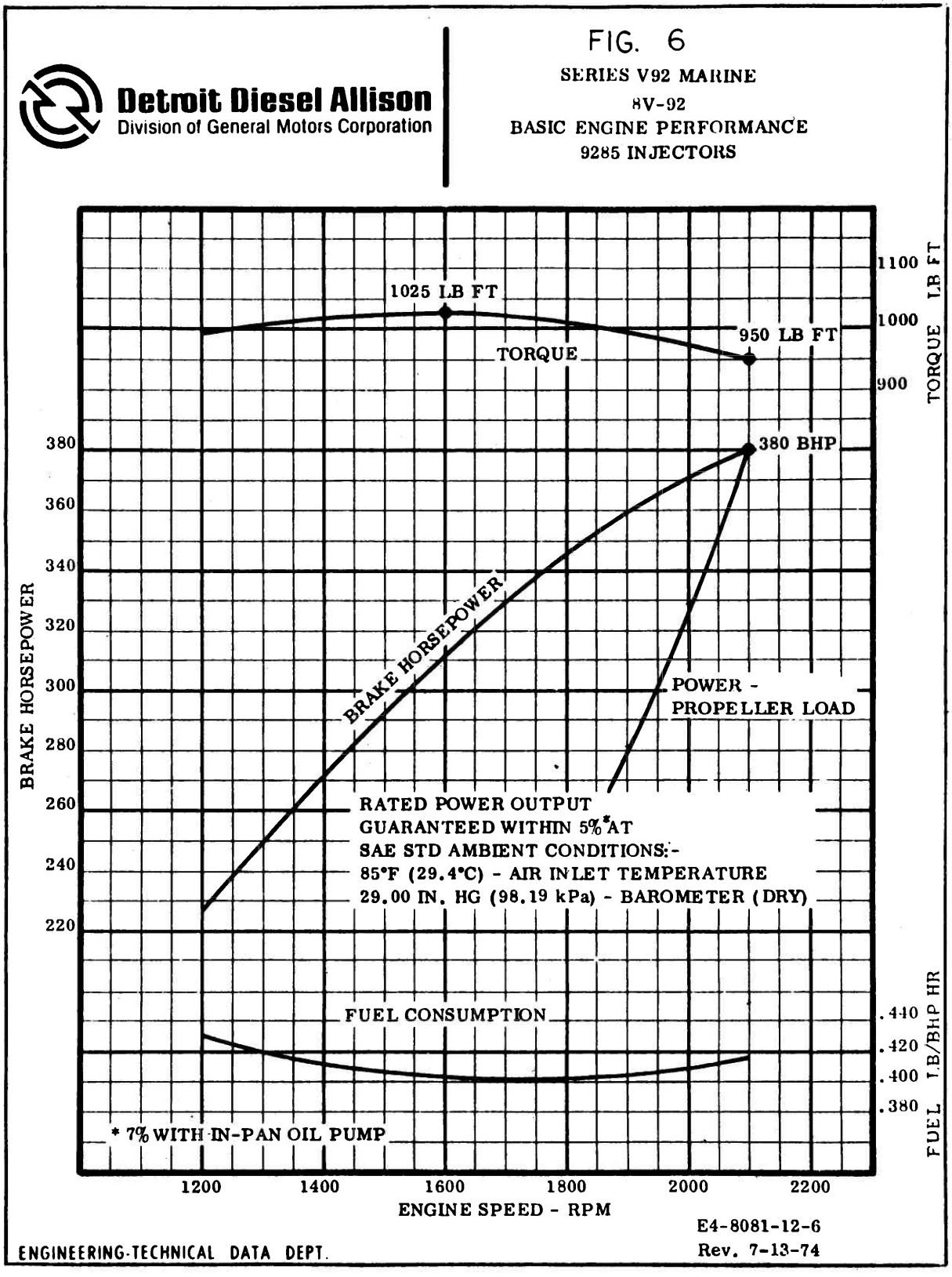


FIGURE 6 - Detroit Diesel 8V-92 Marine Engine Performance

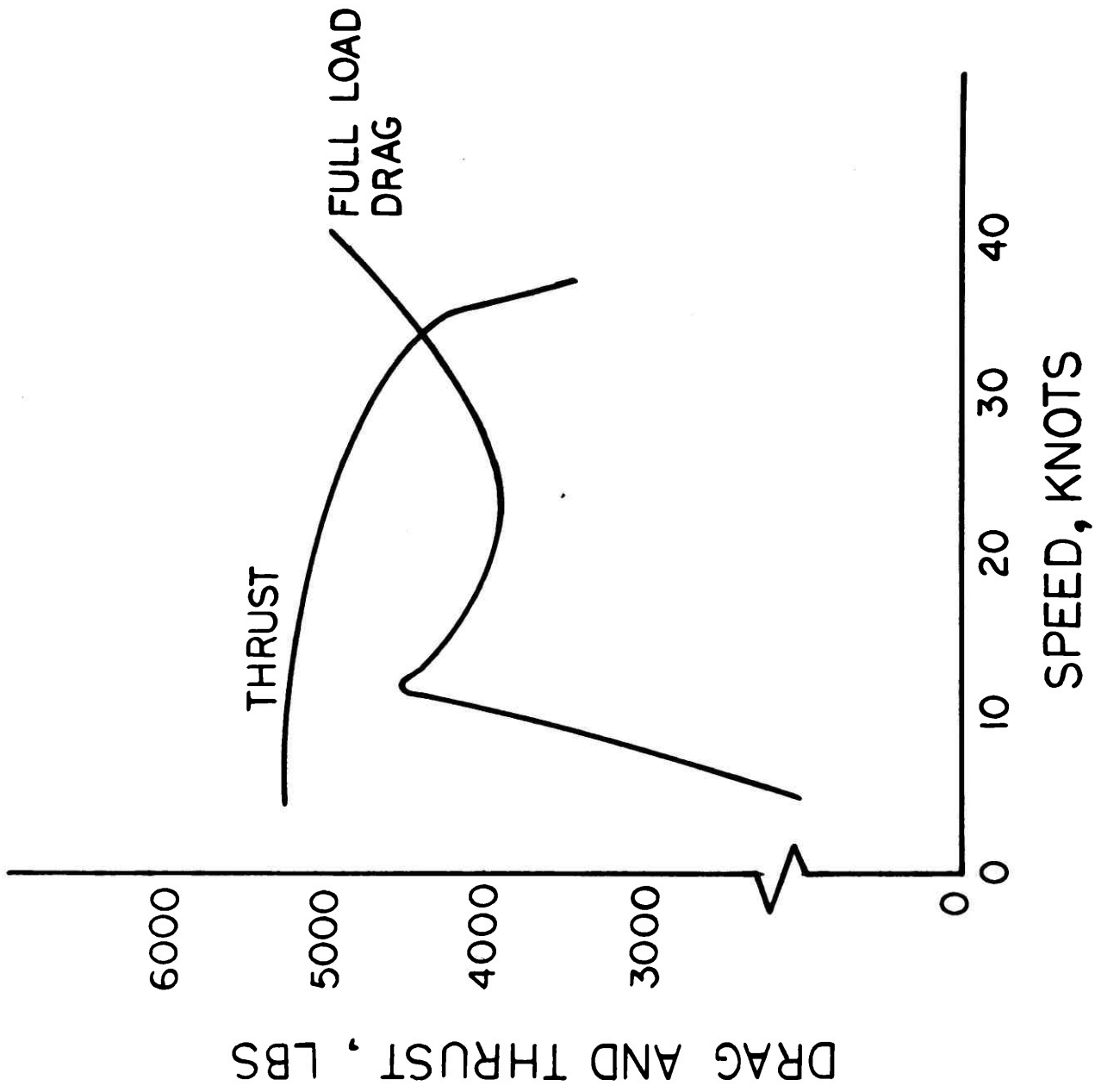


FIGURE 7 - HM.2 Mark 4 Drag and Thrust Vs. Speed

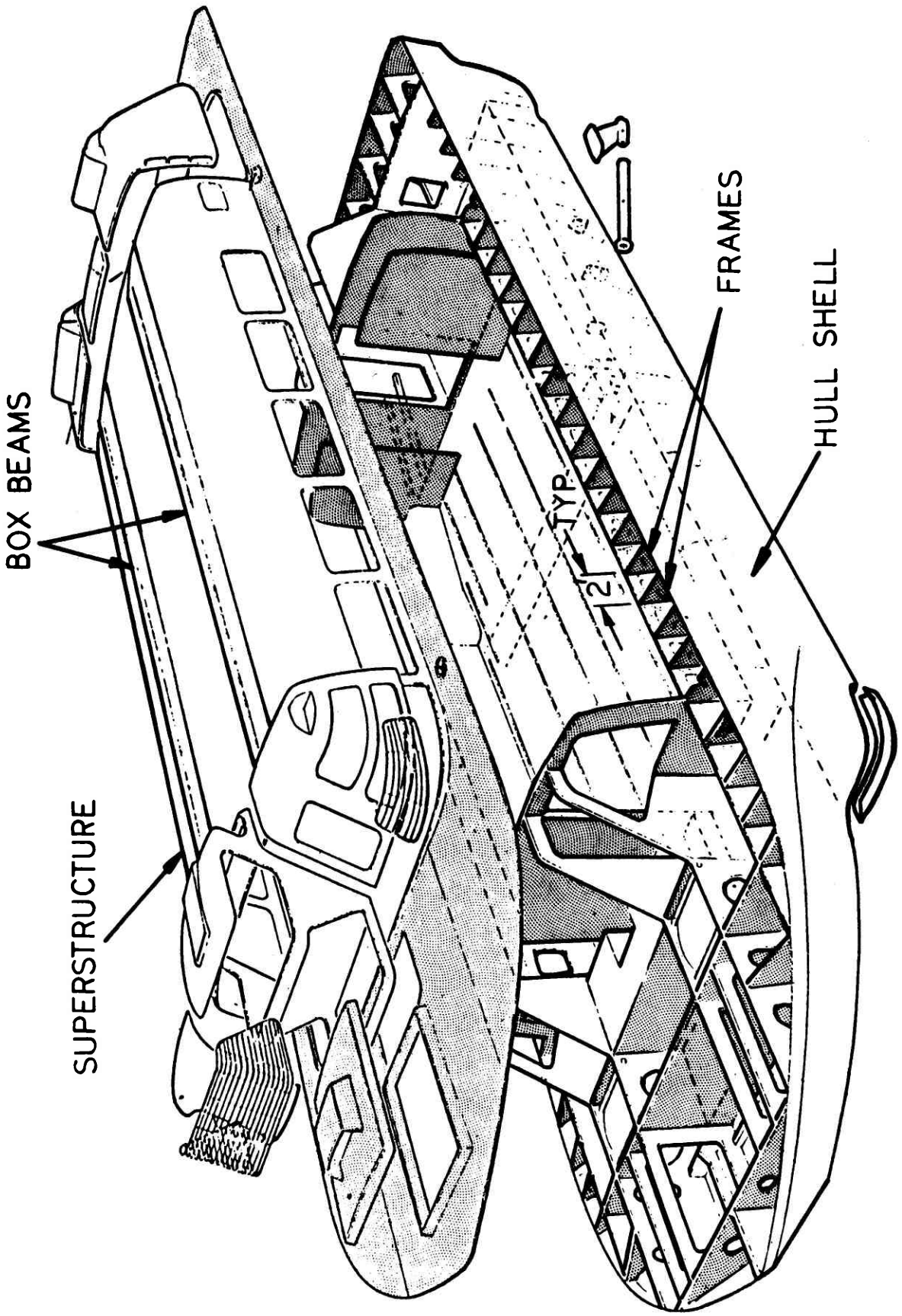


FIGURE 8 - HM.2 Mark 4 Structure

Other structural modifications included those necessary because of the elongated superstructure, reinforcement to the engine foundations and transmission beds based on the increased power, and reinforcement of the slinging points to carry the increased lifting weight. The extended superstructure is now supported by two longitudinal box beams - the upper half of which is external. This support method has reduced the number of internal stantion supports from four to two, even though the cabin length was increased by the full length of the eight foot hull extension, i.e. from twenty-one feet to twenty-nine.

Mark 4 machinery arrangements were of course, also revised where necessary, particularly those associated with the up-rated power. The transmission system has been designed to take the 8V-92 output in turbocharged form at 450 hp. A schematic of the propulsion system based on Reference 5 is shown as Figure 9.

Each engine drives forward at a 6^{o} angle, outboard through a Capitol-type HYH-200 combined reversing clutch and gearbox (each having their own lubrication system), then through two inch diameter stainless steel shafting to a "V" box. This resiliently mounted BPM VD/180 skew gearbox has an included angle of 15^{o} and a self-contained lubrication system. It provides a smooth transmission of torque and slight step-up (1.03) through intermediate shafting to the 2-1/2 inch tail shaft and propeller, through the thrust and support bearings as shown. The tail shaft is supported at the lower end by cutless bearings, housed in a stern tube assembly, and propeller bracket. The latter also houses a forward facing sea water intake for propulsion engine cooling.

The Mark 4 lift machinery remains exactly as that in the Mark III. The simple, effective and reliable system is unchanged. As shown in Figure 10, taken from Reference 5, a Cummins' V504M V8 marine diesel mounted in the bow drives via teethed belts two pairs of 24 inch centrifugal fans which supply cushion air and, via bleeds from the fan volute, directly pressurizes the bow impact attenuator or "A Loop". The lift engine also powers a fifth fan mounted in the starboard engine room, which pressurizes the rear skirt. Engine power to this rear fan is transmitted by a hydraulic pump and motor.

The Mark 4 skirt system also remains unchanged from that developed over eight years for the Mark III. Early systems suffered from some geometry, material and attachment problems and the current loop and segment or "finger" system has been through four evolutions resulting from an intensive development program. Beginning forward and referring to the Mark 4 cutaway of Figure 11, the large A Loop previously discussed extends around the bow from the underside being attached close to the gunwhale level. A smaller loop is joined to it at its base, and both are pressurized slightly above cushion pressure by a bleed from the lift air volute exit. Open loop segments are hung from the smaller loop so as to lie in a radial distribution around the bow. Segments are tied to the hull hard structure by a simple nylon rope attachment. The rear skirt segments are a double loop type, and are pressurized to some 7% above cushion presure by the rear fan. HM.2 skirt systems are ever under evaluation in a

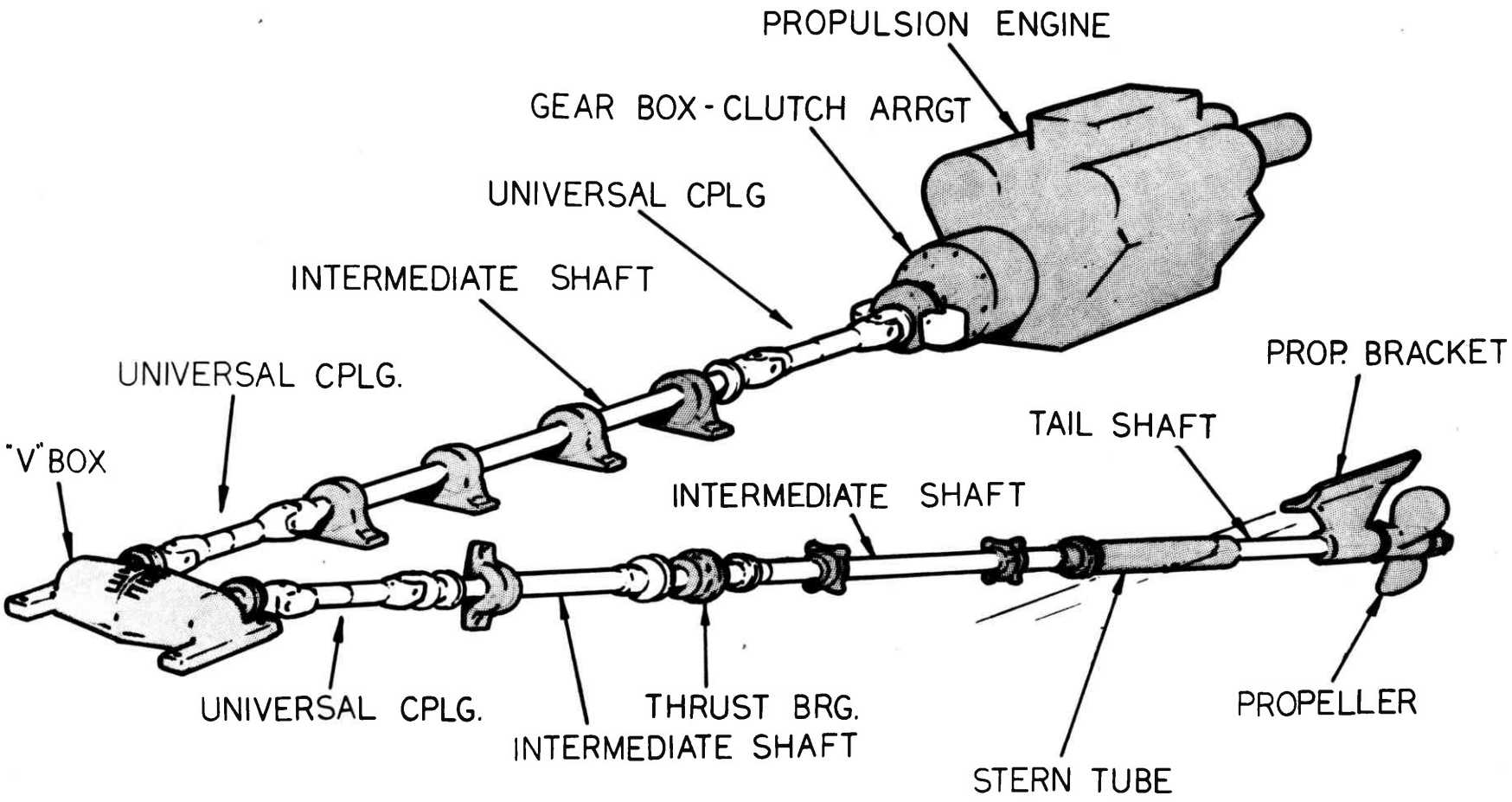


FIGURE 9 - HM.2 Mark 4 Propulsion System

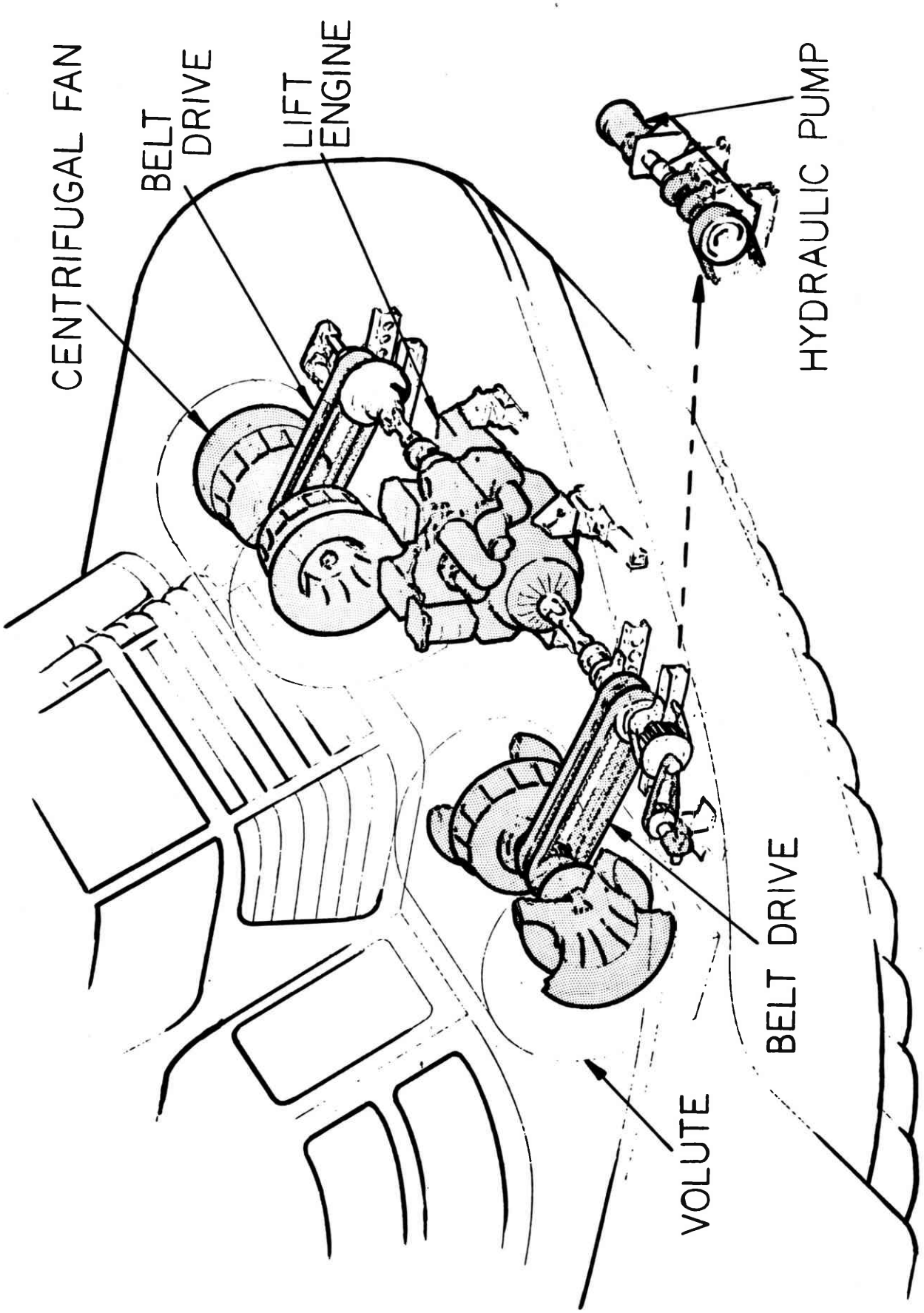


FIGURE 10 - HM.2 Mark 4 Lift Machinery

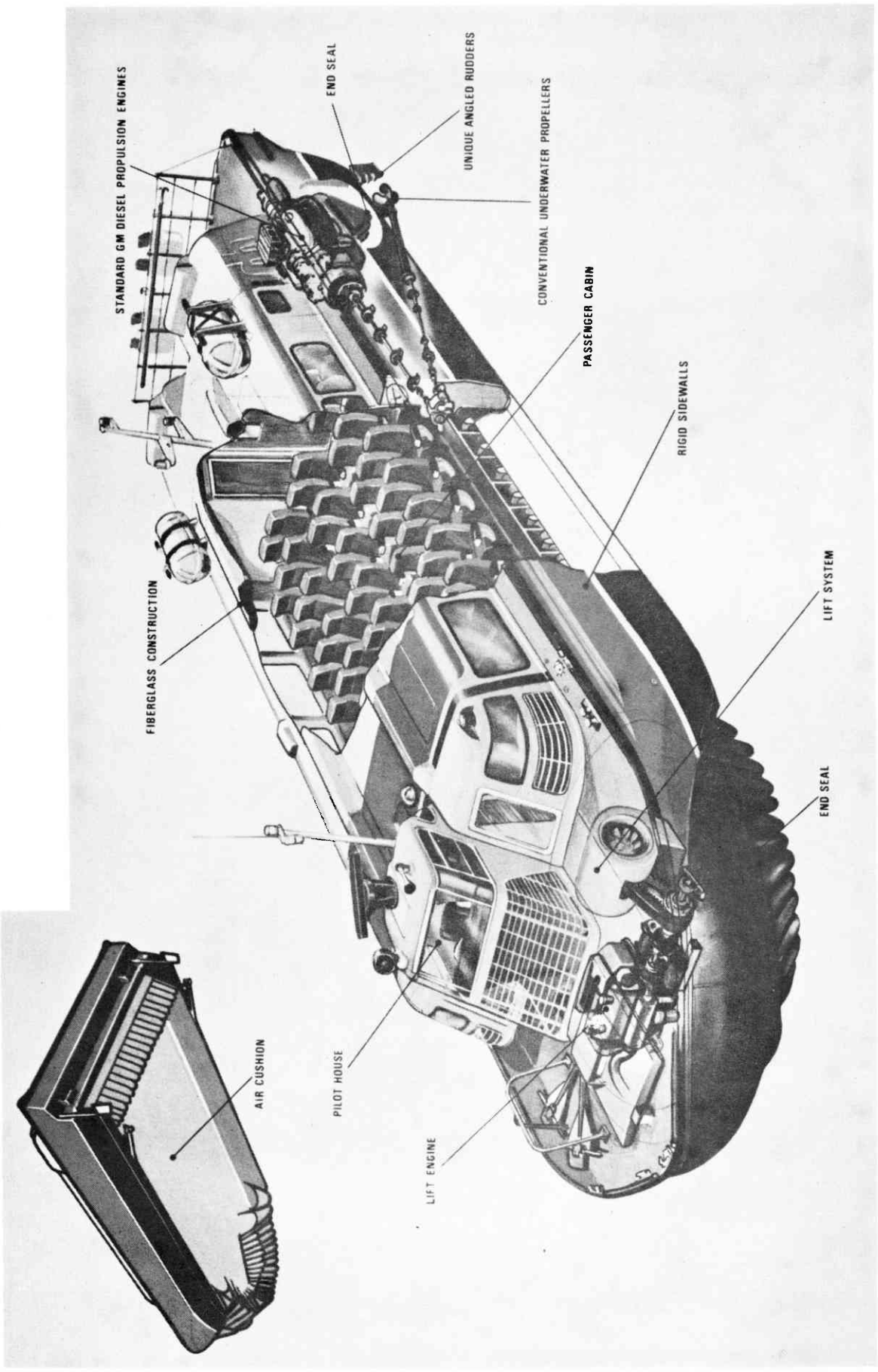


FIGURE 11 - HM.2 Mark 4 Cutaway

continuing development in this key area. Configuration and material development to date have resulted in life expectancies of 700/800 hours for bow segments and 500/600 hours for those at the stern, dependent upon location and operational criteria. Hovermarine's near-term development goal is 1,000 hour life, although it should be noted that skirt lives of over 2,000 hours and 1,300 hours have been recorded respectively for front and rear segments. The loop systems are sturdy and reliable, and only rarely require attention or replacement.

The leading particulars of the resulting Mark 4 craft are shown on Table 1.

MARK 4 CHARACTERISTICS

The "Volkswagon HM.2" was a very successful craft, having excellent performance characteristics and superior economics. Those for the Mark 4 model can, therefore, best be assessed by a comparison with the Mark III. Such a comparison is presented on Table 2. From a performance point of view, Mark 4 is superior in every respect except for the loss of a knot at top speed. All measurement criteria point to a significantly more efficient craft generally on order of the WP/V increase of about 26%. For an approximate 16% increase in first cost, which equates almost exactly to the installed power increase, a payload increase of 36% has been attained. Because cruise speed under normal operation conditions has actually increased somewhat, the increase in seat-miles per cruise speed-hour available to the operator has increased further to 40% and the increase in disposable load of 43% is even more dramatic. The operator, of course, sees these improvements in a decrease in the operating costs per seat-mile of 26%, a figure which matches the increase in transport efficiency.

HM.2 Mark 4 performance in seas has been markedly improved with each successive variant of the craft, and Figure 12 from Reference 6 compares these improvements. The improvement in the Mark III, which has been standard since 1972, was primarily due to the bow skirt configuration previously referred to. The pressurized bow loop absorbs wave impact before contact with the hard structure occurs. On contacting a large wave, the finger segments collapse to seal much of the skirt air leakage. This reduced flow demand is fed back to the fan, and the resultant increase in pressure helps further to sustain the bow loop and reduce deformations. Mark 4 improvements are due essentially to its increased power and greater length. These improvements, of course, mean an increase in cruise speed in any given sea condition, with the commensurate decrease in block times - a faster, more schedule-reliable service.

TABLE 1 - HM.2 Mark 4 Leading Particulars

DIMENSIONS		
Overall Length	60 ft.	
Maximum Beam	20 ft.	
Maximum Draft (loaded)	5 ft. 4 in.	
Height (above waterline)	16 ft.	
WEIGHT		
Maximum	25,520 kilos	56,400 lbs.
Normal Gross Weight	25,000 kilos	55,000 lbs.
ENGINES		
Propulsion	2 General Motors V8-92 Marine Diesel 380 bhp	
Lift	1 Cummins V504M 185 bhp	
FUEL SYSTEM		
Capacity Forward Tank	182 liters	48 U.S. gallons
Aft Tanks	638 liters	169 U.S. gallons
DESIGN PERFORMANCE AT SEA LEVEL		
Speed in Calm Conditions	62 kph	34 knots
Endurance in Calm Conditions	4 hours	(full speed with 10% reserve fuel)
Range in Calm Conditions	220 km	135 nautical miles

TABLE 2 - Hovermarine Mark III/Mark 4 Comparison

	Mark III	Mark 4	Increase (Decrease)
Overall Length	51 ft.	60 ft.	18%
All-up Weight	44,000 lbs.	55,600 lbs.	26%
Total Installed Power	826 bhp	945 bhp	15%
Number of Passengers	62	84	36%
Disposable Load, W_d (Passengers & Fuel)	12,000 lbs.	17,200 lbs.	43%
Disposable Load Fraction, W_d/AUW	.27	.31	15%
Maximum Speed	35 kts	34 kts	(3%)
W_p-V_{max}/P_{tot}	1.37	1.72	26%
Cruise Speed	30 kts	31 kts	3%
Seat Miles per Cruise Speed Hour	1,860	2,604	36%
Approx. First Cost	$565,000	$650,000	15%
Total Operating Costs/ Seat Mile*	$ .047	$ .035	(26%)

*Based on: Three craft fleet.
2,500 hour annual utilization per craft.
Includes 6 crews and maintenance, labor and spares.
Excludes cost of money.

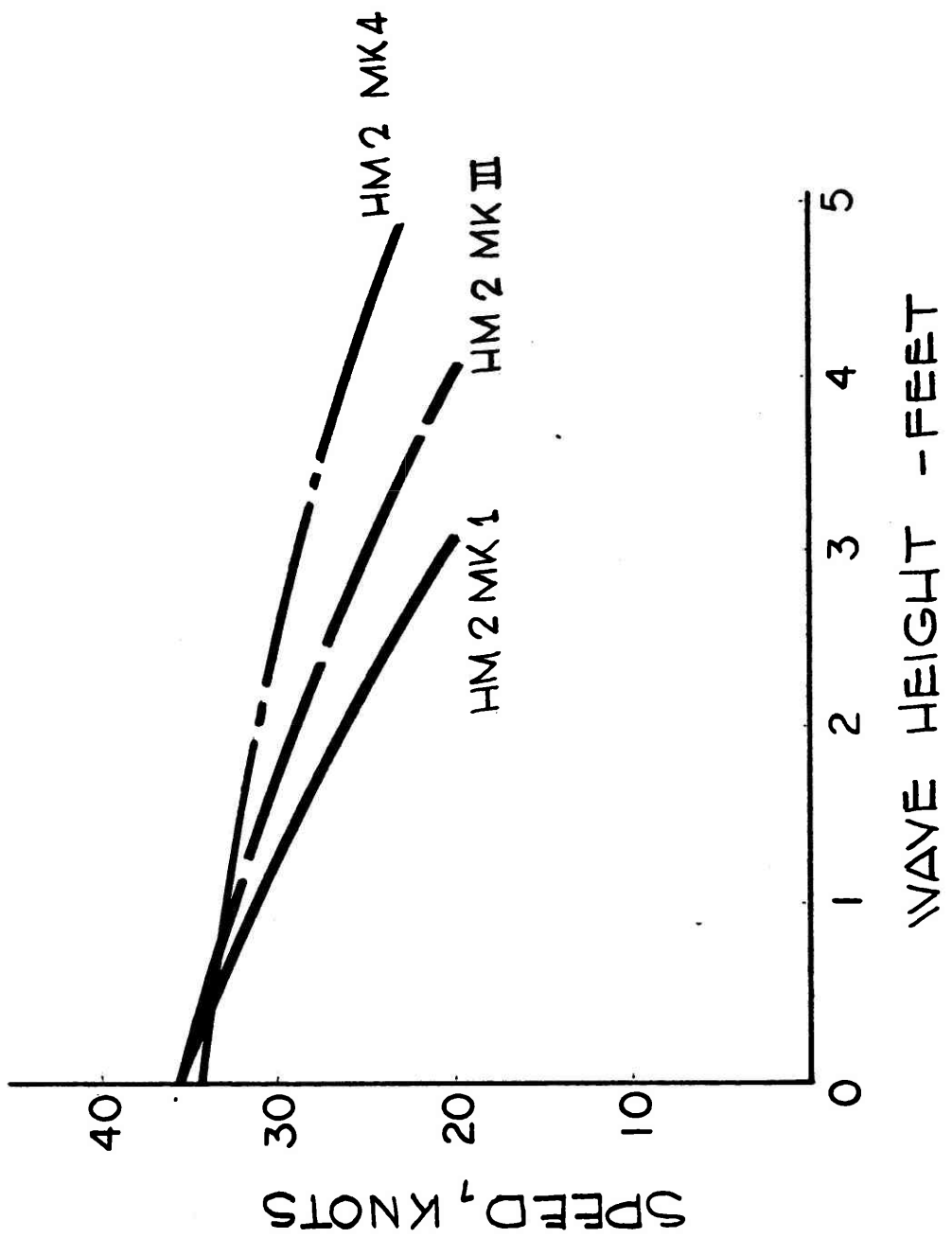


FIGURE 12 - Overwave Performance of HM.2 Variants in Head Seas

MARK 4 OPERATIONS

Hong Kong is situated along the South China coast and is comprised of the twin cities of Victoria on Hong Kong Island and Kowloon on the Mainland. It is a teeming metropolis of about 4-1/2 million industrious people, many of whom seem constantly on the go. Public transport, and importantly waterborne public transport, has played a vital role in the postwar era development and industrialization of Hong Kong. The Hongkong & Yaumati Ferry Company, Ltd. (HYF Co.) is the largest waterborne mass transit operator in Hong Kong. HYF Co. is also the largest ferry operator in the world, in terms of number of passengers carried, largest by a factor of three to four. HYF Co. operates some 90 ferry boats, and in 1976 carried a total of 135 million passengers. The company operates a complete range of ferries - from double ended, double vehicular deck, carrying thousands of passengers to conventional "mini-ferries" operating on feeder routes. The HYF Co. route system, both cross harbor and to the outlying islands, is shown in Figure 13, and some 400,000 people travel these routes each day. The Chinese characters in the title of Figure 13 translate to "The Hongkong & Yaumati Ferry Co., Ltd.".

Hovermarine's are in the HYF Co. vessel mix and HYF Co. operates the world's largest fleet of Hovermarines. From an initial craft obtained in 1974, the HYF Co. fleet of HM.2's has grown to the present total of five. During the first six months of 1977, 672,000 passengers have travelled aboard HM.2's between Hong Kong and Kowloon, an annual rate closing rapidly on 1-1/2 million passengers. Figure 14 shows an HM.2 at speed in Hong Kong Harbor.

Four of HYF Co.'s HM.2's are Mark III craft. Because of their success, HYF Co. took delivery in late 1976 of the first Mark 4 produced. This craft, known as HYF 105, is configured for 92 persons - a 50% increase in capacity over the Mark III craft. As of end-June of this year, HYF 105 had accumulated over 1,200 operational hours. She is used essentially on two Kowloon-Hong Kong routes - from Tsuen Wan and Kwun Tong to Hong Kong Central.

The HM.2 Hoverferries provide a different type of ferry service from HYF's large ferries - an express service. Generally speaking, where passengers have an option for the two modes of travel, they choose the faster crossing by Hovermarine. The savings in time which can run from several to many minutes is evidently very valuable to the commuter. According to HYF management, "the craft has its special appeal in spite of its high fare structure". An example of this fare structure differential is Tsuen Wan-Hong Kong Central route, where the fare by Hovermarine is double that for the conventional ferry - a 100% premium for the service - which is speed. In some other operations, HM.2's command fare premiums of 500 to 700%, so the Hong Kong commuter is really getting off lightly.

A comparison of the new Mark 4 with HYF's previous fleet of HM.2 Hoverferries on this same route is also interesting. HYF clocks the Mark 4 as having an improved block speed of 1.3 knots on average over the approximate eight nautical mile route - verification of the performance curves of Figure 12. It is also interesting to note that 30% of HYF's 672,000

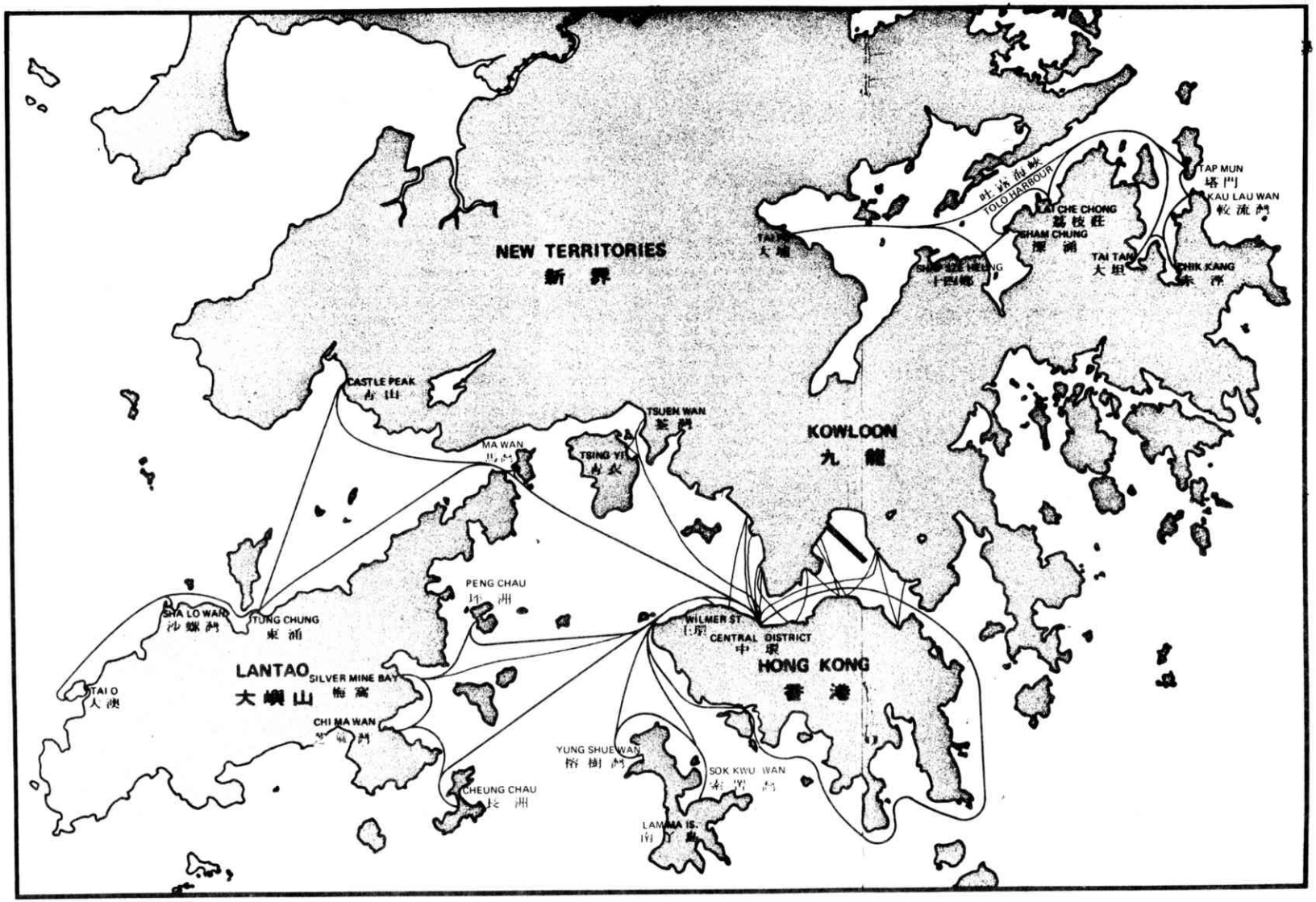


FIGURE 13 - Hongkong & Yaumati Ferry Co., Ltd.
Ferry Route Network

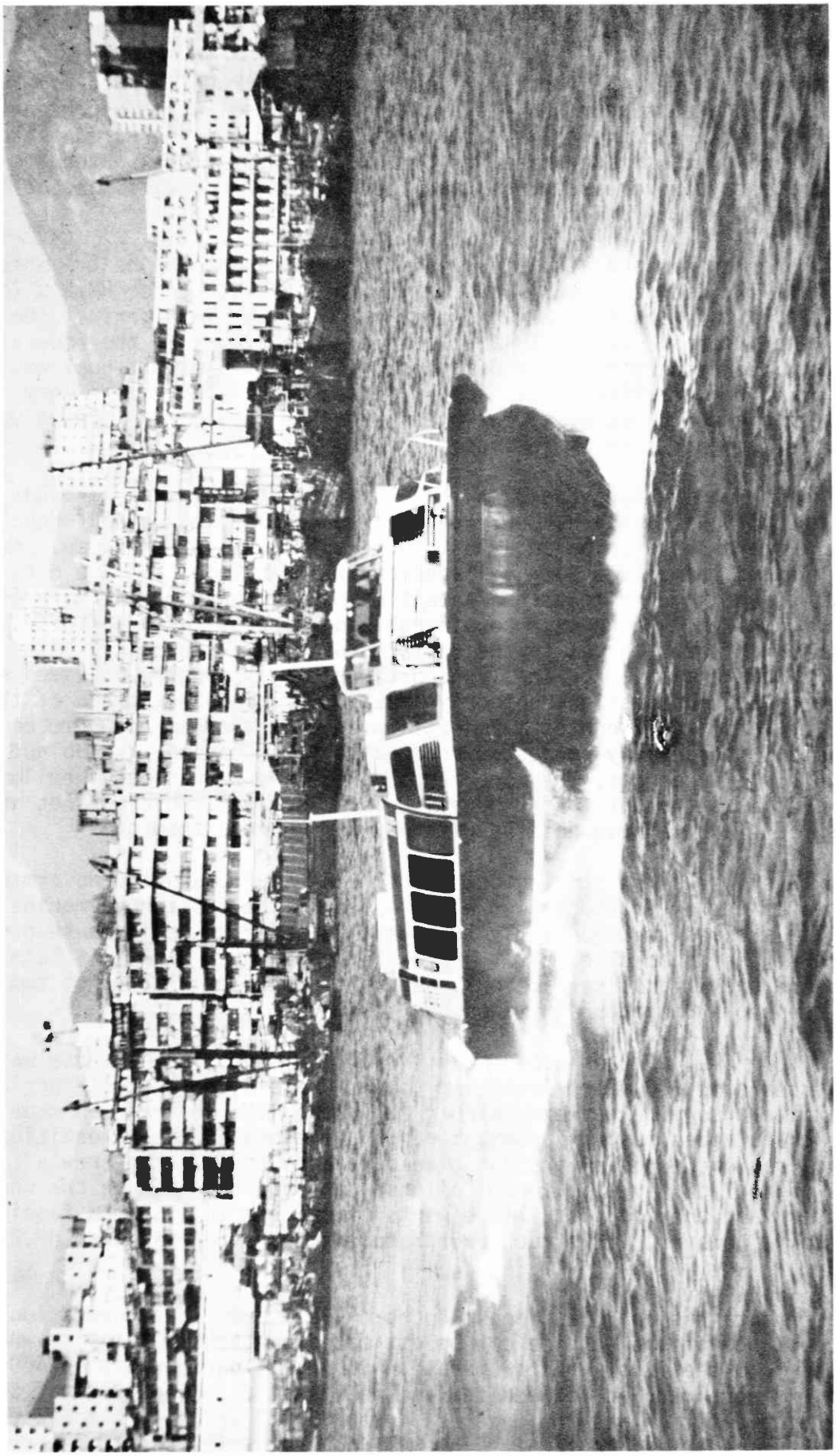


FIGURE 14 - HM.2 At-Speed, Hong Kong Harbor

HM.2 passengers over the first six months of 1977 travelled aboard HYF 105, i.e. 30% of the passengers have travelled on a vessel which represents 20% of the available equipment - a testimonial to both the increased passenger capacity and customer acceptance of the HM.2 Mark 4. The greater acceptance criteria however is perhaps the fact that HYF Co. will take delivery of its second Mark 4 and sixth HM.2 later this year.

Mark 4 Hovermarines are also operating on the African continent - which, prior to 1977, had not seen a Hovermarine in service. Three HM.2's (one Mark III and two Mark 4's) began operation this year in Nigeria. The craft were purchased by the Inland Waterways Department of the Federal Nigerian Government's Ministry of Transport. The Ministry's goal was that of offering the traveller a high-speed option especially in the very heavily congested Lagos area, but other areas of the country are being evaluated for this type of service.

Lagos is not unlike Hong Kong, in that it is made up of three islands spilling onto the mainland. Unlike the industrious "high-speed" Hong Kong, however, there seems to be an almost permanent "go-slow" in Lagos. Even the Lagotians themselves seem to laugh at this attitude, and the city congestion which means that the fastest means of transport is, more often than not, walking - even over considerable distances. Many workers take two and three hours to get to their places of work in the city, both on the islands and mainland. The Transport Ministry's program is aimed at overcoming this congestion, not only in Lagos but in other areas of the country. Reference 7 quotes a Federal Government spokesman, while commenting on the unbelievably congested road network, as saying, "We do not have to build waterways, they are already here and we can use them immediately for mass transit to the benefit of our people. Hovermarines are 'waterbuses' and we have got the waterways to operate them on."

Figure 15 shows Lagos, its lagoon, harbor and rivers, and the Hovermarine routes over these - both current and proposed. The first Hovermarine, a Mark III, arrived in Lagos early this year in order to begin route proving and crew training on-site. This craft was joined by a Mark 4 in late spring and operational service only began this summer. The first two craft are shown operating in Lagos on Figure 16.

Following arrival of the second Mark 4 craft in June, one of these was transferred some 700 miles Southeast to the Cross River State, Nigeria to initiate a service between Calabar and Oron. The journey was made by the craft under its own power, through all types of water conditions ranging from uncharted rivers and creeks to open ocean. The crew's report of the journey, the local "pilots" employed to navigate the uncharted waters and the mud hut village ports of call is in itself a fascinating story, however, it is much overshadowed by the reception of HM.2 at Calabar.

Passenger data has only just begun to be collected on these operations, but acceptance of the service can be estimated on those statistics which resulted from the first week's operation in August during which 5,469 passengers were carried between the two points at a fare premium of 50%. The fare competition was the perennial "slow boat" which took in excess of two hours to make the 17 nautical mile journey which the HM.2 performed

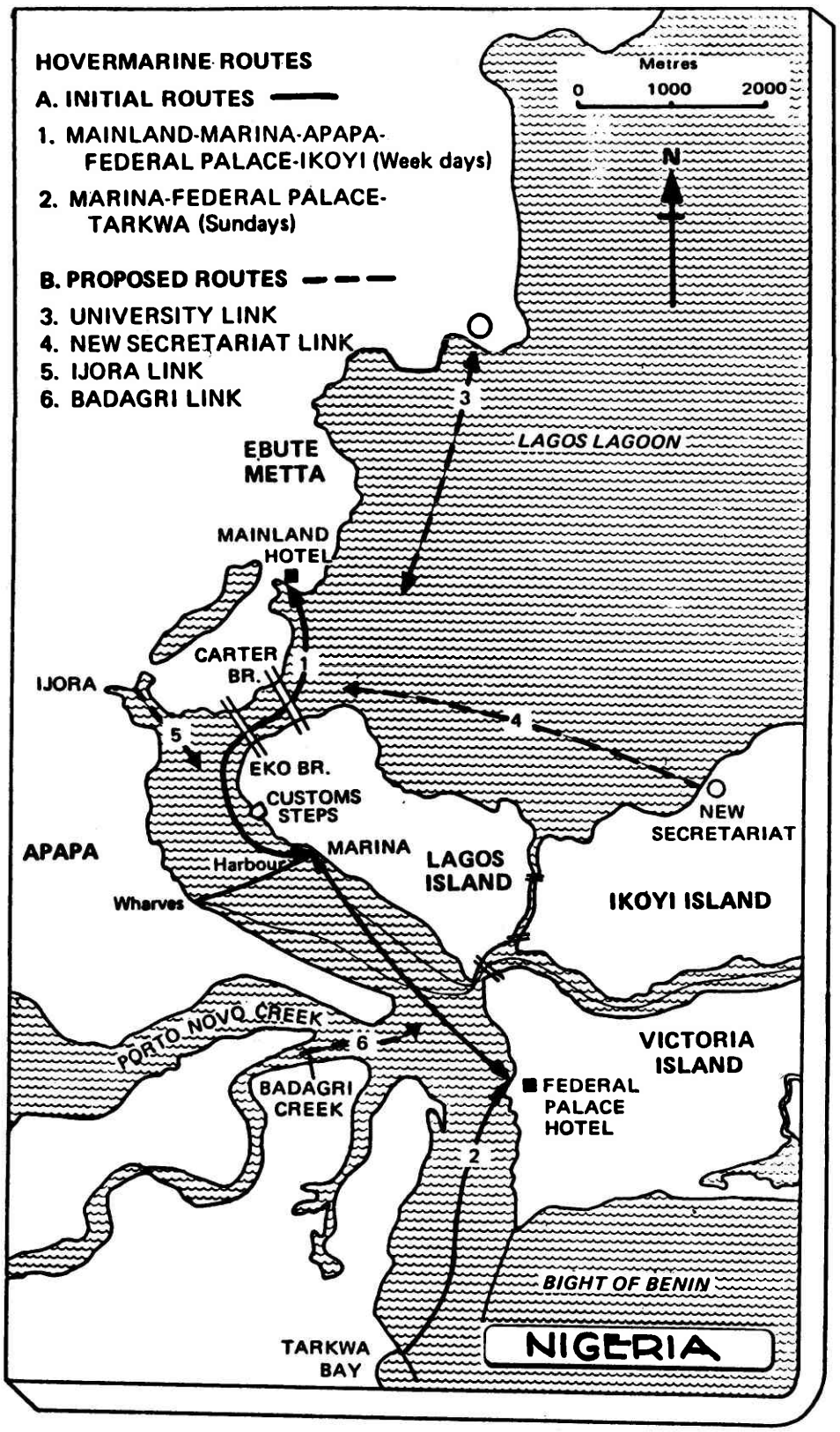


FIGURE 15 - Hovermarine Routes in Lagos



FIGURE 16 - HM.2's In-Service, Lagos

in just over 30 minutes. The Nigerian businessmen, like their Hong Kong counterparts, were more than willing to pay the premium for the more than 90 minute timesaving. Passengers above the 84 seat limit were turned away, and the Ferry Authority actually limited the number of HM.2 trips per day to four in an attempt to preserve "slow boat" income even though both are state owned. The Calabar Sunday Chronicle of August 14th under a headline reading "You are Welcome" reported: "It sounds unbelievable that one can get from Oron to Calabar in half an hour, but it is now a fact."

The Hovermarine story in Nigeria has yet to unfold, but as the Sunday Chronicle continued, "It's made a very impressive start" towards beating the Nigerian go-slow - the original goal of the Ministry of Transport. The key to the problem-solving thinking of the government can be seen in naming the craft. They are called "Innovator I, II, and III". The potential is great.

OTHER HM.2 MISSIONS

The operational characteristics of the HM.2, particularly those of high speed, low wash, shallow draft and excellent manoeuverability, are of course, applicable to missions other than those of passenger transport. The weight of passengers may be transferred into other payload, the superstructure rearranged as necessary and then mounted on the basic HM.2 hull structure to form any number of "General Purpose" versions of the HM.2. This transformation is exactly what has been accomplished in the case of the HM.2 Mark III GP craft shown in Figure 17. This particular craft, "KALLO", is operated by the Government of Belgium out of Antwerp as a survey boat. "KALLO" has the same performance characteristics as a standard Mark III but, instead of passengers, carries a complete survey instrumentation/navigation package and comfortable "day" accommodations for a crew of 10 or 12. She has additional tankage, providing for extended range capability and an alternative flying bridge control station.

The characteristics of the Mark 4 craft which make her superior to the Mark III, principally the 40% increase in disposable load capability, are of course, also applicable to the General Purpose range of craft and really extend the range of mission applicability for HM.2. One such mission is a Fast Response Fireboat.

Fireboats around the world have remained relatively stagnant technologically in terms of both speed and firefighting capability. Most of the existing equipment is more than 20 years old, and even that of lesser vintage still limps to the scene at barely 10 knots, creating much wake disturbance en route, especially in rivers and harbors.

A 1974 U.S. Dept. of Commerce, Maritime Administration funded study (Reference 8), conducted by the City of Tacoma, Washington, surveyed cities and port authorities throughout the country to evolve a set of requirements for a vessel whose first mission was firefighting but which could serve also in attendant police, rescue and patrol roles. The



FIGURE 17 - HM.2 Mark III General Purpose Craft

resultant desired craft capabilities highlighted high speed, low wake and a defined payload capability - an ideal application for the new HM.2 Mark 4, whose disposable payload of 18,000 pounds in this mission configuration shown in Figure 18 is well above the study's requirements.

The Mark 4 fireboat is based upon that same hull structure shown in Figure 8, with reinforcement in those areas necessary to take the fire-main loads, four 450 gallon fuel/foam tanks and the 35 foot telescoping boom. Performance of the fireboat is unchanged from the passenger version, that is the payload is brought to the scene at over 30 knots speed, reducing response time of conventional fireboats by a factor of three. This speed is complimented by the range of firefighting capabilities shown. Once at the scene, a crew of two can pump and station-keep for twelve hours.

Using the same principle of mounting an 18,000 pound disposable payload on the basic Mark 4 hull, many other meaningful missions arise. These include surveying, customs and police patrol, air/sea rescue, logistic support and crewboat. A utility or General Purpose version of this craft combining several of the above missions is shown in Figure 19. This particular design employs the large GP cockpit, a lower cabin with comfortable seating for twenty-four, deck area aft for other payload, and two firefighting monitors are mounted at the bow - a real General Purpose craft - with a 34 knot capability at full load.

SUMMARY

Based upon the 1/4 million operational hour in-service history of the HM.2 Mark III, a second generation Mark 4 craft has been produced with superior characteristics, its design objectives having been well met. The Mark 4 shows significant improvement over its predecessor both in terms of performance characteristics, disposable load ratios and cost effectiveness on a total cost per seat-mile basis. Available for less than one year, successful operations have already been conducted in Hong Kong and initiated in Nigeria. The 40% increase in disposable load capability has expanded mission potential for other than passenger carrying operations; Fast Response Fireboat and general purpose designs utilizing the same hull structure have been developed. The new HM.2 Hovermarine is indeed in-service, successfully, and with new and expanded potential.

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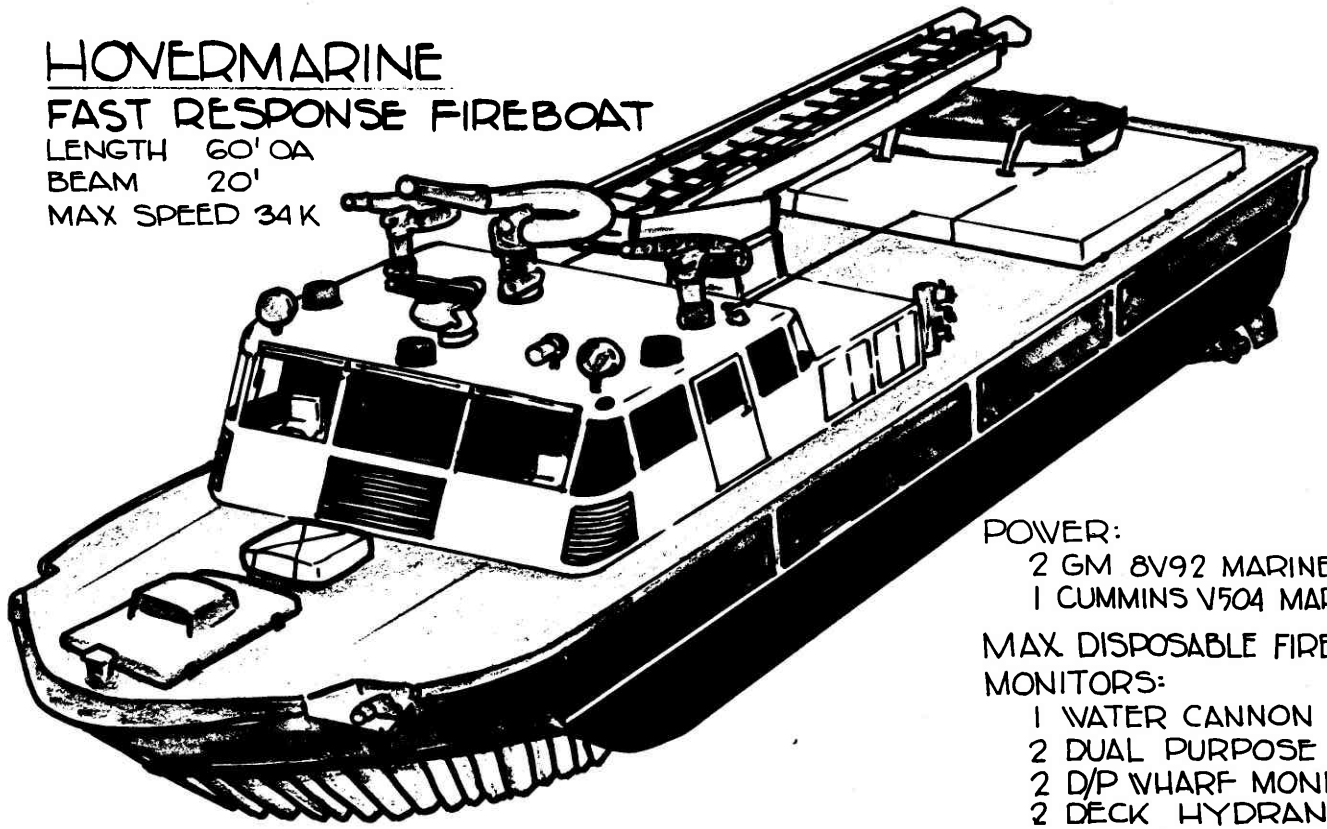


FIGURE 18 - Mark 4 Fast Response Fireboat

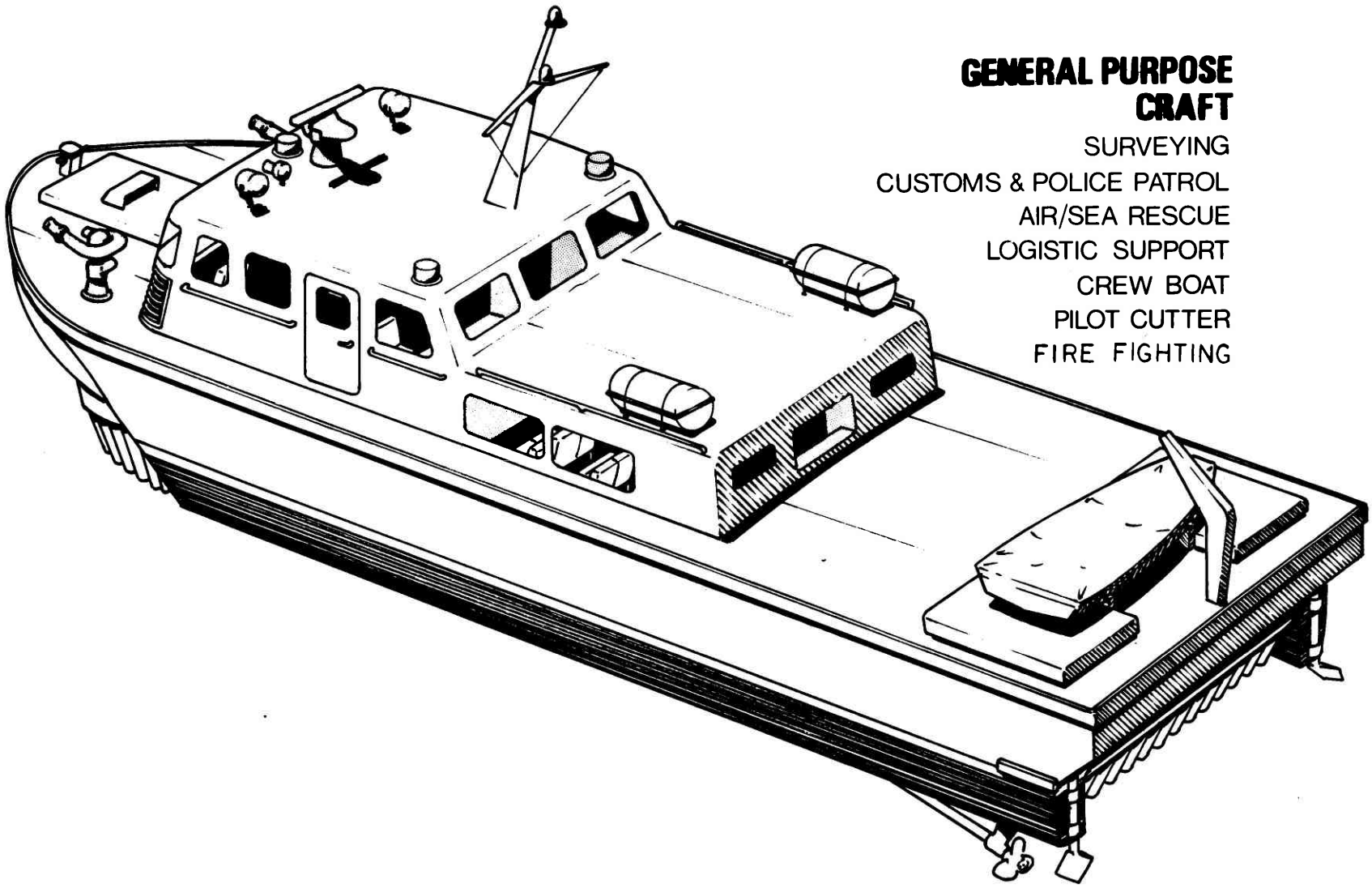


FIGURE 19 - Mark 4 General Purpose Craft

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