Practical Experience with Ground Effect Machines

F. A. H. Ashmead*
Royal Navy, Hants, England

In mid 1960 the military potential of hovercraft was realized in England and the necessary organization set up, which resulted in the formation of the Interservice Hovercraft Trials Unit in January 1962. Trials to date have been on six different types of experimental and civil craft, hired from the manufacturers. The work has been concentrated initially on over-water trials, but, with the introduction of long flexible extensions, more overland trials are becoming possible. Experience has indicated that hovercraft should obey the operating rules and regulations of the environment in which they find themselves as far as possible, and the military Hovercraft will be operated by whichever arm is appropriate to the role. It is the combination of the air-cushion principle with flexible structures that offers the Royal Navy the prospect of a 90-knot ocean-going ship, the Army a truly amphibious logistic support vehicle, and the Royal Air Force a craft capable of an airfield crash reserve performance that exceeds even that of the helicopter. Such a concept opens up a whole new field of tactical possibilities.

Introduction

THE purpose of this paper is to set out the experience of the past two years in the military evaluation of the ground effect machine, more commonly known as the hovercraft, and to describe the trials which have been undertaken in support of the most likely military roles.

The ability of hovercraft to achieve extremely high speeds over calm water has been amply proved in trials and demonstrations. The doubt that has always existed is the ability of the craft to maintain these high speeds in rough seas or across country, without completely uneconomical lift powers being used to raise the craft above the level of the obstacles likely to be encountered in its path. It has been the combination of the air-cushion principle with the introduction of flexibility into the structure which has enabled a craft powered for a hoverheight of a few inches to surmount waves or obstacles several feet high and transformed the aerodynamic oddity of 5 years ago into the 70-knot, 70-seat sheltered water ferry of today.

Military Organization

Military interest in the hovercraft principle did not really materialize in England until about the middle of 1960, following the success of the early experimental machines. To enable the military to play its part at this very formative stage in hovercraft development, the three Services joined together with the Ministry of Aviation to form the Interservice Hovercraft Working Party, the Royal Navy having been given responsibility by the Defense Research Policy Committee for sponsoring the project as the most likely major user, the Ministry of Aviation retaining for the time being both the research and procurement responsibility owing to the obvious similarities in technique between hovercraft and aircraft.

Interservice Hovercraft Trials Unit

One of the first actions of the Working Party was to form the Interservice Hovercraft Trials Unit. The interservice aspect of this endeavor is particularly important in the modern climate of integrated defense forces, for rivalry between the Services gains nothing and can never be justified in the development stage. Where procurement of the developed craft is concerned, there is much to be said for allowing each service to obtain its own equipment, for the operational craft are likely to differ widely in character and each arm is the best judge of its own operational problems. Certainly in operation it should never be suggested that it is necessary to have a hovercraft corps set aside to handle these mysterious machines that are proving so difficult to classify into the neat pigeonholes of the established order.

The background of hovercraft development in England has so far been concentrated in the civil field, in particular on the sheltered water ferry, so that military trials to date have been of necessity confined to craft intended specifically for civil purposes. The opportunity has been taken to gain experience of as many different craft as possible and of learning to adapt conventional test techniques to this new field. The sea-keeping problem, so dear to Naval hearts, has as yet hardly been studied at all. It is not easy to see the application of the ocean-going civil hovercraft, since it offers neither the speed of the aeroplane nor the comfort of the ocean liner, so that this is likely to be a peculiarly Naval development. It must also be realized that, if it is intended to explore the boundaries of operation outside the experience even of the manufacturer, it is somewhat unreasonable to expect to be allowed to do it in a hired commercial craft. It is for considerations such as this that the construction of a 40-ton military experimental hovercraft has been ordered.

However, in work of this kind there is considerable danger of forgetting that the objective is the examination of the air-cushion principle applied to military purposes and not the evaluation of a particular hovercraft in some operational role. It is so much easier to regard every new device as a replacement for something, the employment and equipment of which is already well understood, but the full realization of the potential of a new concept such as this will require as much effort in the development of the weapon system and its deployment as in the development of the craft itself. Unfortunately, it is not possible to get something for nothing, and enhanced performance is bound to cost money.

The Hovercraft Trials Unit has therefore a twofold responsibility to the Working Party: first, for undertaking the development and performance testing of the craft themselves, and second, the operational trials of craft and equipment in their various roles so that the service departments may be advised in the preparation of staff targets and requirements.

Operating Characteristics

We find that there exists a multitude of misconceptions on hovercraft generally; to dispel these, we shall give an account

Presented as Preprint 63-480 at the AIAA/CASI/RAeS 9th Anglo-American Conference, Cambridge, Mass., October 16–18, 1963, and Montreal, Canada, October 21–24, 1963. Published with the permission of The Royal Aeronautical Society and the Canadian Aeronautics and Space Institute.

* Lieutenant Commander.

of some impressions of operating the 5 or 6 British hovercraft with which this unit has had experience over the past 18 months.

The majority of the early trials were conducted over the water because the sea in good weather is predominantly flat and obstacle-free, and one quickly discovers that overland operation, particularly in confined spaces, is a much more hazardous affair. However, the rapid development of flexible extensions has improved the obstacle-crossing capability immensely and more overland trials can now be included.

Over water, as lift power is applied, the cushion causes a depression in the water equal to the craft's displacement, and the edge jets impinging on the surface create a dense cloud of fine spray. As the craft moves forward, the spray falls rapidly aft until at cruising speed it is visible only over the last quarter of the craft's length. The depression in the water underneath, however, moves forward as the craft accelerates, causing waves like any other displacement vessel. As speed increases the craft climbs out onto its bow-wave and begins to plane, with the characteristic bow-up change in trim typical of all planing craft. At this point the wave-making resistance is reduced, and the craft accelerates still further. The depression in the water surface now has no time to form and the wave-making resistance can be shown to reduce to insignificant proportions. The craft ceases to make waves and a bow-down change of trim occurs. The craft at this stage is said to be "over the hump," that is, over the critical wave-drag speed, which occurs at a speed approximately equal to the square root of twice the waterline length.

Maneuvering a hovercraft over water is much easier than over land, since the craft gets some grip due to wave drag. Also water is substantially flat, usually steady wind conditions prevail, and the surface is free of obstacles other than buoys and ships. Care has to be taken when maneuvering near these obstacles at speed, but the judgment of opening and closing angles comes fairly easily, particularly to the sailor and the airman, though this is the sort of consideration that is new to the wheel-borne operator. The fact that all turns at speed are to some extent skidding turns can be disconcerting initially and care is required, as at speed the craft's inertia provides a tendency for turns to tighten. There is a natural tendency for the craft to bank into the turn, but the advantage of being able to apply some side force, allowing reasonably coordinated turns to be made, should not be underestimated, not only for turns over water but especially for maneuvering over land and in confined spaces.

In the majority of the early craft it was not possible to apply any side force at all, and if operating along sloping ground or in crosswinds it was necessary to yaw the craft into the slope and wind. Unfortunately, over land one necessarily operates more cautiously, at slower speeds, and hence the effects of side slope and wind are more marked. As the trials have proceeded it has become evident that the ability to apply a reasonable amount of side force is vital to avoid the necessity of drifting sideways with all the problems this entails. Overland craft, of course, tend to be of a reasonably modest size, which rather conflicts with the complications of the side-force requirement, since these smaller craft should also be kept as simple as possible. One solution, at least for slow speeds, is the use of retractable wheels bearing some proportion of the hovercraft's weight. However, wheels are only really effective over good surfaces and there are other disadvantages, particularly when long flexible extensions are fitted to the craft.

Naturally the ability to decelerate and stop in a short distance in emergency is absolutely essential. Over water, lift power can be reduced and the craft allowed to land on the water even from high speeds. Unfortunately, the craft cannot carry around too much extra weight in the form of strengthened members to enable the same thing to be done over land. However, experience has shown that it is quite possible to decelerate the craft in emergency by partially reducing the lift power and dragging the flexible extensions over the ground. It is quite remarkable how little wear occurs on these extensions, which must be due to the very low contact pressures involved. Present day underbelly strengths require that the craft be brought almost to rest over carefully chosen smooth ground before it can be set down completely without risk of damage. The weight penalty of providing a resilient underbelly of some sort should not be too severe and would be of great benefit for work over natural terrain.

Operation at night has not yet been attempted, but it is recognized that there are problems to be overcome, particularly in the assessment of drift and the anticipation of wave or obstacle encounter in really dark conditions.

Control Presentation

During the trials, the Unit has naturally had the opportunity of studying the various solutions that have been adopted by British hovercraft manufacturers in the provision of adequate control and methods of driver manipulation of these controls. The need is of course for control of lift, forward and backward motion, and yaw and side force.

There have been several different ways of presenting lift control to the driver, varying from forward-moving levers to twist-grip-type throttle controls, like helicopters. The best control in our opinion is an up/down lever working in the natural sense.

The accepted and only practical method of providing thrust for forward and backward motion is by means of variable pitch air propellers. Some craft have hand-operated levers for thrust control, some foot-operated like a motor car. However, the thrust setting required in a hovercraft remains reasonably constant for long periods under cruising conditions, and it is considered that the most attractive method for control of speed is by fore and aft movement of an aircraft-type control column, with a lever for datum setting of engine power or pitch, as appropriate.

Three ways of obtaining directional or yaw control have been encountered so far, aerodynamic rudders, asymmetric application of power in the case of multipropeller craft, or rotation of the thrust line of one or more propellers mounted on swiveling pylons. However, it is in the method of presenting the yaw control to the driver that the main divergence of opinion has occurred. Members of one school of thought wish to avoid any suggestion that the hovercraft resembles an aircraft. They argue that if its controls are similar to those of a motor car, the training problem will be eased, but it must be accepted that driving a hovercraft is not like driving a car or an aeroplane; it is something different. The driver of a motor car under normal operating conditions experiences no side slip, control in yaw producing an immediate side force. In a hovercraft there is of course no significant cross coupling between yaw and side force, and even presented with familiar controls it is doubtful whether the average car driver would find control of a hovercraft natural. The controls should be simple and physically light to operate, they should work in the natural sense, and no deliberate attempt should be made to imitate any other vehicle. It is even possible that the combination of familiar controls with an unfamiliar craft response might prove to be positively misleading.

Yaw control in a hovercraft needs to be sensitive and responsive. To achieve this sensitivity, control movements must be small so that, without power assistance, control forces tend to be fairly high. Since the driver will inevitably be sitting down and the legs are in nature the strongest limbs and those used for steering the body, foot-operated rudder pedals are considered to be the logical yaw presentation.

The provision of adequate side-force control has only been achieved so far on the larger craft. Various methods of displacing the center of pressure of the cushion by the use of spoilers have been tried, but control power is limited with this method and it involves a loss of hover height. By far the best solution, but a mechanically complicated one, is to vector the thrust, since it will be the largest horizontal force available. If it is not acceptable to yaw the craft to counter slopes and crosswinds, the alternative is to yaw the engine or propeller on a swiveling mounting. At first it was thought best to present side-force control to the drive by a lateral leaning stick. However, in rough seas it was found that drivers were making involuntary control applications and exaggerating the rolling tendency. It is thought, therefore, that, in the larger craft at any rate, the side force should be applied by turning a wheel or spectacle.

In the first military machine there will be a spectacle type of control column which is moved forward and backward for control of speed and rotated for sideways motion or bank. Directional control is by means of aircraft type of rudder pedals and lift by up/down levers working in the natural sense.

Navigation and Command

In operation over water, a hovercraft is moving in a truly marine environment and may be regarded as a very fast ship. All but the smallest craft will need to use position and anti-collision radar equipment and its requirements will naturally be substantially the same as those of a ship's equipment. Present-day thought is tending toward the very light and compact aircraft equipments, but ocean-going hovercraft are bound to be of an appreciable size, and limitations of weight and space will be to some extent relaxed. At hovercraft speeds, navigational information must be made available in the shortest possible time in a readily assimilated form, and it is in the presentation of this information to the Command that major differences between hovercraft and marine practice may emerge.

The accuracy required for position fixing varies, of course, with environment. For ocean work, say, more than 50 miles offshore, an accuracy of about $\pm 1\%$ of the distance off is required, and conventional astronomical sights, radio aids, or inertial navigation systems will suffice. For coastal areas, between 3 and 50 miles offshore, these techniques may be assisted by radar and visual fixing on land objects.

Our hovercraft experience to date has naturally been confined to pilotage waters, within 3 miles of the coast. Here instantaneous position and tracking information is most necessary, and an accuracy of $\pm$ 50 yards is required in poor visibility. We have used 3-cm radar and Decca Navigator with automatic plot successfully, aided by visual fixes on prominent marks and navigational buoys. As an exercise, a hovercraft was in fact once conned into Portland harbor and to within a few yards of the beach entirely by reference to the radar screen.

For passage however, it is wise to preplan the route, for although hovercraft are little worried about depth of water, at hovercraft speeds there is all too little time available to assess the incidental hazard without having to worry about routine navigational ones.

At the present time, hovercraft are using standard marine 3-cm radar equipment with a 12-in. stabilized picture. Pilotage plotting is carried out on top of the PPI using a reflection plotter, and in the military craft it is intended to employ a larger radar screen, true motion, and a more flexible plotting arrangement. The route may then be prepared on a suitable chart, showing the coastline and the intended track projected onto the face of the PPI and the craft conned along the track by radar. However, to feed true craft motion into the radar it is necessary to know the track and speed made good, since the craft will make considerable leeway in a crosswind. A twin-aerial doppler radar system is at present being developed to measure the true speed along track and the drift angle which, combined with a gyromagnetic compass, will provide true track and speed.

In order to utilize the hovercraft's high speed safely in crowded coastal waters, the captain of the craft must be able to assess the collision risk with one of a large number of other vessels in the shortest possible time and to decide on the appropriate avoiding action. The problem is aggravaged because the effect of any maneuver on all the other vessels must be considered. Indeed it is almost impossible to devise rigid answers that will cope with the multiple encounter, but the captain must be given sufficient information to enable him to make the best decision in any given set of circumstances. The taking of visual compass bearings of an approaching vessel remains the most reliable, simple, and effective method of assessing a large percentage of collision risks, but it is severely limited in reduced visibility and High-Definition-Warning surface radar has to be used.

Experience, not only of hovercraft but also of fast patrol boats, indicates that the best available radar must be used with the largest aerial that the size of the craft will allow, since it is vital that small objects such as buoys and sailing boats should be detected with certainty, or the fast craft will not be able to use its speed in any but the best conditions of visibility. The radar screen should be as large as practicable, compass stabilized with a true motion facility, and the system should provide radar pictures or plots which show both relative and true motion.

These two presentations will give the captain a very good idea of the general situation, but there may also be a requirement to know the course and speed of another vessel and how close it will pass on present courses. These calculations are usually done by some form of hand plotting, but the process is too slow to cope with multiple encounters at high speed. Equipment is needed which will track an approaching contact for a short while and present the required information in visual form. The perfect solution would be to have all contacts automatically tracked and assessed, so that the captain, by interrogating the contact of his choice, could obtain immediately all the required information and a suggested solution to the problem if a collision risk exists. Unfortunately this is approaching the capability of an early-warning system and is unlikely to be available to ships for some time.

Rules and Regulations

The introduction of hovercraft has received tremendous publicity in England, and because of their revolutionary amphibious capabilities and high speed, they have come to be regarded as being unable to conform to any known rules. The fact is that over the sea hovercraft are no different from any other high-speed craft. However, the legislators are undecided how to exercise effective control, and opinions range from a reluctance to allow hovercraft any rights of way at all to a desire to have all the advantages of right of way that the existing collision regulations confer, without complying with any of the more tiresome rules about sound and visual signals.

It is our considered opinion that hovercraft must conform in all respects to the International Regulations for the Prevention of Collision at Sea. It is argued that a slow tramp steamer cannot keep out of the way of a 60-knot hovercraft that may be the "stand on" vessel, and of course she cannot. Studies carried out on a radar simulator show that it is virtually impossible for the slower vessel to take effective avoiding action in such cases. However, Article 21 requires that "when, from any cause, the latter vessel (stand on) finds herself so close that collision cannot be avoided by the action of the giving-way vessel alone, she also shall take such action as will best aid to advert collision."

Surprisingly enough we have not yet found a query of this nature that cannot be answered in the Rules of the Road. The rules are often criticized for being too broad in their directions, but it is just this flexibility that allows them to accept a new craft like the hovercraft in the same way as they have accepted the planing craft or the hydrofoil in the past. The Rules of the Road are widely understood and obeyed; it is the exceptions that are forgotten and that cause confusion at the vital moment of decision.

The high-speed craft, be it hovering, foiling, or planing, is with us now and should conform to the existing regulations. Since their numbers are growing rapidly, it is necessary to make very minor modifications to these regulations to recognize the fact that relative closing speeds are increasing. Rules such as Rule 21, which behooves the stand-on vessel to take action if the giving-way vessel is unable to avoid collision, will have to be employed far more often and not only as a last-minute emergency maneuver.

Military Applications

Turning now to the various applications that we envisage for military hovercraft, for the first time we are offered the prospect of ships of ocean-going size capable of speeds up to even 100 knots. What field of tactical possibilities this opens up!

The performance of the second-generation machines has so far followed the design predictions very closely, and it is becoming possible to extrapolate experimental results up to vessels of considerable size with confidence. With today's knowledge it is not unreasonable to contemplate a first operational vessel in the 3- to 400-ton range. Such a craft would approach the capability of a conventional frigate, with the additional ability to travel at extremely high speeds where operational necessity justified the expenditure in first cost, power, and fuel consumption. From the Naval point of view, it is of course in the anti-submarine role and in improving the mobility of conventional forces that this justification occurs.

Inevitably however, several years must elapse before all the financial and technical issues can be resolved and the construction of a new vessel begun. To maintain a satisfactory rate of progress, it is not possible to wait for the evaluation of the experimental craft to be completed before undertaking serious studies of the feasibility of constructing the operational craft that will one day follow them into service. Studies of this nature could produce most worthwhile results, but no work has been done in this direction so far.

The 90-Knot Frigate

Four basic requirements can be enumerated for an effective anti-submarine vessel:

1) It should be able to operate detection devices that are capable of making contact with a submarine at any depth.

2) It should have a speed advantage over the target in both the search and attack phases.

3) It should be able to lift a sufficient disposal load to enable attack weapons to be carried in addition to the detection devices.

4) It should have sufficient endurance to allow long search periods and to enable a contact to be held to the completion of the attack.

Consideration of existing systems in relation to these basic requirements will show that none can meet all the requirements specified. This can be achieved only by a surface vessel with so high a cruising speed that it could combine the capability of the frigate with the speed advantage of the helicopter. However, it is important to realize that to take its place in the fleet, the 90-knot frigate must spend a large proportion of its life in the displacement condition, and it must be capable of a range of at least 3000 naut miles at a speed of about 12 knots and of operating economically for long periods at a speed of about 25 knots.

In the displacement mode, the craft must strike an essentially difficult compromise between the circular shape required for efficient application of the air-cushion principle and the long narrow shape required for the achievement of even a modest cruising speed as a displacement vessel. One interesting attempt to solve the problem is the use of immersed side walls or catamarans to provide a physical curtain to contain the cushion along the sides of the craft, with transverse air curtains only fore and aft, so reducing the lift power required and making operation at 30 knots on the cushion an economical proposition. The length-to-beam ratio of the sidewalls can be very high, reducing their wave-making resistance to a minimum. The total power required must exceed that of the annular jet machine eventually due to the water resistance of the side walls, and this exchange is thought to occur above perhaps 40 to 50 knots.

Seakeeping

It is, however, the ability of the fast-surface vessel to maintain its high-speed capability in rough water and even to survive the storms that it must encounter which is of paramount importance. We are at the moment only on the fringe of understanding the seakeeping qualities of air cushion-vessels, and the natural desire to seek open water has to be tempered by considerations of the size of the craft, its intended role, and the complete lack of any previous experience in the seagoing operation of hovercraft in the world. In the event, therefore, explorations into the open sea have been of a very tentative nature, but we have made the 60-mile coastal passage from the Solent to H. M. Naval Base Portland and returned through seas measured to exceed 6 ft from trough to crest, and we have circumnavigated the Isle of Wight, a distance of 50 naut miles, at an average speed of 58 knots in a craft of only 20-ton displacement.

The most necessary adjunct to controlled experiments in seacrossing performance is the accurate assessment of the seastate existing at the time. Visual observation of waves produces notoriously inaccurate results, especially of wave height, and it was decided to measure sea conditions by the conventional method of recording the motion imposed by the sea on a light displacement instrumented buoy streamed from an attendant vessel.

The hovercraft is then driven over the waves on various headings in the area of the wave-measuring buoy. In a statistical analysis of a ship's behavior it is necessary to take samples of her motion over at least 100 wave encounters on any particular heading. This means that, under the conditions to be expected in local coastal waters, each heading has to be maintained over the order of 2 naut miles with runs on eight headings, to investigate all conditions of sea on the bow, beam, quarters, and stern. In order to avoid having to stop and start at the end of each run, it is our practice to operate the craft on a folded octagonal pattern centered on the seastate measuring buoy, in which the craft is turned through 135° at the end of each leg. To insure symmetry in windy conditions, this pattern has to be controlled on radar, which provides valuable command experience as a by-product. However, experience has shown that to arrange a reliable rendezvous between a 70-knot hovercraft and a 7-knot attendant vessel is almost impossible, and a free-floating wave-sampling buoy is being developed which will be launched and recovered from the hovercraft herself. Wave and weather conditions in the local training areas are also being recorded on a long-term routine basis, so that the utilization to be expected of a craft of known capability can be determined.

Early trials with the smaller experimental craft were limited to the Solent where the limited fetch and predominantly shallow waters produce extremely short but steep seas. The first impression given by a hovercraft is of a very smooth motion (free of the frequent slamming associated with the hard chine planing motor boat) and a sense of tenderness, particularly in roll. The amplitude of the craft's motion is not particularly great, but the period is unusually short, giving a sense of continual motion not normally experienced in a ship. Generally the craft were no more difficult to control in waves than over calm water, except that more frequent course corrections were required. The first experience of the open sea, however, showed just how misleading sheltered water operations could be. Heading into waves up to 6-ft high and 80 to 100 ft long in a 60-ft craft, waves of critical length were being encountered for the first time. The motion was severe, causing fatigue and loss of efficiency, the crew being subjected to frequent vertical accelerations such as are experienced in an aeroplane flying in bumpy air. The motion was in fact not dissimilar to that on the forecastle of a 150-ft Coastal Minesweeper butting into a force 6 breeze at about 12 knots, the hovercraft making rather more than twice this speed into a wind of force 4. The relative wavelength can of course be varied by going faster just as easily as it can by going more slowly, but if a wave system of greater than average length were then encountered unexpectedly, the conditions would again become critical and the subsequent impacts more severe than before. However, it is interesting to record that on one occasion in waves up to 7 ft from trough to crest, the motion was markedly easier at 35 knots than at 25.

Beam-on to the prevailing wave direction, the greatest care has to be exercised, since the craft would almost certainly be beam-on to the wind as well as to the sea and making leeway. Under these conditions the craft tends to slide down the waves and impacts occur on the lee beam, not on the windward beam as might be expected in the ship. These impacts can be very severe, as severe in fact as impacts on the bow because the drift angle may be considerable, the craft making a significant component of her speed sideways. These impacts, unsighted on the beam, are also much more disconcerting to the driver than those that he can anticipate on the bow.

Running down the sea, the relative wavelength is greatly increased and the craft rides up and down the waves in a most exhilarating manner, especially when it is realized, as one toboggans down the face of the wave, that the craft cannot broach to, since control is obtained from aerodynamic forces unaffected by the movement of the water in the waves.

Finally, it is not always realized that, floating on the surface without the cushion, the hovercraft becomes literally a raft, and that the structural loads involved are insignificant compared with those of the wave-impact case at high speed. It is encouraging that strain gage measurements taken during seakeeping trials showed that, even under the most severe conditions encountered, the loads imposed by wave impact never approached the capability of the structure. Indeed it was found that crew comfort, and not structural integrity, dictated the speed which could be achieved.

Amphibious and Overland Craft

If it is possible to contemplate the construction of the 90-knot frigate, it is of course equally easy to imagine amphibious assault hovercraft carried in a transport that is itself a hovercraft. Such a vessel would enable powerful forces complete with armored support to be carried from a politically stable base to an area of unrest at twice or even three times the speed of surface transport today, enormously increasing the flexibility of conventional forces.

The most immediate application of the amphibious quality of the hovercraft would seem to be in a logistic support role, since the assault craft, having to bear the weight penalty of armor, is likely to be too large to be carried at the davits or in the docks of the assault ships. It is fascinating to contemplate a craft of the modest size required to float its load in the displacement condition, which is capable of inflating extra side members of flexible fabric construction after leaving the mother ship. The craft could then lift off and skim ashore, only to deflate itself again for traveling along the roads on retractable wheels.

Army overland use of hovercraft has become a practical possibility only since the introduction of long flexible extensions. Trials so far have been confined to obstacle crossing tests and short excursions over mud, sand, shingle, and surf. It is not easy to find a suitable area for overland trials in so crowded a place as England, and therefore long-distance trials are planned in the Libyan desert.

Overland, comparisons between potential hovercraft and the equipment existing in the Army must of course be made. Trials have shown that the craft is quite indifferent to the composition of the flat surface, fears of its sticking to soft mud or digging a hole for itself in sand having proved quite groundless. The obstacle-crossing ability, whether boulder, wall, or ditch, depends entirely on structure clearance, and sufficient capability must be provided for the task the craft is to do. Compared with wheeled vehicles the craft is prodigal of power, but studies of comparative economics must be most carefully made to include all the pertinent factors. For example, in studying a 9-ton payload logistic support craft it was discovered that carrying 9 tons of stores across country required not three 3 tonners, but no less than 1 officer, 17 men, and nine vehicles. This convoy would consist of one scout vehicle, cook, repair wagons, and six three-tonners, with payloads reduced to $1\frac{1}{2}$ tons for soft going, compared with one hovercraft with a crew of 3 or 4.

The capabilities of the long-skirted hovercraft were, however, best demonstrated during crash/rescue trials for the Royal Air Force over the salt marshes surrounding the airfield at Thorney Island in Hampshire. These saltings consist of grassy hummocks rising out of the soft mud leaving channels and gullies 2 to 3-ft deep and 10 to 20 ft wide at low water. The mud in the channels and surrounding the saltings varies in texture, but nowhere exceeds a bearing capability of 2 psi. Terrain of this sort is commonplace in tidal estuaries and low-lying coastlines throughout the world, and has proved a formidable obstacle to special vehicles of many kinds. A hovercraft with a 3-ft obstacle-clearing capability was able to travel over these saltings at speeds up to 30 knots without difficulty, although a considerable drag force results from contact of the flexible extensions with the muddy banks and long grasses. These trials have resulted in a Staff Target being prepared for a specially designed hovercraft for airfield crash rescue purposes, which could find wide applications in both the military and civil fields. This craft is likely to be the first to see operational military service in perhaps two years time, because the performance required is within today's design capability and the craft will be small and relatively inexpensive.

Conclusion

Only five years have passed since a manned hovercraft first took to its cushion in England, and in that time these craft have emerged from the experimental stage to achieve serious consideration for a variety of both civil and military roles. The Services have been actively engaged in its development even before wide acceptance has been achieved in the civil field and at a time when they could have a real influence on the course of events.

History has shown the time-honored military resistance to innovation, based upon an attitude of mind that prefers accepting the replacement whose performance is predictable and well understood to facing the risks involved in developing a new principle. It was 19 years after the invention of the horseless carriage that the potential of the motor car in increased mobility was accepted by the Army. It took 9 years and the pressures of war for the contribution of the airplane to Naval strategy to be realized. The hovercraft principle offers unrivaled mobility over natural terrain and the prospect of an ocean-going ship capable of 100 knots. In the age of rapid technological advance in which we live, let us not again be reluctant to explore the tactical possibilities of such an exciting new concept.