JAMES CLAYTON LECTURE

Problems Encountered by the Royal Electrical and Mechanical Engineers in the Field

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INTRODUCTION

When I was afforded this opportunity of addressing the members of the Institution on the work of the Royal Electrical and Mechanical Engineers during the Second World War, there appeared to be two methods of approach to the subject.

First, one might describe the events leading to the formation of the Corps in 1942, its general organization and distribution in the various theatres of war, and the results which were achieved. Such a review, however, would inevitably contain much historical, organizational, and administrative matter of little personal interest to engineers.

Second, one might select certain definite engineering problems which were presented to the Corps, and describe the measures taken to overcome them. This, I think, would be of greater interest to members and this is, therefore, the line adopted.

The work of the Corps included the inspection, maintenance, modification (where necessary), and repair of all electrical and mechanical items of equipment in the Army—a very wide term which ranged, on the mechanical side, from 15-inch coast defence guns down to pedal-cycles.

I have selected problems affecting guns, armoured fighting vehicles, transport vehicles, and the passage through the sea (in amphibious operations), of all natures of equipment, to give you a picture of typical mechanical engineering problems which faced us from time to time.

Lest these sketches should convey the impression that design and production were seriously at fault, I must stress that equipments were designed and produced during the war years under compulsion of such speed of production that nothing like the recognized time was available for development of the perfect article, while the distribution of production and processes—sometimes even of design—between a number of independent firms and departments, whilst achieving the desired speed of production, opened the door to difficulties in inspection, in the working of tolerances, and so forth, which were almost bound, in a few instances, to react unfavourably on the performance of the earlier completed equipments.

GUN TROUBLES

(*1*) *The 6-pounder Gun.* My first subject is some teething troubles of the 6-pounder gun, which gave us all some worry in 1942. It is common knowledge now (made public in a Parliamentary White Paper in 1946) that in the see-saw struggle between tank and gun (with which can be included the tanks' own armament) this country, with its standard 2-pounder tank and anti-tank weapon, was behind the Axis in early 1942.

Great hopes were then centred on the 6-pounder, supplies of which, both as an artillery weapon and as a tank weapon, were beginning to make their appearance in the second half of 1942, some 140 having been shipped to the Middle East on the eve of El Alamein, and a larger number being in units or in reserve equipments at this time in the U.K. Base.

Our consternation may be imagined, therefore, when the discovery was made, in August 1942, that, owing to certain combinations of tolerances, the tank version of the gun, when used for sustained rapid fire in excess of 8 or 10 rounds, was liable to jam, due to expansion of the barrel within its cradle.

The Faults. This discovery led to a minute checking of all the assembly drawings and of the assemblies themselves, in the course of which—and as a result of "defect reports" from users—the following five defects came to light.

(*a*) The cradles (Fig. 1) constructed of manganese bronze, were liable to distortion from internal stresses *after* manufacture.

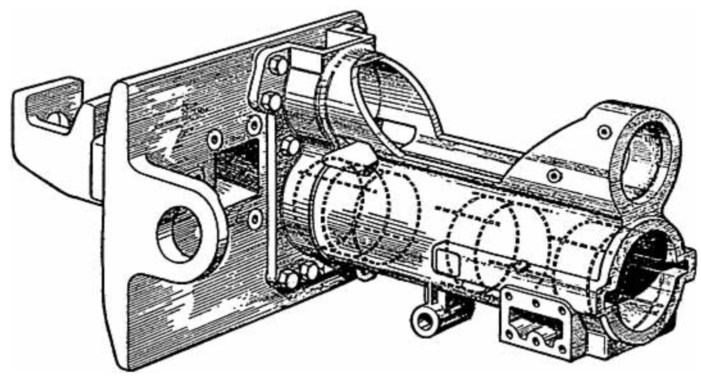

Fig. 1. Cradle for 6-pounder Tank Gun

This distortion affected the freedom of the barrel to run back after recoil and affected, too, the clearance of the piston in the recuperator cylinder.

(*b*) The tolerances of barrel and cradle, if all operating one way, could give a clearance when cold of only 0·005 inch. This was little enough when the gun was cold or only slightly warmed by deliberate firing, such as is normal on proof ranges. With the exercise of rapid fire the gun, especially the barrel, quickly heats up; and thirty or forty rounds (rapid fire), was found enough, in the cases of weapons with the least clearance permitted by the tolerances on barrel and cradle drawings, to absorb the clearances entirely and to cause the barrel to jam completely in the cradle. In this connexion, it must be remembered that the barrel, a steel structure, is subjected to considerably greater heat than its surrounding manganese bronze cradle.

(*c*) As a corollary of (*a*) (cradle distortion), the alignment of the recoil piston and rod in the buffer cylinder was thrown out. Fig. 2 shows the assembly of the recoil system. Here again, very fine clearances were laid down, and these could be as little as 0·001 inch between piston and cylinder. Consequently any misalignment or bad machining, and the least expansion of the piston "out of step" with expansion of the cylinder, led to a further jam. The minimum allowable clearance of 0·001 inch was, owing to the 50 per cent greater coefficient of expansion of the bronze piston as compared with the steel cylinders, wholly taken up by a 120 deg. C. (248 deg. F.) rise in temperature.

(*d*) The recoil spring of this gun was a close fit within its casing. The main troubles here were, first, the provision of too little clearance between the spring parting plate (the spring itself

The MS. of this lecture was received at the Institution on 5th May 1947.

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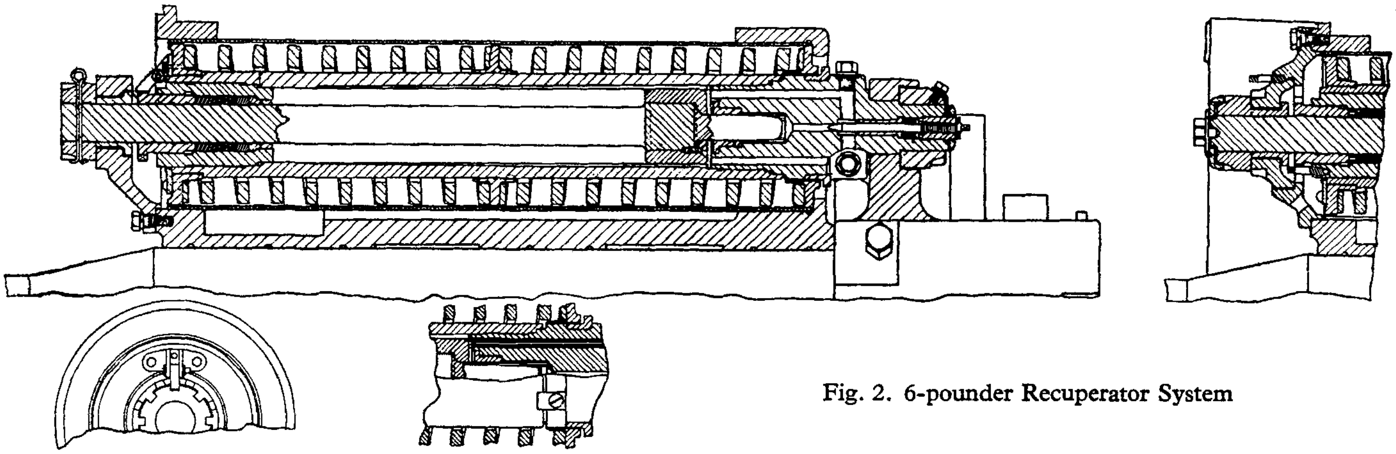

Fig. 2. 6-pounder Recuperator System

was in two portions separated by this plate) and the buffer cylinder, and second, bowing of the springs caused by the spring ends not being square. These faults also caused jamming.

(*e*) Finally, the "semi-automatic bracket" (Fig. 3) showed an alarming tendency to break. This bracket carries a cam against which a roller on the breech mechanism strikes on the run-out of the gun, thus causing automatic opening of the breech, extraction of the spent cartridge, and cocking of the firing pin.

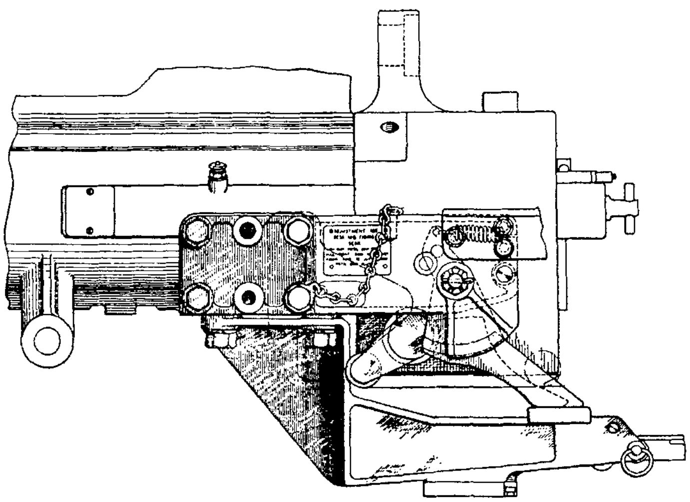

Fig. 3. Semi-automatic Gear (cast)

Displacement of the cam, with possible resultant failure of the automatic action—or, worse, the shattering of the bracket—were the possible results of this fault.

This was a formidable series of faults, all admittedly rectifiable, but time was short and, moreover, the troubles did not *all* come to light together.

An immediate conference of all concerned was summoned, attended by both Ministry of Supply and War Office representatives, and measures were concerted for checking every 6-pounder gun—those mounted in A.F.V.'s for all the above faults, those on field carriages for the recoil spring troubles only.

The Remedies: (*a*) To remedy distortion of the cradle, every gun had to be dismounted from its tank and checked with a special gauge made in numbers by the Ministry of Supply. Those found to be distorted were, if within reasonable limits, honed to give a minimum clearance of 0·007 inch between barrel and cradle.

(*b*) To ensure free run of the barrel in the cradle, every barrel and cradle was measured with a micrometer. Any with a clearance of less than 0·007 inch were brought to this clearance, either in the process of relieving the distortion of the cradle already referred to, or by scraping and smoothing the barrel, or (in the worst cases) by rejecting the barrel in favour of one made to lower external dimensions within the tolerances permitted by the drawing.

Fortunately, enough low-limit barrels were available to meet immediate needs in most cases. About 60 per cent were found to be defective, of which 20 per cent were beyond local adjustment.

(*c*) The buffer cylinders were checked at the same time for alignment, freedom of action for the pistons being given by relieving the gun lug. The clearance between piston and cylinder was increased to 0·002–0·004 inch.

(*d*) Recuperator springs had their ends ground square, while the internal surface of the hole in the parting plate was provided with a radius.

(*e*) The original semi-automatic brackets were incapable of satisfactory strengthening. A new bracket was produced by the Ministry of Supply, and the exchanges were carried out by the R.E.M.E.

As will have been gathered, the work required on each task was considerable, amounting to about 80 man-hours. The number of distorted cradles found was considerable, too, but most of them were so little out of alignment that they could be rectified.

The proportion of barrels which required exchanging was 20 per cent, while the bulk of recoil assemblies required rectification. All semi-automatic brackets had to be exchanged eventually, although an attempt was made to stiffen them by the fitting of a plate. *All* recoil springs, likewise, on both tank and artillery mountings had to be modified.

It is satisfactory to record that the work was done in time; and I only heard of one 6-pounder failure through faulty recoil in the early stages of the attack. This one jammed after two or three rounds only, so the trouble may not have been due to any dimensional faults. There may have been other cases; but they were so few and far between as to avoid anything in the nature of a serious epidemic.

The lessons, which the Ministry of Supply, as designers, and the R.E.M.E., as maintainers and modifiers, learned, were the vital need for closer link-up in the design of barrel, recuperator, and cradle; the value of the closest liaison between the Ministry and ourselves over the remedial measures to be taken; and the necessity for the instant response of the R.E.M.E. in the field to the totally unexpected instructions which I was constrained to send to them at a time when they were already strained to the limit in preparing for the two assaults in North Africa and the Middle East. We can count ourselves lucky that the "horror" came to light just in time to be rendered innocuous.

The 6-pounder gun, whether mounted in armour or as a field piece, was a success until outmoded by further improvements in tank and anti-tank artillery and, after this inauspicious start, never gave any serious trouble. That the confidence of the troops in the new weapon was not undermined at the start (a fatal and by no means unknown occurrence) was due to the very prompt and effective remedial measures taken. Few of those concerned in the first hastily summoned meeting in August 1942, or of those who took part in the campaign for rectification in time, will forget the urgency and hustle of those weeks.

(2) *The 5·5-inch Medium Howitzer.* Secondly, in connexion with guns, mention may be made of barrel troubles with the 5·5-inch medium howitzer.

The ammunition for these weapons was produced with several alternative charges; and it was, very reasonably, assumed that they would be largely employed at comparatively short ranges, using the lower charges and suffering a comparatively slow rate of barrel wear.

The practice of the Germans of holding defensive positions in very great depth, however, meant that our medium artillery, to neutralize the rearward enemy positions, had perforce to fire at extreme ranges; and the 5·5-inch howitzers were, therefore, very frequently employed in putting down heavy concentrations of fire at these extreme ranges, using, of course, the maximum charges of propellant and incurring the maximum wear. I mention this matter as one small illustration of the effects of tactics on weapon and equipment design and maintenance.

Complaints were received during the North African and Sicily campaigns that 5·5-inch howitzer barrels were developing bad oval wear and consequent scoring, with the result that their useful life was reduced to less than 50 per cent of that expected. Investigations were put in hand by the Ministry of Supply in this country and by the R.E.M.E. in Italy. The symptoms of the defect were as follows:—

(i) Oval wear developed at bottom centre ("down") at the start of the rifling after about 700 full-charge rounds.

(ii) Ovality developed to about 0·040 inch after 2,500 rounds, when scoring started at top centre ("up") and developed so rapidly that barrels were unserviceable at about 2,900 full-charge rounds.

The life of the bore of a gun is determined by several factors. The two effects of gas erosion, namely wear and scoring, are the most important. The term "wear" is used to denote a general and, usually, more or less even increase in internal diameter as firing proceeds. "Scoring" refers to more severe and localized erosion of the bore. In this instance scoring started opposite the area of maximum wear when ovality reached approximately 0·040 inch. As the weapons were being condemned for scoring long before the limit of wear was reached, it was thought that, if the ovality could be held below 0·040 inch, scoring would not develop and the gun would remain serviceable until the limit of wear was reached.

The 5·5-inch shell now weighs 80 lb., but at the time of these troubles it weighed 100 lb., which was somewhat heavy for this calibre, and it was thought that this weight was causing the initial wear. Experiments were, therefore, put in hand to rotate the barrels at intervals through various angles to equalize the wear.

The 5·5-inch howitzer is fitted with a loose barrel which is prevented from turning by two grub screws located half in the lip of the barrel and half in the jacket in which the barrel is carried, at top and bottom centres respectively (Fig. 4).

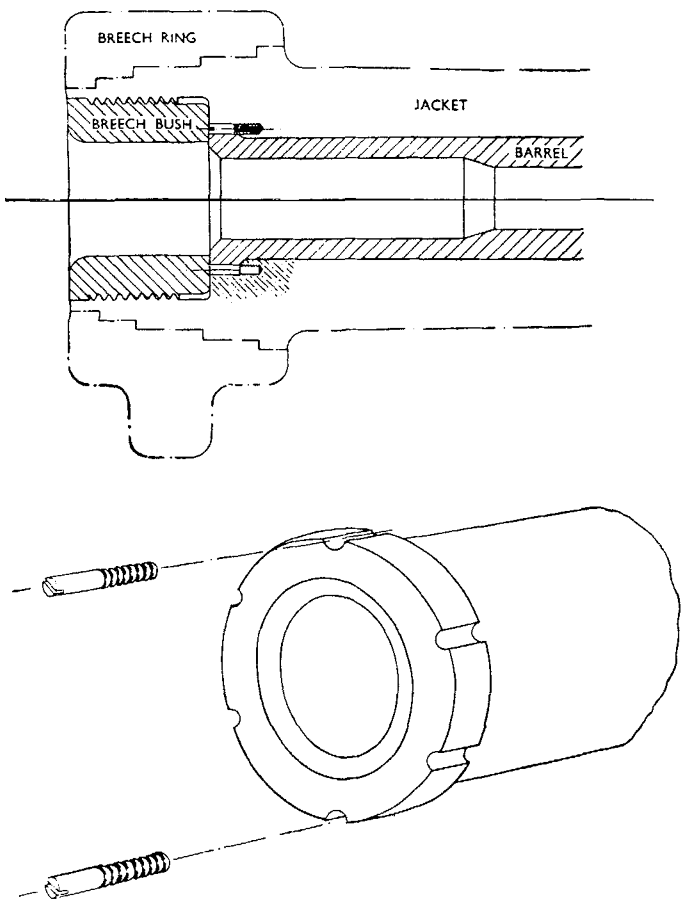

Fig. 4. Barrel of 5·5-inch Howitzer, showing Locating Screws

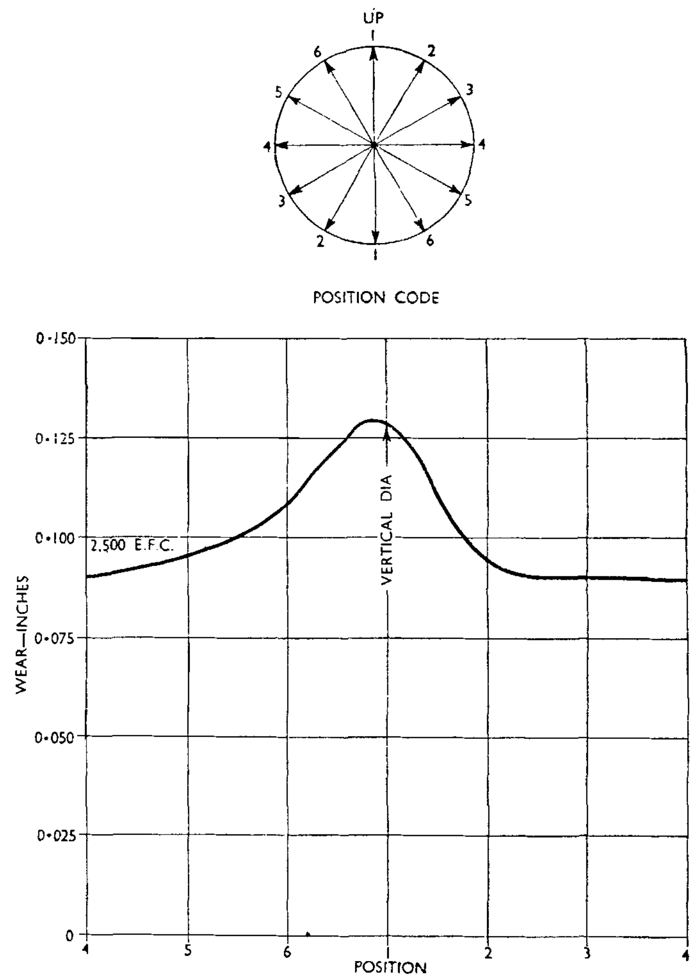

Fig. 5. Ovality of Barrel of 5·5-inch Howitzer at 2,500 Full-charge Rounds

In order to reduce the machining necessary, the rotation of the barrels in "steps" of 90 deg., as soon as ovality reached 0·010 inch, was tried. This only entailed cutting two extra slots for the locating screws, and was moderately successful.

Rotating the barrels through 120 deg. as soon as ovality reached 0·010 inch was tried next. This entailed cutting four extra slots, but was very successful; it almost completely prevented scoring, and increased barrel life to the full estimated duration of 6,000–7,000 full-charge rounds. To simplify the machining operations, R.E.M.E. workshops manufactured a suitable jig. Fig. 5 shows graphically the ovality of a barrel at 2,500 full-charge rounds without turning, when scoring started.

Figs. 6 and 7 show the effect of turning barrels at intervals of approximately 700 and 400 full-charge rounds respectively.

It will be appreciated that all these experiments were carried out in the field on guns which were in action and that the ex-

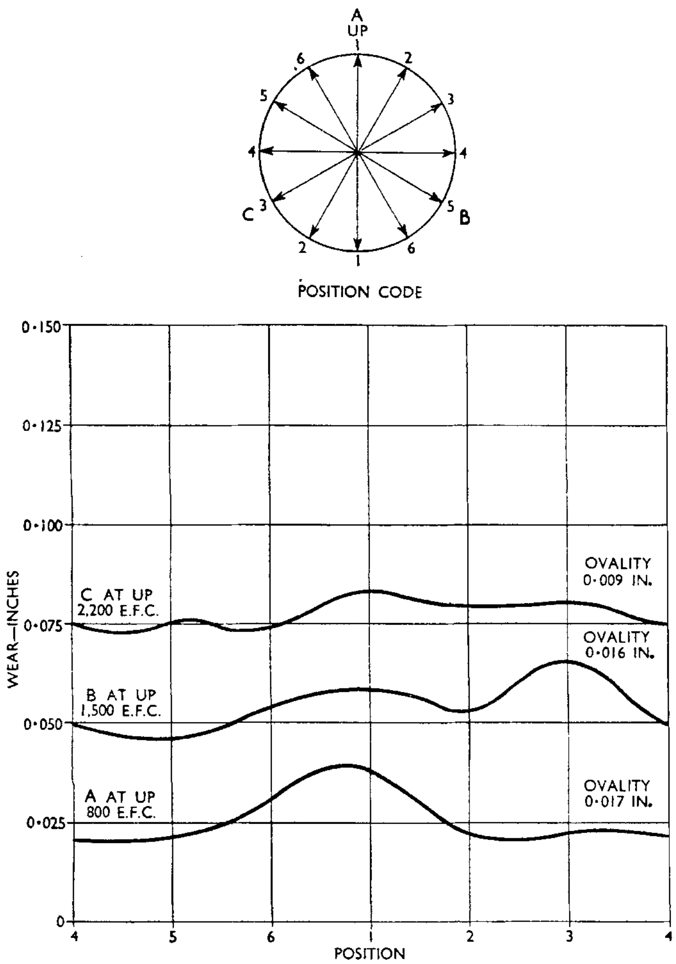

Fig. 6. Effect of Turning Barrels of 5·5-inch Howitzer, at 700 Full-charge Rounds

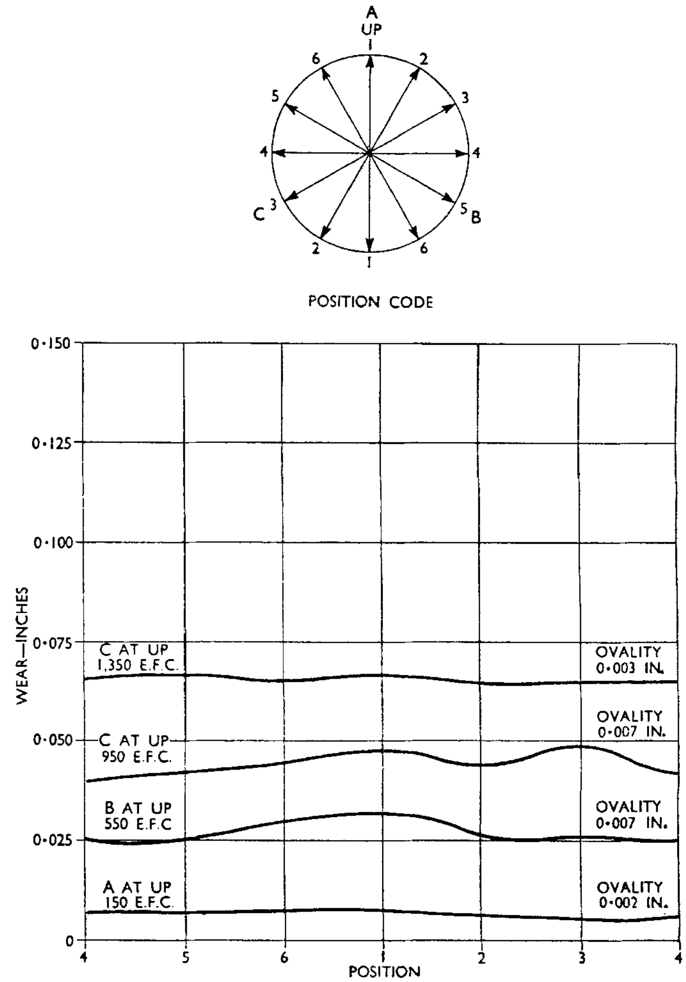

Fig. 7. Effect of Turning Barrels of 5·5-inch Howitzer, at 400 Full-charge Rounds

periments had, therefore, to be carried out as and when conditions permitted.

RECOVERY OF ARMOUR

Two of the eight principles of war laid down in the "good books" of the soldier are the inculcation of the offensive spirit and the concentration of forces to give that spirit free rein and a fair chance.

The commonest cause of the petering out of an offensive is the failure of the attacker, through lack of resources, through restriction of communications and through difficulties of maintenance, to replace casualties in men and material, either by bringing in fresh men and machines or by "repairing" men and machines on the spot.

Dealing with the equipment side only, the equipments most vulnerable to both mechanical and battle damage are tanks. In the 1914–18 war, our tank losses in each major action averaged about 50 per cent, so that, with a limited stock and a limited output of new tanks, we were able to put fewer and fewer tanks into battle in each succeeding attack from August 1918 onwards. Fortunately, the enemy's resources and will to win were diminishing with equal or greater rapidity (partly due to these same tank attacks) and we were not called upon to pay in full for this "law of diminishing returns".

In the Second World War the Germans, with their standardized equipment and their more lavish scales of repair personnel and material, started well ahead of us in the mechanical maintenance line, and with growing experience they reached, eventually, the very high standard of forward recovery and repair displayed by the Afrika Korps, where disabled tanks were snatched out of the battle line itself, repaired in the vicinity and returned to the fight within hours.

The creation of the R.E.M.E. afforded opportunity for the reorganization of *our* maintenance services on new lines, which featured (*a*) strengthening the forward repair echelons at the expense of those farther back, and (*b*) as time and opportunity offered, increasing and improving the equipment at the disposal of these forward echelons.

In the early campaigns in the Middle East we lost out of the battle line, through enemy action and mechanical breakdown, over 80 per cent of the tanks which became casualties, i.e. less than 20 per cent were repaired and returned to their regiments within a few hours, while over 80 per cent were evacuated to the base for repairs. As this evacuation had to be made along a most congested line of communications, hundreds of miles in length, the system was impossibly slow.

With some slight improvements in technique and in recovery vehicles, the proportion rose by mid-1942 to between 40 and 50 per cent repaired forward; but this was not enough.

When the El Alamein campaign was staged, the R.E.M.E. had just been formed; new establishments in men and equipment had been drawn up but, particularly as regards the latter, these establishments had not yet been filled.

Our basic recovery vehicles then were 3-ton breakdown lorries (Fig. 8, Plate 1), useless in sandy or rough terrain; six-wheeled four-wheel-drive tractors (Fig. 9, Plate 1), excellent in all but the softest sand; "D.8" tractors (Fig. 10, Plate 1) carried on wheeled trailers behind "White Diamond T" six-wheeled four-wheel-drive tractors. For the carriage of immobilized tanks we had a few articulated transporters (Fig. 11, Plate 2) and a greater number of "Diamond T" tractors and Crane or other trailers (Fig. 12, Plate 2).

None of these machines was ideal but, combined, they put up a most creditable performance at the cost of much man-power, time, and improvisation. But the numbers!—our calculated requirement in six-wheeled tractors alone was over 230. We had 29. On the eve of the battle a number of such vehicles in reserve were "persuaded" out of the vehicle depots of our friends the R.A.O.C. and swelled our numbers to a little more than twice the original. For the rest, we had to rely on our own ingenuity and hard work, our new principles of maintenance, and on the generous support, whenever possible, of the R.A.S.C. Tank Transporter Companies—whose real work was the carriage of live tanks into action, not the removal of the dead.

Nevertheless, through improved technique and some slight increase in equipment but, most of all, through the redeployment *forward* of much of our resources, the proportion of casualty tanks restored to their regiments in a matter of hours (without evacuation down the lines of communication) rose sharply to 83 per cent and never, in any theatre of war, did it subsequently fall appreciably below this figure, whatever the conditions.

We were not satisfied, however, with the wheeled and tracked recovery vehicles at our disposal, especially with the opening of the European Front or Fronts in mind, and since February 1942 a study had been made of the possibilities of adapting a fighting tank hull to recovery purposes.

By mid-1942 a prototype Churchill A.R.V. (armoured recovery vehicle) had been produced (Fig. 13, Plate 2). In this machine the turret was removed and a flat hinged lid was substituted. A jib, drawbars, flame-cutting equipment, and a certain amount of fitters' gear was carried, together with "spuds", holdfasts, tow ropes, and snatch blocks. There was, however, no winch and no heavy-lift jib—that provided being capable of a 3-ton lift only. The reasons for these omissions were the lack of manufacturing capacity and also the lack of time.

A number of these A.R.V.'s were produced in time to accompany the expedition to North Africa in 1942, where they earned golden opinions but where the need for a powerful winch and for a heavy-lift crane were demonstrated.

A little later, in Italy, the British Army were fortunate to get a few American "T.2's", recovery tanks on Grant hulls with a mechanically operated winch and a high-lift jib (Fig. 14, Plate 2). These proved invaluable for recovery work in mountainous terrain where it was frequently impossible to get a straight pull and a clear run for the recovery vehicle.

So strongly did the commander in this theatre feel about the necessity for a winch and jib-carrying recovery vehicle that he tabled an insistent demand for American "T.2" tracked recovery vehicles and another type of wheeled recovery vehicle. Neither of these, unfortunately, was forthcoming in any numbers.

The wheeled recovery vehicle (Fig. 15, Plate 3) was a very fine six-wheeled four-wheel-drive type, resembling existing makes then in use, but with a larger-capacity engine, a more powerful winch, and a greater capacity luffing jib-crane.

Very limited numbers of both were secured for our forces both in the Central Mediterranean Forces and, later, in North West Europe; and they gave excellent service.

Meanwhile, we had been pushing on with the idea of the jibbed and winched A.R.V. and, eventually, after many vicissitudes and an intensive search for production capacity in the United Kingdom, we produced, for issue in 1944, the A.R.V. Mark II in its Churchill form (Fig. 16, Plate 3) and in its Sherman form (Fig. 17, Plate 3).

The salient features of these machines were their winch drive, giving a pull on the rope of up to 60 tons, their armoured accommodation for the winch operator in a dummy turret, their dummy gun and their powerful 9½-ton lift fixed jib at the rear end, backed up by a 3½-ton detachable high-lift jib at the front. Finally, to enable the rear jib or the winch to exert the necessary lift or pull, a substantial earth anchor was fitted at the rear, of a simple, robust, and quick-acting type.

The amphibious development of this machine—the "Beach A.R.V." (B.A.R.V.)—will be dealt with later when I describe some problems in connexion with amphibious operations.

A particular feature of the design and production of these A.R.V.'s and B.A.R.V.'s was that, owing to the absorption of all Ministry of Supply design and production capacity on existing programmes of work, the entire design and production of A.R.V.'s and B.A.R.V.'s was carried out by the R.E.M.E., using R.E.M.E. workshops and two small civilian establishments (Hayes Plant and the L.P.T.B. Railway Workshops, Fulham) made over to us by the Ministry of Supply. The winches and drives were produced for us by Messrs. Crofts, who gave us splendid assistance and service.

The whole of the research, design, and production of prototypes was carried out at the R.E.M.E. Experimental Recovery Section and Experimental Beach Recovery Section, at Arborfield and Budleigh Salterton respectively.

We claim that the A.R.V. Mark II was ahead of any other country's equipment of similar type, comparative trials having been made with equivalent American and German equipment, the former yielding to the A.R.V. in the matter of maximum winch pull, thickness of turret armour, and earth anchor capacity, and the best of the latter (developed on "Tiger" or "Panther" hulls) wholly lacking armoured protection for the crews and having an earth anchor which, though good, was inferior to our own.

TRANSPORT VEHICLES

During the early part of 1942, chassis failures were experienced in the Middle East, on sandy terrain, on certain 3-ton transport vehicles.

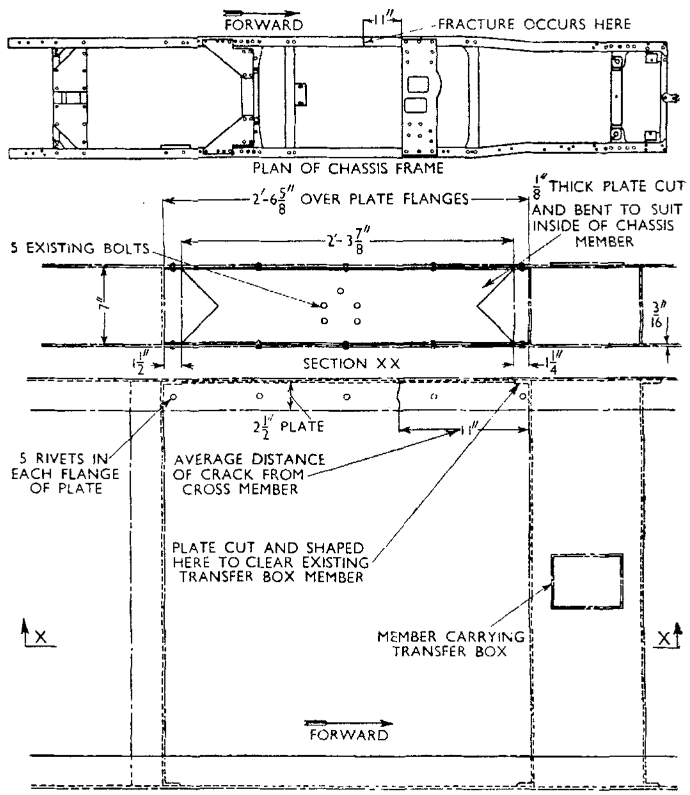

Fig. 18. Repairs carried out in Middle East to Chassis of 3-ton Transport Vehicle

The failure consisted of a chassis frame fracture across the top flange, approximately 11 inches to the rear of the transfer-box cross-chassis supporting member; and was attributed by the manufacturers' representatives in the Middle East to the severe conditions which caused body holding-down bolts to work loose, resulting in excessive strain on the chassis members. Prompt action was essential, and a Middle East local instruction was issued to effect a repair by inserting flitch plates, approximately 2 ft. 6 in. long inside the chassis-frame members (Fig. 18); portions of old chassis frames were used, wherever possible, and any existing holes in the web of the chassis were also utilized. The flitch-plates were relieved at each end by an arrow-head shaped "cut-away" in the web to avoid any abrupt change of section.

The modification was a complete success and, the matter having been taken up through the Ministry of Supply with the makers, chassis members of future vehicles produced in North America were reinforced during manufacture.

At the time of the failure referred to above, there were many thousands of vehicles of the types affected in the Middle East. The time to repair both side members of a vehicle was about six man-hours.

WADING

My next theme concerns the preparation of the mass of equipment planned to land on the Normandy coast on "D-Day" and subsequent days without the benefit of any dock facilities, piers, or landing stages.

The problem was fantastic. Most of our transport vehicles would wade up to 1 ft. 6 in., and our fighting vehicles up to 3 ft. in calm water at slow speeds. We had now to cater for entry into water of very much greater depth, down a ramp inclined at about 20 deg. to the sea bottom, and to make our way ashore through a moderate surge (1 ft. 6 in. waves were stipulated) as fast as we could, in the face of a lively defence and subject to moving both parallel to, and across, the path of the waves.

We had to be prepared for immersion for one-half to three-quarters of a mile, and in the case of certain special equipments for periods up to 45 minutes or more continuous immersion.

There were four main types of equipment to consider:—

(*a*) Armaments.
(*b*) Armoured fighting vehicles.
(*c*) Transport vehicles.
(*d*) Miscellaneous equipment, such as radar sets, signal vehicles, and trailers, etc.

(*a*) *Armaments.* Armaments were simple, the requirement being to prevent the ingress of water to the barrels, to protect the breech mechanism and traversing gear from damage by sand and water, and to ensure that the towing attachment did not foul the junction between ramp and landing craft, with its contained angle of 160 deg.

These objects were achieved by the simple process of plugging the gun muzzle; protecting the breech mechanism and traversing gear by a liberal application of grease (and in some cases by the addition of an outer covering of balloon fabric); and by altering the position of towing hooks on prime movers to ensure clearance of the ramp joint.

Nevertheless, every type of equipment had to be tried out; the method had to be approved and written up; instructions understandable by the troops had to be produced, printed, and issued; and the stores requirement had to be worked out and passed to the War Office provision branch concerned. All this was the responsibility of the R.E.M.E.

(*b*) *Armoured Fighting Vehicles.* The design and production of the wading equipment and the necessary modifications for each type of armoured fighting vehicle (A.F.V.) was the responsibility of the Director of Tank Design, Ministry of Supply.

When his design was complete for any one type, a "one-off" trial was run at a Ministry "wading trial centre" at which representatives of the manufacturer and of the Director of Tank Design, as well as the War Office General Staff and the Director of Mechanical Engineering were present. If satisfactory, enough equipment was then produced for a "large-scale trial" in which a sub-unit (such as a troop, squadron, or company of anything up to twelve or sixteen vehicles, driven and waterproofed by their own crews) was put over the side. Any weak points or (very important) impractical points when it came to application of the scheme by troops were eradicated, and trials were continued until the scheme was perfect and was accepted by the General Staff.

Writing of instruction books, profusely illustrated, and the provision of the bulk supply of stores for all vehicles of that particular type, was then put in hand.

The actual waterproofing consisted of: the provision of external fittings, such as air chutes, exhaust chutes and the protective covering of armament, by the Director of Tank Design and the Provision Branches; the fitting of angles, brackets, etc., to take these fittings (known by the generic term of "weldware") by the R.E.M.E.; and finally, the actual waterproofing by a proprietary sealing compound or asbestos compound of such components and of rivet and bolt heads, welding seams, apertures and joints for armaments or equipment such as periscopes, etc., which was the duty of unit crews.

The bringing together of the equipment and the vehicles was a task of no mean order; for the fittings for a tank were of such bulk that only three sets could go into one 3-ton lorry, and a special transport service had to be provided just before "D-Day" to deal with this requirement.

Tanks and self-propelled artillery, being of the nature of closed vessels themselves, gave less trouble in detailed preparation, by their crews, for wading than did transport vehicles, but meticulous care in sealing all rivets, bolts, and welded seams was always necessary. The welded seam rather surprised us, for few of the perfectly sound, shot-proof, and well-executed seams proved to be actually *waterproof*. Fig. 19, Plate 3, shows an A.R.V. Mark II leaving the ramp.

The removal of the external chutes, which were a hindrance to the tank's tactical role once ashore, was carried out by automatic means and fabrics, enveloping guns, instruments, air inlet louvres and turret rings, were blown off by explosive operated by the driver. Figs. 20–23, Plate 4, show the process.

Having in view the likely need for fresh waterproofing after the beaches had been secured and passed (possibly, for example, in the crossing of the Seine) we caused stringent instructions to be issued for the collection and storage, on the beaches, of jettisoned gear. It was collected well enough, but was then used to form numberless dug-outs, bivouacs, and foxholes, the gear being intermixed with piles of shingle, sand, and turf; and most of it was quite unserviceable when extracted from these edifices. No amount of orders from above can remove the urge to build oneself a shelter when hot metal is flying about in the open!

Amongst the A.F.V.'s, the armoured and scout cars (owing to the design of their hulls) and the carriers (owing to their tendency to float) gave us considerable trouble.

Fig. 24, Plate 5, shows a scout car wading, and Figs. 25 and 26, Plate 5, a carrier. The latter had its sides artificially increased in height by panels secured to brackets welded on to the original structure. Fig. 27, Plate 5, shows an armoured car wading.

A difficulty encountered with certain carriers was the failure of the steering brakes due to the effect of sea water. When these little machines were towing 6-pounder guns in the water, the brakes failed to grip sufficiently to guide both carrier and 6-pounder; the driver had to move straight ahead in whatever direction he found himself pointing on leaving the ramp, and this was by no means always in a straight shoreward direction.

Eventually, by grooving the brake linings, we got enough control to make the project practicable; but it entailed the provision of special liners for every towing carrier. Later, in time for amphibious operations in South East Asia, a special insert for the linings was produced by a British firm and approved by the Ministry of Supply. These then had to be fitted by the R.E.M.E.

To give an idea of the amount of stores required to waterproof a tank, Fig. 28, Plate 6, shows a Churchill tank with its wading kit laid out but not fitted.

(*c*) *Transport Vehicles.* These were the most numerous class of equipment to be waterproofed, and the most difficult.

Initially, the Ministry of Supply worked out, with manufacturers, a number of methods suited individually to each make. These were tried in fresh and salt water, approved, and scheduled for use. Large numbers of vehicles were then waterproofed under Ministry of Supply arrangements at a depot at Treforest, and were stored for some months prior to March 1943.

Then two difficulties arose: first, the methods of waterproofing were sound in themselves, but were not suitable for application by comparatively untrained troops; second, a test wade of a number of these vehicles showed that the materials deteriorated in storage and none of them waded successfully.

About this time the responsibility for waterproofing of equipments passed to the Director of Mechanical Engineering at the War Office, and we set ourselves the task of producing, for transport vehicles, a scheme which would be simple of application, as universal as possible in its application to the wide range of vehicle types to be covered, and as durable as possible in its results.

A special Deputy Directorate at the War Office was formed under the control of Brigadier H. R. Howard, C.B.E., M.I.Mech.E., whose name should be marked well, for the co-ordination of the waterproofing schemes, instructions, and trials for all equipment was in his hands, and the actual preparation of the schemes for everything except A.F.V.'s was also his. That he was the right man in the job was proved by results.

I must turn back to the methods evolved by the Ministry of Supply, which came to be known as "the manufacturers' methods". When these were finalized, the materials available were limited. Such parts as electrical fittings (plugs, distributors, etc.) were sealed with a compound known as "pressure plastic", a red wax which hardened on application and produced a very fine gastight and watertight joint. It was rather difficult to apply, being stiff, and great care was required to ensure that the surfaces were clean and free from oil and grease before application.

Air and breather intakes and apertures were fitted with pipes which were led up to a height safely in excess of the wading depth, which at this time was laid down as 3 feet plus 1 ft. 6 in. waves. Exhaust outlets were similarly unswept. The dynamo and starter motor, if not wholly enclosed, were protected by special sealing or by being placed bodily in a bag of waterproof material.

The drawbacks to all these measures were that the pressure plastic sealing compound hardened and lifted with long storage; its application was difficult and required great patience on the part of the operator; the bags were difficult to fit and their final watertightness was difficult to achieve; and the exhaust uptakes were bulky and extravagant in material, and were found, eventually, to be unnecessary.

A compound was produced by one of the petroleum companies in 1943 which offered considerable resistance to the passage of electricity, was comparatively soft and easy to apply, and was obtainable in large quantities. This was known as "asbestos compound", and was a compound of finely flaked asbestos and a low-melting-point grease of more than average purity. It was not safe to rely on this stuff for parts where considerable heat and possible pressure from leaking gases might be met. Here the "pressure plastic" remained supreme until another more easily worked material known as "Gripon" became available. This was a white compound and had the two very desirable characteristics of being easy to work and having excellent dielectric properties under varying temperatures.

Eventually these two superseded all compounds previously employed for producing the electrical insulation of coils, starter motors and dashboard wiring and instruments; and when the depth to be waded was raised steeply in two successive steps by the General Staff between August 1943 and June 1944, these two compounds enabled us to face the increased depth with comparative equanimity.

Stages in waterproofing a motor vehicle ignition coil and distributor are shown in Fig. 29, Plate 6.

For the dynamos, it was found, after much trial that the most effective method was also the simplest, namely, to spray the interior with ordinary engine oil, remove all brush covers and protecting plates, and let the dynamo take a salt-water bath.

The exhaust outlet gave us another pleasant surprise. We found that the universal bogey of the motorist in the water splash, namely the possibility of water entering his engine through the exhaust pipe if the engine were allowed to stall, was a myth. This was conclusively proved by stalling the engines of several types of vehicles in an experimental water tank and allowing the engines to cool and stay submerged above the exhaust outlet level for anything up to 45 minutes. In no case was there ingress of water via the exhaust system, though in some cases there was evidence of water in crankcases, due to normal seepage, aggravated no doubt by the drop of pressure within the crankcases. We therefore abandoned all exhaust pipe extensions and saved much time, labour, and material thereby.

The process by which "perfection" was reached with the waterproofing of transport vehicles was the same as that recorded in the case of A.F.V.'s—"one-off" trials until a project was proved satisfactory; then large-scale trials; next the writing of the instruction books or cards; then the ordering of the stores; and, eventually, the actual waterproofing of the vehicles.

This last process was carried out as near to "D-Day" as time and labour permitted. It should preferably have been done within six weeks of the operation, but we had to fit many vehicles earlier. This covered the first stage, and ensured the proofing of the ignition system, the fitting of extensions to air inlets, breathers, etc.

The second stage, carried out by crews a few miles from the point of embarkation, consisted of the preparation of batteries and headlamps, filling and sealing fuel tanks and oil dip-sticks, and a "check" inspection of the first stage.

Finally, at the embarkation point, the distributor was fully sealed (if done earlier, condensation takes place and failure occurs within); the waterproof sheet was fitted over the radiator and under the front of the engine, not to keep out water but to damp down surge under the bonnet; and a last-minute check was made.

The stages in waterproofing are shown in Tables 1–3.

Certain vehicles present special difficulties in waterproofing; in one the distributor is tucked away low and close to the radiator, the radiator having to be removed bodily to waterproof this item. In others the dashboard presents special difficulties, while yet in others the size of the vehicle is such that the height of the driver's mouth above water is the governing factor.

In all of them the driver gets a sudden cold bath, at least up

TABLE 1. STAGES OF WATERPROOFING—"A" VEHICLES (HEAVY) (OVER 12½ TONS)

Type of vehicles	Stage	Description	Maximum subsequent distance	Time taken	Where done	By whom
"A" vehicles (heavy)	Preliminary work	Fitting weldware	No restriction	—	By R.E.M.E. or manufacturers before issue.	
Tanks and SP's for all formations	Before embarkation 1.	Maintenance and inspection. Sealing hull, turret, etc., fitting hardware, cowls, etc., greasing internal parts, and testing in fresh water pit, etc.	100 miles	70–84 daylight working hours	Concentration area	Crews, fitters, and electricians.
	Before embarkation 2.	Final adjustments, fitting extensions to air intake and exhaust, etc.	20 miles	6–8 hours	Marshalling area	Crews, and for some vehicles, fitters, and electricians.
	During voyage 3.	General attention to details (vide Wading Instruction Book)	—	—	On craft	Crews.
	After landing 4, 5, and 6.	Removal of waterproofing	*Externals* blown off—as tactical situation demands. *Internals* removed—beach transit area or where possible. (Does not affect performance)			

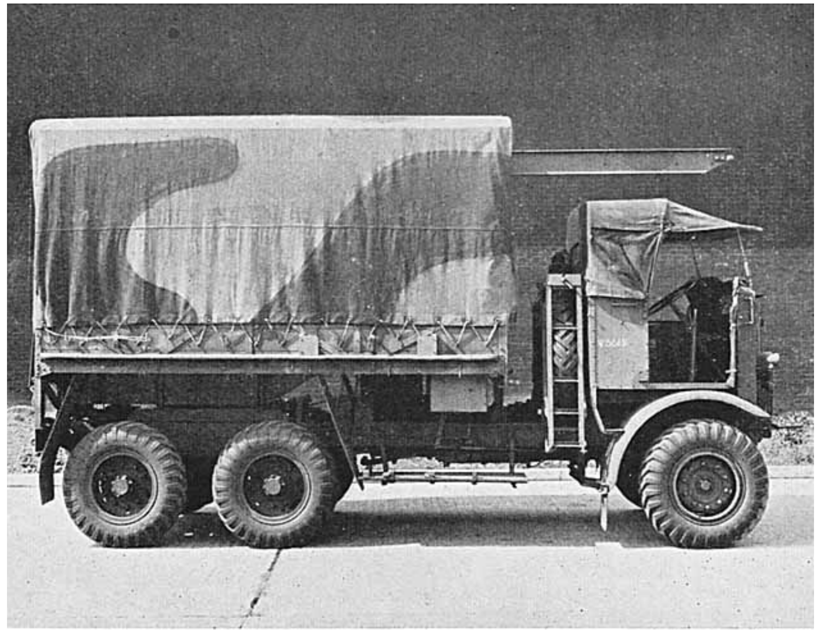

Fig. 8. 3-ton Breakdown Lorry

Fig. 9. 6-wheeled Tractor with 4-wheel Drive

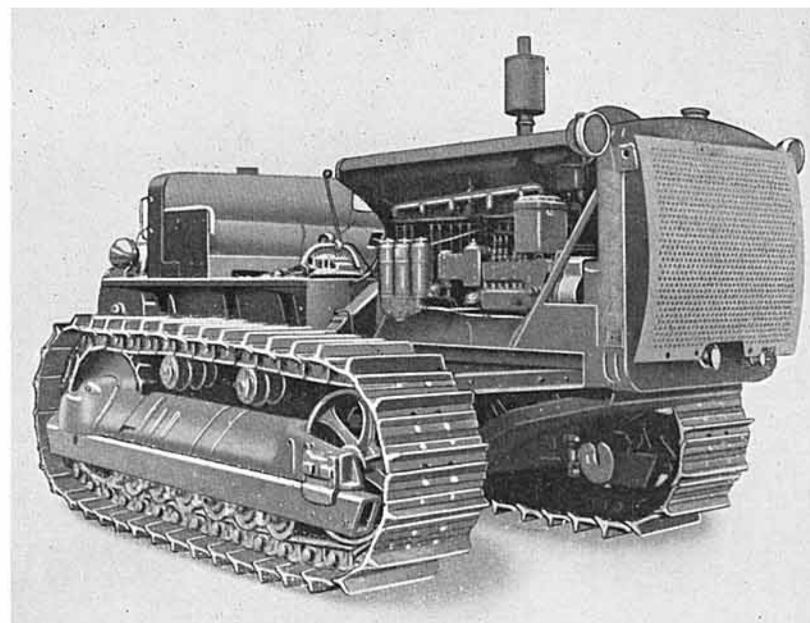

Fig. 10. "D.8" Tractor for Recovery of Armoured Vehicles

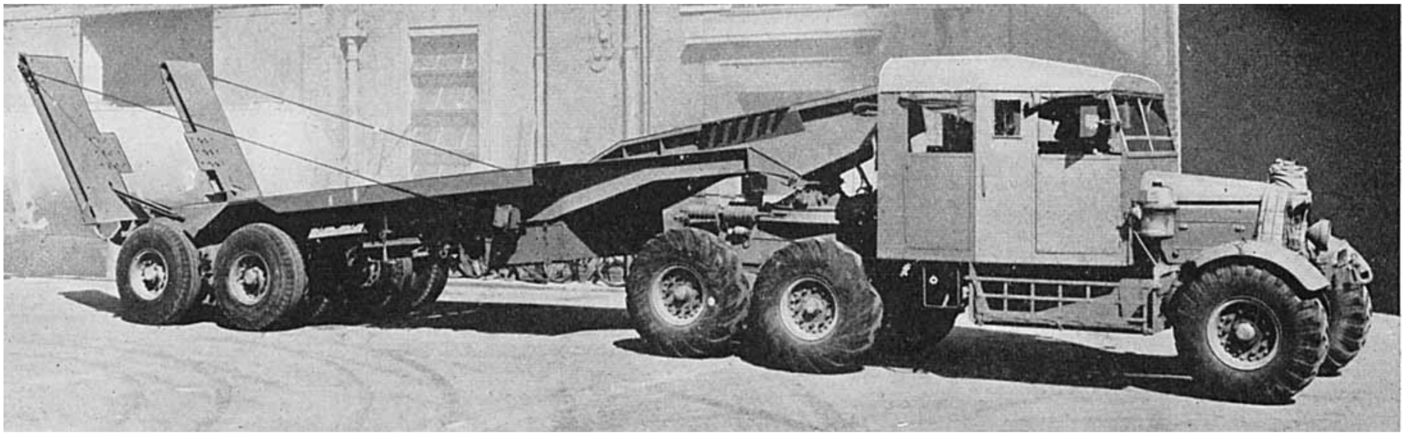

Fig. 11. Articulated Tank Transporter

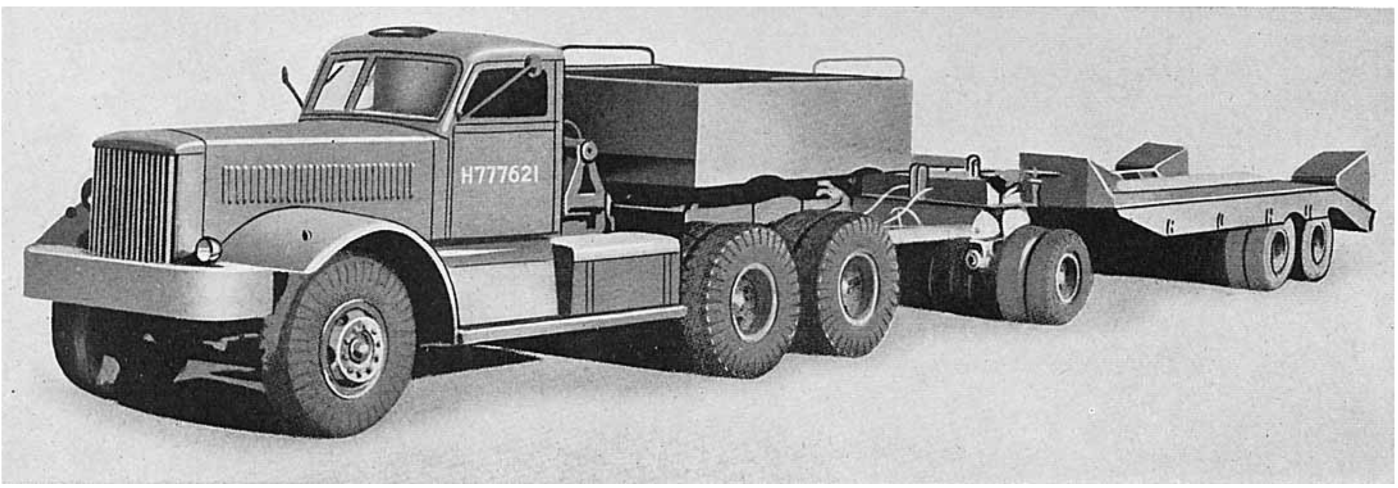

Fig. 12. Diamond "T" Tractor and Tank Transporter Trailer

Fig. 13. Churchill Armoured Recovery Vehicle ("A.R.V."), Mark I

Fig. 14. American "T.2" Recovery Tank

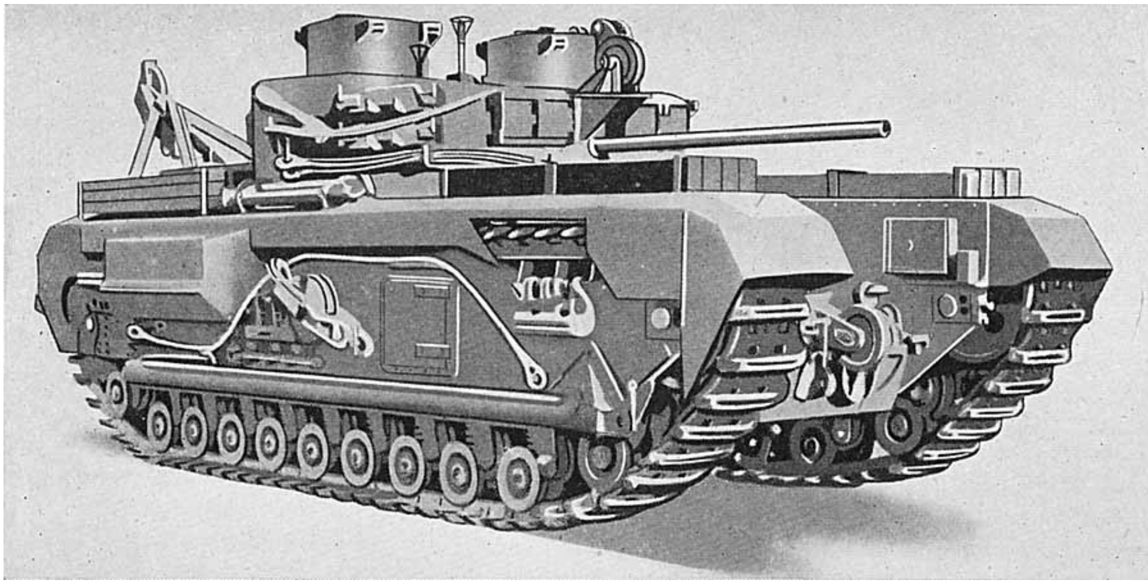

Fig. 16. Three-quarter Front View of Churchill A.R.V., Mark II

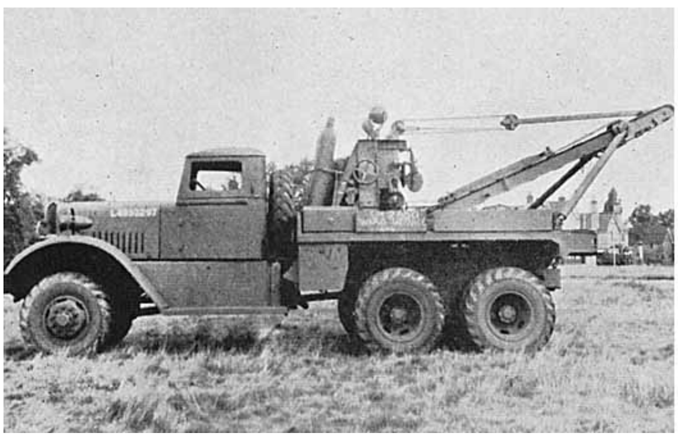

Fig. 15. Another Type of Recovery Vehicle

Fig. 17. Sherman A.R.V., Mark II

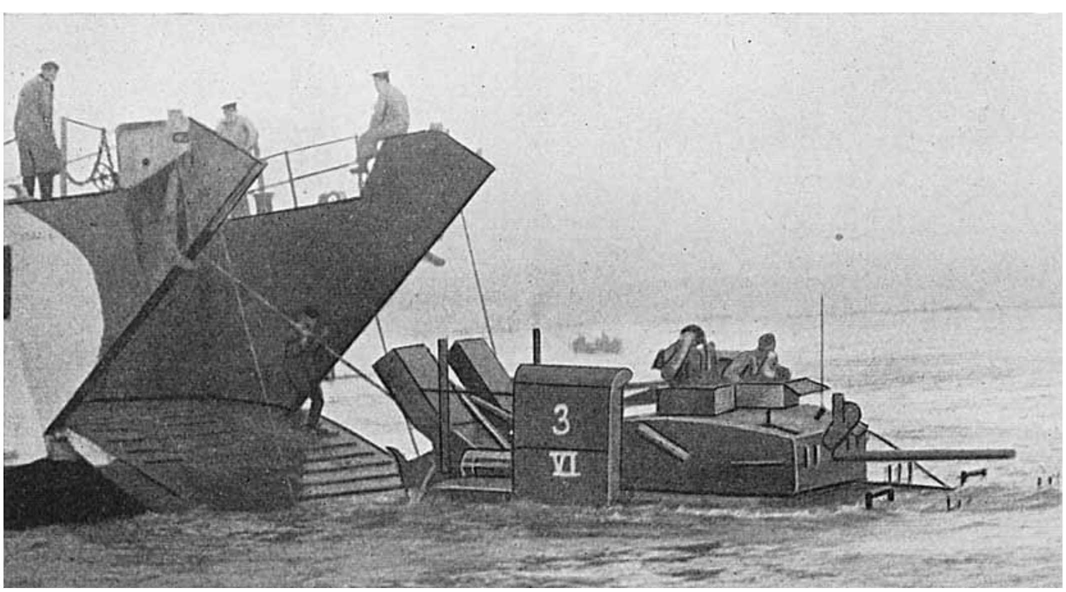

Fig. 19. Churchill A.R.V. Mark II Leaving Ramp

Fig. 20. A.F.V. Wading with Waterproofing Equipment

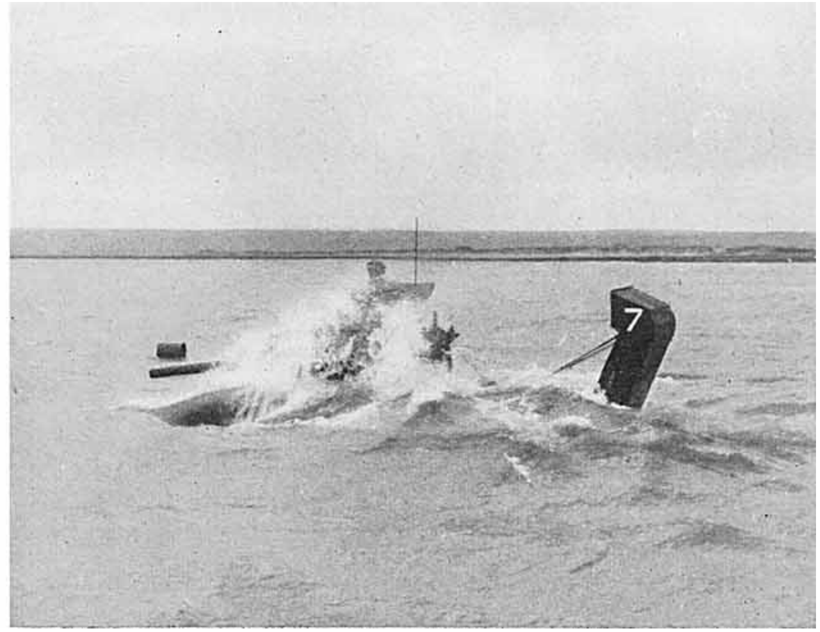

Fig. 21. Waterproofed A.F.V. nearing Shore

Fig. 22. A.F.V. just landed, prior to discarding Waterproofing Equipment

Fig. 23. Waterproofing Equipment blown off by Explosive

Fig. 24. Scout Car Wading

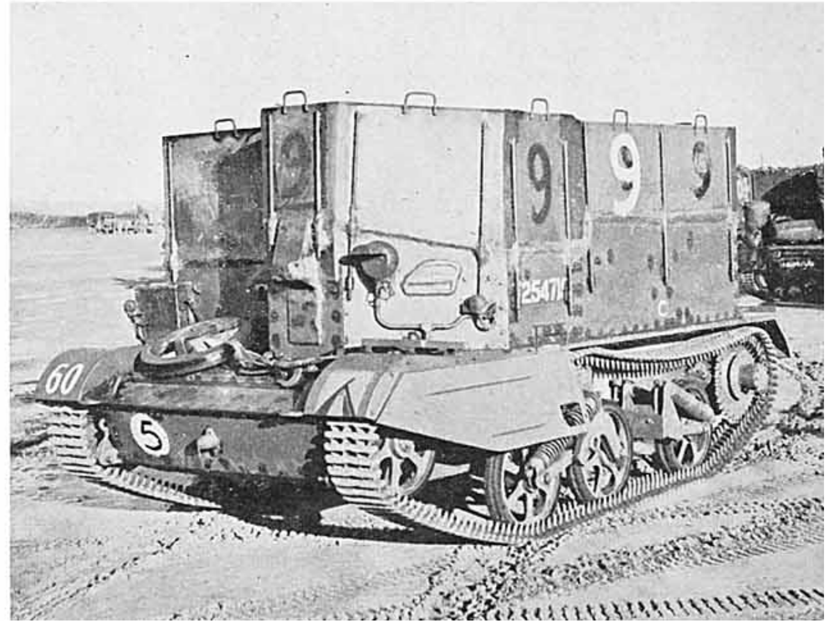

Fig. 25. Universal Carrier

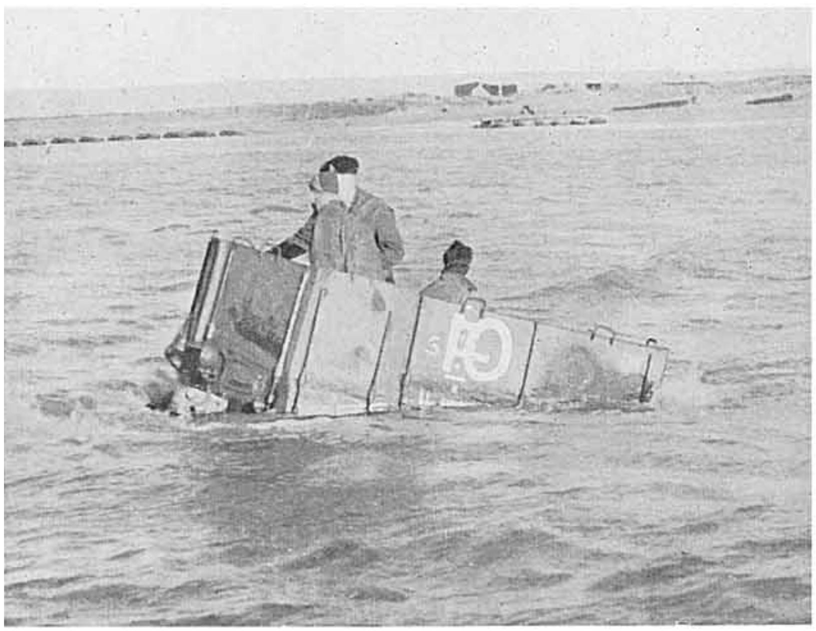

Fig. 26. Universal Carrier Wading

Fig. 27. Armoured Car Wading

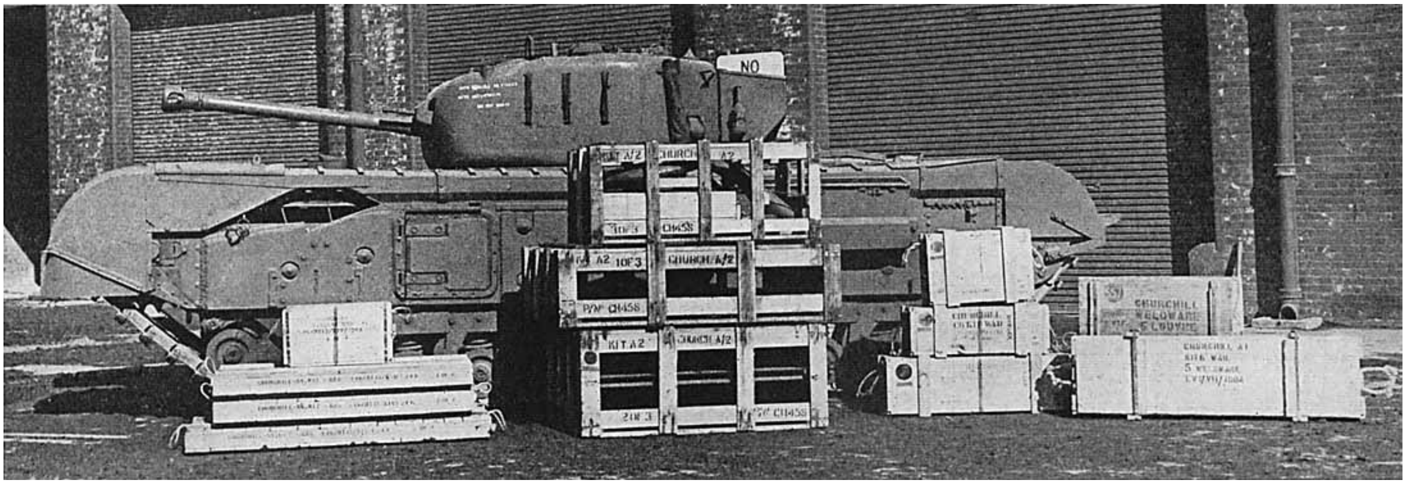

Fig. 28. Churchill Tank with Wading Kit laid out

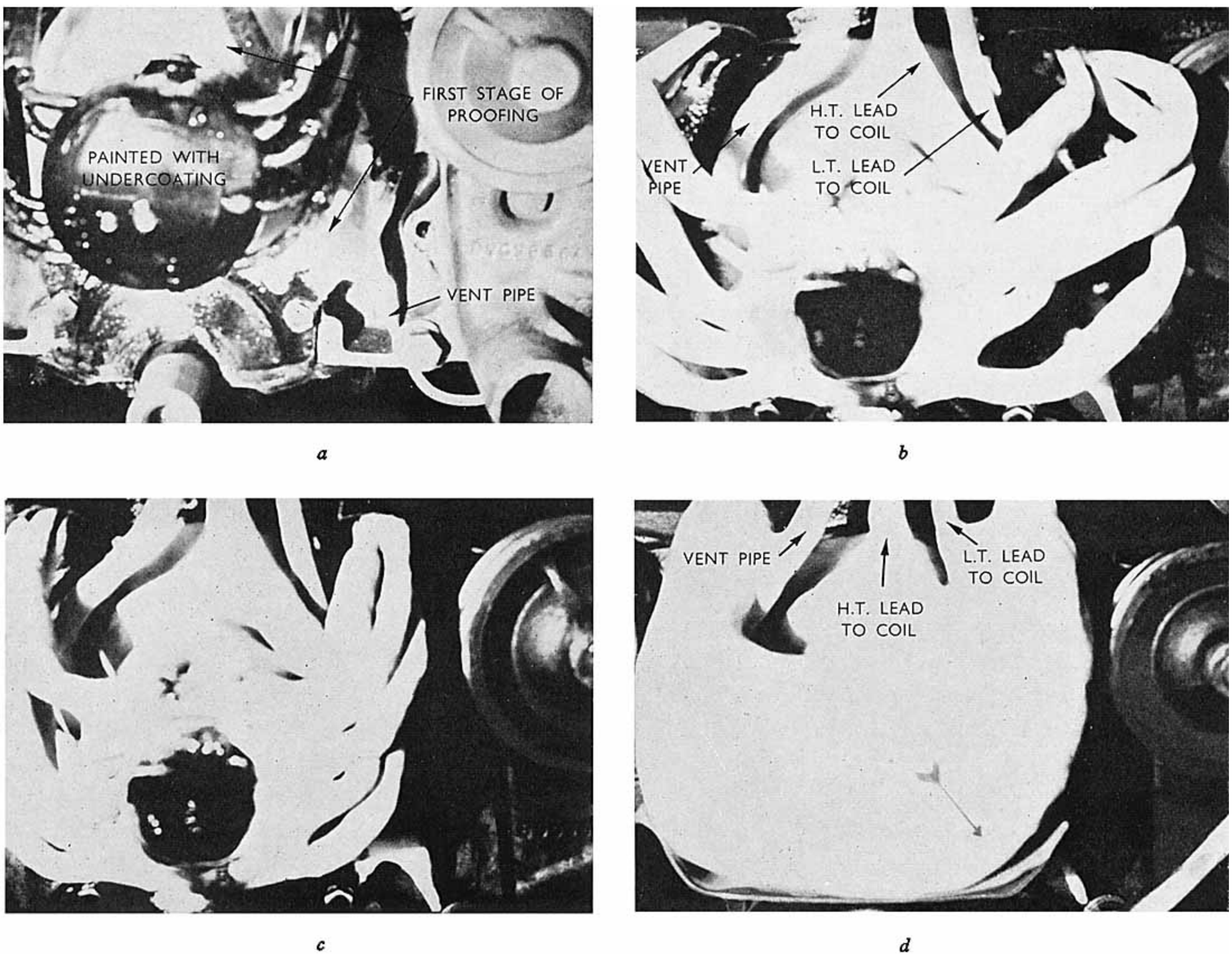

Fig. 29. Various Views of Ignition Coil and Distributor arranged for Waterproofing Tests

Fig. 30. "Jeep" wading in 5 feet of Water

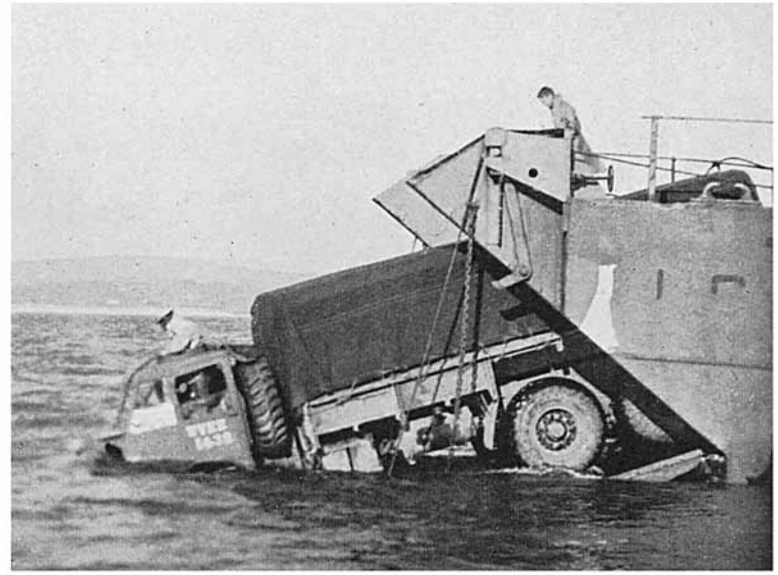

Fig. 31. 10-ton Vehicle (Waterproofed after Manufacture) Leaving Ramp

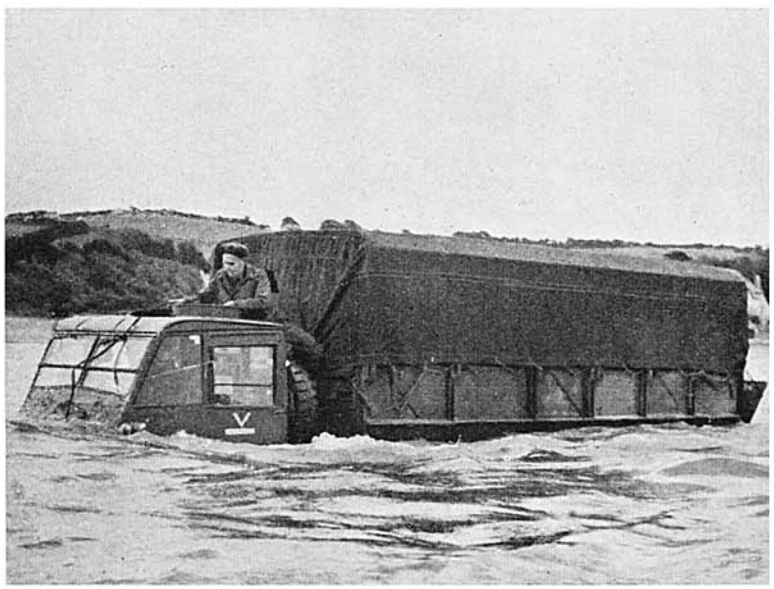

Fig. 32. 10-ton Vehicle (Waterproofed during Manufacture) Wading

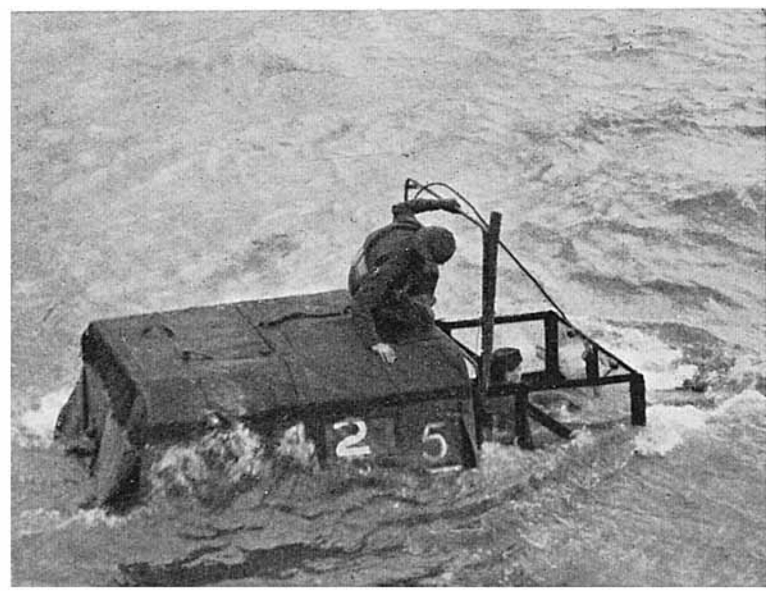

Fig. 33. 3-ton Vehicle Wading

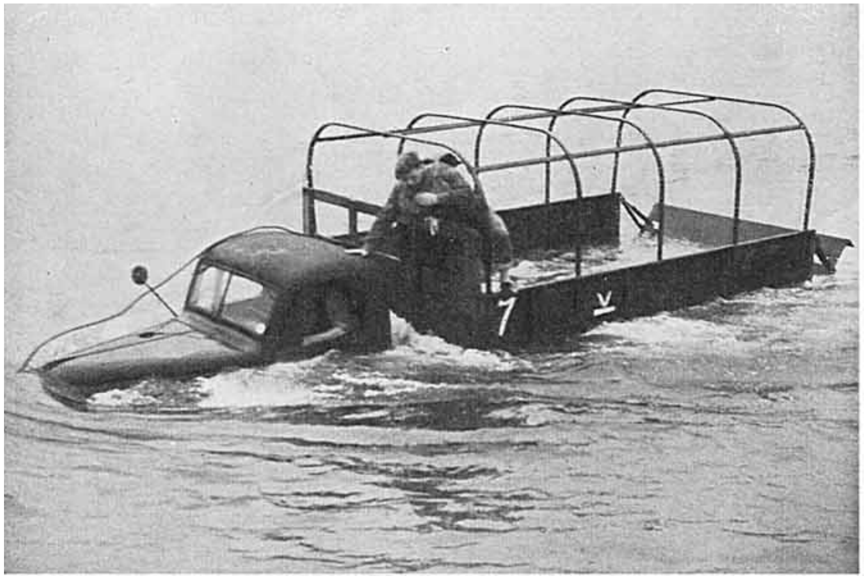

Fig. 34. American 3-ton Vehicle Wading in 5 feet of Water

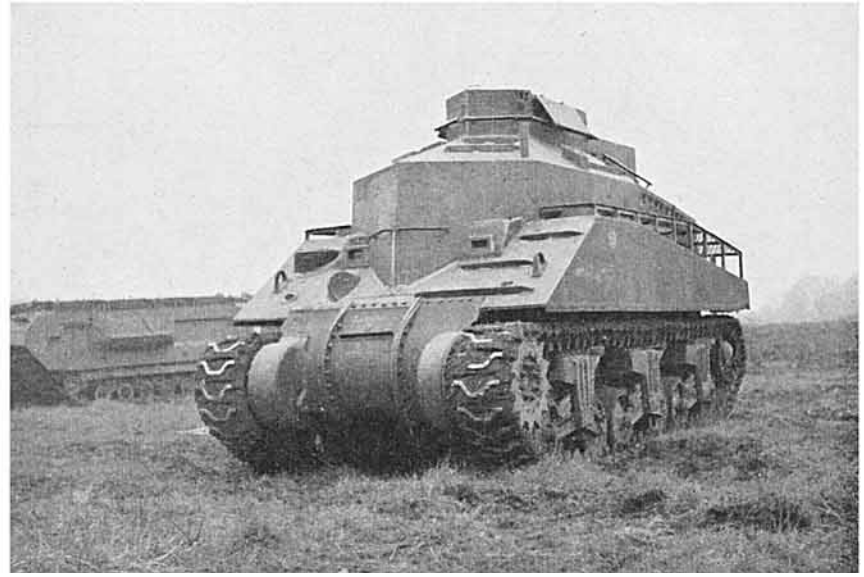

Fig. 35. Beach Armoured Recovery Vehicle ("B.A.R.V.")

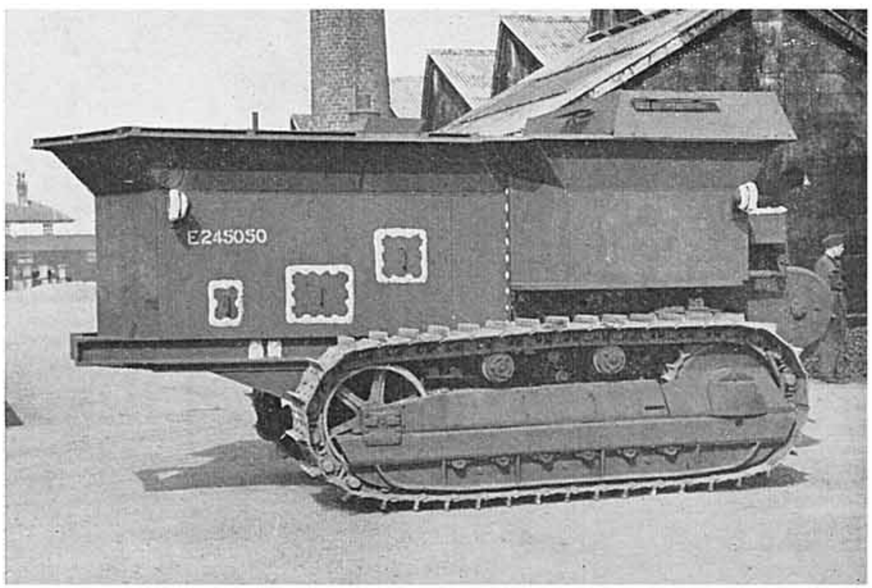

Fig. 36. Armoured Amphibian "D.8" Tractor

Fig. 37. The Army Wades Ashore: Normandy, 6th June 1944

to the waist, as he leaves the ramp, and one of the hardest things in training crews is to accustom the driver *not* to snatch his foot off the accelerator pedal when he gets his bath. A colder and longer immersion is the inevitable result of such squeamishness, but it is a very natural reaction.

One type of vehicle, perfectly—in fact, outstandingly—successful on land, had barely sufficient tractive power under wading conditions to push aside its own volume of water. Another had such fine clearance between piston and cylinder that when the cylinder block was suddenly cooled by immersion, piston seizure occurred. A rush order for refitting (we gave them an additional 0·004 inch clearance) some thousands of vehicles with undersize pistons was carried out in an exemplary manner.

Carburettor jets had to be changed; our engines on Home Service were "jetted down" fairly severely in the interests of petrol economy. On immersion we encountered carburettor failure, so literally tens of thousands of jets had to be changed, during the first stage of waterproofing. As an example, one common type of vehicle running under land conditions on a "145" jet had to be re-equipped with jet size "180".

Those who have not experienced it will have difficulty in realizing the power of even moderate seas when they play on a submerged vehicle. We rarely waded in waves of a size greater than 2 ft. 6 in. to 3 feet, but often wings were buckled, bonnets stove in, and any loose fittings were carried away. Further, particularly if moving parallel to the line of the waves, vehicles were lifted off the sea floor; or, more frequently the weight on the front axles was so reduced during the passage of a wave that the steering wheel spun free in the driver's hands, until the vehicle resettled. This lifting tendency could be felt even on a laden "10-tonner", and one of these vehicles was actually overturned by surf during trials at Westward Ho!

Superimposed on these excitements were a number of maddening but quite understandable minor failures—failures in

TABLE 2. STAGES OF WATERPROOFING—"A" VEHICLES (LIGHT)

Type of vehicles	Stage		Description	Maximum subsequent distance	Time taken	Where done	By whom
"A" vehicles (light) Carriers, armoured cars, scout cars for all formations	Before embarkation	1.	Inspection and maintenance, cleaning, waterproofing engine, sealing hull, etc. Testing in fresh water pit	150 miles	49–70 daylight working hours	Concentration area	Crew, fitters, and electricians.
		2 (*a*).	Semi-final preparation, e.g. stowage bins, sealing visors, lamps, etc.	20 miles	4 hours	Marshalling area	Crew, and for some vehicles, fitters, and electricians.
		2 (*b*).	Final preparations, sealing breathers, etc.	½ mile	15 minutes	Vicinity of point of embarkation or on craft	Crew.
	During voyage	3.	General attention to details (vide Wading Instruction Book)	—	According to duration of voyage	On craft	Crew.
	After Landing	4.	Removal of stage 2 (vide Instruction Book)	150 miles	—	Beach transit area	Crew.
		5 and 6.	In accordance with Instruction Book	No restriction	—	As soon as conditions permit	Crew.

TABLE 3. STAGES OF WATERPROOFING—"B" VEHICLES

Type of vehicles	Stage		Description	Maximum subsequent distance	Time taken	Where done	By whom
"B" vehicles for all formations	Before embarkation	A.	Major preparation	200 miles	3 days	Concentration area	Unit drivers, under formation R.E.M.E. supervision except R.A.S.C.units under their own technical supervision.
		B (i).	Semi-final preparation	20 miles	6 hours	Marshalling area	Unit drivers under static R.E.M.E. supervision.
		B (ii).	Fitting of waterproof ground sheet, sealing engine and distributor breathers	½ mile	15 minutes	Vicinity of point of embarkation	
		C.	Preliminary de-waterproofing	2 miles	—	Beach transit area	Unit drivers. Maximum distance from beach to stage C is 2 miles, but ground sheets will be removed immediately on landing.
		D.	Final de-waterproofing; general inspection and complete lubrication	—	—	As soon as conditions permit	Unit drivers and formation R.E.M.E.

co-ordination between Government Departments; failures of the financial authorities to appreciate the superlative need for uniformity in the composition of waterproofing materials (open tender for the compounds was resorted to, unknown to us, a crop of failures drew attention to it, the faulty stuff had to be traced and rejected, while thousands of vehicle kits, already made up, had to be broken open, remade, and resealed); the software programme fell out of phase with the rest of the programme, due to departmental shortcomings; the quality of the explosive employed in certain parts of the scheme suddenly fell off, and stringent precautions had to be taken; the composition of the force varied from week to week—in detail, it is true but always, it seemed, with devastating effect on our plans; and, finally, as all the world knows, the weather broke in June, and we had higher tides and bigger seas on the Normandy coast than had been known, in that month, for thirty years.

(*d*) *Miscellaneous Equipment*. This was divided into two categories—equipment which had to be protected from salt water as a complete installation and which we, therefore, sealed in the trailers or containers carrying it (radar sets were the outstanding example); and equipment which could be waterproofed in detail and allowed to become immersed in an open trailer (wireless trailers were the chief examples). In the latter, great use was made of waterproof bags and wrappings.

This whole class of equipment gave very little trouble in the preparation of projects, the chief danger being that of flotation of the completely sealed equipment. Not only did flotation tend to lift the tail of the towing vehicle off the sea floor, but there was also a grave danger in many cases of the floating trailer "turning turtle". Such tendencies had to be corrected by judicious weighting of the trailer; but a nice balance had to be drawn between the amount of weighting and the power of the towing vehicle.

The preparation of this waterproofing programme necessitated the closest collaboration between the War Office, 21 Army Group, and the Ministry of Supply; and our particular thanks are due to Sir Claude Gibb, C.B.E., M.I.Mech.E., F.R.S. (*Vice-President*), who performed his usual role of "one-man shock unit" in the Ministry of Supply and, having put gun production on its feet and then tank production on its feet, came into the waterproofing programme as late as December 1943, and produced order and speed out of what had hitherto been rather a slow and mixed business.

To cover possible eventualities, we had calculated on losses through drowning of not more than 10 per cent of all vehicles put through the surf; and the Royal Army Ordnance Corps made provision in their Beach Detachments of a 10 per cent supply of items such as starter motors, dynamos, batteries, and so forth. Brake mechanisms could be ignored in this provision, since all that was required, happily, after emerging from the water was some 2 or 3 miles running to dry out any water which had collected in the brake drums, this rough and ready dry-out being followed at the first opportunity by the stripping and cleaning of brake drums, blocks, and actuating gear. The General Staff accepted the risk of 10 per cent failures.

The next few illustrations show the results achieved by sound waterproofing. Fig. 30, Plate 7, shows a "Jeep" wading in 5 feet of water, and Fig. 31, Plate 7, shows a "10-tonner" entering the water from the landing craft ("L.C.T.") and gives an idea of the degree of immersion at this stage.

Fig. 32, Plate 7, illustrates the same type of vehicle moving along the sea floor, whilst in Figs. 33 and 34, Plates 7 and 8, 3-ton vehicles are seen wading. The waves in all these pictures are well under the stipulated 1 ft. 6 in. in height, so the vehicles in these instances are performing under optimum conditions.

RECOVERY IN AMPHIBIOUS OPERATIONS

A word must be said on recovery in amphibious operations, since recovery is the responsibility of the R.E.M.E. and is a matter of supreme importance on the beaches. Once a start has been made in disembarkation from landing craft to shore, the way *must* be kept clear of breakdowns and drowned vehicles. This essential principle holds good not only during the journey from the landing craft to the water's edge but also—with added force—at the stage when the shore line has been reached and equipment is necessarily confined to paths cleared by the Royal Engineers through beach mine-fields.

To accomplish this we used, for the under-water part of the work, Beach Armoured Recovery Vehicles (B.A.R.V.'s) and armoured "D.8" tractors (Figs. 35 and 36, Plate 8).

The former were Sherman Diesel-engined tanks, thoroughly waterproofed, with the turrets replaced by special steel superstructures, so that they can remain for hours immersed in anything up to 9 or 10 feet of water. Coupling and uncoupling under water was done by personnel wearing shallow diving apparatus, who had been trained by the Royal Navy in its use.

Fig. 37, Plate 8, shows the passage in progress. The vehicles were a great success, and even achieved a tactical surprise, as on "D-Day" the first "L.C.T." landing craft to touch down was unfortunately the wrong one. It was filled with R.E. vehicles and a B.A.R.V., which took the water first and struck terror into the local opposition. The German *communiqué* spoke of the "new British Goliath tank" being the first to land. This was it!

The armoured "D.8's" had a smaller wading capacity but, their tracks being wider and the track loading lighter than in the case of the B.A.R.V.'s, they did invaluable work in the shallows, or above the water-lines. The armoured, waterproofed hulls of the "D.8's" were designed and produced by the R.E.M.E. at short notice. In addition to these two types of vehicle, six-wheeled tractors, unarmoured, did yeoman service above the tide-line, and the R.E.M.E. teams, as a whole, kept the beaches clear. Any vehicles which broke down were first dragged clear of the traffic lanes and then, at the first opportunity, passed into a "drowned vehicle park" where they were dealt with by the workshops of whichever brigade was, at the moment, passing across that beach. As brigades moved inland, their workshops packed up and followed, handing over their beach task to the workshops of the succeeding brigade.

And the results? The net result of the waterproofing activities prosecuted by the R.E.M.E. from July 1943 to June 1944 (and, be it noted, the spadework done before and after July 1943 by the Ministry of Supply) was that 99·85 per cent of the waterproofed vehicles made shore successfully. We had guaranteed 90 per cent. We were satisfied.

CONCLUSION

I have touched on enough of the aspects of the work of the Royal Electrical and Mechanical Engineers to give, I hope, some idea of the fascinating variety and the astonishing scope of their work—even ignoring the electrical side.

The tale could be continued for hours longer, but in the interests of my readers and listeners I must leave it here, lest someone is wrongly tempted to fasten on me the attributes of Oliver Goldsmith's village schoolmaster, of whom he said

"And still they gazed and still the wonder grew
That one small head could carry all he knew".

It is not my head that carries all this, but the corporate heads of the whole of the R.E.M.E.