The truck becomes a DUKW. (n. a.)
General Motors Corporation. [October, 1945]

THE TRUCK BECOMES A DUKW

In the summer of 1941, the U. S. Army was planning troop movements from ship to shore, across streams and lakes, and through the jungles of the tropics preparing for every phase of amphibious warfare. The office of Scientific Research and Development, through its subdivision, The National Defense Research Committee, had made some studies of landing boats and amphibians in an effort to help solve the problem. Work had already started on the amphibious "jeep" - the "seep". Sparkman & Stephens, marine architects, had been commissioned by NDRC to provide a basic design, using a standard truck chassis. The GMC "6x6" was the natural selection for this purpose, as its high traction and flotation charateristics, together with good service facilities at overseas bases, were established facts.

Arrangements were made with GMC Truck & Coach Division of General Motors to build a sample vehicle in their Engineering Department. GMC engineers were assigned to the project and proceeded with the design and drawings to basic specifications and limitations. These specifications and limitations were established jointly with the marine representatives who had build and tested small models of the design to establish certain marine charateristics.

The project was officialy started Friday, April 24, when a selected group of draftsmen began the first layouts. The same day, a "mock up" was started in one of the Experimental Department's "secret" rooms. Around a standard "6x6", the size and approximate shape of the hull were simulated in wood, sheet steel and cardboard, while the water propeller and shaft were dummied by a wood disc and steel tubing. Working through Sunday, the "mock up" was completed by Monday morning. Thrity-eight days after the job was started in the "secret" room, the vehicle was driven out of the Experimental Department. Carried out as a secret project, the nature of the vehicle was never mentioned except when necessary, drawing rooms were screened and guarded at all times, and drawings sent by registered mail or special messenger.

So the DUKW, or amphibious truck, became a GMC "6x6" army truck with a steel hull fitted over the axles and around the frame. Axle and water propeller shafts pierced the hull through sealed tubes. The steering gear, which provided conventional steering on land, was connected to the rudder so that normal operation of the steering wheel also guided the vehicle through the water. The water propeller thrust, which pushed the vehicle through the water, could be augmented by the treads of the tires on the driving wheels when thrown into gear. Thus the driver, prior to entering or leaving the water, could shift controls to provide a land and water drive, and avoid getting stuck in deep sand or mire at the shore line. This unique vehicle had the same qualities of performance that distinguished the GMC "6x6" army truck, plus the ability to operate in and out of water of any depth.

When the project was started, the following model designation was given to this amphibious-type vehicle:

DUKW-353

In explanation, the letter "D" designates 1942 year model; the second letter "U" indicates amphibian; the third and fourth letters "KW" indicate "6x6". The number "353" is the serial designation used for the first DUKW. To the men on the production line, the vehicle immediately became the "Duck", and this name has followed the vehicle around the world.

THE HULL

The boat, or hull, was a welded steel, water-tight vessel of light gauge sheet steel. Weight was kept low by reducing the thickness in all areas where service conditions permitted. For instance, the bottom panel of the bow, which rides over heavy brush on land and surf in water was made .1046", whereas the side of the bow, less vulnerable, was .0747"—a saving of 1.25# per square foot. The sides, still less vulnerable, were made .0598" thick—1.375# per square foot less than the bow bottom panel. Thus, in side panels alone, careful designing saved 275# per unit.

Hat-sectioned rails were welded to the outside of the panels to serve as reinforcement and as rub rails and skid bars. On the inside, channel cross-members, floor angles and bulkheads tied the sides together, while the inset coaming stiffened the cargo opening in the deck. The bottom of the hull required painstaking layouts. At the front end, the sheet was fitted closely to the bottom of the engine, and moulded carefully around the bouncing axles; a tunnel was carried rearward around the propeller shaft to the transfer case, and from the rear of the transfer case, a deeper tunnel flared backward to provide adequate clearances under all operating conditions for propeller shafts and torque rods. To speed the building of the hull, layouts were dimensioned and given to the Experimental Department as soon as the drawings were ready.

CHASSIS DESIGN

The cab-over-engine chassis originally used on the "Duck" required surprisingly few major changes, considering the unique function of the proposed vehicle. The first major requirement was a means of driving the water propeller. Consideration was originally given to two alternatives—(a) the redesign of the axle transfer case. (b) the adding of a power-take-off assembly to the rear of the transmission. However, in the interest of interchangeability, it was decided to place the power-take-off assembly in the drive shaft behind the transmission, and support it with a new cross member. A pair of "6x6" transfer case jaw clutch gears, a splined shaft and bearings were mounted in a housing along with new mating gear and shaft, in line with and connected by a universal joint to the main drive shaft. A shifting control was provided for the driver to engage the drive. The gear ratio selected was an over-drive, which, in combination with the transmission, provided a wide range of propeller shaft speeds.

The drive to the propeller consisted of two tubular shafts, with needle bearing joints supported on standard Army truck rubber-cushioned center bearings. They were jointed to a short shaft at the rear mounted in a standard double row ball bearing in a single housing to take the thrust from the propeller. A solid shaft ran from the short shaft through a marine type stuffing box and the hull to the propeller supported by a babbitted bearing to a vee-strut, mounted from the top of the hull tunnel. All shafts were carefully located to insure that each was at a slight angle to the other. Thus the needles were moving slightly as the shafts turned, preventing the "Brinelling" of bearing surfaces.

A standard 6x6 steering gear was reworked for the rudder control, by cutting off the jacket tube above the gear housing and attaching a split spool, or drum, on the steering column shaft. The split spool clamped a cable, permitting one end to wind and the other to unwind on the spool as the steering wheel was turned. A housing, to support the jacket tube and permit cables to pass to and from the spool, was bolted to the top of a steering gear housing. The cables were threaded rearward on the left-hand side to pulleys in the rear compartment where they were directed to a long lever on the rudder post.

There was also the problem of sealing the "wet" chassis housings. For instance, steel tubular housings enclosed the propeller shafts from hull to axles, and these were sealed at the hull and pinion ends by large diameter rubber bellows. This kept water out of the hull and pinion bearings. The spherical joint seal on the front axle and the hub seals on all other axles were redesigned to keep water out. The steering gear trunnion was sealed with a rubber shield where it projected through the hull.

The brake booster was relocated to clear the propeller shaft tunnel. The rear trunnion frame corssmembers were revised, and torque rod brackets were relocated to permit improved tunneling around the water propeller.

A standard "6x6" winch, with right-hand worm, was set into the top rear deck at the stern. This was driven from the transmission power-take-off by universal shafts angling upward to the rear. Provision was made for front and rear "winching" by providing openings (chocks) in the base of the windshield and the coaming for the cable to pass forward.

A new cab structure, utilizing the Army open-type cab windshield, was covered with a canvas top and sides. The cargo space was simply and effectively sheltered by an "tent-like" tarpaulin extending from the cab to the rear of the cargo space, providing a "low silhouette" in the water, making the vehicle a difficult target.

A "6x6" fuel tank was strapped below-deck at the left-hand side in the stern. The filler neck, which projected through sealed openings in the deck was covered by an easy on-and-off cap chained to the neck. A rubber hose connection from the bottom of the tank through the side of the hull facilitated draining.

THE DUCK TAKES TO THE WATER

On June 2, the "Duck", less the cab and cargo tarpaulin, was driven around the field alongside the GMC experimental shop, and water-tested by filling the bottom of the hull with water. Bilge pumps were checked by pumping the water out, and the vehicle was then considered ready for its first water test.

The following day, with a crew of mechanics and engineers, the "Duck" took to the water. Rolling over roads and across fields to the mucky shores of Crystal Lake, near Pontiac, Michigan, it entered the water, and with a few motions of the driver's hands was churning away as a boat. This test was repeated each day for a week checking speed, turning radius, cooling, etc. Each night the vehicle was returned to the "secret room" for revisions and preparations for the test on the following day. At the same time, improvements were in progress in the drafting room. Propellers of various diameters and pitch were tested to increase speed. New designs for the water tunnel were laid out, and propeller relocation was under consideration.

In the midst of these activities, the Army asked for a demonstration of the vehicle. The first was held at General Motors Proving Ground on June 12, 1942, for a group of Army officers. The "Duck" gave a satisfactory performance that day on smooth water. The vehicle was driven to Washington, D.C. on June 14, the trip requiring two runs of eleven hours each. It was then ready for further tests. At the request of high Army officers the "Duck" was put through its paces at Fort Belvoir, Virginia, on the 15th. Carrying a group of 18 Army officers, trips were made in and out of water, over steep hills, through the woods, and across a stream. These tests were continued for several days. Dual outboard motors were installed in an attempt to boost speed in the water, but the results were negligible. The "Duck" then proceeded to Virginia Beach, Virginia, for surf tests, and on one trip it carried 75 troops. On June 23, further surf tests were started at Virginia beach, but it was decided to conduct the balance of the test at Kitty Hawk, North Carolina, because of the higher surf there. Water rolling over the "Duck" shorted the ignition, and swamped the vehicle climaxing the tests. It was then driven back to Pontiac for further changes in design.

[illegible]

[illegible] production [illegible], "Mock", GMC engineering was authorized [illegible] pilot models. Three [illegible] were for the training of Army personnel [illegible] to be built with all possible speed. The fourth was to [illegible] production drawings. This procedure was necessary to help get production vehicles ready for the Army in the least possible time. Production drawings were complete in every respect, to the last [illegible]. [illegible] 1,500 [illegible] for preparation of the first "Duck". The four pilot "Ducks" required many more [illegible]. During the [illegible] period, changes were made freely as a result of further design study, tests and directives. [illegible] were changed, and [illegible] frequently. As a result of the changes, and in spite of short cuts, [illegible],000 GMC [illegible], compared to 1,500 [illegible] were [illegible] the [illegible] pilot "Ducks".

[illegible] in production in the shortest possible time, all [illegible] work with special facilities provided. [illegible], 6' x [illegible] layout and checking of a complete vehicle. [illegible] on the [illegible] interchangeability, and the [illegible] of units and parts could be [illegible] confidence.

The original "Duck" [illegible] The hull, engine compartment, driver's compartment and controls [illegible] had [illegible] revised. The [illegible] structure and the [illegible] were [illegible] times. The cargo space was covered with a roll back tarpaulin, supported on standard Army truck roof bows. A sand-tight floor was added in the cargo space, and a gun mounting was supported over the co-driver's space in low silhouette truck fashion.

The steering gear was relocated, the rudder control was revised with a compensating lever, and a shaft added to provide for the deflected and offset position of the rudder.

Many other changes were made—the water transfer case was made lighter and more compact, with a more suitable ratio provided. The water propeller shafts were changed to eliminate one shaft and provide a heavier thrust bearing at the rear, with provisions for alignment. New sealing tubes and bellows around the axle propeller shaft were designed for increased clearance and accessibility. An emergency hand-operated starter was added behind the driver's compartment. A spare tire carrier was mounted on the rear deck, and emergency tool equipment located on the bow. All the detailed refinements cannot be given; however, some of the major test work and changes will be pointed out below.

MARINE [illegible]

The top water speed of the sample "Duck" was about 5.5 M.P.H. The Army wanted more, so GMC tried all possible combinations of propellers and hull fairing to get it. A course was staked out on Crystal Lake where, from June to August tests were run to check speed. Combinations of propellers, tunnel designs, tires and streamlined cover were tried out. During this time, the hull was lengthened at the bow and stern and 24 different propellers were installed,—some in different locations. A practical combination was finally selected which produced a 20% increase in water speed. The turning radius of the first "Duck" was poor. Checking the turning radius was done from shore, by using a surveyor's transit over a marked water course. More than a dozen tests were made using four different rudders. During these tests, it was discovered that the boat with the rudder set straight ahead tended to veer to the right. Tests made with the rudder offset to the left corrected this difficulty. As a result of these tests, the turning radius was reduced 50%.

COOLING A "DUCK"

The basic cooling problem on the "Duck" engine was to be able to take sufficient air in and at the same time keep the water out. The later condition was accomplished by reversing the direction of the air as compared with a truck. The air was sucked in through a grilled floor back of the driver's compartment, and pushed through the radiator into the forward compartment. From there it was directed to the rear along each side of the hull to grilled openings above the coamings adjacent to the driver's compartment. Deflecting the air backwards and pushing it through ducts reduced cooling. How much this was reduced could be determind only by tests.

Initial tests of the "Duck" on water indicated poor cooling at high engine speed. As a result the outlet ducts were increased 1/3 in area, and subsequent tests showed cooling increased 8°. Decisions were made to install baffles ahead of the radiator, move the radiator forward, redesign the shroud, increase the area of air ducts still more and to provide a larger fan. Tests conducted on July 20 and 21, after installation of the changes, showed increased engine cooling at high engine speed, but low speed results were still poor. Additional tests, using fans of various combinations, were made before cooling at low engine speed was satisfactory.

For land cooling performance, tests were started on the chassis dynamometer at General Motors Proving Grounds but were abandoned when the conditions under which the tests were run produced unreliable results. Tests were then started the hard way, by pulling another vehicle, and, as a result, drastic changes in design were ordered. A larger radiator with more fins per inch was installed. On September 5, another "Duck", incorporating the latest changes,— the new radiator, additional cooling hatch, etc.—was available for test. Test runs at General Motors Proving Ground on September 9, showed cooling had been raised to acceptable standards.

[illegible]

The "Duck" was originally equipped with 7.50 tires,--single front and dual rear. The Army, early in 1942, had found them unsatisfactory for use on "6x6's" in loose, dry sand, and was conducting tests for a solution. A tire company had developed a wide-tread tire for that purpose and loaned a set for tests on the "Duck". Tests revealing their superiority were made at the Oxford, Michigan, sand pits. Other tire companies favored the 10.00 size tire, using low air pressure, so they were procured and tested. The Army, at that time, decided the "6x6" desert trucks should take 11.00x18 size tire. Ultimate decision to use the 11.00x18 on the "Duck" was prompted by favorable results obtained on trucks using all sizes in the sand pits. Decreased resistance when the 11.00x18 was dragged through the water was an additional factor favoring their use on the "Duck".

In military service, each "Duck" had to supply its own air for tire inflation. A tire pump could not be located, as on the "6x6" desert trucks, opposite from the winch take-off because the propeller shaft tunnel interfered. A 2-shaft power-take-off was secured—one shaft for the winch, and the other for the tire pump. Above the take-off, a 5 cubic-foot, low-speed, air-cooled compressor was mounted on a hinged base which could be adjusted to take up the slack in the drive chain. An air reservoir was installed, and two inflation hoses were piped from there and coiled in a rack, ready for instant use.

A control lever for shifting the pump drive in and out of engagement was placed near the driver.

Tests on the original production air pump indicated that time required for the inflation of the tires was greater than desired. Output was low because the pump speed was limited by the maker. A high-speed, water-cooled pump was secured and a test set-up proved it possible to inflate tires in half the time required by the production pump. A second pump of larger capacity was checked; however, it produced no additional capacity, and was more costly and difficult to install.

Thus, the "Duck", when faced by poor traction conditions in loose sand, could increase traction by reducing the air pressure in the tires. When the return to high air pressure was necessary under enemy fire, a minimum time for inflation was desirable.

The first attempt to meet the problem of inflation or deflation was made by contacting valve companies. One of them submitted a valve that was screwed on the existing tire valve stem. A turn of the new valve deflated the tires to "sand pressure", whereas, inflation to normal driving pressure was obtained by pressure hose from the air reservoir. Upon reaching the desired air pressure the valve would automatically blow off excess air. While much faster than the original set-up, stopping a vehicle exposed it to enemy fire and a stationary "Duck" is often a dead "Duck".

To overcome this difficulty GMC Engineering was requested to investigate the possibility of inflating and deflating the six tires simultaneously with the vehicle in motion. On September [illegible], 19[illegible], the first design proposed for running connections direct to tires was completed. This called for a single hose to each hub, using tire pump pressure to inflate and engine vacuum to deflate. Then came the [illegible]-hose design, using tire [illegible] pressure to either inflate or deflate. Both of these systems retained the tire valve core, which automatically retained the air in the tire should a hose or connection break. A later design used a single hose connection without the tire valve core and employed a running joint which retained air pressure in the supply line at all times. From October, 1942, until February, 1943, a great many tests were made of these various designs before adopting the last described as standard.

The friction, or drag, of the large diameter joint used in this design tended to make the stationary air sealing cover on the hub turn with the wheel against the restraining effect of the hose. This torsional force was reduced subsequently by adding an air supply arm to the hub chamber and connecting the hose to its outer end. This was released to production on February 17, 1943, and subsequent testing led to more improvements that were incorporated on vehicles after Ordnance approval had been received.

Central inflation on the "Duck" enables the driver to inflate or deflate all tires simultaneously while the vehicle is stationary or moving full speed on land or water. Thus over-inflation or under-inflation is held to a minimum, and by adjusting the tire pressure to suit ground conditions, maximum vehicle performance is possible, and tire life extended.

The system comprised an air pump that ran constantly with the engine, an air tank, gauge, pressure regulator, a driver's control for inflation for deflation, and six valves by which the driver could shut off the air line to any or all tires. An inflation hose was furnished for use in an emergency, or for inflating the tires of other vehicles.

BILGE WATER

All boats collect some water. The "Duck", which plunged off embankments into the water and churned thru heavy surf, was particularly exposed. Furthermore, the hazards of irregular ground and enemy fire leaving holes through the hull were emergencies to be provided for. Two pumps were installed. One, a gear pump of 60 gallon-per-minute-capacity, sucked water from the four hull compartments. The other pump, a centrifugal type of 160-gallon-per-minute-capacity, was located low in the hull, amidship, to provide for emergencies beyond the capacity of the gear pump. Both pumps were belt-driven from the water propeller shaft, which meant each pump would automatically do its job when the boat was moving through the water.

Original tests of the pumps were made by partially filling the boat with water and weighing water pumped out into barrels on scales. The pumps failed to meet rated capacities, apparently because the driving belts slipped. Tests were then run on the dynamometer with belts in wet and dry conditions to determine if slippage was the reason for failure. Four new pumps were also checked for capacity and horsepower. The main decision resulting from the tests was to replace the belt on the centrifugal pump with a chain drive because its low position in the boat subjected it to water, while the gear pump was relocated to reduce hazard. Although many additional tests were made on pumps, the original types were retained and released for production.

PRODUCTION CHANGES

The paradox of the "Duck" released for production in September, 1942, and the vast amount of time spent on changes during the next three months should be explained. Changes were in process throughout that period. Reference has been made to the major changes previously--cooling, tire pumps, bilge pumps, etc.--some of which were made in October. Other calls for changes, about 70 from September through November, came from several sources. Ordnance directives called for reinforcements and equipment to fit the "Duck" to carry equipment developed by GMC engineering, such as, sand anchors, canvas water buckets, stowage for tarpaulin and roof bows, cab covers and door assemblies etc. Engineering errors had to be corrected, i.e., the hatch cover channels were too long, with winch holes were located incorrectly, insufficient adjustmade had been provided for linkage, etc. In addition, requests came from Production for investigations and tests, increased clearances for shop variations, decreased cost of assembly, and for material specified but not available. These were difficulties that had to be considered during the first months the "Duck" was on the production line.

[illegible]

At the request of military authorities, demonstrations were staged at proving grounds or on the job sites, and all arrangements were handled by GMC Engineering. Obviously, the transportation of vehicles, equipment and personnel was considerable, and the delays and [illegible] were frequent and [illegible] in [illegible] of GMC's willingness to cooperate. An example of this was the demonstration at Solomon's Island, Maryland, on August 25, 1942. GMC equipment and men arrived the evening before and were told to be ready for a demonstration the following day. Unable to get details of the program, they ascertained by telephone the location of the demonstration, and proceeded to that point. No introductions were made, and no instructions given. The two "Ducks" made various trips into the water, but little notice was given them by the officers present, a few questions, however, were asked about changes made since the earlier demonstration.

Another series of demonstrations held at Camp Edwards, Massachusetts, early in September, might be used as further evidence of GMC's readiness to be wherever the Army requested. "Duck" - 353-003 left Pontiac September 8, 1942, arriving at Camp Edwards on September 10, 1942, where it was received by Ordnance, and issued to the Development Section of Engineering Command. The weekend was used to demonstrate operations of the vehicle to about thirty-five officers at Camp Edwards and nearby Camp [illegible]. On Monday, September 14, 1942, schooling was started for a detail of two officers and ten men, all of them had previous experience driving the "6x6" truck. Training continued through

Tuesday under various conditions, such as operations in brush, climbing steep banks, operating in sand, etc. On Wednesday, September 16, 1942, the "Duck" took part in the amphibian demonstration for the Commanding Officer at Camp Edwards, who, at the conclusion of the performance, stated the vehicle had done everything he had expected of it. GMC personnel returned to Pontiac, September 17, 1942.

On October 2, 1942, a second "Duck" was sent to Camp Edwards in accordance with instructions received by telegraph from Washington. This vehicle, along with "Duck" -353-003 that had been delivered September 10, was to have a part in the maneuvers being held in the vacinity of Martha's Vineyard Island. The equipment "stood by" for a three-day period, answering only one call from a group of Army officers who wanted to come ashore from a speed boat about 300 yards off shore. These men seemed interested, and spent a little time inspecting the vehicle. This mission and the pulling of two vehicles out of the sand, where they were stuck, were the "Ducks" only part in the maneuvers.

The first "Duck", which had been delivered in September at Camp Edwards, and been in service every day and no trouble of any kind had been experienced. Those who had worked with it were loud in their praise of its possibilities. GMC engineers had decided it needed reinforcements to the hull sides for further tests. Since the maneuvers were over, the second "Duck" was left at Camp Edwards, and "Duck" #003 driven back to the factory, where it was reworked and later returned to Camp Edwards.

UNCOMMON ENGINEERING

Tactical equipment, for the "Duck" was sponsored and authorized by the National Defense Research Committee, whose representatives were trying to "sell" them to the various Using Services of the Army and Navy. GMC Engineering's job was primarily the design and development of ideas to meet directives from NDRC, provide sample equipment, conduct tests and to provide vehicles, equipment, mechanics and engineers when and where they were needed. Many complications were involved in the usage of Ordnance vehicles built in Engineering, and the building and fitting of equipment, authorized by NDRC, and its use in the various demonstrations requested by the Army. The story is herein given in chronological order.

WET FERRY

Later in July, 1942, GMC Engineering received a directive from the National Defense Research Committee to work out a method of carrying a tank from shore-to-shore or ship-to-shore by using two "Ducks". NDRC proposed a layout showing a tank (partially submerged) hung from two large tubes (8" diameter pipe, 14' long) which ran from the far side of one boat to the far side of the other. The tubes were to rotate by the unwrapping of a cable pulled by the power winch of the "Duck" through a combination of snatch blocks. The rotating tubes wound up chains which were fastened to the tank, thus permitting it to be raised or lowered.

The method seemed unnecessarily heavy and complicated. Wood models, studied in a water tank, indicated weaknesses in the proposal, and provided data for other proposals worked out in GMC engineering. The theory behind the "wet ferry" idea was that the tank did not have to be lifted into position. After sealing the openings, then partially submerged, the tank would be buoyed up by the weight of the water displaced. The "Duck" would support the difference between the weight of the tank and the upward thrust from the displaced water.

A tank of the desired size was under test at the General Motors Proving Ground. GMC Engineers inspected it and secured data for the sealing and distribution of weight. Sealing was an important part of the wet ferry. Water in the tank might not only short the electrical equipment, but also might send everything to the bottom. The tank was supposed to be water-tight up to a 30" level, but much sealing work had to be done below that level as well as above before it was ready for the tests.

In the meantime, work was proceeding on the craft on board. The tank was located, fore and aft, so that the center of its weight was in line with the center of bouyancy of the "Ducks". This was a tedious calculation. The tank was suspended from the near side of each "Duck" by four chains — two on each side. Adapters to which chains were hooked, were applied to the tank at the front and rear. The upper end of the chains were hitched to sawed-off Army truck pintles, which had been welded to angle brackets on the deck and coaming. Hanging the tank from the sides of the "Ducks" tipped them towards the tank, and might capsize them. To correct this tendency, two cables at the front, and two at the rear, of the tank were crossed in a verticle plane, and hitched to the sides of the "Ducks". The same cable arrangement was used horizontally at the front end to keep the boats from "nosing" ahead of one another. To keep all cables under tension, and the "Ducks" parallel, adjustable spreader tubes — one at the front and one at the rear, were hitched to cleats on each "Duck". They could be quickly adjusted or spread by the ratchet screw built into one end. A horizontal cable, or "spring line", was installed diagonally at the rear to pull the rear ends of the "Ducks" together during these operations. The sides of the "Ducks" were protected from being scuffed by plank and rope fenders that were hung from the deck. The complete equipment, including alterations to the two "Ducks" and the special tools for handling was designed, detailed, built or procured, installed and ready for the test in one month.

Testing started September 1, 194[illegible], on [illegible] Lake at the General Motors Proving Ground. While the first trial was successful, some improvements were in order, i.e., more space was required between the "Ducks" for the tank, better sealing of the tank was needed, and connections between the "Ducks" could be improved. These changes were made and all was in readiness on September 7 when a group of Army men came to the General Motors Proving Ground to watch the latest accomplishments of the "Duck". The tank-lifting device was demonstrated. Several trips, carrying the tank, were made across Moon Lake. The average time for coupling was [illegible] minutes, and 1-1/2 for uncoupling. Four "Ducks" were on the lake. Two were fitted with tank-lifting apparatus, one with a full canvas cargo space enclosure, and the fourth was a standard open type. Demonstrations were entirely successful.

At some time after lunch, there seemed to be no fixed opinion among the Army personnel present as to the value of the tank-lifting device as demonstrated. GMC representatives suggested that the Corps of Engineers send representatives to Pontiac so that their ideas could be used to improve the device. It was also suggested that the first [illegible]00 production "Ducks" have no provision for the installation of the tank-lifting device.

Officers of the Corps of Engineers were present for the September 8th demonstration at the General Motors Proving Ground. After a detailed examination of the ferrying equipment, and a demonstration of the method to be used, the group retired to the club house for discussion. They expressed the desirability of developing a device to not only carry a medium tank, but also reconnaissance vehicles. Interest was also expressed in proposals for the construction of power rafts and pontoon bridges.

GMC Engineering was now faced with a real challenge. This was a proposal to ferry the medium, or M-4, tank weighing [illegible],000 pounds, twice the weight of the light tank previously carried. All the M-4 seams had been welded, and were water-tight to a 48" level. The air ducts to and from the radiator were lighter, and were simpler to handle. The fundamentals of suspension and rigging remained the same, but it required more space between the "Ducks". Cables were used in place of chains for suspension, and surrender tubes and all cables were revised. Two drag lines were added between the front of the tank and the "Ducks". Also added was a separate hose, attached to the bilge pump, that would siphon the water seeping into the tank during ferrying operations.

An M-4 tank was procured from the Army about the first week in October. At that time, the new tank rigging was available, and the "Ducks" readied for trial. The success of preliminary trials led to a demonstration at the General Motors Proving Ground, October 10th.

Attending the demonstration of October 10th was an impressive group of military men not only from our own Armed Forces, but from the British and Canadian armies as well. High lights of the demonstration were as follows: (1) the newly-developed GMC "dry raft" of the "Caster ramp" type, with a capacity of 30,000 lbs., was put through its paces. Various vehicles, including the "6x6" truck and the T-17 armored car were loaded, maneuvered on the lake, returned to shore and unloaded. Everything went well during the demonstration. (2) single "Duck" #001 was used in the demonstration by carrying the visiting military personnel in and out of water. GMC offered to attempt anything suggested. This resulted in drives from the steep, rocky shore of the causeway into the lake with the "Duck", getting stuck in the reeds and marsh requiring the use of the winch to extricate. Comments were all favorable. (3) the 65,500-lb. medium tank "wet" ferry was demonstrated after a full explanation of all the work that was required to waterproof the tank. Attachments were extremely simple, and readily attached and removed for the sealing operation. It required 8 minutes for the crossing, 1-3/4 minutes for the hook-up and one minute for unhooking. All comments on the operation were favorable, and in contrast with those made after the first demonstration.

DRY FERRY

Rafting, or dry ferry, operations by Army engineers was usually done by maneuvering ponton bridge sections loaded with men and vehicles. GMC engineers proposed using two "Ducks" tied together with cross tubes, which was a radical departure. The tubes supported two treadways, running fore and aft, on which rested the vehicle to be ferried. On two "Ducks" this type of ferry was limited to the carrying of trucks, armored cars and light tanks. The total weight of any one of these vehicles could not exceed 30,000 pounds. The problem of stabilizing and spacing "Ducks" on the water, under this load, was somewhat the same as the "wet ferry". However, in the case of the dry ferry, all of the weight of the vehicle to be ferried rested on three spreader tubes and, as a result, these had to be stiffened by cable trusses. Two light sheet metal treadways, each 10 feet long, spanned the tubes, spaced for wheel or track-laying vehicles. Ramped treadways, which rested on the ground, and were hooked over the tube in line with the horizontal treadway, permitted the vehicle to run up or down under its own power.

The original idea was to drive the vehicle up the ramp at the stern end, and off the bow end. Driving off the bow end placed a tremendous overload on the front of the "Ducks", as most of the 30,000 pounds rested momentarily on the four front tires. One suggestion made was to limit the load on these tires by placing load-limit struts under the spreader tubes during the loading and unloading operations, but this idea was rejected as impractical. Tests were then conducted on stern loading by backing the vehicle up on the rig and unloading it in forward gear from the stern. This method worked, but not without difficulties.

A design was laid out which eliminated the sharp approach to the ramped treadways, thus permitting bow loading and unloading, which provided equal load distribution on all the tires during the operation. This was the "teeter" type, using 31-foot treadways, which rested on three cross tubes between the two "Ducks". When the vehicle to be ferried was in position, the treadways were parallel with the Ducks.

For unloading, the front support was uncoupled, which permitted treadways to teeter on center spreader tube and descend to ground. For loading the vehicle would be driven slowly up the ramp until its weight would rock the ramp about the center spreader tube to a horizontal position. The 31-foot treadways were inclined upward slightly at each end to give a centering effect on the vehicle as it rocked into position.

The low angle ramp, 11 feet long and replacing the 1[illegible]-foot length previously used, was easy to climb even with mud or snow on it. Also, it readily adapted itself to various levels and irregularities of terrain when loading.

The 31-foot treadways were split and bolted together at two places to permit carrying the three pieces in the boat cargo space. The 11-foot ramp, over which the [illegible]0,000 pound vehicle rolled, was ingeniously stiffened by dual cables that were tensioned by an adjustable jack under the bow cross tube. This weight-saving construction was effective, and facilitated the handling of treadway sections.

The tests that followed on October 10, as previously described, led to a directive whereby GMC engineering was to provide two more sets of "dry ferry" equipment, and fit four "Ducks" to take that equipment.

The "teeter" type had some objectionable features. Its three-piece treadways were secured with many bolts to resist the bending of its long span. These bolts required too much time for assembly. It created heavy concentrated loads on the two "Ducks", as vehicles being ferried rocked over the center spreader tube. This tube had to be very heavy, and was difficult to place in position.

It was decided to investigate another idea. The treadways were disconnected at the center tube and midway on the ramped sections. The ramped sections were pinned together so that they could readily be removed, and the upper sections were laid on the center tube and locked into position by a chain. At the joints midway in the ramp, a light sheet steel rectangular beam ran transversely under the treadways. From the ends of the beam, verticle cables ran to a pulley on each bow deck and this brought the cable in line with the chock at the base of the windshield. Each cable was carried through the chock to a snatch block, which was coupled to the winch cable. The operation of both winches simultaneously raised the ramp and vehicle to a horizontal position, the weight being distributed between the cables and spreader tubes during this operation. The proposal was considered quite practical; therefore, the "teeter" principle was discarded, and a test of this new idea was made after reworking the teeter type material.

Later, it was also decided to increase the widths of the treadways for a safer approach in order to accommodate vehicle of various treads. The spreader tubes were made lighter, a two-jack cable truss was used under the tubes, and the ends of the tubes were "shouldered" to bear on the corners of the pintle reinforcements. This permitted a reduction in size of tube eyes, pintle reinforcement, and in the "beam" and "column" of the tubes.

During this period, another interesting type of dry raft was proposed. Four "Ducks" were to be tied together with spreader tubes and cables, similer to the two-"Duck" raft. The treadways and trussing had to be deeper and stronger in order to carry the 66,000 pound M-4 tank. The only advantage was the elimination of water sealing difficulties and devices. The idea was not carried beyond the proposal stage, because the necessity of using equipment of greater weight, which placed high load concentrations on the "Ducks", more then offset any advantage gained.

These rafts were all completed under pressure to meet dates for test trials or Army demonstration. On October 2, the first dry raft was tested. The same day, a new design was started—the "teeter" type. Another sample was completed on October 7, which used materials from the original raft, and a test of this was made. Detail refinements were then made, and the raft demonstrated to the Army on October 10th.

"DUCKS" AND BRIDGES

The idea of using the "Duck" for pontoons had been suggested by the Corps of Engineers at Fort Belvoir in June. Later, blueprints of their equipment used in building bridges were received for study by GMC Engineers, who then made tentative proposals. Following the General Motors Proving Ground demonstrations of September 7 and 8, GMC Engineers were requested to study further the application of Army Engineers H-10 highway bridge and the Armored Force Treadway Bridge to the "Duck".

The H-10 bridge was composed of a planked roadway about 11 feet wide, laid on steel box type girders two feet wide, four feet high and twenty feet long. These girders rested on wooden bearing supports laid across the pontoon. Each pair of girders resting on the pontoon was pinned flexibly to adjoining ones, thus facilitating the distribution of load to pontoons.

The center of roadway of the bridge was placed on the "Duck" as close to the center of bouyancy as clearance between the front box girder and the steering wheel would permit. The girders had to be 17¼" above the "Ducks" deck to clear the radiator air outlets. The adopters were steel channel welded and gussetted to a bearing plate at the top and to a load distributing angle at the bottom. The latter was bolted through the deck to lugs, and was reinforced by angles on the inside of the pannels. There were four adopters, each about 40 inches wide, two on either side of the "Duck". They were stiffened laterally by a cross channel bolted to the rear of each adopter. Each "Duck" would support a maximum load of 3,000 pounds, which brought the water line within 6 inches of the deck.

The treadway bridge, as used by the Armored Forces, consisted of two built-up steel troughs, or chutes, about three feet wide by thirteen feet long, and these were surfaced with grilled anti-skid, and laid on inflated rubber pontoons. The GMC adopters, which supported the H-10 bridge, served the same purpose for treadway sections as used in the "Duck" bridge.

Sample sets of adopters were made, and sample "Ducks" fitted to receive them. During the design of the dry raft, it was possible to provide some interchangeability between the dry and wet ferry equipment by using the same spreader bars, pintle locations, etc. Later, it occured to GMC engineers that bridge sections might be built by utilizing many of these same parts, and, as a result, a number of "Ducks" could be equipped and loaded with this equipment to ferry a tank, carry a truck, or build a bridge.

In the design of the GMC bridge, the Army engineer's standard planked roadway, consisting of chess, balks, and clamps, was used. This roadway was laid on top of three GMC spreader tubes, the same as used with wet and dry ferries, just above the coaming, as close to the center of boyancy as its low level permitted. The spreader tubes were laid across the "Duck" on notched adopter angles, which were bolted to the deck and coaming as permanent equipment. Each bridge section could be mounted on a "Duck" at some sheltered spot, and then driven to the water where it could be maneuvered against a current, or over and around obstacles into bridging position. At this time, verticle diagonal cables were hitched to each adjacent "Duck" at the front and rear. These cables were then tightened by hand-adjusted jacks, which were coupled to pintles at the front and rear of each "Duck". The small gap between the support tubes was bridged by channel spacers that rested on the eye ends of tubes, thus providing a continuous surface for roadway chess.

SALT WATER "DUCKS"

On November 7, 1942, GMC sent two "Ducks" to Provincetown, Massachusetts, for ship-to-shore tests. One "Duck" carried "wet ferry" equipment for testing this operation in rough water. The latter demonstration was postponed by N.D.R.C., who then decided two more "Ducks" would be required for an adequate ship-to-shore demonstration.

Cape Cod is reputed to be one of the worst "ship graveyards" on the U.S. Coastline. Here the water runs high, and the cold, from November to March, cuts to the bone. Provincetown, near which the Engineers' Amphibious Command is located, is on the inner shore of Cape Cod Hook. The tests and demonstrations, however, took place on the outer shore, where the vehicle was exposed to the full fury of the ocean.

N.D.R.C. and GMC engineers collaborated on the arrangements of tests, demonstrations, and the instruction of driver crews. The object of these tests was to develop a procedure for loading "Ducks" with men and material from a Liberty Ship. A 105-foot lighter was used in the preliminary trials. After many trials at ship's-side, a method of controlling a "Duck" in rough water while loading was worked out. This was done by keeping the "Duck" pulling on a leash parallel to the ship.

Various sizes of cargo boxes, simulating those normally used to carry engines, shells, etc, were made up and filled with sand. These were handled by nets and slings which were lowered into the cargo space of the "Duck". The addition of flared coamings to later vehicles was a great help in this operation. The use of the "A" frame, designed and built by GMC Engineering, increased the usefulness of the "Duck". The frame was mounted above the winch on the "Duck", and operated by the winch cable. Thus, it was possible to pick up heavy, awkward loads, such as a jeep or 105mm howitzer.

Many trials were held carrying material from ship to inland dump until a procedure was established whereby a "Duck" could handle 10 tons of cargo per hour. Also the "Duck", loaded with men, was tested going into and out of the water, and up sandy slopes of beaches. In addition, the "Duck" pulled a 50-foot lighter off the beach where it had been stranded.

A side trip was made by one of the "Ducks" to Quincy, Massachusetts, where an L.S.T. boat was at anchor. This boat could be opened at the bow, and a ramp lowered into the water. The "Duck" went out, climbed up the ramp into the ship, and then down again. This operation was repeated several times, after which the "Duck" "winched" itself up backwards into the ship.

"DUCK" TO THE RESCUE

On December 2, about 2:00 A.M., a distress call was received at the "Duck" headquarters from the Coast Guard. A Coast Guard yawl, with seven men aboard, was stranded on a reef about 6 miles across the Cape, 150 yards off shore. A 70-mile wind and high waves made the launching of a life boat extremely difficult.

Two "Ducks" were driven over sand and brush to the beach, where a group of coast guardsmen had assembled with life-saving equipment. One of the "Ducks" churned out to the stranded boat, took the seven men aboard, and returned to the beach--the round trip having taken six minutes. The "Ducks" then returned to the boat and removed its anchor, dropping it in deep water for security. By morning, the boat had disappeared, but the men had been saved from possible drowning.

GMC Engineering had six men on hand for the entire four weeks period dealing with a variety of problems under trying conditions. These problems were the feeding, housing and handling of more than 100 men including Army and Navy personnel and civilians. Other problems were the supply of fuel oil for the lighter, oil, gas, garaging and maintenance for the "Ducks", etc.

During the entire period, the GMC "Home Office" was in daily contact with all these activities. Material was made up and forwarded under great pressure, and changes were investigated, tested and released. It is interesting to note that more than 75 different items were being changed or under consideration for change as a result of these tests or directives from N.D.R.C. or Ordnance. Some of these were extensive, and one was revolutionary. This was the centralized control for tire pressure that had been authorized by N.D.R.C., and developed by GMC.

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The demonstration held at Cape Cod on December 6 and 7, was before the largest group yet assembled to see the "Duck" put through its paces. The roster of those present contains the names of high ranking officials from the U.S. Army, Navy, Marine Corps, U.S. Coast Guard, the F.B.I., British Army, Canadian Army, N.D.R.C. and GMC.

Ten "Ducks" were used in this demonstration--two carried observers to ship's-side and four others were preloaded with a cargo of 105mm gun, gun crew and ammunition, in the hold of the Liberty Ship, which was anchored about 3/4 of a mile off shore. Four more were stationed on the beach for loading at ship's-side subsequently. The "Ducks" aboard the ship were picked up by the ship's crane and lowered into the water. They then proceeded to the beach and by roadway to the dump, where the supplies were unloaded.

Demonstrations were made by the "Duck" carrying men and a 105mm howitzer in and out of the water, and up the sandy slopes of the beach. The 105mm gun was then unloaded, pintled behind the "Duck", and drawn over rough terrain.

These operations evoked favorable, though restrained, comments.

As a result, arrangements were made to hold further trials and demonstrations at Fort Story about January 4, 1943, which would involve a much larger group of "Ducks". Four "Ducks" were driven down from Provincetown on December 14,—six more were to come from GMC Engineering, and 23 from the production line. The six from Engineering were supplied with various combinations of special equipment, including the "wet ferry", and the "dry ferry", the central tire inflation system, the latest type air compressor, extended cargo coamings, etc., for special test work. In addition, other kits of some of this equipment were being prepared for subsequent use.

A great variety of tests were made from December 15 to January 15. The initial job was to instruct 34 crews of drivers to handle the "Ducks". A simplified driver's instruction manual was prepared for their use. Tests were made, carrying a medium tank by "wet ferry" in rough water. The tank was pulled by the "Duck" over a sand bar on which it grounded. Trials of "dry ferry", or rafting, utilizing equipment brought from GMC Engineering shop, were made, including the transporting of a truck in which a jeep was carried. A new type of dry raft was made up using wood instead of steel in order to reduce weight, use a noncritical material and made assembly possible on the "Ducks" at ship-side.

The highlight of all these tests was the demonstration on January 5, 1943. While the group of officers attending was not as large as the December 7th group, its decisions were to be of equal import. Twelve "Ducks" were used in competition with twelve landing boats in a ship-to-shore demonstration from an Army transport anchored a mile off shore. The "Ducks" and landing boats were preloaded and started from ship's-side simultaneously to the dump on the beach. The landing boats, however, had 100 men for handling materials who waded out in the water to the landing boats as they came to a stop. A "bucket brigade" was formed to pass the cargo from the boats to a "sand sled", which was then pulled away by a tractor.

As a result, the "Ducks" handled about 50 tons of material in 26-1/2 minutes-- the landing boats required 1-1/2 hours, or 3 times as much time, for handling the same amount of material. A more obvious disadvantage of the landing boat operations was the concentrated grouping of the 100 men who would be exposed to gun fire and weather while unloading the boat.

Coincident with the demonstration, GMC was directed to prepare 100 "Ducks" by February 1 for this work. These were to be delivered as rapidly as possible for shipment to the various fighting fronts, where their tactical value could be developed under combat conditions. Crews were to be trained at Fort Story, and ready to go along with the vehicles.

FURTHER TESTS AND IMPROVEMENTS ON THE "DUCK"

From November 28, 1942, to March 1, 1943, GMC requested Ordnance approval on one hundred and seventy one changes on the "Duck". These changes were the result of increased experience with the "Duck" from a production standpoint as well as the result of tests conducted by GMC engineering in an effort to improve the "Duck" and extend its usefulness. Changes were made on many items and included a new exhaust muffler, revised seat cushions, a revised rudder shaft, demountable brake drums, a new gun-mount, a new type windshield, etc.

As an example of an improvement, the windshield design change will be cited. While the windshield could take the pounding of the ten-foot waves that were encountered on the east coast tests, it failed when subjected to the fifteen-foot waves encountered on the west coast. Revision of the surf plate by extending it to the top of the windshield and strengthening of the top rail and side posts were necessary before the design was considered satisfactory.

Another interesting change was the redesigning of the water propeller case. The first 2500 "Ducks" had a fixed ratio in the case for both forward and reverse speeds. Experience in maneuvering the "Duck", braking its speed and backing up, had shown a higher speed in reverse gear was desirable.

Tests were run in January 1943, at the Rouge Ship Basin to secure data for the propeller case revision. A two-speed case was then designed to permit the use of the regular propeller shaft. Following the completion of the design, GMC built a sample in engineering and installed the new case in a "Duck" for testing. Results of the tests proved that the higher speed in reverse, when used as braking control, substantially improved the water performance of the "Duck".

Following approval by Ordnance, six of the new water propeller speed cases were built up in the GMC engineering shops in advance of production.

THE A-FRAME AND NEW A-V-FRAME

As previously mentioned, the A-frame was a lifting device mounted on the rear of the "Duck" to facilitate loading or unloading other vehicles. The two legs of the A-frame straddled the winch and joined at the top. From the top, two stay cables were run to the front end of the "Duck" and fastened on either side to hold the frame in position. The winch cable was passed through a sheave and snatch block at the top of the A-frame. This permitted the lifting of loads up to 5,000 pounds. Overloading would result in the front wheels of the vehicle being lifted from the ground.

The A-frame was designed so that it could be quickly disassembled and carried in the "Duck". The device was useful not only in handling cargo boxes, jeeps and the 105mm Howitzer, but also the various ferrying devices and bridging equipment that had been designed to be carried in the "Duck".

The original A-frame, as first demonstrated at Provincetown, used round cedar posts as legs fitted with metal connections. A later design used steel pillars made up of sheet metal sections welded together. This design provided increased lifting height which improved the use of the A-frame. The limited supply of steel soon made the use of cedar posts necessary again. Later, when the use of steel was authorized for fifteen A-frame assemblies, the design utilized I-section legs with tubular struts. When a production order for 600 A-frames followed, a simplified design was released using both tubular struts and tubular legs.

A method for utilizing the A-frame to carry a load "on the hook" above the water was worked out. During the operation empty oil barrels were used as pontoons by lashing them to the sides and rear deck of the "Duck". This prevented the "Duck" from tipping over in rough water, which might have resulted from the weight of the swinging load on the hook of the A-frame.

The A-frame was redesigned in April 1944 by GMC engineers and the new design was known as the A-V-frame. This new design used the A-frame in an inverted position. Its apex fitted over a davit eye on the center line of the rear deck at the coaming. One leg was placed in a verticle position and held in place by six cables from its top to two mooring eyes amidship and to four eyes at the corners of the rear deck. The other leg was free to swival horizontally over the cargo compartment swinging through an arc of 90°. A single adjustable cable from the top of the verticle leg held the angular leg in position.

The load was lifted by winch power. The winch cable was directed forward around a standard "Duck" snatch block hooked to the base of the V, thence to and over a pulley built into the outer end of the angular leg. Although the winch power raised the load vertically it was necessary to manualy move the load horizontally by the use of guide ropes attached to the boom.

The A-V-frame had an advantage over the V-frame. The V-frame could be used only to load or to unload other vehicles. The A-V-frame could do this and in addition could handle the cargo of the "Duck" on which it was mounted.

Ordnance ordered two samples of the A-V-frame which were built in the GMC experimental shop. Tests disclosed that loads up to 6,000 pounds could be lifted without tipping the "Duck" but that an additional snatch block was necessary to overcome the 5,000 pound limitation of the winch. The two sample sets of equipment were shipped to Hampton Roads, Virginia, on September 7, 1944.

AMPHIBIOUS TRAILER

Following preliminary discussion with N.D.R.C. in November of 1942, GMC engineers were requested to proceed with the design and building of a sample "two-wheeled boat" for hitching behind the "Duck". Several proposals with drawings were submitted, one with a stepped bottom that would drop between the wheels, a second with a V-bottom design. The later was selected for the final design.

The trailer was to be used to double the carrying capacity of the "Duck" for certain military operations. A cargo compartment duplicating that of the "Duck" was provided within the hull of the trailer whose displacement would result in the same "free board" as the "Duck".

The sample "Duck" trailer built in GMC engineering shops used wood in the construction of the hull. At the time wood could be readily obtained and the sample could be finished in a shorter time and at a lower cost. GMC engineers visited the Gar Wood shop at Algonac, Michigan, for information and data on boat building.

The hull of the trailer was constructed of panels. The material selected was mahogany plywood bonded with resin glue. The parts were nailed and glued together and the completed hull coated with chemiseal waterproofing. A cargo top, similar in design to the "Duck", was mounted over the cargo space.

The bottom of the hull was reinforced and fitted with brackets to take the "Duck" front axle and springs. The axle was first modified by removing the bango housing and driving parts and replacing them with a tubular load-carrying member. Shock absorbers were also provided. A hydrovac cylinder, vacuum tank and master cylinder were piped to the wheels and connected to the "Duck" controls for brake operation while being towed. The trailer hitch was a tubular tripod arrangement fitted at the front with an eye for attachment to the pintle of the "Duck". A supporting leg was hinged to the tripod and when lowered would hold the trailer in a horizontal position when parked alone.

The sample was completed February 9, 1943 and shortly thereafter tested at the Rouge Ship Basin. Tests showed the turning radius of a "Duck", with the trailer attached, to be larger due to the straightening effect of the trailer load. The distance between the trailer and "Duck" was too small resulting in the propeller wash rolling over the coaming of the trailer. Also the turbulence of the water in front of the trailer reduced the normal water speed of the "Duck" considerably.

The sample "Duck" trailer was shipped to Camp Gordon Johnson, Florida, on May 20, 1944. Design changes were planned, but never authorized, to correct the faults found in the trailer during the Rouge Ship Basin tests.

WAKE CAMOUFLAGE

In January, 1943, GMC was requested by N.D.R.C. to adapt wake camouflage equipment to the "Duck". This equipment was to be used to make the "Duck", traveling through the water, more difficult to detect from the air. GMC representatives visited the Woodshole Oceanographic Institute at Woodshole, Massachusetts, where data on wake camouflage was secured.

Using this data, GMC engineers designed the equipment and built six sets in the experimental shop. This equipment consisted of two spray nozzles aimed forward and outward from the bow and a third nozzle in the propeller tunnel aimed to the rear ahead of the propeller. These nozzles were piped from the bilge pumps and could force a mixture, 1 part oil to 1000 of water, through the nozzles and onto the foam as it was formed. The action of the spray from the nozzles on the foam was to break it up and give wave suppression. A control was provided for the driver to put the nozzles in operation.

Further wake concealment was effected by the use of canvas curtains. One curtain hung from a frame at the bow, concealing the waves formed at the bow caused by the forward movement of the "Duck". At the stern, hooks were provided so that the cargo tarpaulin could be trailed to cover the short wake formed by the propeller.

INVISIBLE LIGHT

In February 1943, a "Duck" was delivered to GMC engineering from Fort Story. This vehicle was equipped with infra-red ray lighting. GMC engineers were asked to improve the lighting power plant installation, particularly with reference to noise.

GMC's engineer's response to this request was to reduce exhaust noise by the use of a new type muffler. The power plant was moved into the engine compartment and placed on a new mounting frame to the right of the engine. Battery and fuel tanks were relocated.

The reworked "Duck" was then returned to Camp Edwards, Massachusetts. Stops enroute were made at Cleveland and Princetown for adjustments to the new equipment by the G.E. and R.C.A. companies. Later GMC cooperated in tests made by the General Electric Company at Fort Story and Fort Knox.

TANDEM "DUCK" BRIDGE PIER

Interest in the use of "Ducks" as bridge pontoons and piers was revived during February 1943. The Army had previously had trouble with the single pontoon type bridge which seemed to lack stability. A two pontoon type bridge placed end to end was much more stable. The idea was suggested for "Ducks" which were to be connected stern to stern by a pair of girders.

GMC was asked through N.D.R.C. to design, build and test a new arrangement. As developed by GMC engineering, each girder was split midway between the two sterns and two pins provided for each girder coupling. Screw jacks for elevating the pin ends of the girders above the deck provided a means of aligning holes in the mating parts.

In operation, each "Duck" would be fitted with girders ashore and then proceed to its position in the water where the two ends would be pinned to the last "Duck" in the bridging line. In this manner a series of "siamesed Ducks" would be spaced across the stream to receive the H-10 or the steel treadway bridge super structure.

Two sets of the equipment were made up in the GMC engineering department. This would equip four "Ducks". One set was installed on two "Ducks" and subjected to grilling tests. The rigidity of the "siamesed" structure was proven when the unit was driven over rough ground so that one or more axles of the "Ducks" were at times hung in the air. The second set was used, in addition to the first, in demonstrations in March, on Crystal Lake near Pontiac.

A later proposal, by GMC engineering to N.D.R.C. was also built using a bow to stern hookup. This design separated the propeller wash of the stern to stern arrangement so that the paired "Ducks" had more maneuver ability in strong currents. The truss, of light weight tubular construction, stood up under rough road driving and severe overloading in the water. The latter tests at Ford's Rouge Basin consisted of lowering an M4A3 tank on a platform laid on the trusses. Loads were increased until the decks of both "Ducks" were pushed below the water line without any indication of failure of the trusses. The design of this bow to stern type tandem was further developed as an all-purpose unit to provide wet ferry, dry ferry and for bridging operations.

AIRPLANE LANDING MAT

A landing mat is usually composed of heavy wire woven into a wide strip of considerable length. The use of the mat converts soft or irregular ground into a safe runway for planes or a roadway for vehicles. A means of laying the mats quickly, following landing operations, was made possible by the use of the "Duck".

The installation and demonstration of the equipment was completed during April and May of 1943. GMC engineers cooperated in the installation of the equipment, which had been designed by the Tri-State Company of Washington, Pennsylvania. In operation the mat was carried on a "Duck" with the end pulled over the cab and bow on a frame. By placing the end of the mat under the front wheels, the "Duck" could lay the mat as it proceeded down the field. Thus the "Duck" could start from a ship with the mat on its deck, proceed to the beach and lay the mat over the sandy beach or inland to the air strip as needed.

[illegible]

About the middle of February 1943, N.D.R.C. made various contacts with scientists and manufacturers regarding the latest developments in rocket projectiles. GMC was requested to start work on the application of rocket launchers installed in a "Duck". As a result GMC submitted sketches showing basic arrangements for an installation on a "Duck". The design was approved and work started on a model for test firing and firing controls.

The 4.5 B.R. Launcher as developed for the "Duck" consisted of a "honeycomb" of 120 steel tubes pointing forward and upward from the cargo compartment of the "Duck" at an angle of 45°. A shield extended over the drivers cab to protect the occupants during the firing. An electrical firing box was operated by a "gunner" from the drivers compartment and the 120 rocket projectiles could be fired at split second intervals while the "Duck" was moving at full speed towards the target.

The launching tubes were grouped in longitudinal assemblies or "banks" of ten, supported on a cross rail at the front and rear and held in place by jiffy clamps. The supporting rails were hung from the coaming at each side and were braced to prevent horizontal movement by struts and cables at the front and rear. The complete tube unit could be hoisted out of the "Duck" or each 10 tube "bank" quickly unclamped and handled by two men.

Each "bank" was made by forming ten half tube impressions in steel sheet and welding the halfs together. The "bank" was then strengthened by headers at the top and bottom. Each "bank" had a U-shaped trough at the base to protect the cargo deck from the rocket blast during firing. Burned gases were carried rearward to curved scoops which directed them out of the cargo compartment.

Each tube was swelled out slightly at the bottom to provide clearance for base of the rocket and permit positive contacts between the rocket tail rings and firing contacts. These contacts were leaf springs which were strong enough to hold the rockets in firing position while the "Duck" was in motion.

The compact fire control mechanism was designed by a GMC engineer and patented in his name. It was contained in a metal waterproofed box (10-3/4 x 10-3/4 x 9-3/4 inches) with a hinged cover. Both the feed and fire control harness could be instantly disconnected and the box stowed away. The 41 point plug connector on the box end of the fire control harness was of GMC design.

The firing mechanism provided for continuous or intermittent firing at one half second intervals by means of a motor driven contactor. Firing could be stopped at any point in the firing sequence by lifting the finger from the firing switch.

Hand firing was also possible by means of a spare plug to engage the firing mechanism and fire the rockets as desired. Progress of the firing could be watched through a window in the protection shield to the rear of the drivers cab. Accidental firing was minimized by an indicator light and a safety plug which prevented the closing of the box when the contacts were "alive"

The original launcher design contemplated the use of 144 tubes - 12 "banks" of 12 tubes to the "bank". A sample "bank" was built in GMC's experimental shop and shipped by plane to the west coast on March 13, 1943. GMC collaborated in the successful test held off the coasts on March 17. A complete sample equipment for a "Duck", was then built and shipped to the same place on May 6, 1943. Tests of the equipment on May 19 to 30 revealed some difficulties which were eliminated by minor changes made during the tests. Orders were then received by GMC to build four sets of equipment with all possible speed for tests in the combat area. The last of these were shipped on July 19, 1943. A set was also built and shipped to Camp Edwards on October 6, 1943.

On October 6, 1943, GMC received an order for nine additional sets of the rocket launcher equipment for the "Duck". This was a production quantity and involved 1100 launching tubes with the necessary mountings, firing mechanisms etc. Temporary tools and fixtures were built in haste. Women welders were obtained from production and retrained in the welding of light gauge metals. Delivery had been promised to start in nine weeks and to be completed in thirteen weeks. Actualy, shipments of the finished equipment were completed on November 23, 1943, fully six weeks ahead of schedule.

All of the GMC tools and fixtures were later shipped to a manufacturer who used them to produce the rocket launching equipment in larger quantities.

WOOD PLATFORM FERRY

The wood ferry which GMC had designed, built, and demonstrated at Fort Story, January 5, 1943, was practical but needed improvement. In April 1944, a directive was received to simplify the design and build a sample for test. This was done by reducing the number of pieces and providing accessible external connections instead of internal connections below the platform. No parts had to be welded to the "Ducks" then in use, to accommodate this revised ferry platform.

A sample set of parts was built in GMC engineering but was not tested as a new design was suggested at that time. This newer design utilized treadways built up of wood planks which could be spaced to suit the tracks of various rolling equipment. This eliminated planking between the treadways.

A sample set of the equipment was built during June 1943, and installed on a "Duck". It was never tested by the Army as interest in the project has subsided.

CAMP EDWARDS AND YUMA DEMONSTRATIONS

On June 4, 1943, two "Ducks" equipped for dry ferry demonstration were driven to Camp Edwards, Massachusetts, as directed by N.D.R.C. GMC engineering's representatives cooperated in the various trials, one of which was the transporting of a "6x6" truck from a stranded L.C.T. boat to the beach.

While these demonstrations were in progress, five "Ducks" were being equipped in GMC engineering shops as follows:

DUKW - 002	Dry Ferry	Stern to Stern Bridge Pontoons
DUKW - 003	Dry Ferry	Bow to Stern Bridge Pontoons
DUKW - 004	Dry Ferry	Bow to Stern Bridge Pontoons
DUKW - 134	A-Frame	Central Tire Inflation
DUKW - 147	Dry Ferry	Stern to Stern Bridge Pontoons

These equipped vehicles and the two used in the Camp Edwards demonstrations were sent to Yuma, Arizona, for tests by the Army Engineers Test Board.

GMC engineering representatives assisted with the tests which were held near Yuma on the Colorado River. Beginning July 26, 1943 and continuing for eighteen days the "Ducks" were put through their paces in desert temperature as high as 168°. The Army engineers built the various combination of two and three section tandem pontoons and used the "Ducks" for all kinds of ferrying operations. So impressed were the Army men by the versitility of the "Duck" that it was necessary to leave the vehicles with them for further tests.

AIRPLANE FERRY

The P-38, like most fighter planes, cannot fly to the combat areas which may be separated by vast stretches of water. If carried completely assembled on ship, dockage was necessary to unload the planes. The Army through N.D.R.C. asked the GMC engineering department to assist in the design and building of a rigging to get the planes ashore from ships.

Two "Ducks" were to be used, in parallel, to form a "catamaran". The rigging to be assembled at shipside consisted of spreader bars spacing the "Ducks" and diagonal cables for holding them square. A treadway directly above each inner sidewall of the "Ducks" provided support and a runway for the outside landing wheels of the P-38 tricycle landing gear while a catwalk midway between the "Ducks" supported the nose wheel. Removable treadways could provide ramps to roll the plane off the rigging to the ground.

The center of gravity of the 14,000 pound P-38 plane was placed over the center of buoyancy of the "catamaran". In this position the plane's propellers were at the stern end of the "Ducks". A procedure for unloading the plane from the ship and on shore had to be worked out and dimentions of the plane secured. All this information was obtained by a GMC representative who, on September 3, 1943, had arrived at Charleston, North Carolina, where an Amphibious Vehicle Training Center was located.

Data had to be obtained and drawings made before GMC could proceed with the design layout. As neither the plane nor drawings were available at Charleston a trip by the representative was made to Wright Field, Dayton, Ohio to obtain them. A return trip to Charleston was made on September 15 to obtain approval of the design. It was on this trip that GMC was informed the "catamaran" was to be fitted to carry the P-39, P-40, P-47, P-51, P-61 and A-20 planes as well as the P-38. A second trip to Wright Field was made on September 20 to secure data and drawings for each installation.

Sample parts for the P-38 installation were ordered and fitted to a pair of "Ducks" at GMC's factories in Pontiac and then expressed to Charleston on October 8, 1943. From October 12 to 28, GMC representatives were present at Charleston to assist with the installation of the parts and to observe the trials and demonstrations of the "Duck" "catamaran". One trial was made in strong wind and rough water. A method was worked out to handle a P-38 with wind tips assembled. To do this the "Duck" sterns were against the mother ship in contract to the original position which was parallel to the mother ship. Final demonstrations, on October 28, 1943, were made before a group of high ranking officers whose comments were very favorable.

At conferences held in Washington D.C. on October 29 and 30, 1943, the Army decided that the developments should continue and prepared to issue directives to cover this as well as work on a new but associated project. The latter project concerned the problem of using "Ducks" to unload deck cargo from oil tankers by means of a 50-foot A-frame. This "floating crane" contemplated the use of two "Ducks" in tandem connected rigidly bow to stern. The 50-foot A-frame was to be hinged at the joint between the "Ducks" and a cable arrangement provided to use the winches in handling loads.

During this time development work on the "catamaran" was continued, including investigations of an adjustable platform which would support the landing gear of the various type planes to be carried.

However, work on these projects was discontinued when authorization failed to materialize.

SAILS FOR THE "DUCK"

Following the development of the A-V-frame the thought of using one leg as a mast and the tarpaulin as a sail was suggested. GMC engineers made an installation on a "Duck" by clamping one leg of the frame vertically to the gun mount at the right of the driver and stabilizing it by three stay ropes, from the top of the leg and anchored to the top of the deck. The tarpaulin was rigged to the top of the mast and spread by using the two gaffs as a yard from which the sheet was suspended. Ropes were fastened to the lower corners of the sail and could be used in maneuvering the craft.

A trial on a lake near Pontiac disclosed the idea had possibilities. In a favorable breeze a stalled "Duck" could be brought to shore. The possibility of a noiseless approach to shore was also proven. Work on the project was discontinued when authorization was not received.

"DUCK" ARTILLERY

The "Duck" had been used to transport the 105mm howitzer from ship to shore. By the use of an A-frame it was also used to load and unload the howitzer into and out of other vehicles. On December 23, 1943, a representative of N.D.R.C. requested GMC engineering to investigate the practicability of firing the 105mm howitzer from the "Duck".

A GMC engineer was assigned the task of obtaining data and securing details for the project. Contacts with D.O.D. were made on December 31, with limited success. Contacts were then made in Washington on January 3 with various Army officials. As a result the project was given a top priority at the Aberdeen Proving Ground and an Army Major assigned to follow it up.

On January 4, 1944, at the Aberdeen Proving Ground, a howitzer was placed in a "Duck". The GMC representative obtained the needed data and made sketches from which to design the layout. Under his supervision the A.P.G. personnel worked day and night through January 4 and 5, to complete the rigging. On January 6, the mounted 105mm howitzer was fired from the "Duck" on land. The following day, after several minor adjustments to the mounting, it was repeatedly fired in various combinations of elevation, transverse and powder charges. When fired with a 115% powder charge the "Duck" with its brakes applied was rolled back 21 inches.

Firing was also tested with the "Duck" in the water. The "Duck" was steady for straight firing ahead but was unsteady for transverse firing. Following these tests it was decided to send the first set of rigging overseas and GMC was asked to build a second "kit" and mount a 105mm howitzer in a "Duck" at Pontiac.

Between January 10 and 22, the "kit" was designed, built and a howitzer installed in a "Duck" by GMC engineers. On Sunday the 22nd, it was tested for roadability at the General Motors Proving Ground and on Monday driven overland to the Aberdeen Proving Ground where the howitzer was test fired on Tuesday. In the meantime a cab for the "Duck", to protect the driver's ears during firing, was completed in the GMC experimental shop and shipped to Aberdeen where it was installed on the "Duck".

On January 27th, the "Duck" with the howitzer and new cab was driven to Fort Story, Virginia and left with the Army for tests. On the 25th, GMC was asked to prepare six "kits" for overseas service. One of the sets was ready and picked up by an Army plane on February 2. On the 5th, two "Ducks" were loaded with wet ferry equipment and five howitzer "kits" and then driven to Fort Story, arriving there on the 11th. In the meantime two more "kits" had been ordered, built and were shipped to California on February 16.

Tests at Fort Story began on February 15, and continued until February 27. One of the demonstrations, which included the firing of the 105mm howitzer from the "Duck", was made before a large assembly of high ranking officers including four Brigadier Generals. The climax was reached on February 27, when a demonstration was held for the Army Chief of Staff. The accuracy of fire in surf was improved during the tests. A headrest ring sight and an airplane bank indicator were utilized to correct the fire of the howitzer as the "Duck" pitched through the surf, during the tests.

The howitzer "kit" boxed for overseas shipment weighted 605 pounds and the containing box measured 9-1/2 x 25-1/2 x 66 inches long. The "kit" consists of a sling for lifting the gun in and out of the "Duck", two steel braced hollow wheel blocks, the wood planks for distributing the gun load on the deck, right and left trail support assemblies and two cable harness assemblies to hold the gun tightly to the "Duck". Accessories for the gun, included in the "kit" were a ring type sight, head rest, pitch indicator, auxiliary lanyard, bow and windshield sight, lucite lenses for the headlamps, and bow hatch hold downs.

The "kits" were built and assemblied in the GMC experimental shop. A simple but interesting assembly line utilized many temporary tools which facilitated delivery. An order for 100 "kits" was received on March 21, 1944 and was increased to 201 by April 20. By April 26, 29 "kits" were ready for shipment, but delayed for the inclusion of an instruction manual at the time being prepared by Ordnance. The first shipment of 108 "kits" was made on May 24, 1944 and the entire order was completed and shipped by July 10, 1944.

As the result of GMC's activities on the installation of the 105mm howitzer to the "Duck". Ordnance requested assistance with other projects. The first was the installation and testing of the eight tube rocket launcher on the "Duck" at the Aberdeen and Edgewood Proving Grounds on January 25 and 26, 1944. Also in March 1944, a mounting on the "Duck" was designed to take the 4.2" mortar. This device was tested at the Aberdeen Proving Ground and approved by Ordnance.

"DUCK" ARMOR

The versitility of the "Duck" in the combat areas since 1942 has made it a target for enemy fire. The fire was directed at the front of the "Duck" and in many instances had left the vehicle without power or control. Ordnance had requested GMC in December of 1943, to mockup an armor which would protect the driver and the engine compartment from small arms fire up to 50 calibre. Two mockups were made of plywood to determine how the armor was to be split, fastened, hinged, and made detachable. After visits and criticisms by Ordnance representatives a design was agreed upon which properly covered the areas where protection was needed.

As first designed in GMC's engineering shop, the "Duck" armor was to be made of 3/8 inch thick steel for the head-on plates and 1/4 inch stock for the rest of plates. Both were to be face hardened on the exposed side only.

The total weight of the armor assembly would be 1400 pounds which was to be centered over the front axle. Tests on a "Duck" at Fort Ord, California were made in January 1944, using sand bags to simulate the weight of the armor. As a result of the tests it was decided to reduce the area of protection and reduce the thickness of the bow plates from 3/8 to 1/4 inch stock. This would reduce the weight of the armor to about 1000 pounds.

On February 2, 1944, GMC was requested to develop and make an installation of mild steel armor applicable to all "Ducks". This required a survey of the many changes which had been made in the building of some 10,000 "Ducks" to insure interchangeability. The armor was located in three general areas. (1) the windshield, (2) around the bow, (3) the engine compartment.

The windshield armor was made to fit both the verticle and sloping windshields. It consisted of ten panels, six in the center assembly and two on each side. The six center panels were sloped at an angle of 45° from the top of the windshield to the front deck with a 1-1/4 inch clearance between the armor plate and the windshield. Hinged panels directly ahead of the driver and co-driver had lever control permitting them to be opened for vision ahead or closed for protection. All the other panel joints were firmly fastened and backed up to prevent bullet splash. The entire armor section could be installed in twenty minutes and removed in ten minutes.

The armor protecting the engine compartment consisted of five panels fitted snugly around the bow. A shallow apron, which swept under the nose, was clamped to the chock at the top and bolted to the rub rail at the bottom. On each side two panels, one curving from the front apron, the other extending straight back, were hung flush with the deck and locked in position by the fender eyes. The lower edge of the straight [illegible] sloped upward to the rear of the windshield where it was fastened to the rub rail by bolts.

The armor "kit" was designed so that a minimum number of holes had to be drilled in the "Duck" for its installation in the field. No holes were drilled in the armor nor was welding required for its installation. The heaviest panel weighed 120 pounds and could easily be positioned by two men.

Following the installation of the sample armor the "Duck" was tested on the road and at the General Motors Proving Ground. Its performance was but slightly reduced with the exception of reverse speed in the water. The "Duck" without a cargo load was tipped up at the rear by the weight of the bow armor. This raised the propeller so that a portion of the blades was out of water thus making it less effective in reverse gear. To correct the difficulty a panel was hinged behind the propeller tunnel. In reverse the panel would "dig in" and force a head of water to the propeller. In forward speed the panel dragged on top of the water.

Two sets of face hardened armor, which had been ordered, were built and fitted to a "Duck" in GMC's engineering shops. These were removed from the vehicle and shipped to Camp Gordon Johnston at Carrabelle, Florida, where GMC representatives supervised installations for tests in the surf. In October 1944, GMC engineers were requested to supervise additional installations of the "Duck" armor at Fort [illegible], California.

"DUCK" PRODUCTION AND MANUFACTURE

No attempt is being made here to enumerate in detail the countless difficulties, obstacles and set-backs encountered by GMC Truck & Coach in its efforts to get into volume production on the amphibious truck the "Duck". Without a doubt, many of these same troubles were encountered by many other manufacturers in their efforts to get under way on new war time assignments. The same problems, were confronted which, undoubtedly, were common in all other critical manpower areas. The same difficulties of material procurement which faced other manufacturers of war material were encountered by GMC, and, fundamentally, the same manufacturing readjustments were found necessary. Probably the history of many manufacturers would read about the same when the early stages of war-time production are being described.

At the factories of GMC Truck & Coach, the "Duck" was manufactured in factory space formerly used for production of coaches. It was necessary to clear substantially half the manufacturing space of GMC's plant No. 2 of all equipment, including jigs, cranes, hoists, wiring, piping, etc., for the installation of machinery and equipment for the "Duck".

In the manufacture of the "Duck" it must be remembered that the vehicle presented an altogether different problem, and one for which there was no previous production experience anywhere. It was an entirely new project—with many things completely foreign to normal production practice. A few of the problems referred to above were as follows:

1. The arc welding of thin metal in the production of a hull or boat that was subject to tremendous shock loads from heavy seas presented one of the first problems for GMC from a manufacturing standpoint. Hulls had to be free from leaks and resistant to fatigue failures in the welds which might result from the pounding and twisting of the hull in operation.

2. Another problem was presented by the necessity of assuring tight joints at all the openings, coamings and fittings.

3. Special precautions had to be taken to prevent failures of the electrical system which might be expected when the "Duck" was operating in excessive salt water spray or extreme moisture.

4. The entire gasoline fuel system had to be made leak-proof to prevent fires and explosions.

5. It was necessary to develop a special processing in order to assure protection against corrosion and rust which usually resulted from subjecting the hull alternately to salt water and air on land. Freedom from corrosion in hinges, hatch hold-down bolts and fastenings was a point that had to be particularly watched.

The above were a few of the production difficulties encountered in the buildings of this unique vehicle. The following are a few production highlights which are of sufficient importance to be included in this necessarily brief description of GMC's manufacture of the "Duck".

Extensive use was made of zinc alloy drop hammer dies to form the sheet metal parts, thus effecting a tremendous saving in die cost, and reducing appreciably the blank sizes of sheet metal required to make the parts.

The design and construction of "home-made" spot welding equipment were necessary. GMC utilized available elements of welding equipment belonging to the General Motors Corporation, and this made it possible to secure and put into operation equipment much sooner than would have been possible had standard welding machines been obtained. At the same time, this special welding equipment enabled the GMC factory to secure better welds, increase the rate of production and appreciably reduce the cost.

Offal from the larger panels was utilized to the maximum degree possible for the production of smaller parts, thus saving critical steel.

Many and substantial savings in the cost were effected by methods such as the following examples:

(1) Forming ends on rub rails in place of caps welded on as originally released for production. Making one piece take the place of two or three.

(2) Foremen were called together for meetings once each week to discuss production problems, and were encouraged to make suggestions regarding savings.

(3) The original estimate of all the production labor performed in GMC plants on the "Duck" was 816 hours. The following table shows the actual results secured.

12-31-42	876 Actual Hours	
1-30-43	734 " "	
4-15-43	704 " "	
11-16-43	724 " "	(Tire Inflation Device Added)
7-17-44	542 " "	
12-31-44	489 " "	

Inasmuch as the "Duck" was developed from a simple outline sketch drawn around the "6x6" truck chassis, it is almost obvious that the vehicle had to be improved and refined as production proceeded. The list of changes is many pages long. Approximately 205 changes were released by the Engineering Department in the period from October, 1943, to June, 1944, including such major items as a new bilge pump installation, the addition of hull drain valves, front brake hose protector and wire cutter, improved cargo floor structure, and the adoption of a chrome-type iron manifold to withstand severe operating conditions. Thus, it will be seen that there was no actual design "freeze" at any time. This handicap presented one of the most difficult manufacturing problems.

ASSEMBLY AND WELDING METHODS

When GMC Engineering planned to manufacture an amphibian, it was decided to "mock-up" a wood model. Originally, the plan was to manufacture the complete "6x6" chassis, build a complete hull, drop the entire "6x6" chassis through openings in the hull, and then make arrangements to seal the openings afterwards. It was discovered early that this was not practical, and, therefore, it would be necessary to build only the frame assembly, drop this frame into the hull, and complete the installation of the wheels, axles and the remainder of the chassis.

After the preliminary "mock-up" had been made from wood in the Engineering Department, a number of layout men were transferred from Sheet Metal Layout to the Experimental Department to build a hull. This hull was designed with a welded construction similar to that used on GMC's various coach and truck assemblies.

Since this project was an extremely confidential one, the entire area was enclosed, and great secrecy prevailed while the model was being built. After the first model had been nearly completed, and a letter of intent had been received from the War Department to build this vehicle, a meeting was held in GMC auditorium at which the Production, Engineering and Purchasing Departments were represented. Various problems were discussed, and the schedule was laid out as to the quantity and type of vehicle that GMC was to build. It was explained at the time that there were to be several changes incorporated in the preliminary design, and that the Engineering Department was to build a small quantity of this vehicle experimentally. Production, Tooling and Engineering representatives were then invited to inspect the model which had been completed.

Inasmuch as only 60 days were allowed to produce some of these vehicles, one of the first problems which presented itself was that of tooling. It was immediately decided that the tools would have to be kept to a minumum in order to expedite production. The original intention was to stamp the rub rails in the sides and bottom directly from the panel, but a review of the tooling requirements showed that this would be impractical if deliveries were to be made as scheduled. Therefore, it was decided to follow Engineering's design as originally laid out, and apply the rub rails to the bottom and sides by welding.

At this point, it was necessary to determine the methods to be employed in welding in order to decide what equipment would be required. The Engineering model employed rails running the entire length of the vehicle, and, if this process was to be used, it would be necessary to build large welding fixtures on the line, install guns in these fixtures, and weld completely at that point. This was inadvisable due to the delivery time required and the fact that painting would present a problem. It was desired to have paint sprayed beneath the rub rails and on the attached panels in order to eliminate salt water corrosion.

After much discussion, it was decided that the entire hull would be broken down into major sub-assemblies, and these sub-assemblies would be welded completely in the Sheet Metal Department on existing seam, arc, and other welding equipment. Therefore, a panel would be made approximately half the length of the hull, the rub rails would be applied, as well as the inside posts, and this sub-assembly completely welded. It would then be possible to apply a cap over the joint of these rub rails in the Assembly Department. In this manner, the panel joint could be completely welded at the joint of the rub rails. This also permitted a sub-assembly of the front end panel and of the rear panel.

There were several compound curves included in the original design, and various parts, such as the rear tunnel, were studied with a view of straitening them and making the surfaces wrapped or warped so that they could be more easily formed. Engineering cooperated splendidly in this work, going so far as removing certain sub-assemblies from the hull, having those proposed by Production inserted and conducting water and speed tests in the Lake. After this was done, the pieces were then released for production.

One of the major problems presented was the method of buying the material. Inasmuch as there was considerable footage of the rails on the sides and bottom of the hull, it was proposed originally to set these up as raw materials, and purchase them on the outside as a formed section which could be rolled by various form section companies. This would necessitate an enormous storage problem of raw material, and also would increase the cost per piece as many of the parts have mitered joints, pierced holes, and various formed edges at the ends. It was, therefore, decided that the parts could be manufactured better from the flat material. Sheet Metal would have two or three simple forming dies which could be operated on a brake or punch press, and which could form these sections from the flat material. This would apply to the upper rails, the rub rails, the inside posts and the rails beneath the hull. In this manner, GMC could also use much of the sheet steel which remained from the coach program.

In order to eliminate the necessity of changing all the drawing records at that time, it was arranged that Engineering would release the parts as new material, and Production would figure the size of the material required and route accordingly. The straight panels in the job were to be made on Cincinnati brakes, which would eliminate the necessity for having form dies. It was planned to use the drop hammer and zinc dies as much as possible to form the various panels as this would produce them in a minimum amount of time. Later, it was found that, with Kirkeite available, the various drop hammer dies could be made from this material, which resulted in a smoother panel with fewer wrinkles and more accuracy, as well as a longer-life die.

A meeting was held between the various supervisors involved, and the hull broken down into the various sub-assemblies. It was decided that the side panels would be made in the Sheet Metal Department. The front and rear side panels, and the various wheel pockets would be assembled completely in that department. Also the floor assembly would be broken down into various sub-assemblies and assembled there. Since most of these parts do not have compound curved surfaces, but are merely wrapped or rolled, it was decided to use the various rolling machines in Sheet Metal, and to build bending or rolling fixtures for forming the different panels.

Inasmuch as steel varies in temper to a very great extent and owing to the shortages of critical material, rolling also permitted better forming of the panels since these fixtures could be changed readily and thus with the variation in hardness and spring back of the material a more accurate panel would result.

Experimental sub-assemblies were made up on the major assemblies, and the welding procedures worked out in such a manner that the best possible quality could be obtained. The various jigs were discussed, and the position of welding determined. For example, in joining together the various side panel assemblies on the line, it was decided that, inasmuch as part of the welding would be down hand, part of it horizontal, and some verticle, the pipe positioners, which had been previously worked out on the "8x8", would be utilized on these jigs. This was done, as it permitted the use of a lower quality of operator.

The type of jig utilized throughout the construction of this vehicle was predominately the same as had been worked out over a period of years on coaches, and the construction of this job was very similar to that of some of GMC's all-steel coach models. This fact was borne out by the method of assembly which was carried out throughout the entire program.

JIGS AND TOOLING

The following photographs show 25 steps in the actual assembly and testing of the Amphibian. The index gives the photograph number, as well as a brief description of the operations portrayed. The description will also be found on the back of each photograph. The pictures are arranged in the sequence that was followed on the production line, and the jigs used are clearly shown. Particular attention is called to the hold-down and positioning clamps or jacks which were of GMC design. It should be noted that the main assembly is accomplished in an inverted position. Wherever possible, the hull was positioned so that down-hand welding could be performed instead of the more difficult overhead welding, thus greatly simplifing the operation. This was deemed necessary to obtain as high a quality of weld as possible considering the quality of welders available during that critical period.

Tooling, in all cases, was limited, due to the low quantity of actual orders, and, in many cases, improvised and temporary tools and fixtures were employed. Due to the inadequacy of tools, considerable ingenuity was shown by supervision in the fabrication of parts for the vehicles.

Constant changes in design made permanent set-ups impracticable and short runs necessary. The critical material situation also contributed to the short runs and increased production costs.

DUCK ASSEMBLY - PHOTOGRAPHIC INDEX

PHOTOGRAPH NO.	BRIEF DESCRIPTION
24776-6	Water tunnel welding operation. Two jigs are used for positioning and welding, one in inverted position.
24776-7	Testing of water tunnel for leaks. This is done by brushing a soapy solution over the welded joints and watching for soap bubbles as air pressure is applied at the rear.
24776-2	The 3 panels of the side assembly are positioned in the side assembly jig and welded.
24776	Jig being loaded for the assembly and welding of the understructure, showing water tunnel, front wheel pockets and floor boards.
23303-556	Rear half of understructure in jig showing propeller tunnel.
24776-5	Starting to load the main hull assembly jig, note the understructure of the previous photo being carried to the jig. Bottom halfs are first welded together.
24776-1	Side assembly being positioned to bottom on the main jig.
24776-4	Bow is placed and sides spot welded in place. Note hold down clamps of GMC design.
23303-554	Hull is removed from main jig and turned over by means of turn-over attachments, one of which is shown in the foreground. Men are here positioning the gussets from the inside positions to the cross member in the bottom of the hull.
23303-548	Hull positioned on side. Remainder of welding is performed in this position as it gives a better welding position eliminating vertical welds. Joints are again soap tested.
24776-3	Completed hull is lowered in empty test tank, hold down bars placed across the top of the tank. Space between the walls of tank and the hull is filled with water. Men inside hull mark leaks. Water is drained out of tank and the hull hoisted out as shown by rear "Duck".
24211-6	Hull is cleaned and here shown in spray booth for primer coat of paint.
24211-7	Primer is quickly baked on by a battery of infra-red lamps.

PHOTOGRAPH NO.	BRIEF DESCRIPTION
24776-8	Frame is dropped into the hull and bolted into place.
24776-10	Hull with frame is brought to the wheels and axles by an overhead track. Here the hull is being lowered on wheels.
24776-11	The engine is dropped into the frame. The cab compartment has just been lowered in the vehicle to the rear.
23303-533	Front deck, side and rear coamings, hatch covers and surf boards are next to be installed. The welding of miscellaneous attachments are completed here.
W23884-201	Vehicle enters the paint department for an overall olive drab paint.
24776-13	Final upfitting department. This view shows "Duck" tilted to speed up installation of the drive shafts.
23303-511	Head of the assembly line, "Duck" is driven under its own power from this point directly to road test.
23303-569	Vehicle entering test pool following road test.
24776-9	Ducks in duck bath or test pools. Vehicle at left normally submerged for leak test. Duck at the right is testing propeller, bilge pumps and rudder cables. Note hold back cable which restricts forward motion of the vehicle.
22777-70	Final conditioning department.
24776-14	Final paint is being baked on by infra-red lamps.
2477 -12	Final touch up and stenciling. All equipment is in place - note spare tire. From this point completed vehicle is driven out of the factory.

WELDING ROD PROBLEMS

One of the major problems of the Amphibian Program was the procurement of suitable welding rod in adequate quantities to maintain production schedules. For a long time GMC Truck & Coach had been using, in the Sheet Metal Department and on Truck Chassis Line, a type of welding rod which was particularly adapted to welding sheet metal. Inasmuch as this was an all-purpose rod for both AC and DC, it was originally determined that this was the type of rod to be used. (Westinghouse Sheet-Weld). The entire industry found, with increased war production, that greater quantities of this welding rod would be required for their needs. Demands reached a point where it was no longer available in sufficient quantities to meet all of GMC's production requirements. Therefore, a suitable substitute had to be found. The substitute had to be an all purpose rod, suitable for welding in all positions on both AC and DC equipment.

It was found that such a rod was not available however, a welding rod had been developed by a manufacturer for use on AC equipment for welding sheet metal only. This rod was known as the Harcraft rod, and was stipulated to be used on the production line.

In order to secure an alternate source of material, the Engineering Department worked with the Production Department and various welding rod manufacturers, and another rod was developed which was called Plane-Weld. A quantity of this rod was purchased and tried. It was found that production runs varied to a great extent from the original samples and the degree of skill required by the operators was so much greater with this rod, that it was early abandoned. However, it was found that other rods, such as Fleet-Weld 7, were suitable for welding on DC equipment, although not so well on AC, and quantities of the rods were purchased.

A major problem in the welding program of this vehicle consisted of the large number of engineering changes which were added from time to time due to the development nature of the project. This necessitated the addition of enormous quantities of welding rod, which was not readily procureable on the open market due to the large demands placed upon the arc welding industry. Therefore, various substitutes had to be employed from time to time.

One of the major welding problems in connection with the production of this vehicle was the necessity of having a water proof product. Inasmuch as the lightest material to be used was 16 gauge, and many of these welds were fillet welds, or buttwelds, it was found that the average operator experienced a great deal of difficulty in welding without burning holes through the panel. This caused a great deal of trouble, and was finally overcome by the exact selection of operators for each particular type of work, proper positioning of the welded assembly, and the various changes in design such as change in joint and combination of parts in a manner that the difficult welds could be eliminated as much as possible.

On July 20, 1942, when methods of assembly and welding of the Amphibian hull were initially under discussion, in order to make use of existing equipment, it was decided to spotweld the side panels to the streamers and ribs in the Sheet Metal Department and assemble a capping over the streamers on the line. To check this method an entire side assembly was made up on the seam and pedestal welders in the Sheet Metal Department. The two panel assemblies were then welded together thus making an entire side.

Several Supervisors inspected the side and agreed that the method of priming was not satisfactory and steps were taken to correct this condition. It was decided that the assembly would have to be clamped to eliminate distortion and that the entire assembly would have to be positioned to eliminate vertical welding. It was further agreed that it would be better to use Sheet-weld (Westinghouse) rod rather than Fleetweld #7 rod.

On July 27, 1942, GMC management requested that tests be run to determine the type of arc welder (AC or DC) to be used on the Amphibian line. Six average men welders were used on the tests alternating on both types of welding machines, and making the types of welds used on the "Duck". The conclusions drawn from the tests were that the AC welder would give equal performance with the DC and maintenance should be appreciable better. The purchase of AC Westinghouse Flex Arc Welders was recommended for the job. However, if DC welders could be secured more readily it was agreed that they would do a satisfactory job.

At the January 9th, 1943, meeting held to discuss the anticipated additional order for 5,000 Amphibians, it was stated that welding rod requirements were approximately 150 lbs. per vehicle or a 750,000 lb. requirement for the order. It was stated that, at the time, welding rod was the worst shortage item and that something would have to be done to meet these requirements. Only 1,000 of the anticipated 5,000 had been ordered by the Government, which had reduced the poundage requirements to 150,000 lbs.

Extensive tests were conducted by GMC welding engineers to determine the welding electrodes or rods best suited for work on the Amphibian. A report was submitted on January 16, 1943, showing the results of tests on twenty-three different types and sizes of welding rods. Only six were recommended as satisfactory. The results of these tests did much to eliminate the conglomeration of rods which had been used on the production line. Certain rods were standardized and sizes definitely agreed upon. This greatly aided in clearing up the difficulty which had been experienced in ordering rods in sufficient quantities.

Early in the production program, it was estimated that an average of 150 pounds of welding rod would be needed for the welding of each hull. A later average, based on six months consumption of the rods raised the figure to 195 pounds for each hull. The increased consumption of rod was due to the many changes in the hull, and the addition of numerous attachments for holding tactical equipment. An attempt was made to keep a six weeks' supply of rods on hand; however, occasionally, it was necessary to get an emergency shipment so that production could be maintained.

In order to eliminate the waste of electrodes, a rod salvage department was established. Two women were placed in charge of a crib where the welding rods were issued. New rods were issued to the welders when the stubs of the used ones were turned in. Any stubs left on the floor or in the hulls were removed daily. These were placed in a salvage receptical in the crib. They were constantly sorted and any unused portion of rod was returned to a welder on the production line, who was instructed by the foreman to completely use it. Under normal production, salvage of rods had not been attempted, but due to the difficulty of obtaining them in war-time, it was considered a necessity.

AMPHIBIAN TEST TANKS

One of the problems that early presented itself was that of determining whether or not the vehicle was leak-proof. At first it was thought that the vehicle would not be tested in a body of water, but that certain pilot models would be tested in a nearby lake. With the advent of cold weather this, of course, became impractical. It was originally decided that all welded joints would be tested with air and soapy water, a soap bubble being very easily discernible as a leak. Accordingly, the first sub-assembles were all tested by this air and soap method, and, in addition the completed vehicles were water tested in the lake. The number of leaks was surprisingly small considering the inexperience of the welding operators, and the points causing trouble were quickly eliminated.

It was decided, however, that it would be preferable to have in the plant, two test tanks, one for testing the hull before chassis parts were assembled to it and the other, a final test tank for checking the completed vehicle.

The major problem experienced with the preliminary test tank was that of sufficient depth immersion, since the Amphibian hull covered such a large area and was fairly light in weight. In order to satisfactorily make a test it was required that the hull be immersed as deeply as possible along the sides in order to test the individual joints, therefore, it was found necessary to pull the hull down into the water. The initial attempts were unsuccessful and it was finally decided to install two regular Army Winches, and, by means of cables and pull down bars, obtain the proper submersion. Breather tubes were attached to the vehicle to eliminate air locks in the wheel housings and tunnels. When the correct pull down power, 2,000 pounds on each cable, had been determined the method was found to be satisfactory.

Subsequently, a simplified test tank was designed to eliminate the pull-down equipment and shorten the time required for the hull test. A new tank was constructed on the floor in each of the four production lines to a height of four feet and was built of reinforced steel. Its shape and size were approximately that of the "Duck" hull, but slightly longer and wider. The hull to be tested was lowered into the empty tank, and two steel hold-down bars were securely fastened across the top. The space between the hull and the walls of the tank was then filled with water. Two men inside the hull marked the points where leaks were found. The water was then drained from the tank, the hold-down bars removed and the hull hoisted out.

After the hull had been completely assembled and the chassis, power plant, cab, and equipment installed, the normal immersion was obtained by driving the vehicle into the final test tank. Ramps at each end allowed the vehicle to enter and leave the tank under it's own power. A hold back cable attached to the stern, restricted forward movement of the vehicle. This permitted the testing of the propeller in motion as well as the rudder. Increased production later necessitated the construction of a second test tank. The test tanks have proven essential and have assured delivery to the Government of leak-proof vehicles.

PROCESSING

The Amphibian was a distinct departure from the type of product which GMC was accustomed to producing and it presented several unique processing problems.

This vehicle was proposed for use in salt water and would consequently be subject to severe corrosion. The hull was constructed of approximately 16 gauge sheet metal and was reinforced by the addition of 6 rub rails along the bottom, 4 along each side, made of the same material and extending longitudinally along the hull. The rub rails were formed with a "U" shaped cross section and were fastened to their respective hull panels by spot welding. After the hull panels had been assembled to one another by arc welding there still remained a small open space between the ends of the rub rails of each sectional joint. Consequently a short section of rub rail was arc welded in place to close this gap. After the completion of this weld the interior of the rub rail was absolutely inaccessible for any further processing. It can be seen, therefore, that any protective coatings to be applied would have to be applied either before the rail was attached to the hull plate or at least before the plate sectional assemblies were welded together. This situation presented the major problem.

Ordnance representatives were ready to concede that there was no method of applying an acceptable corrosion preventive to the rub rail interiors and were willing to accept the vehicle without any such protection. Their line of argument was that the "Duck" was intended strictly as a one way conveyance to be used for such things as landings, river crossings in combat use, etc. GMC, however, was convinced that some method could be devised by which these rub rails could be protected, and went ahead in its search for the means and material.

There were two angles from which to approach the problem. The protective coating would have to be applied either before the rub rails were attached to the hull plates or after the hull plate assemblies were made.

The initial attempt to solve this problem was by the first method mentioned above, through the use of spot welding primer. Spot welding primer is a primer that is a conductor of electricity and would constitute no appreciable barrier to the passage of current during the spot welding process.

In general the use of spot welding primer proved to be a complete failure. Several different varieties were tried with the same results. Each different product had its own desirable characteristics, but it was impossible to incorproate all of them in any one product. Some of the outstanding difficulties encountered with the various primers were as follows:

<u>Non-conductivity of dried film:</u> The dried film was such a good insulator that the flow of electrical current was obstructed to such a degree that the quality of the spot weld was definitely affected. This resulted in inadequate welds and spasmotic operation of the welding machines.

<u>Poor corrosion resistance:</u> The primer was such a poor corrosion preventive that its application offered practically no protection against rusting of the metal parts.

Usually when a product has good welding characteristics it lacks the necessary resistance to corrosion and when it has good corrosion resistance it lacks good welding characteristics.

There was one basic fundamental, however, that had to be recognized. In order to produce a sound weld, the temperature of the adjoining metals must be raised above the fusion temperature of the steel. It was evident, therefore, that any spot welding primer would be burned off by the high temperature at the point of weld and that a small portion of bare metal would remain as a starting point for corrosion. To get around this difficulty, it was suggested that GMC seal the welded joints with a material similar to the Dolphinite Sealer used on coaches, by applying it between the metal to be welded before assembly. This procedure met with considerable opposition because of some of the difficulties involved in applying it during the welding process.

After extensive tests a product was selected by the Engineering Department for use in production. This product fell far short of the expectations, but it was probably as good as any tested.

A very short period of its use brought forth numerous objections, principally from the sheet metal production department. The quality of the welds was definitely lower than average and the time involved in assembly was increased to such an extent that it became impossible to maintain the necessary production schedule. The primer tended to build up on the welding tips to the extent that the time for cleaning the machine tips exceeded the time of productivity of the machines. There was also a material waste of copper since the only way to clean the tips was to file them, thus causing them to wear rapidly.

As a consequence of this situation spot welding primer was discontinued completely and production was carried on for a short time with the parts being assembled in bare metal.

It then came to light that the Dolphine Company had a marine battan which could be sprayed over oily metal and was very resistant to salt water corrosion. The only disadvantage in its use was that it had to be applied after the welding had taken place because the welding heat would burn it. This objection was overcome by the use of a spray gun having a long flexible nozzle which could be inserted into the rub rail after assembly and thus effectively rust proof it.

CONCLUSION

As of January 1, 1945, 16,396 Production Units have been completed exclusive of the five (5) Engineering Samples built early in the program. Experience has proven that this type of vehicle is readily adaptable to production methods and in normal times quantity runs would present no serious manufacturing problem.

The obstacles that had to be overcome, due to the nature of the vehicle and the critical conditions that existed for the entire period of the war, might be summarized as follows:

1. Vehicle foreign to normal production items.
2. Still in development stage.
3. No actual design "freeze" at any time.
4. Lubrication sealage against water.
5. Inadequate tooling for economical quantity production.
6. Procurement of material.
7. Adaptation of substitute material.
8. Reworking vehicles to new specifications.
9. Delivery dates set by directives.
10. Manpower shortage.

While it is true that the amphibian chassis has been a major item of GMC's production, still the adaptation of the standard 6x6 chassis for amphibian usage presented numerous and difficult problems. Underwater operation of working parts such as Wheels, Brakes, Axles, Pillow Block Assemblies, Steering Mechanism, and etc., called for lubrication sealing against water.

While the hull was formed and assembled similarly in many ways to GMC coach bodies, however, waterproofing was involved as well as protection against salt water corrosion. The unusual contours and welded construction of the hull greatly complicated its manufacture.

The GMC Manufacturing Division, as a whole, contributed to the development and improvement of this important military vehicle. All departments played a major part in the production job that has been accomplished. In some cases costs have, by necessity, been excessive due to the time limitations imposed and the fabrication of parts by hand and tool-room methods, while on the other hand, economy had been exercised in regard to dies and tooling because of the uncertainty of actual production quantities. Improvised and temporary tools and fixtures were created to make possible the delivery schedules set by directives.

Parts, Material, and Equipment, were delivered to the lines in sufficient quantities to avoid gaps in production. This was accomplished, in these difficult times, only after the closest and the most zealous follow up. The constant revision of requirements caused by the constant changes in specifications with immediate procurement in many cases a requisite, made this accomplishment even more outstanding.

The National and Local manpower shortage of skilled labor, in particular, welders, and the continuous loss of experienced workers to the armed forces, was a decided handicap to this program. Expensive rework operations caused by defective materials, such as the steel received for forming the rear tunnel assembly, were primarily due to the critical conditions of the period. The fabrication of parts and assemblies, normally purchased, presented major problems.