Report 1866

LARC 5-7X GAS-TURBINE APPLICATION

by

Samuel M. Hickson

August 1966

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
FORT BELVOIR, VIRGINIA

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LARC 5-7X GAS-TURBINE APPLICATION

Task 1M443012D25605

August 1966

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The Commanding Officer
U. S. Army Engineer Research and Development Laboratories

Prepared by

Samuel M. Hickson
Marine and Bridge Division
Military Department

SUMMARY

This report covers studies and tests of an experimental gas-turbine installation in a prototype LARC 5. A principal feature of the experiment was determination of a satisfactory method of handling large quantities of engine aspiration air and exhaust gases without taking in excessive amounts of sea water. This is likely to occur when the vehicle is operating in high surf during amphibious resupply operations. The LARC 5 prototype was used as a typical vehicle because of its immediate availability and the store of test information compiled during its recent development. The Pratt and Whitney ST6B turbine, secured on loan from the manufacturer, was installed as a typical turbine which had a good record of reliability in the power range desired.

The investigation consisted primarily of the accumulation of 400 operating hours in the environment of an amphibious operation. This included 100 hr accumulated in engineering design test by the Consolidated Diesel Electric Corporation, Stamford, Connecticut, the contractor for the detail design and installation, and 300 hr accumulated in component development test by U. S. Army Test and Evaluation Command at Fort Story, Virginia. Some additional tests were conducted by USAERDL before and after modification to the exhaust system. The investigation began in May 1963 at USATRECOM and was transferred in June 1964 to USAERDL with the Surface R&D Mission. The work was completed and the turbine was returned to the manufacturer in January 1966.

It is concluded that:

a. The Pratt and Whitney ST6B gas-turbine application to the LARC 5-7X was entirely successful within the scope of this investigation.

b. Much worthwhile experience was gained to aid in future turbine applications to amphibian vehicles.

c. The method of handling the large requirement for turbine aspiration air proved satisfactory, although some means of filtering the oil from the air seem desirable.

d. Both methods of handling the turbine exhaust gases were satisfactory as far as the turbine performance was concerned. The system as installed at USAERDL is considered superior because of its lighter weight,

its reduced cost, and the fact that it relieved congestion in the engine compartment.

e. The lack of test operation in extreme surf conditions leaves some doubt as to ultimate performance of the aspiration and exhaust systems, but the indications are that little else could be done to insure success in future applications.

FOREWORD

Authority for the investigation covered in this report is contained in Task 1M443012D25605, "Amphibian Concepts and Designs (U)." A copy of RDT&E Project Card 1D443012D25605 is presented as Appendix A to this report.

The investigation was made from May 1963 through 15 April 1966.

The design, installation, and tests reported herein were conducted by S. M. Hickson, Project Engineer, under the supervision of F. X. Stora, Chief, Marine Branch, and Ira S. Varner, Chief, Marine and Bridge Division, USAERDL.

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I. INTRODUCTION

1. Subject. This report covers studies and tests of an experimental gas-turbine installation in a prototype LARC 5. A principal feature of the experiment was determination of a satisfactory method of handling large quantities of engine aspiration air and exhaust gases without taking in excessive amounts of sea water. This is likely to occur when the vehicle is operating in high surf during amphibious resupply operations. It was also considered that the operating experience gained from this installation would lend reliability to future amphibian applications which would require more horsepower and minimum weight. The LARC 5, typical of current and future amphibians, was immediately available and easily adaptable. This amphibious vehicle had recently been tested with conventional power plants; therefore, it made an excellent test bed. The intention was not that turbine power would be substituted for conventional diesel power in the current production model LARC.

2. Background. Investigation of the feasibility of gas-turbine power for amphibian vehicle use began with a study produced by the Ingersoll-Kalamazoo Division, Borg-Warner Corporation, in November 1958. Based on suggestions made in this study and the LARC 5 development authority, Project 9R57-02-018-03, two vehicles, LARC 5-6X and LARC 5-7X, were delivered with the GMT-305 automotive turbine built by the Allison Division of General Motors Corporation. This turbine was in its early development stage and, because of related development problems, failed to operate reliably. Consequently, the test program was cancelled before any usable data were produced. Experience up to that time, however spasmodic, gave some direction for future use relative to the handling of the aspiration air.

In December 1962, a proposal was received from Consolidated Diesel Electric Corporation for the resumption of the program by installation of a different turbine in one of the prototype LARC 5 vehicles. In May 1963, Contract DA 44-177-AMC-44(T) was awarded on a fixed price, with Consolidated Diesel Electric Corporation absorbing approximately one-half of the cost. The contract specified that the contractor would perform necessary engineering design, hull modification work, and the like, for the installation of an ST6B gas turbine in the LARC 5-7X. The contractor secured the turbine on loan from the manufacturer, United Aircraft of Canada, at no cost.

The turbine was installed, a 100-hr engineering design test was completed, and the vehicle was prepared for delivery in July 1964.

In June 1964, the contract and the project were transferred from U. S. Army Transportation Research Command (USATRECOM) to USAERDL as part of the Surface R&D Mission.

II. INVESTIGATION

3. Description. The LARC 5-7X (Fig. 1), which has an aluminum hull, is an amphibious vehicle 35 ft long, 9 ft wide, 9 ft high, and has a net weight of 17,950 lb. It is capable of transporting 10,000 lb of cargo at 35 mph on land and 10 mph in water. On land, the vehicle is rigidly supported on four large low-pressure pneumatic tires.

a. Power Train. The vehicle was powered with the Pratt and Whitney ST6B gas turbine, manufactured by United Aircraft of Canada. This engine is considered to be representative of any gas turbine with respect to its airflow characteristics. It is a conventional split shaft turbine, nonregenerative cycle, is governed to deliver approximately 300-hp burning diesel oil, weighs 285 lb, and has a fresh water wash system. The 6,230-rpm output shaft speed is reduced to 3,115 through a gearbox especially made to mount on the torque converter transmission input housing. From this point, the power train was not changed in any respect from the original design except that a production LARC 5 29-1/2 D x 30 P propeller was used in lieu of the 30 D x 25 P.

b. Air Aspiration System. The basic concept for inlet air handling in this design is one utilizing the main body of the hull under the cargo deck as a plenum chamber for separation of air from sea water and other contaminants which might otherwise be injurious to the turbine. To avoid or minimize temperature rise in the aspiration air, the annular turbine air inlet screen was shrouded, and two ducts, one on each side, were provided to carry the air through the engine compartment aft from the hull plenum (Fig. 2). Air flows into this plenum chamber through openings inside the driver's compartment (Fig. 3) and ducts which extend up to the top of the forward cargo well bulkhead. The openings inside the driver's compartment are provided with a sliding closure so that in cold weather and when sea conditions are favorable (the only times the openings are closed), the crew will not suffer from the draft. When these openings are closed, alternate openings in the coaming below the side windshield (Fig. 4), fitted with louvered closures, are opened. Because the normal

Fig. 1. LARC 5-7X at Fort Story, Virginia, site of component development test.

Fig. 2. Turbine installation facing aft.

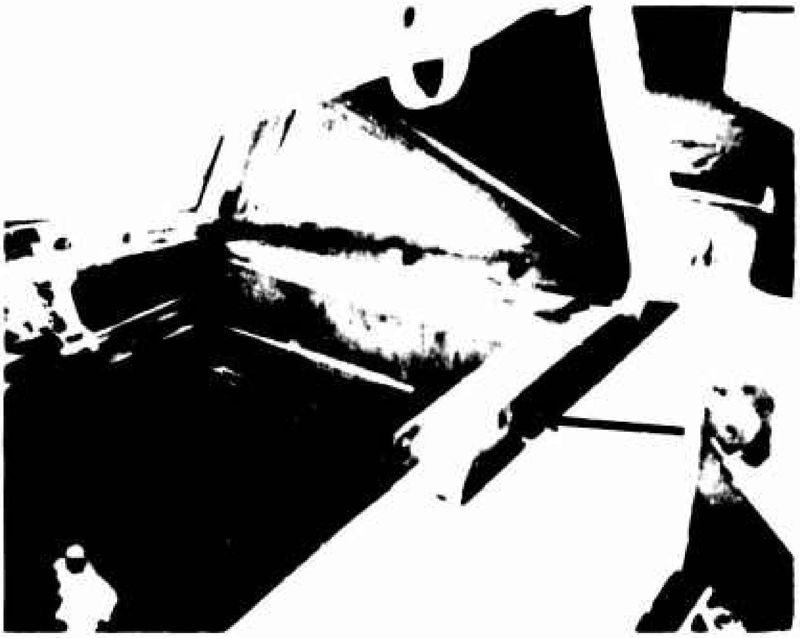

Fig. 3. Cockpit air inlet openings.

Fig. 4. Auxiliary louvered air inlet opening.

maximum airflow requirement at sea level and other standard conditions is 5.3 lb/sec (4,160 cfm), the air was boosted through the hull by two hydraulic motor-driven fans capable of handling approximately 7,500 cfm each, thereby maintaining a minimum pressure of -2.8 in. of water at the turbine inlet screen. These booster fans are installed behind oil radiators; one fan cools the turbine lubricating oil and operates continuously, and the other fan operates only during land operation for cooling the torque converter oil. The excess air over that required for turbine aspiration ventilates the engine compartment and exhausts through the exhaust stack eductors as described in the following paragraph.

c. Turbine Exhaust System. Two exhaust systems were tested during this investigation; one system was developed and delivered by the contractor, and the other system was designed by the author and fabricated by the USAERDL machine shop. Each system consisted of two ducts, one on each side, because the engine had dual side outlets from the combustion section.

(1) The system delivered by the contractor (Fig. 5) consisted of a 90° elbow with a nozzle fitted into an eductor tube. This large-diameter eductor tube extended forward where it turned upward and made a transition from a circular section to a rectangular section to terminate in a tapered flange. This matched and joined a section attached to the hinged hatch cover and simultaneously made a 90° turn outboard as it passed through the hatch. With this system, the exhaust was more or less straight up when the hatches were open.

(2) The system installed at USAERDL (Figs. 6 and 7) was considerably shorter, more direct, and lighter in weight. The line of the exhaust was angled up, aft and outboard, and passed through the corner of the engine compartment coaming between the hatch and the side deck. The elbow attached to the engine was fitted with a nozzle which extended into the eductor tube which, in turn, extended straight into a sleeve that was welded into the coaming (Fig. 6). This sleeve was fitted with a hinged cover which was counterweighted to reduce resistance to the gas flow in order to prevent entry of water when the engine was not running (Fig. 7).

4. Test Procedure. In order to satisfy the objective of this investigation, the Project Engineer planned that a total of 400 operating hours would be accumulated on the turbine in a salt-laden atmosphere with occasional passage through surf, up to 10 ft in height, if possible.

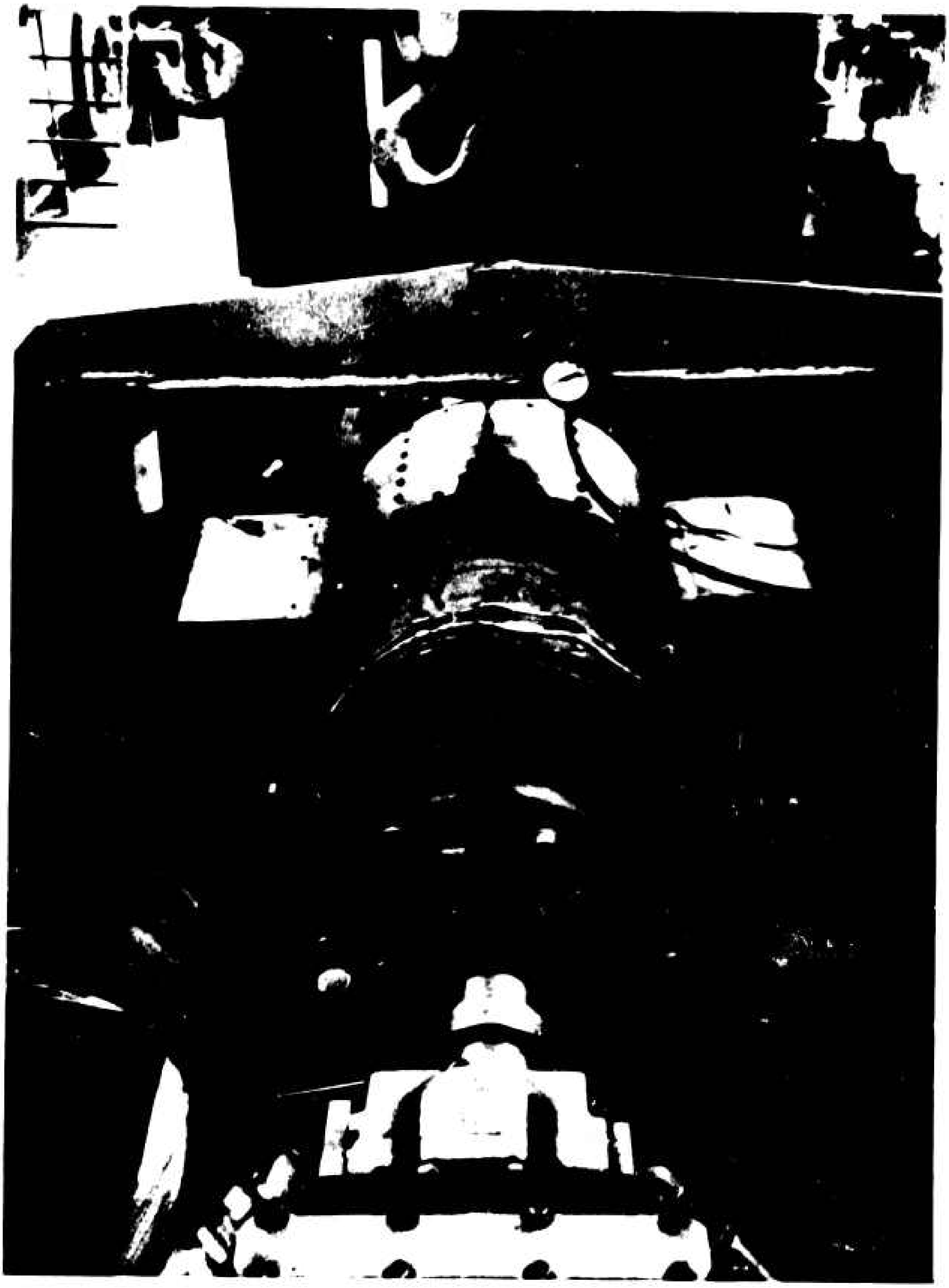

Fig. 5. Original exhaust system.

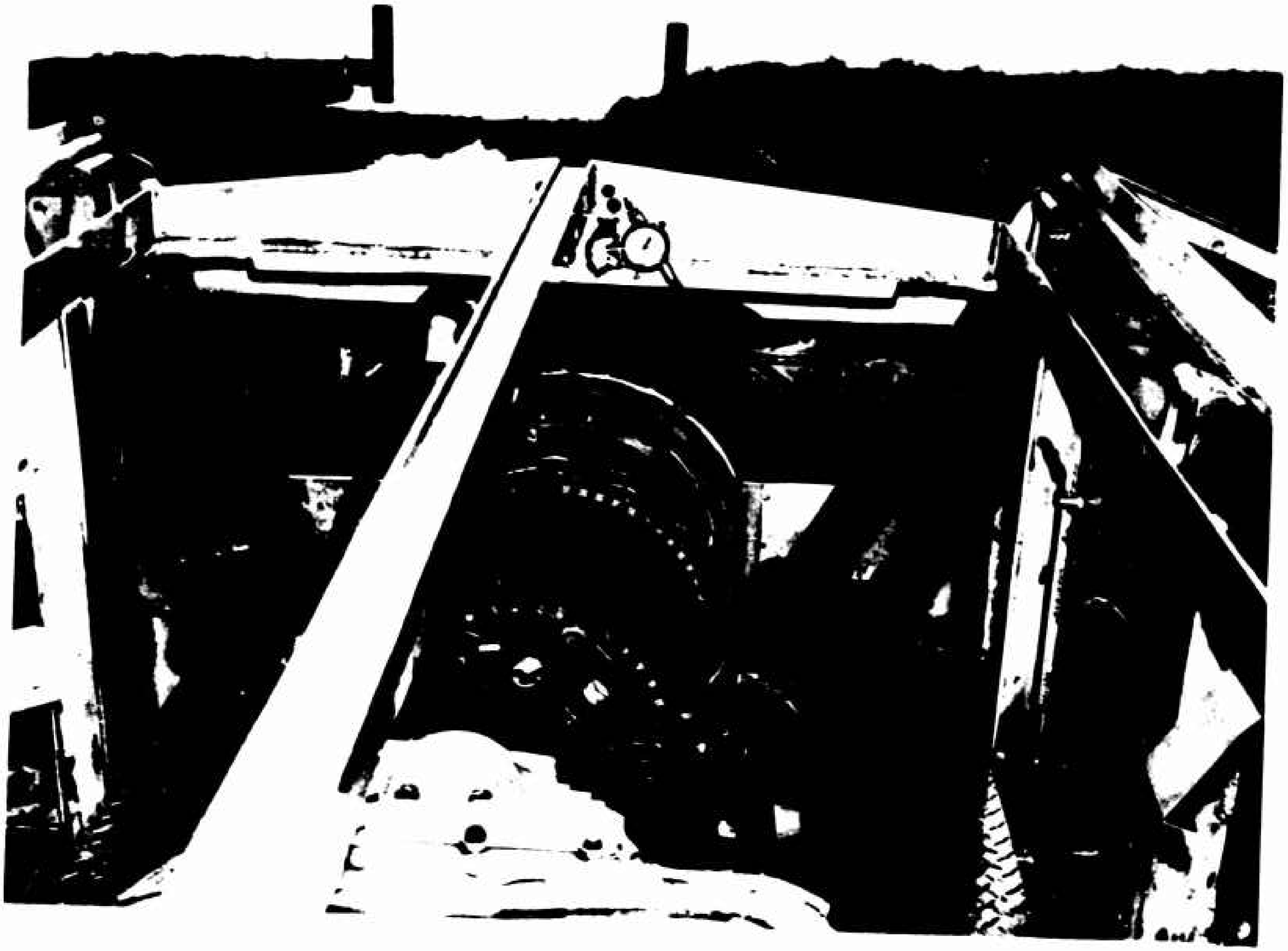

Fig. 6. Modified exhaust system, facing aft. M10311

M10314

Fig. 7. Modified exhaust system.
Note: Hinged covers open only when turbine is running.

The first 100 hr of engine time were accomplished by the contractor in performing an engineering design test of the installation. The test was planned primarily to solve problems and establish readiness for further testing by the Government. Testing was started in November 1963 and was completed in June 1964. The report of the 100-hr test on LARC 5-7X can be found in USAERDL, Marine Branch files. After this test was completed the turbine was removed from the vehicle and shipped to the manufacturer for inspection.

Following the manufacturer's inspection, the turbine was reinstalled and operationally tested. On 7 August 1964, the vehicle was made available to the U. S. Army Test and Evaluation Command at Fort Story, Virginia, for a 300-hr component development test. The test was performed on a safari basis by Development and Proof Services, Aberdeen Proving Ground, in accordance with the "Test Plan, LARC 5-7X Gas Turbine Powered" (Appendix B), prepared by the Project Engineer. The General Equipment Test Activity, Fort Story, Virginia, furnished administrative support, local procurement of repair parts, fuel and lubricants, maintenance assistance, and the necessary escort and rescue vehicles. Work was performed at Fort Story because the location more nearly approximated the environmental conditions required. It was realized that surf heights would probably not exceed 5 or 6 ft even during the storm season, but fund limitations prohibited surf testing in more remote areas. The test officially began on 19 August 1964 and was completed on 3 July 1965; however, because of two successive engine failures through no fault of the engine, delays were experienced, and the test did not really begin until 1 May 1965.

When the test phase at Fort Story was completed, the LARC 5-7X was shipped to Fort Belvoir where it arrived at USAERDL on 14 July 1965. The vehicle was checked, some necessary repairs were made, and portions of the engineering design test, primarily standarization tests, were rerun to determine losses, if any, in engine and vehicle performance. Because surf operation at Fort Story did not prove to be of any consequence, a simulated plunging wave test was conducted in the USAERDL boat basin.

After modification to the turbine exhaust system, the turbine and vehicle performance was again checked, and the simulated wave test was rerun. This work was finally completed on 21 December 1965.

During the water and surf operation at Fort Story, observations were made of the maximum wave height, and measurements were made of the amounts of water, if any, that were taken in through the turbine air inlet opening and the exhaust duct openings.

During all operation, the turbine performance was monitored periodically with respect to power level, turbine speeds, exhaust temperatures, air inlet temperatures, air inlet pressures, and exhaust pressures. These readings were taken from the vehicle-mounted instruments.

An engineering design test conducted by the contractor prior to delivery established operating parameters for the turbine installation and performance characteristics of the vehicle. The significant performance characteristics of the vehicle, that is, water speed, power requirement, and fuel consumption, were reestablished at USAERDL before and after modification of the turbine exhaust system.

5. Method of Test. In order to meet the requirements of the test plan, the LARC 5-7X and its components were tested as follows:

a. Turbine Performance. The hours of operation during the test were divided into 75 percent water operation and 25 percent land operation with power level at maximum or nearly maximum at all times. During these hours, turbine performance was monitored periodically with respect to the following:

(1) Compressor Turbine Speed (N_1) and Power Turbine Speed (N_2). These were both read in percent of maximum on a common indicator with a three-position toggle switch spring loaded to hold the N_1 position.

(2) Turbine Output Torque. This was read in pounds per square inch difference from the hydraulic torquemeter built into the planetary reduction gear. Readings were made from a panel-mounted differential pressure gage.

(3) Exhaust Gas Temperature. The turbine was equipped with four thermocouples; two were located in each of the two exhaust outlets. Average temperatures were read from a single meter calibrated in $^{\circ}$F and $^{\circ}$C with a limit switch built in which was wired to shut down the turbine in the event of an overtemperature.

b. Turbine Aspiration System. The following ambient conditions were recorded:

(1) The air temperature into the system and into the turbine inlet screen was measured with one thermocouple mounted beside the operator at the forward intake and another one mounted in the duct around the turbine inlet screen. Readings were taken from panel-mounted meters in the operator's cab.

(2) The atmospheric pressure drop was measured in the duct at the turbine inlet screen with a Pitot-tube pickup transmitting to a panel-mounted Magnahelic gage calibrated in inches of water.

c. Turbine Exhaust System. The exhaust pressure produced by the eductor nozzle was measured by a static tube pickup located at the flange of the elbow on one side of the engine exhaust port. Readings from this point were taken in two ways, with a Magnahelic gage calibrated in inches of water and with a standard "U"-tube water manometer.

d. Simulated Surf Test. Because only light surf was encountered during the 300-hr test at Fort Story, a test which used a large pneumatic-tired front-end-loading construction machine was devised. Its bucket was made watertight and filled with approximately 450 gal of water, and the vehicle was placed over the bulkhead in the boat basin. The bucket was raised above the water a height of about $14\frac{1}{2}$ ft to the top edge and then dumped onto the stern deck, engine hatches, and turbine exhaust outlets of the LARC, moored with its stern to the bulkhead. This was done several times with the turbine running at various speeds while the exhaust temperature, the exhaust back pressure, and the compressor turbine speed were closely observed for any change. This test was conducted for the exhaust duct arrangement as originally installed and repeated after modification at USAERDL. Both times, motion pictures were taken from various angles and at various speeds for study of the exhaust and surrounding water flow patterns.

e. Vehicle Water Speed. Water speed tests were conducted in light condition, 18,050-lb displacement, and in loaded condition, 28,050-lb displacement, timed with two stopwatches over a measured course. The course was 339 ft in length, with two well-defined targets at each end, located in smooth deep water with no current. This area was in the recently dredged channel adjacent to the USAERDL boat basin. Time over the course was measured for four passes at each of four turbine output shaft speeds, that is, 25 percent, 50 percent, 75 percent, and 100 percent.

f. Vehicle Power Requirement vs Water Speed. At each of four turbine output shaft speeds torque meter pressure readings were taken for conversion to shaft horsepower (SHP). The following formula was used:

$$SHP = 13.10 \times T(PSID) \times N_2(\%)$$

where

T = Pressure drop in pounds per square inch differential
N_2 = Power turbine speed, percent of maximum
13.10 = Engine manufacturer's experimentally determined constant

g. Fuel Consumption vs Water Speed. In loaded condition at each of four turbine output shaft speeds, the time required to use 5 gal of fuel was measured with a stopwatch. The fuel was measured into a glass container, and the fuel supply line was interrupted between the engine fuel pump and the electric fuel booster pump, with both ends of the line fixed in the container. With this arrangement the container of fuel could be maintained at the proper level until the timing started and could be refilled at the exact time the container emptied and timing was stopped. These data were then converted to gallons per hour and pounds per horsepower per hour.

6. Results of Tests. The tests performed in accordance with the previous procedures and methods resulted in the following data and information:

a. Turbine Performance. During the first 100 hr of operation accumulated by the contractor, the turbine ran without any difficulty. At the start of the component development test, considerable difficulty was experienced with the automatically sequenced starting system. When the turbine failed to start on several occasions, a lengthy procedure by test personnel failed to locate causes of such failures. These difficulties might have been the results of many possibilities, one of which was the lack of experience which existed with the new crew assigned. Failures were found to center around unreliable lubricating oil pressure switches and poor connections to the overtemperature limit switch. When these problems were solved and everything appeared to be in order, the test operation began. On 26 August 1964, after approximately 45 min of water operation, the turbine was observed to emit a series of low-frequency explosions followed by loss of power. This condition is termed a "compressor stall" by the manufacturer. With the assistance of the manufacturer's service representative, the turbine was removed from the vehicle and disassembled for inspection. Examination of the turbine revealed that several of the inlet nozzle guide vanes were burned away, power turbine blades were damaged, and the combustion chamber cooling air holes were plugged with salt. These conditions occurred because a small hatch in the cargo deck, located directly over the open ends of the turbine air inlet ducts, had not been fastened securely and had allowed large quantities of sea water to be drawn into the turbine as water washed over the after section of the cargo deck. This incident necessitated return of the turbine to the manufacturer for overhaul and caused interruption of the test program.

On 1 October 1964, after the turbine was overhauled, it was reinstalled, and preparations were completed for resumption of the test. During preliminary test runs on the beach, the oil pressure line from the engine torquemeter to the differential pressure gage vibrated off its fitting. Thus, loss of all the engine lubricating oil occurred and resulted in severe damage to the planetary reduction gear. It was believed that damage to all other bearings in the turbine would be found because of the obvious contamination of the oil. Once again, the turbine was removed and shipped to the manufacturer for overhaul.

After considerable delay because of divided responsibility for cost of the overhaul, the turbine was returned to the test site and reinstalled in the vehicle on 28 April 1965. Immediately prior to the reinstallation, changes were effected to the forward air inlet openings and to the turbine starting system. The change to the air inlets allowed the driver to make selection of air from outside the cab as well as inside. The change to the starting system eliminated the troublesome features of the automatic sequencing by installation of manual switching for starter engagement, ignition, and fuel admittance. The operator now visually determines from indicated cranking speeds the proper time for fuel admittance and observes gages for low oil pressure and high exhaust gas temperature. If either of these conditions exist, the start is aborted by releasing the starter switch and closing the fuel shutoff. Formerly, sequencing was accomplished with a speed-sensing switch driven from an engine power take-off. Oil pressure and temperature limit switches would interrupt the starter and fuel control circuits in the event of low oil pressure or high exhaust temperature.

The component development test was resumed on an overtime schedule and continued for the planned 300 hr without further significant incident. The table, p. 15, shows typical readings recorded during the 300 hr of operation. The complete report of the component development test of the LARC 5-7X can be found in the files of USATECOM.

Typical Instrument Readings

N_1 (%)	N_2 (%)	Torque (PSID)	Inlet Temperature (°F)	Exhaust Temperature (°F)	Compartment Temperature (°F)	Ambient Temperature (°F)	Inlet Pressure (in. H_2O)	Exhaust Pressure (in. H_2O)
96	100	22.5	82	1050	130	50	3.0	--
98	100	25.0	85	1050	130	42	3.0	--
95	100	22.5	75	980	140	62	3.0	5.0
97	100	27.5	65	1000	120	55	3.2	5.0
96	100	25.0	75	975	140	55	3.0	5.0
98	100	25.0	70	975	140	50	3.5	5.5
96	100	25.0	72	950	120	55	3.0	5.0
--	100	22.6	95	1075	145	75	--	--
--	97*	23.0	43	1100	--	32	4.0	8**
--	100	23.7	--	1050	110	45	--	5**
85	75	18.0	98	975	128	52	1.7	--
85	75	16.0	80	900	135	60	2.0	3.0
85	75	18.0	80	900	125	60	2.0	3.0
85	75	16.0	80	900	125	53	2.0	3.0
85	75	17.5	75	890	120	48	2.0	3.7
83	75	15.0	65	875	100	50	2.0	3.0
--	75	17.5	--	--	--	75	--	--
--	75*	13.0	40	975	--	32	2.7	4**
--	75	16.5	--	975	80	45	--	0.5**
70	50	8.0	80	900	125	48	1.0	--
70	50	10.0	80	890	120	50	1.5	--
70	50	10.0	80	890	120	50	1.6	--
70	50	10.0	60	875	110	50	1.0	--
71	50	9.7	90	875	130	52	0.8	--
70	50	10.0	78	850	120	52	1.0	1.5
--	50	10.0	--	--	--	75	--	--
--	50*	5.0	42	925	--	32	0.9	**
--	50	10.0	--	925	75	45	--	**

Note: Hyphens signify no data were taken.

* Loaded displacement

** Modified exhaust

b. Turbine Aspiration System. Because only light surf was encountered during the 300-hr component development test, no measurable amount of sea water was taken into the hull through the louvered outside air inlet openings at any time. The inside air inlet openings were sufficiently protected behind the windshield and, therefore, did not take in any water. The turbine air inlet atmospheric pressure drop at maximum power was 3.0 to 3.5 in. of water. Typical readings are shown in the table for different turbine speeds.

c. Turbine Exhaust System. As was true of the air aspiration system, because the vehicle encountered only light surf during the component development test, no water was taken aboard through the exhaust duct openings. The maximum exhaust back pressure recorded at maximum turbine speed was 5.0 to 5.5 in. of water with the original duct system. Typical readings of exhaust back pressure taken at various turbine speeds are shown in the table. No water was taken aboard through the exhaust ducts during the simulated surf test, and no change in exhaust back pressure, exhaust temperature, or turbine speed was observed with either the original duct system or the modified duct system. Visual results of the tests are recorded in USAERDL Motion Picture No. RF 2113, "Simulated Surf Test, LARC 5-7X."

d. Vehicle Water Speed Tests. In the light displacement condition, 18,050 lb, the maximum average water speed attained was 10.38 statute miles per hour at a torque converter input speed of 3,020 rpm (97 percent N_2). The converter was locked up, and a propeller speed of 893 rpm resulted. In the loaded displacement condition, 28,050 lb, the maximum average water speed attained was 9.93 statute miles per hour at a propeller speed of 893 rpm. Results of these speed tests at various propeller speeds are shown in Fig. 8.

e. Vehicle Power Requirement vs Water Speed. In the light displacement condition, at the maximum speed attained, 10.47 mph, the turbine was producing 272 shaft horsepower as calculated from the differential pressure gage reading of 21 psi and 99 percent N_2. In the loaded condition, 292 shaft horsepower was produced (23-psi differential and 97 percent N_2). Power requirements for other speeds are presented in Fig. 9.

f. Fuel Consumption vs Water Speed. At the maximum loaded speed attained, the turbine consumed the 5-gal-test quantity of diesel fuel in 7 min 20 sec (7:20) or 41 gal/hr. The specific fuel consumption calculates to 0.98 lb/hp/hr. Consumption at other speeds is shown in Fig. 8.

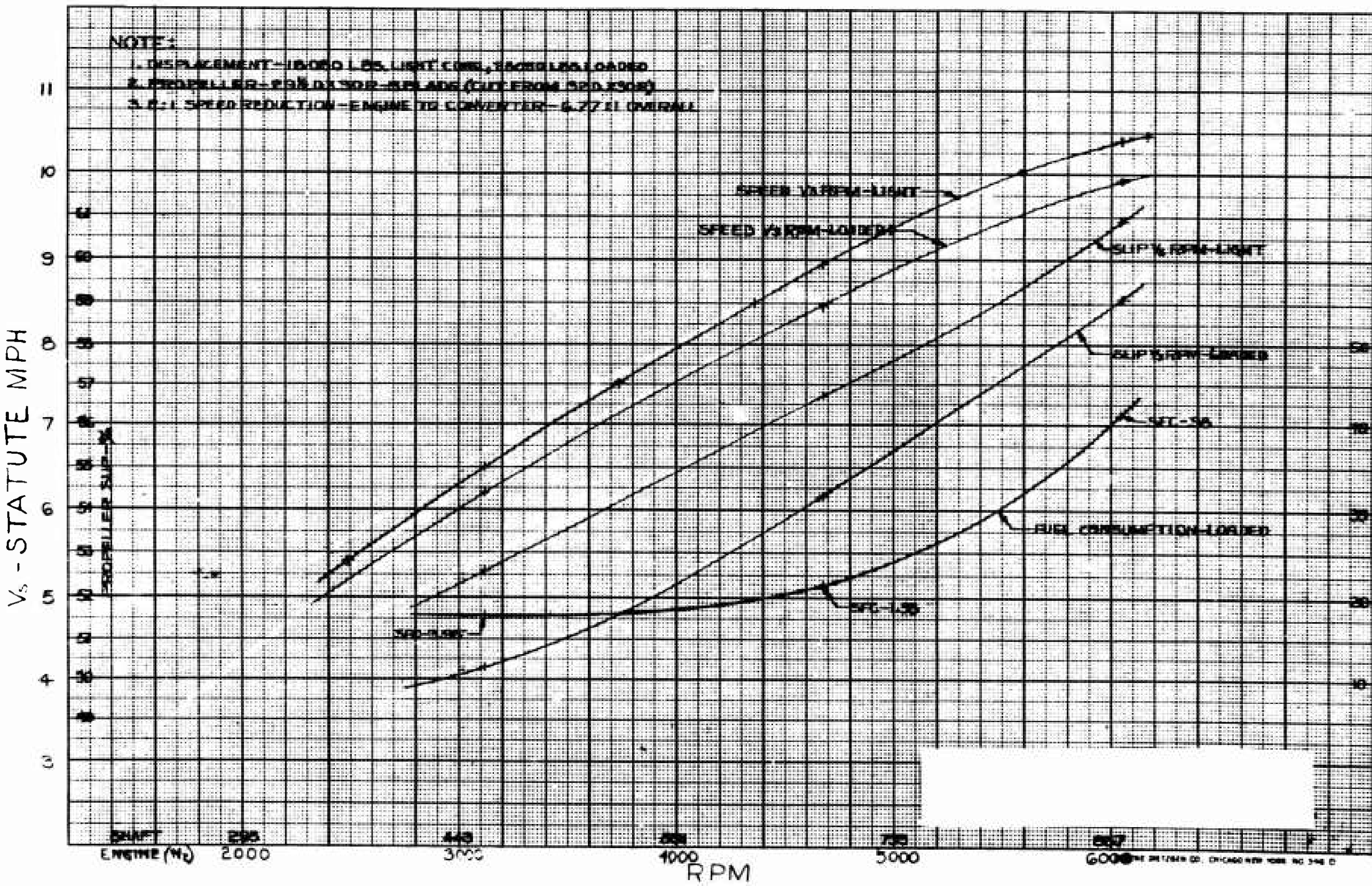

Fig. 8. LARC 5-7X water performance.

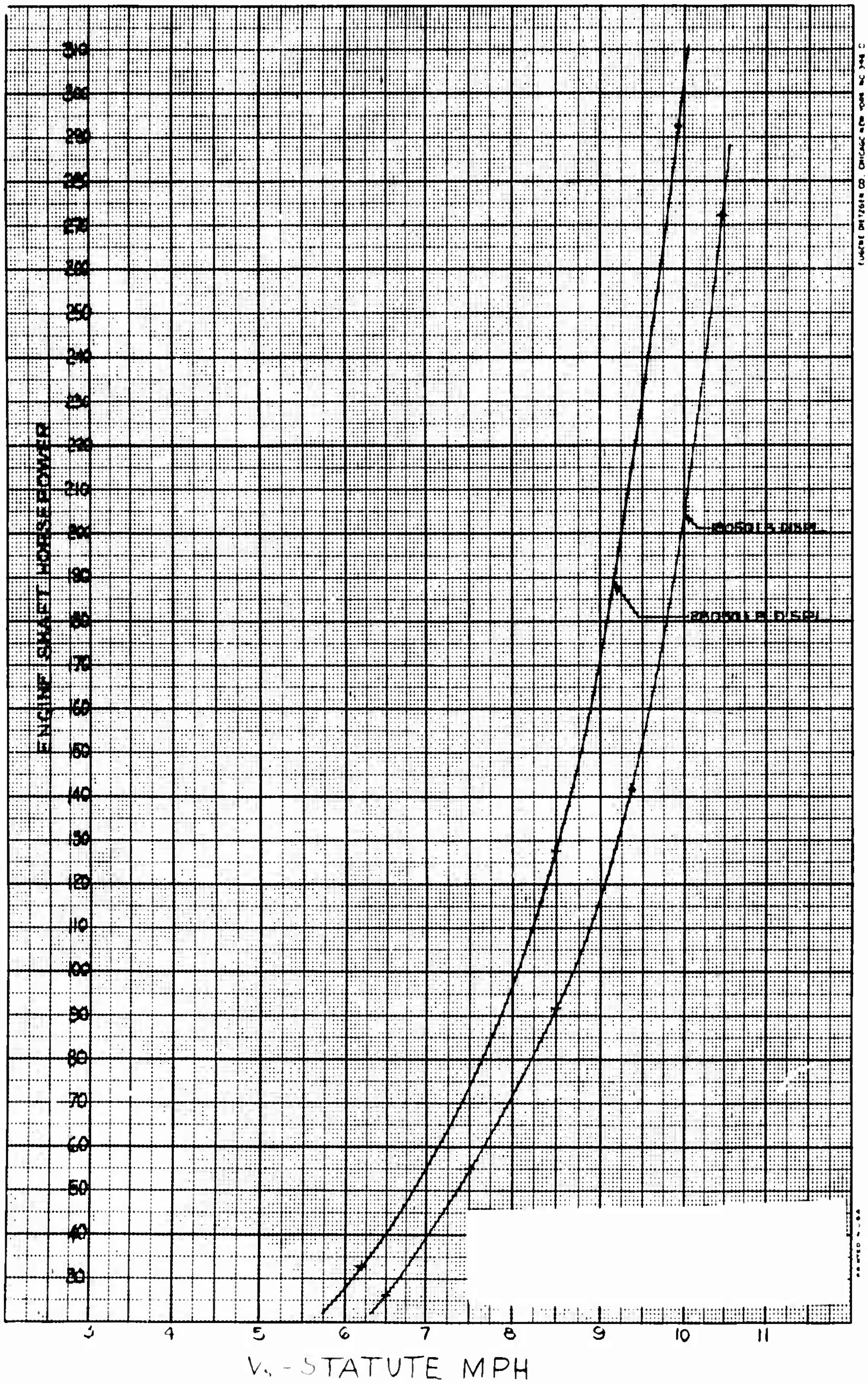

Fig. 9. LARC 5-7X marine power requirements.

III. DISCUSSION

7. Examination of Test Methods. The method of evaluation and test planned from the outset was sound in many ways; however, the operation at Fort Story was undertaken with considerable optimism. It was known that any degree of high surf in that area is dependent on severe storms, and it was hoped that the testing there would coincide with the storm season and thereby satisfy the basic objective with a minimum of cost and effort. This condition did not materialize. The simulated surf test was effective in that the desired wave height was achieved, but the quantity of water spilled onto the LARC was considerably less than that to be expected in a breaking wave equivalent to test height.

8. Analysis of Test Results. An evaluation of the test results follows:

a. The typical gage readings shown in the table are not consistent, as can be noted. This is so primarily because of the basic quality of the instruments. It is believed, however, that they were adequate, as a high degree of precision was not required.

b. The results observed from tests conducted on the turbine inlet aspiration system confirmed the theory around which the system was designed. Because no high surf was encountered in which the entire vehicle would have been virtually under water, the ultimate proof is lacking. It is known that some water would be taken aboard through the hull openings when the vehicle passed through extremely high surf; however, because of the sheltered inlet location and the plenum between the inlet and the turbine, the water would settle to the bilge and be pumped overboard. It is practically impossible for raw sea water to enter the turbine with this arrangement.

c. The turbine exhaust back pressure gage was incorporated as a means of determining whether sea water was entering the exhaust duct during surf operation. Here again, because no high surf was encountered, no results were recorded. The simulated surf test was the nearest approach, and no increase in back pressure was noted. By manually forcing the hinged covers to close at idle speed, the back pressure was observed to rise slightly as the exhaust gases then were forced out the eductor and into the engine compartment. During the simulated surf test, these hinged covers must have been forced to close for an instant because the small access hatch in the center of the cargo deck, which had not been secured was observed to lift momentarily and drop back as the inside of the hull became pressurized. If this momentary pressurization took place during high surf operation, water could be prevented from entering through the aspiration air inlets. It is not known how long the turbine would continue to run if it were forced to recirculate a portion of its exhaust gas. In the short duration of the test, no ill effects were noted.

Comparison of the exhaust system modified by USAERDL with that originally installed by the contractor revealed that no difference existed in engine performance and that the aft-facing stacks with the covers were no more vulnerable to flooding than were the side-facing originals. Improvement in access alongside the engine and transmission was obvious, and less heat loss took place into the engine compartment. With the elimination of the side discharge of the exhaust, it was possible to work in the aft end of the cargo area and in the engine compartment and not be in the hot gaseous environment, which was extremely disagreeable.

d. Water speed tests were not required as a means of evaluating the gas turbine or the installation but were conducted to gain more information relative to propeller performance, hull resistance, and power requirements, because this turbine was equipped with a torquemeter. The information that resulted from these tests can be compared readily with test results from earlier vehicles which were fitted with reciprocating engines and tested with a torquemeter in the marine propeller shaft.

The water speed and power requirement test results can be used to evaluate power requirements for amphibian vehicles of this same configuration, the LARC 5 in particular. The LARC 5 results compared with the earlier trials show that the power train losses can be accurately pinpointed rather than estimated. Data recorded show that with no load a maximum average speed of 10.38 mph was achieved at 3,020 converter input rpm (converter locked) and that the turbine was delivering 260 hp. With a 10,000-lb load, the maximum average speed was 9.93 mph at 3,020 converter input rpm, the turbine delivering 292 hp.

e. As was predicted at the outset, this particular gas turbine has a high fuel consumption rate. At the part throttle power level which the gas turbine was operating in this installation delivering a maximum of 292 hp, the best specific fuel consumption rate was 0.98. The turbine actually is capable of operating much more efficiently at its maximum rating of 400 hp.

During warm weather, starting the turbine on diesel fuel presented no problems; in fact, starts were accomplished as rapidly as when JP-4 was used. In cold weather, the compressed air assist was mandatory during the start cycle up to normal engine idle speed, namely, 50 percent to 55 percent gas generator speed (N_1). This procedure was and is necessary in order to effect any start in extreme cold and to avoid the possibility of a "hot start" which will damage the power turbine blades and inlet guide vanes. When this air was added into the combustion chamber, the fuel ignited immediately upon admittance.

The use of the fresh water wash system after each 8 hr of operation, or daily, in a salt-laden atmosphere is effective in the prevention of any salt buildup on the compressor or power turbine blades. Throughout the test of this turbine installation, the washing procedure was followed carefully, and no evidence of power loss or salt deposit was noted on teardown inspection.

After final removal of the turbine for return to the manufacturer, a considerable buildup of oil film, lint, and some small metallic particles was observed on the annular turbine air inlet screen and on the screens in the ends of air ducts which terminate forward of the engine compartment bulkhead. This is the only detrimental effect that resulted from the use of the hull bilge as an air plenum. Because this space is also occupied by gearboxes, many hydraulic lines, and bilge water covered with an oil film, a considerable amount of oil is accumulated in the air as it flows aft into the turbine air inlet ducts. A small amount of dust is also picked up from the service brake disks as they become worn during land operation. None of these contaminants appeared to affect the turbine performance during the test operation, although a residue, found to be primarily silicon, was discovered throughout the hot section after the first 50 hr of operation in the Stamford, Connecticut area. The source of this residue was never found.

9. Evaluation of Installation. This gas turbine installation in the LARC 5-7X served as an adequate tool for the exploration of the suitability of turbines in amphibian vehicles. It demonstrated a smooth, quiet flow of power which has been uncommon in conventional installations utilizing reciprocating engines. The light weight of the turbine for applications which require much higher power levels is an obvious advantage in that the designer has much greater flexibility in arrangement of machinery, that is, because the weight is such a small percentage of the total, the turbine location has much less critical effect on longitudinal trim.

IV. CONCLUSIONS

10. Conclusions. It is concluded that:

a. The Pratt and Whitney ST6B gas-turbine application to the LARC 5-7X was entirely successful within the scope of this investigation.

b. Much worthwhile experience was gained to aid in future turbine applications to amphibian vehicles.

c. The method of handling the large requirement for turbine aspiration air proved satisfactory, although some means of filtering the oil from the air seem desirable.

d. Both methods of handling the turbine exhaust gases were satisfactory as far as the turbine performance was concerned. The system as installed at USAERDL is considered superior because of its lighter weight, its reduced cost, and the fact that it relieved congestion in the engine compartment.

e. The lack of test operation in extreme surf conditions leaves some doubt as to ultimate performance of the aspiration and exhaust systems, but the indications are that little else could be done to insure success in future applications.

APPENDIX A

AUTHORITY

RDT & E PROJECT CARD	1. TYPE OF REPORT ☐ NEW ☐ FINAL ☒ REPLACES (No. & Date) 1D443012D25605, 1 Jan 63		REPORT CONTROL SYMBOL CSCRD-1(R3)
2. Task TITLE Amphibian Concepts and Designs (U)	3. SECURITY OF Task U	4. Task NO. 1D443012D25605	
	Program Element 6.41.30.12.1	6. REPORT DATE 1 Jul 63	
7. RD Category Engineering Development	8.	9. CATEGORY DT/AR	
10a. COGNIZANT AGENCY USAMC	11a. CONTRACTOR AND/OR GOVERNMENT LABORATORY	b. CONTRACT NUMBER	
b. DIRECTING AGENCY USAMOCOM-USATRECOM			
REQUESTING AGENCY USAMC			
PARTICIPATION BY OTHER MILITARY DEPTS. AND OTHER GOVT. AGENCIES	14. SUPPORTING PROJECTS	18. EST. COMPLETION DATES DEV. ENGR TEST. USER TEST OPERATIONAL	
12. COORDINATION ACTIONS W/OTHER MILITARY DEPTS. & OTHER GOVT. AGENCIES IEL 5-4-101-5 Dept Navy/Marine Corps	15. DATE APPROVED 1 June 1961 16. PRIORITY II 17. BUDGET CODE 5400	19. EST. SUPPORT LEVEL ☒ UNDER $50,000 ☐ $50,000 - $100,000 ☐ $100,000 - $250,000 ☐ $250,000 - $500,000 ☐ $500,000 - $1,000,000 ☐ OVER $1,000,000	
20. CDOG: Ref: Par 1010b, 1012d, 1610c(1), 1612c	21. SPECIAL CODES		

22. REQUIREMENT AND/OR JUSTIFICATION

The U. S. Army has a requirement for Amphibious Lighters of various concepts and designs which will materially increase the effectiveness of its logistic over-the-shore operations.

23. Brief of project and objective:

a. Brief:

(1) Brief of amphibious lighter is attached as supplement III.

(2) Objective: To investigate amphibious concepts and designs, including various means of powering. See supplement. See also para. 23g.

b. Approach: Supplement indicates specific approach. See also para. 23g.

c. Tasks: Work will be accomplished under the following supplement: III High-Speed Amphibian (Medium).

d. Coordinated test plan (CTP): N/A

e. Other information: Participation/coordination/interest: UK (I); Marine Corps (I)

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RDT & E PROJECT CARD CONTINUATION	REPORT DATE 1 Jul 63	Task NO. 1D443012D25605

f. Background history and progress:

(1) Lighter, 5-Ton, Amphibious; Task initiated in January 1958 as Task 114M, Project 9-57-03-000, for preliminary design studies. Upon completion of studies a contract was awarded Ingersoll-Kalamazoo Division, Borg-Warner Corp., for construction of one LARC 5. This was later increased to seven. Type classified in FY 1961.

(2) Lighter, 15-Ton, Amphibious; Task initiated in March 1958 as Task 113M, Project 9-57-03-000 (subsequently redesignated as Task 9R57-02-018-02). Original contract of one prototype awarded simultaneously with Lighter, 5-Ton, amphibious, to Ingersoll-Kalamazoo Division, Borg-Warner Corp., was subsequently increased to three. Type classified in 1st Quarter FY 63.

(3) Studies have been completed establishing as fact, that amphibious craft capable of water speeds in excess of 25 MPH are technically feasible. Hydroplane, Hydrofoil and GEM concepts have been considered and designs have been developed for the hydroplane types. Experimenting and testing has been conducted on a Hydrofoil Amphibian using a WWII DUKW as a test bed.

(4) Engineering tests of the GMT-305 gas turbine powered LARC 5 prototypes have been delayed because of turbine failure and limited funds for resolution of the problem and accomplishment of necessary repairs and modifications.

(5) Supplement I, High Speed Amphibian (Light) (U) is being replaced by Task NEW High Speed Amphibian Resupply Cargo, 5-Ton (U).

(6) Supplement II, Plenum Air Tread Amphibian (PATA) was replaced by Task 1D443012-D256-09 Plenum Air Tread Amphibian (PATA).

g. Future plans:

(1) Refit one or both of the turbine powered LARC 5 prototypes with different and more reliable gas turbines and resume test program.

(2) To investigate and evaluate new and promising concepts of amphibious lighters which appear to offer greater performance over existing equipment.

(3) Conduct model basin tests to improve hull configuration and propulsion systems in order to further reduce power requirement, reduce weights and reduce complexity while improving maintainability and reliability.

(4) Continue studies in amphibian design expected to result in increased efficiency in performance of assigned missions. New concepts and designs will be prepared, with military and technical characteristics, resulting from studies and analysis of test results returning from the field on recently type classified items.

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RDT & E PROJECT CARD CONTINUATION	REPORT DATE 1 Jul 63	Task NO. 1D443012D25605

h. References:

(1) TCTC Item 1725, Meeting 102, held 22 March 1956, Development Project 9-57-03-000, Marine Craft; initiation of project and consolidation of projects approved by Tech Committee 22 March 1956 and by CH/R&D, OCofS on 19 Nov 1956.

(2) DF, Cmt #2, C/R&D to CofT, file CRD/D 13752, dated 30 May 58, subject: "Development of Amphibious Lighters(U)", directing initiation of the development of amphibious lighters.

(3) TCTC Item 2261, Meeting 114, held 6 March 1958, Task 113M, Project 9-57-03-000, Lighter, 15-Ton, Amphibious (U), initiation of military and technical characteristics of item; subsequently redesignated as Task 9R57-02-018-02.

(4) TCTC Item 2267, Meeting 114, held 6 March 1958, Task 114M, Project 9-57-03-000, Lighter, 5-Ton, Amphibious (U), initiation of military and technical characteristics of item; subsequently redesignated as Task 9R-57-02-018-03.

(5) TCTC Record and Information Item 3313, Meeting 126, held 17 December 1959. Renumbering of TCR&D Projects and Tasks: Changes in Titles.

(6) TCTC Item 3395, Meeting 128, held 16 June 1960, LIGHTER AMPHIBIOUS: (LARC-5) self-propelled, gasoline, aluminum, 5-ton, design 8005; revised military and technical characteristics and type classification as STD-A; Task 9R57-02-018-03 Lighter, 5-Ton, Amphibious (U); completion.

(7) TCTC Item 3556, Meeting 131, held 17 November 1960, LIGHTER, Amphibious; (LARC-5) self-propelled, gasoline, aluminum, 5-ton, design 8005; amendment of military and technical characteristics.

(8) TCTC Coordinating Subcommittee Item 1011, Meeting 54, held 23 May 1961, Task 9R57-02-018-05, Amphibious Concepts and Designs (U); initiation; approved for referral to TC Technical Committee.

(9) TCTC Item 3695, Meeting 136, held 1 June 1961, Task 9R57-02-018-05, Amphibious Concepts and Designs (U); initiation.

(10) TCTC Item 3841, Meeting 138, held 21 December 1961, Task 9R57-02-018-02, Lighter, 15-Ton, Amphibious (U); supersession.

i. Responsible project officer: Mr S. M. Hickson, Marine & Amphibious Research Group, USATRECOM, Fort Eustis, Virginia, Telepnone TRinity 7-1311, Ext 24300.

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APPENDIX B

TEST PLAN, LARC 5-7X GAS TURBINE POWERED

3 March 1964

OBJECTIVE

The objective in the installation and test of a turbine in the LARC 5 is to evaluate the use of gas turbines in amphibious craft; to determine qualitative requirements of turbine inlet air and exhaust systems when operating in a salt water and beach environment and through high surf. The gas turbine selected for this evaluation is not under test, nor is the vehicle in which it is installed, per se, they are considered to be tools, typical of future applications, from which basic installation data can be derived.

BACKGROUND

Under Contract DA 44-177-AMC-44(T) with the Consolidated Diesel Electric Company, Stamford, Conn., the LARC 5-7X, formerly fitted with the Allison GMT305 gas turbine, has been repowered with a Pratt and Whitney ST6 gas turbine engine. This turbine is the industrial/marine version of the PT6(T74) aircraft turbine and has a maximum continuous rating of 350 SHP at sea level on a standard day, derated to approximately 250 SHP for this application. The turbine has been secured by the contractor on a loan basis at no cost for the duration of the test which shall be for a total of 400 operating hours or until August 1964, whichever occurs first.

For the duration of the test, the contractor is to furnish all repair and service parts peculiar to the turbine installation and furnish the necessary labor as required.

At the end of the first 100 hr, the first 200 hr, and the first 400 hr of operation the contractor is to remove the turbine engine and ship it back to the manufacturer for a complete inspection. Costs incurred in the removal, shipment, and reinstallation will be borne by the contractor. This work will take place at or near the test site being utilized at the time.

TEST CONDITIONS

1. Throughout the test the LARC shall carry a 10,000-lb load with a vertical center of gravity not in excess of 20 in., placed on deck to give a stern trim of approximately 2 in. when waterborne.

2. Operating hours during the test shall be proportioned approximately 75 percent in water and 25 percent on land, all in salt-laden atmosphere.

3. Water hours shall be accumulated in salt water with occasional passage through surf. Surf height up to 10 ft is desirable.

4. The test shall be conducted with the engine operating at 80 percent to 100 percent power turbine speed to the maximum practicable extent.

5. During the test, the turbine shall be operated in accordance with the instructions furnished with respect to prestart check, starting procedure, shutdown procedure, and lubricants.

6. During the first 100 hr, the turbine shall be operated on JP-4 fuel, MIL-J-5624. After the first 100-hr teardown inspection, the engine fuel system will be reset for diesel fuel, Fed. Spec. No. VV-F-800 Grade DF-1, which will be used for the remainder of the test.

7. Vehicle parts and repairs to components and structures not peculiar to the turbine installation will be a responsibility of the Government. Parts for the prototype LARC 5 are only available from the TRECOM LARC Detachment. LARC maintenance procedures shall be observed to minimize deadline time caused by vehicle component failures.

8. In the event of a need for contractor service or repair parts, notify the Project Engineer so that appropriate action can be initiated.

9. Standard safety precautions shall be observed at all times.

DETERMINATIONS AND REQUIREMENTS

1. Hours of operation, engine hourmeter readings, and land miles traveled shall be recorded on a daily basis.

2. During water and surf operation, maximum wave height shall be observed and recorded with measurements or estimates of the amount of water, if any, taken in through turbine air inlet openings and the turbine exhaust duct openings.

3. Maximum instrument readings shall be taken from the auxiliary panel on a daily basis for the following:

a. Turbine output shaft torque (PSID)

b. Gas generator speed (N_1 tachometer)

c. Ambient temperature (^oF)

d. Engine compartment temperature (^oF)

e. Turbine air inlet temperature (^oF)

f. Turbine air inlet pressure (in. H_2O)

g. Turbine exhaust outlet pressure (in. H_2O)

h. Power turbine speed (N_2 tachometer)

DD Form 1473 continued

Abstract (continued)

b. Much worthwhile experience was gained to aid in future turbine applications to amphibian vehicles.

c. Method of handling large requirement for turbine aspiration air proved satisfactory, although some means of filtering oil from air seem desirable.

d. Both methods of handling turbine exhaust gases were satisfactory as far as turbine performance was concerned. System installed at USAERDL ,is considered superior because of its lighter weight, its reduced cost, and fact that it relieved congestion in engine compartment.

e. Lack of test operation in extreme surf conditions leaves some doubt as to ultimate performance of aspiration and exhaust systems, but indications are that little else could be done to insure success in future applications.

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Distribution of this document is unlimited.

11 SUPPLEMENTARY NOTES

12 SPONSORING MILITARY ACTIVITY
USAERDL

13 ABSTRACT Report covers studies and tests of an experimental gas-turbine installation in a prototype LARC 5. A principal feature of the experiment was determination of a satisfactory method of handling large quantities of engine aspiration air and exhaust gases without taking in excessive amounts of sea water. LARC prototype was used as typical vehicle because of its immediate availability and store of test information compiled during its recent development. Pratt and Whitney ST6B turbine, secured on loan from manufacturer, was installed as typical turbine which had good record of reliability in power range desired.

Investigation consisted primarily of accumulation of 400 operating hours in environment of amphibious operation. This included 100 hr accumulated in engineering design test by Consolidated Diesel Electric Corporation, Stamford, Connecticut, contractor for detail design and installation, and 300 hr accumulated in component development test by U. S. Army Test and Evaluation Command at Fort Story, Virginia. Some additional tests were conducted by USAERDL before and after modification to exhaust system. Investigation began in May 1963 at USATRECOM and was transferred in June 1964 to USAERDL with Surface R&D Mission. Work was completed, and turbine was returned to manufacturer in January 1966.

Report concludes that:

a. Pratt and Whitney ST6B gas-turbine application to LARC 5-7X was entirely successful within scope of this investigation. (continued)

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
LOTS Amphibian						
Amphibious Operations						
Wheeled-vehicle						
Gas-Turbine Application						

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